Feasibility of Implementing Carbon Capture and Storage Technology in Sri Lankan Power Sector

K.M Guruvita
178609E

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Declaration

I declare that this is my very own work and this thesis doesn't incorporate without affirmation any material previously submitted for a Degree or Diploma in any other University or foundation of higher learning and as far as I could possibly know and conviction, it doesn't contain any material recently distributed or composed by another individual aside from where the affirmation is made in the content.

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Dr.Thushara . D. Rathnayaka

Abstract

Earth is consistently getting hotter with the most noteworthy recorded temperature was at 2016.Gobal warming is the principle explanation behind the temperature increase on the planet. As one of major greenhouse gas, CO_2 has a strong influence on global warming. In addition to the global warming, CO_2 concentration on the earth atmosphere will directly affect the physiological processes and growth of plants and indirectly for the changes in precipitation patterns and frequency of weather extremes. Non-renewable energy sources, and fossil fuel based electrical power plants are primary CO_2 producers to the environment. Carbon Capture and Storage (CCS) is one of the most forthcoming technologies that captures CO_2 emissions produced from fossil fuel power plants. However, this technology is highly resource intensive and therefore it is required to estimate the impacts beforehand.

This thesis estimates the feasibility of implementing Carbon Capture and Storage technology in Sri Lankan fossil fuel power plants. In addition to the CO_2 emission, other harmful gases, SO_2, NO_x, and HCl emissions are also considered in this study. Author proposes the most suitable CCS technology for each and every thermal power plant by considering the reduction of CO_2 emission and effective resources usage. In addition to that, cost feasibility of implementation of technology is also discussed.

Acknowledgement

Above all else, I might want to offer my true thanks to my supervisor Dr.ThusharaD.Rathnayake, Senior Lecturer from Electrical Engineering Department at University of Moratuwa for the ceaseless help of my M.Sc. study and research, for her understanding, inspiration, eagerness, and colossal knowledge. Besides my consultant, I might want to thank the remainder of the talks from Electrical Engineering Department at University of Moratuwa for their support, savvy remarks, what's more, hard inquiries in progress reviews. Last but not least; I might want to pass on my genuine appreciation to my folks, relatives and companions for helping me from multiple points of view to accomplish my objectives constantly.

The simulation section in this work has been done utilizing the Coordinated Environmental Control Model (IECM), developed by the Carnegie Mellon University, USA. I might want appreciative to the IECM group for making the product unreservedly accessible.

Chapter 1

1.0Introduction

1.1 Background

Our general public is intensely reliant on non-renewable energy sources, which supply about 81% of the world's essential demand [3]. Petroleum products are utilized to produce about 67% of the world's power, to which coal, gaseous petrol and oil contribute about 41%, 21% and 5%, individually. The developing worldwide interest for energy administrations, just as the family member wealth of petroleum derivatives and the demonstrated innovations for utilizing them, propose that petroleum derivatives will keep on being broadly utilized later on. This raises worry of atmosphere destabilization brought about by expanding climatic centralization of carbon dioxide CO_2 discharged during the burning of petroleum derivatives [3]. Advancements are being created to catch a piece of the CO_2 discharged by fuel burning and mechanical procedures and to sequester the CO_2 in long haul stockpiling destinations.

Carbon Capture and Storage (CCS)is these days frequently viewed as an urgent innovation in the long haul carbon reduction procedures of numerous nations and global associations. In any case, in spite of its potential, the innovation presently can't seem to be demonstrated as an incorporated framework at a full-scale in order to be a viable method for environmental change moderation, thinking about the suitability, development and effects. While CCS is viewed as indispensable by certain entertainers, others guarantee it's anything but an alluring choice and may not be an important piece of the change towards a low carbon economy. While CCS is currently entering a period of showing of full scale incorporated frameworks in different areas around the globe, there are still noteworthy specialized, monetary, political and money related vulnerabilities about CCS.

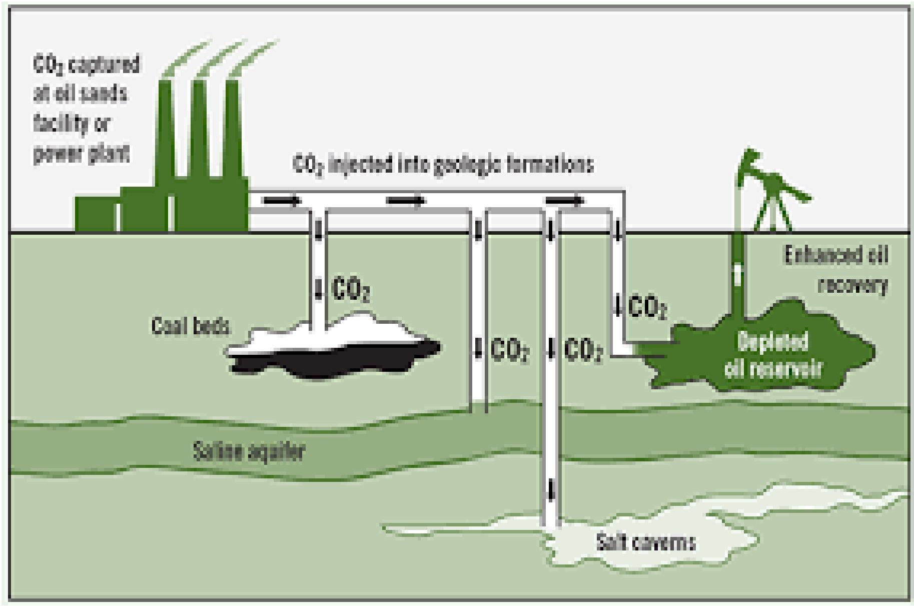

Figure 1: CCS process

1.2 Sri Lankan Context

According to Ceylon Electricity Board (CEB) long term generation and expansion plan too, Carbon Capture and Storage (CCS) has identified as a novel technology that gathers the CO_2emittedfrom enormous point sources like power generation plants, transport them to a chosen site and store, averting the discharge into the air. With the rising worldwide energy utilization and innovations, CCS gets unavoidable to keep away from global warming by reducing environmental carbon emission. Not only that, CCS technology may capture other environmental harmful substance emissions and related atmosphere outcomes too.

1.3 Problem Statement

Although CCS technology is a proven upcoming technology in the world to mitigate CO_2emission to the environment, that is highly resources intensive (fuel and cooling water requirement will increase drastically with the implementation of technology) and require a large cost investment for the implementation of technology, those vary from country to country. Therefore, to implement the technology in the commercial scale or some selected plants, it is desirable to have a proper understanding on technology, cost and environmental factors beforehand in Sri Lankan scale.

1.4 Motivation

Sri Lanka represents less than 1% of worldwide GHG emissions. Transport and power are the two segments to a great extent answerable for emissions in Sri Lanka. Regardless of being a low producer, Sri Lanka is helpless against environmental change. In 2017 alone, the nation experienced extreme atmosphere related catastrophes as dry spells and floods. The outcomes of these calamities included nourishment and water deficiencies, and the death toll.

Therefore, as a member of Paris agreement, Sri Lanka has a responsibility to reduce CO_2 emission to contribute for mitigation global warming and other severe climate disasters. Global warming is a world problem that all people in the world are affected and therefore all the nations have a responsibility to take necessary actions to overcome it. To mitigate the global warming the main option that available is to decrease the carbon emission. One of major contributor of carbon emission is the electricity sector. If we take necessary actions to reduce the emissions from electricity sector that is effecting to global emission as well.CCS technology has been globally identified as an upcoming proven technology to capture CO_2 emitted from power plants by eliminating carbon emission to the environment.

The CCS technology can capture up to 90% of CO_2emitted from fossil fuel burning in electricity generation. The important thing is, this technology is 90% efficient in capturing carbon. Therefore, by implementing this technology, the emission of the thermal power plants can bring down to almost zero. Not only that, other toxic emissions also can mitigate or can reduce to near zero by this technology.

However, CCS technology is highly resource intensive and therefore essential to estimate impacts on environmental resources beforehand. This work emphasizes the feasibility of implementing the CCS technology in Sri Lankan thermal power sector.

1.5 Objective

In this research, the main objective is to estimate the viability of implementing the Carbon Capture and Storage (CCS) technology in Sri Lankan thermal power sector.

It is addressed through following sub objectives.

i. Propose the most suitable CCS technology for each and every thermal power plant.
ii. Estimate the implications on increase of resource usage
iii. Estimate the cost feasibility of implementing the technology.

1.6 Scope of work

In this research, the main scope is to study the feasibility of implementing carbon capture and storage technology in Sri Lankan power sector. We are going to address that through following sub topics.

1. **Determine the most suitable CCS technology for different power plants:**

- All Sri Lankan fossil fuel power plants are simulated using IECM software for without CCS technology and for including variety of CCS technologies. Then the most suitable CCS technology for each and every power plant is proposed by analyzing the reduction of CO_2 emission and increase of resource usage.
- CO_2 emission figures are validated by comparing with the data on CEB long-term generation and expansion plan.

2. **Calculate the cost of implementation of CCS technology in Sri Lankan thermal power sector :**

   In this stage, the implementation cost for Sri Lankan thermal power plants are calculated. In this cost calculation, in addition to the technology implementation cost, the transportation and storage costs are also considered. This analysis will give out the basic idea to the decision makers about the cost of implementing CCS technology in Sri Lankan thermal power sector.

3. **Determine the change of unit cost of electricity with implementing CCS technology :**

   Implementing the CCS technology is an additional cost for the power system. That cost should be covered. Therefore, there is a cost increment in the unit price of the electricity. In this part of the work, the increment of unit price and the affected factors for that with the implementation of the CCS technology are addressed.

4. **Calculate the environmental economic benefit value of reducing CO_2 emission through the implementation of CCS technology :**

   When calculate the economic benefit to the environment through the reduction of carbon emission, the values obtained on the reduction of CO_2emissions are converted into values of 'carbon credits'. Because, 'carbon pricing' has been evolved as a market based strategy for lowering global warming emissions.

A carbon price is a cost applied to carbon pollution to encourage polluters to reduce the amount of greenhouse gases they emit into the atmosphere. Economists widely agree that introducing a carbon price is the single most effective way for countries to reduce their emissions. The costs of climate impacts and the opportunities for low carbon energy options are better reflected in our production and consumption choices through that.

5. **Analyze the economic feasibility :**

Finally, we will be doing an economic analysis using 'Project Management Theory' to analyze the most economical way of finding capital cost to implement the CCS technology in Sri Lankan thermal power sector

To find the project feasibility Internal Rate of Return (IRR) analysis will be done.IRR is a famous method in business analysis that helps project managers to determine the most suitable funding option considering the rate of return. According to this analysis, as long as the financing cost is less than the rate of potential return, the project adds value.

1.7 Structure of the thesis

Following the Introduction, including background, problem statement, motivation, objectives and the scope of this research, this thesis is organized as follows.

Chapter 2 Contains a detailed discussion about CCS technology and its background. Also this chapter focuses more on the current technology improvements and materials that can be used in CCS technology. Furthermore, possible storage capacity of CO_2 in Sri Lanka is also calculated at the end of the chapter.

Chapter 3 Include the information about how we collected data of the power plants for simulation and contains some important data. Also includes an introduction about the software we used for simulation of power plants.

Chapter 4 Presents the simulation results and then those results are analyzed. First base plants are simulated and coal emission figures are validated using CEB data. Then all thermal power plants are simulated for without CCS technology and considering 4 different CCS capture technologies. In these simulations, the increase of fuel consumption and other resource usage are analyzed with the carbon capturing. Finally, analyzing all data, most suitable CCS technology for different thermal power plants are proposed.

Chapter 5 Included the cost analysis of the CCS project and project feasibility of CCS technology. First calculate the total capital cost for implementation of technology, and transportation and storage cost per year. Next, economical benefit value by reducing carbon emission is estimated. Unit price of electricity with and without CCS technology is also calculated and compared here. Finally, a project cost analysis is done to identify most suitable funding (Loan) option to cover the capital cost of technology implementation.

Discussion

Conclusions

References

Chapter 2

2.0 Introduction to CCS technology

2.1. The basis for CO_2 capture

The CCS chain consists of three parts; capturing, transporting, and securely storing the carbon dioxide emissions, underground in depleted oil and gas fields or deep saline aquifer formations.

First, capture technologies allow the separation of carbon dioxide from gases produced in electricity generation and industrial processes by one of three methods: pre-combustion capture, post-combustion capture and oxy-fuel combustion.

Captured carbon dioxide is then transported by pipeline or by ship for safe storage. Millions of tons of carbon dioxide are transported in the globe annually for commercial purposes by road tanker, ship and pipelines.

The carbon dioxide is then stored in carefully selected geological rock formation that are typically located several kilometers below the earth's surface.

At every point in the CCS chain, from production to storage, industry has at its disposal a number of process technologies that are well understood and have excellent health and safety records. The commercial deployment of CCS will involve the widespread adoption of these CCS techniques, combined with robust monitoring techniques and Government regulation.

2.1.1 CO_2 capturing systems

There are four basic systems for capturing CO_2 from use of fossil fuels and/or biomass:

• Capture from industrial process streams.

• Post-combustion capture.

• Oxy-fuel combustion capture.

• Pre-combustion capture.

2.1.1.1 Capture from industrial process streams

CO_2 has been caught from modern procedure streams for 80 years and vast majority of the CO_2 that is caught is vented to the air on the grounds that there is no motivator or necessity to store it. Current instances of CO_2 catch from process streams are purification of common gas and creation of hydrogen-containing blend gas for the assembling of smelling salts, alcohols and manufactured fluid fills. A large portion of the systems utilized for CO_2 catch in the models referenced are likewise like those utilized in pre-combustion catch. Other modern procedure streams which are a wellspring of CO_2 that isn't caught incorporate concrete and steel generation and aging procedures for nourishment and drink creation. CO_2could be caught from these streams as well.

2.1.1.2 Post-combustion capture

CO_2can be caught from the fumes of a burning procedure by engrossing it in an appropriate dissolvable. This is called post-burning capture. The retained $CO_2$is freed from the dissolvable and is compacted for transportation and storage. Different strategies for isolating CO_2 incorporate high weight film filtration, adsorption/desorption forms and cryogenic partition. In this method, Amine, Ammonia and Membrane are used as solvents to capture the carbon.

The greatest test in post-burning catch is isolating CO_2 produced during ignition from the lot of nitrogen (from air) found in the vent gas. Right now, R&D exertion is centered on cutting edge solvents, strong sorbents, and layer frameworks. Furthermore, novel ideas, for example half breed innovations that proficiently consolidate characteristics from different key advancements (e.g., solvents and films) are being researched.

2.1.1.2.3 Pre-combustion capture

A pre-start system incorporates first changing over solid, liquid or vaporous fuel into a mix of hydrogen and carbon dioxide using one of different methods, for instance, 'gasification' or 'changing'. Changing of gas is settled and right currently used at scale at treatment offices and creation plants far and wide. Gasification is comprehensively cleaned far and wide and is near in specific respects to that used for quite a while to make town gas. The hydrogen conveyed by these systems may be used, not only to fuel our capacity creation, yet what's more later on to control our vehicles and warmth our homes with near zero releases.

2.1.1.4 Oxy-fuel combustion capture

During the time spent oxy-fuel ignition the oxygen required is isolated from air preceding burning and the fuel is combusted in oxygen weakened with reused vent gas as opposed to via air. This oxygen-rich and nitrogen air brings about definite vent gases comprising predominantly of CO_2 and H_2O (water), so delivering a progressively thought CO_2 stream for easier purification.

2.1.2. Types of CO_2separation technologies

CO_2 capture systems use many of the known technologies for gas separation which are integrated into the basic systems of CO_2 capture identified in the last section. These separation methods are briefly discussed below.

2.1.2.2 Separation with sorbents/solvents

The separation is practiced by passing the CO_2-containing gas in close contact with a liquid light or solid sorbent that is prepared for getting the CO_2. In the general arrangement, the sorbent stacked with the absorbed CO_2 is moved to another vessel, where it releases the CO_2 (recuperation) in the wake of being warmed, after a weight decrease or after some other change in the conditions around the sorbent. The sorbent coming to fruition after the recuperation step is sent back to get more CO_2 in a cyclic procedure. In specific varieties of this arrangement the sorbent is a solid moreover, doesn't hover between vessels considering the way that the sorption what's more, recuperation is cultivated by cyclic changes (in weight or on the other hand temperature) in the vessel where the sorbent is contained. A make-up flow of fresh sorbent is continually required to change for the typical spoil of activity or conceivably sorbent adversities. In a couple of conditions, the sorbent may be a solid oxide which reacts in a vessel with non-sustainable power source or biomass making heat and fundamentally CO_2. The spent sorbent is then streamed to a second vessel where it is re-oxidized in air for reuse with a couple of adversity and make up of new sorbent. The general arrangement of oversees various huge CO_2 get structures, including driving business decisions like engineered absorption and physical ingestion and adsorption. Other creating techniques subject to new liquid sorbents or new solid re-generable sorbents are being made with the purpose of vanquishing the containments of the present structures. One ordinary issue of these CO_2 get systems is that the flow of sorbent between the vessels is tremendous since it needs to arrange the gigantic flow of CO_2 being set up in the force plant. Thusly, equipment sizes and the essentialness required for sorbent recuperation are tremendous and will all in all disentangle into a noteworthy productivity discipline and included cost. Furthermore, in systems using expensive sorbent materials there is always a danger of raising cost related to the securing of the sorbent what's more, the exchange of sorbent developments. Extraordinary sorbent execution under high CO_2 stacking in various dull cycles is plainly a crucial condition in these CO_2 get structures.

2.1.2.2 Separation with membranes

Layers are particularly created materials that license the particular invasion of a gas through them. The selectivity of the layer to different gases is by and by related to the possibility of the material, yet the flow of gas through the film is typically dictated by the weight differentiate over the film. Thusly, high-pressure streams are commonly supported for film separation. There are various different sorts of film materials (polymeric, metallic, pottery) that may find application in CO_2 get systems on Carbon Dioxide Capture and Storage extraordinarily disconnected H_2 from a fuel gas stream, CO_2 from an extent of methodology streams or O_2 from air with the separated O_2 along these lines supporting the age of a significantly thought CO_2 stream. Disregarding the way that film separation finds various current business applications in industry (a bit of a colossal scale, similar to CO_2 parcel from combustible gas) they have not yet been applied for the enormous scale and mentioning conditions in wording of reliability and negligible exertion required for CO_2 get structures. A gigantic by and large R&D effort is in progress gone for the creation of continuously proper layer materials for CO_2 get in colossal scale application.

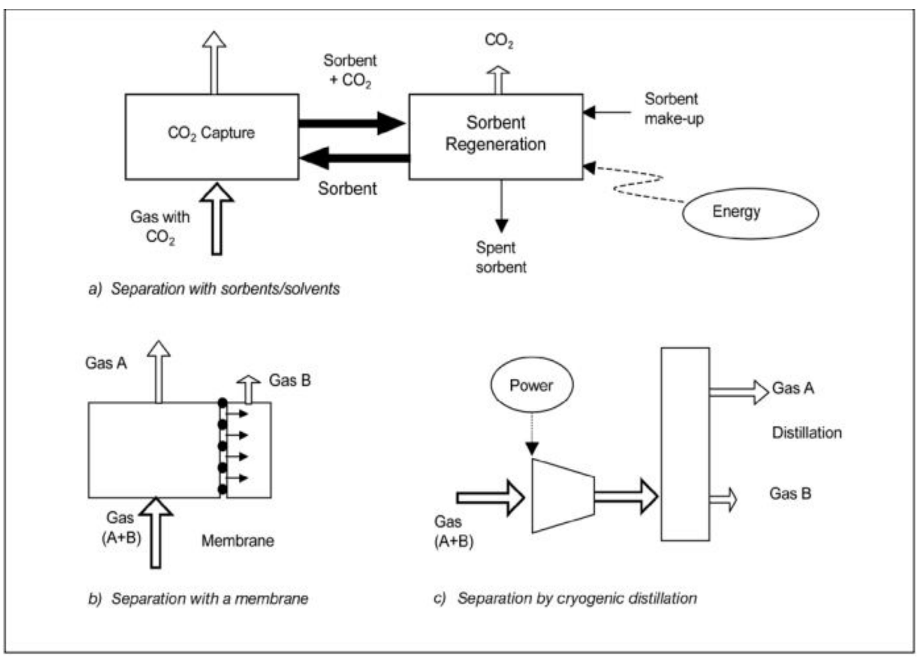

Figure 2 : Separation technologies [9]

2.2 Transportation

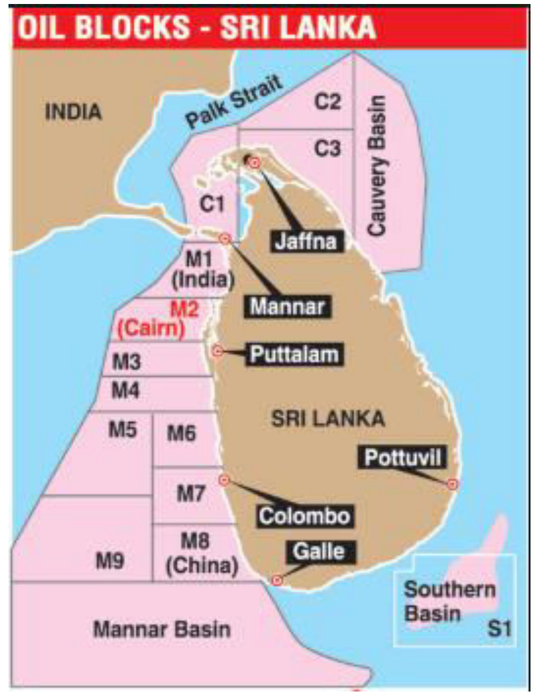

Figure 3 : Oil Blocks in Sri Lanka [16]

Once caught, carbon dioxide (CO_2) should then be shipped by pipeline or ship to a storage site with reasonable capacity. The advancements engaged with pipeline transportation are equivalent to those utilized widely for shipping gaseous petrol, oil and numerous different liquids around the globe. Now and again it might be conceivable to re-utilize existing yet repetitive pipelines. Carbon dioxide is at present shipped for business purposes by street tanker, ship and pipeline. Every carbon capture task would pick the most proper technique for shipping carbon dioxide and be liable to arranging and wellbeing and security guidelines.

Enormous business systems of carbon dioxide pipelines have been in activity for over 30 years in globe with astounding wellbeing and unwavering quality records. There is noteworthy potential for the advancement of neighborhood and local CCS pipeline foundation, prompting CCS "bunches" where CO_2-escalated businesses could find. Creating groups, where framework can be shared by various modern wellsprings of carbon dioxide emanations, will bring about the savviest approach to convey CCS foundation advancement and at last lower expenses to shoppers [12]

- To be transported by pipeline or ship.
- The CO_2must be pressurized to at least 73 bar to reach a supercritical state and high density, bringing its properties similar to the liquid state.
- When transport distances exceed 500 to 1,000 km, transport by ship is considered as the economical option.

In our system, as the distance from plant to storage site is around 100 km, it is assumed that road or ship is the most economical way of transportation.

2.3 Storage

At the point when the carbon dioxide (CO_2) has been moved, it is taken care of in porous topographical plans that are normally discovered a couple of kilometers under the world's surface, with weight and temperatures to such a degree, that carbon dioxide will be in the liquid or 'supercritical stage'. Sensible amassing areas consolidate past gas and oil fields, significant saline courses of action (penetrable rocks stacked up with salty water), or depleting oil fields where the imbued carbon dioxide may extend the proportion of oil recovered. Depleted oil and gas stores will undoubtedly be used for early errands as wide information from geographical and hydrodynamic assessments is starting at now open. Significant saline springs address the greatest potential carbon dioxide storing limit eventually, less.

At the limit site the carbon dioxide is imbued under strain into the geological advancement. Once mixed, the carbon dioxide moves through the limit site until it lands at an impermeable layer of rock (which cannot be penetrated by means of carbon dioxide) overlaying the limit site; this layer is known as the top stone and traps the carbon dioxide in the limit advancement. This accumulating framework is grouped "helper storing".

Fundamental amassing is the basic accumulating segment in CCS and is a comparable technique that has kept oil and oil gas securely got under the ground for a long time giving conviction that carbon dioxide can be safely taken care of uncertainly. As the implanted carbon dioxide moves through the land accumulating site towards its top stone some is relinquished in the microscopic pore spaces of the stone. This carbon dioxide is solidly trapped in the pore spaces by a framework known as "waiting amassing". After some time, the carbon dioxide set away in a land improvement will begin to separate into the incorporating salty water. This makes the salty water denser and it begins to sink down to the base of the limit site. This is known as "deterioration storing". Finally, "mineral accumulating" happens when the carbon dioxide held inside the limit site attaches falsely and irreversibly to the enveloping stone.

As the limit frameworks change after some time from helper to remaining, breaking down and a short time later mineral accumulating the carbon dioxide ends up being less and less compact. Thusly the more drawn out carbon dioxide is taken care of the lower the threat of any spillage.

Oil blocks in Sri Lanka are shown in Figure 3. Sri Lanka's Government has opened an international bidding round to explore and produce oil and natural gas two blocks in the Mannar and Cauvery Basin shown in that figure. Their plan to cover Mannar Basin's M1 Block and the Cauvery Basin's C1 block.M1 block cover 2779 $km^2$and 2246 km^2 respectively. According to petroleum Corporation they are planning to start the project in 2020. As oil excavating places are the most suitable places to store the

CO_2, this will be added advantage to the CCS projects to reduce the initial cost of implementing the technology [12].

2.3.1 Storage capacity calculation

The CO_2 storage capacities of an oil field can be calculated using following formula [10].

$V_{CO_2} = A \times ACF \times SF$ .... (1)

Where ,

- V_{CO2}=CO_2 storage capacity [Mtonnes]
- A=area of the basin [km^2]
- ACF=aquifer coverage factor
- SF=storage factor, [Mtonnes / km^2]

Table 1Storage capacity of M1 & C1 blocks

Block number	A	ACF	SF	Capacity(Mtonnes)
M1	2779	0.5	0.6	833.7
C1	2246	0.5	0.6	673.8

According to this calculations, the total CO_2 storage capacity of those two considered blocks are approximately 1508 Mtonnes.

Chapter 3

3.0 Data Collection and simulation

3.1 Data Collection

The data were collected from different coal and oil fired power stations in Sri Lanka. Starting at 2016, about 1,464 MW of the absolute introduced limit was from state-possessed non-renewable power generation plants: 900 MW from Lakvijaya, 380 MW from the state-claimed bit of Kelanitissa, 160 MW from Sapugaskanda, and 24 MW from Uthuru Janani. The remaining 641 MW of the introduced warm limit are from six exclusive power stations. All warm power stations run on fuel oil, with the exception of Lakvijaya, which run on coal. Sri Lanka's power request is currently met by nine main thermal power stations. Generally hydroelectric and warm/petroleum derivative based power stations in the nation are possessed or potentially worked by the administration by means of the state-run Ceylon Electricity Board (CEB), while the sustainable power source division comprises for the most part of secretly run plants working on a power buy concurrence with the CEB.

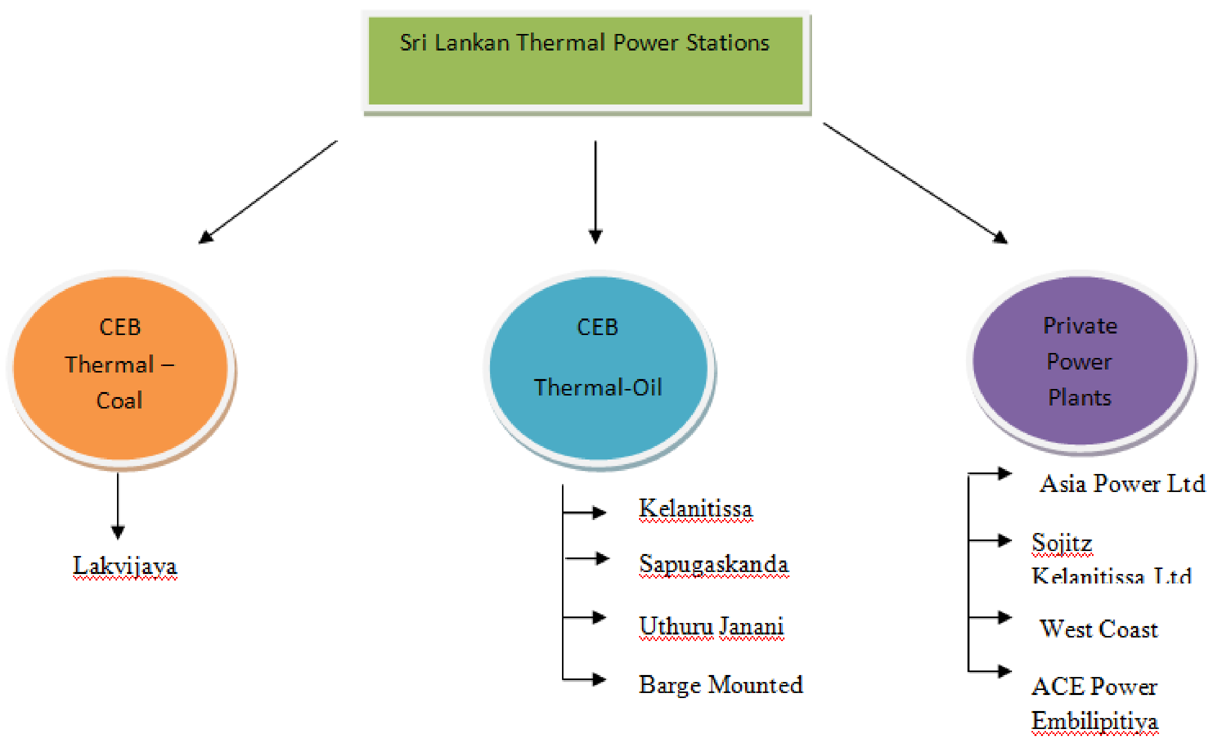

Figure 4 : Strategy of Sri Lankan thermal power stations

While thinking about the ozone harming substances, CO_2 is one of the essential gases which contribute towards warming of earths' climate. Table 2 demonstrates CO_2 discharges from fuel burning in every part in Sri Lanka for the year 2014. It could be seen that around 41% of CO_2 emissions from the power segment while significant supporter for CO_2emissions is the vehicle area which account for around 48%.

Table 2: CO_2 emission levels in different energy sectors in Sri Lanka [14]

	CO_2 emissions *Million tons of CO_2*	
Total	**16.74**	**100.0%**
Electricity and heat production	6.79	40.6%
Other energy industry own use	0.04	0.3%
Manuf. industries and construction	0.99	5.9%
Transport	7.99	47.8%
Other sectors	0.91	5.5%

Source: IEA CO_2 Emissions from Fuel Combustion (2016 Edition) -2014

Source: Sustainable Energy Authority

Figure 5 :Average Emission Factor of the energy sectors in Sri Lanka [14]

Figure 5 shows the variation of the average emission factor in the energy sector in Sri Lanka. According to sustainable energy authority data, year by year emission is increasing. Therefore, it is a direct indication about air pollution due to electricity generation in Sri Lanka. According to the graph in Figure 5 in some years pollution factor becomes higher and another year's pollution factor becomes slower.

3.2 Base plant simulation

To validate the carbon emission figures obtained from the simulation using the IECM software, we first simulated the base plants using their operational data. As a sample, the data of one unit of the largest thermal power plant, 3 x 300 MW Lakvijaya coal power plant, that we used for simulation is shown in Table 3.

Table 3 Base plant data of one unit of Lakvijaya coal power plant

Coal Plant	
Net Capacity	300 MW
Aux. Consumption (%)	0.4
Unit type	Sub-Critical
Boiler Efficiency (%)	85.7
Source of Coal	Indonesia
Coal of properties	
Carbon (%)	48.96
Sulphur (%)	0.55
Ash (%)	13.99
Calorific value (kCal/kg)	6300
Coal consumption (Mtonne/day)	2000
Plant factor	86.3
Average Gross plant heat rate (kJ/kWh)	10413.98

Source: Generation performance in Sri Lanka 2016, Public Utility commission.

3.3 Simulation of the Capture Unit

Next, we simulated the CO_2 capture unit. It must be guaranteed that the net yield stays consistent even after implementing the CCS technology. It is evident that energy penalty is lowest around the capture efficiency range of 85-90 % [10]. Therefore, we assumed 90% capture efficiency for all the capture technologies. The pressure of the CO_2 stream leaving the capture unit is taken as 10 MPa.

Along with CO_2 capture, we have to consider other pollutant gas emissions too, to ensure an optimal functioning of the CCS capture technologies. For example, in the amine-based capture, acidic gases such as SO_2 and NO_2 are reacted with the amine to form heat stable salts which may reduce the CO_2 absorption capacity of the amine and make solvent losses [9]. Therefore, capture efficiencies of other pollutant gases were assumed as shown in Table 4.

Table 4 : Assumptions regarding other emission controls

	Amine	Ammonia	Membrane
SO_2 removal efficiency	99.5	99.5	99.5
SO_3 removal efficiency	99.5	99.5	99.5
NO_2 removal efficiency	99.5	99.5	99.5
HCL removal efficiency	99.5	99.5	99.5

3.4 Impact of key factors

Boiler efficiency, coal quality, pressure of CO_2 product and the capture efficiency are some of the key factors, which can affected on the performance of CCS technology. Sensitivity analysis is to be done for those four parameters to get an understanding of the effects they have on the resource consumption.

3.5Simulation software

For the simulations of power plants, we used Integrated Environmental Control Model (IECM) and Interface that were created for the U. S.Department of Energy's National Energy Technology Laboratory (NETL), once in the past known as the Federal Energy Technology Center (FETC). The base for the model is to compute the presentation, emissions and cost of utilizing elective ecological control strategies in a coal-terminated power plant. The model comprises of a base plant and different control innovation modules; these modules might be actualized together in an assortment of blends.

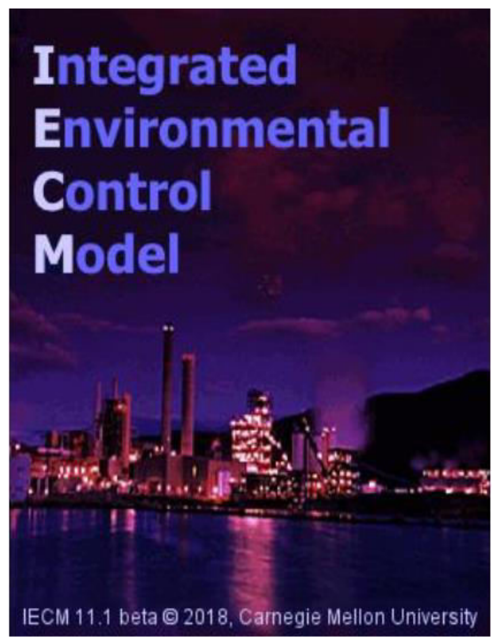

Figure 6 : IECM software

IECM Modeling Approach

- System analysis approach
- Process performance
- Engineering economic models

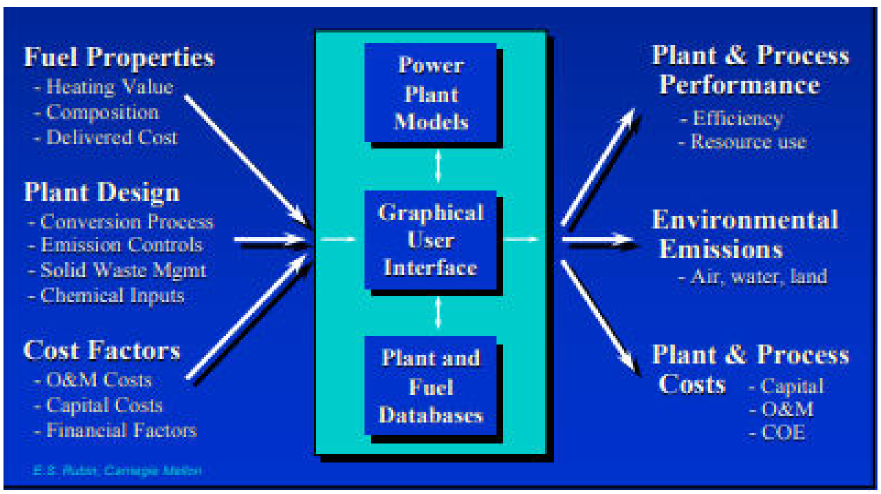

Figure 7 : IECM Software package

Chapter 4

4.0 Simulation Results and Analysis

4.1 Simulation Results

When user supply input data of each power plant, IECM software will give outputs of carbon reduction of those separately. Three types of capture technologies that is pre-combustion, post-combustion and oxy-fuel combustion are available in this software. Since we are considering already installed power plants, we consider only post-combustion and oxy-fuel combustion technologies at this analysis. Three post combustion technologies, ammine-based, ammonia-based and membrane are considered in this simulation analysis.

To run the simulation, user has to enter power plant data separately for each plant and need to set parameters according to the Figure.8.

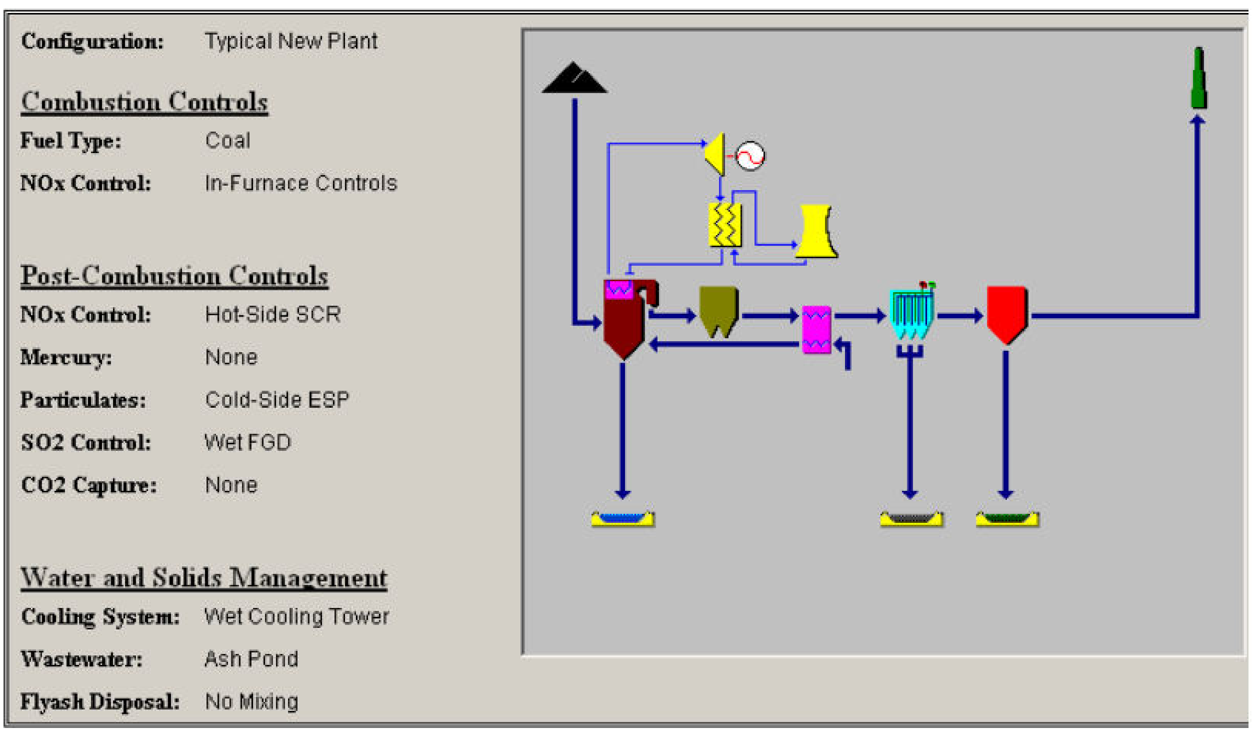

Figure 8 : Parameter setting of the software

4.1.1 Validation of coal emission figures of base plants

We first simulated base plants that are without considering any CCS technology, to estimate the CO_2 emission figures. CO_2 emission figures of few power plants are shown in Table 5. CO_2emission values that have been published by Ceylon Electricity Board (CEB) are also included on the table to compare with our simulation results [11]. Data shows a good compatibility by validating results obtained from IECM software.

Table 5: Comparison of simulation results of CO_2 emission of base plants with CEB emission figures

Source: CEB long term generation plan 2018 - 2037

Source	Capacity (MW)	CEB (kg/kWh)	IECM Software (kg/kWh)
Puttalam Coal I	300	0.9858	0.9832
Puttalam Coal II	300	0.9419	0.9461
Puttalam Coal III	300	0.9419	0.9461
Uthuru Janani	26	0.9493	0.9432

4.1.2 Other simulation results

With the implementation of CCS technology, resource usage will be increased and harmful gaseous emissions will be decreased. In this analysis, we try to estimate the changes in fuel consumption, water consumption, particulate emissions, and as well as gaseous emissions for different CCS technologies for different thermal power stations. Table 6 summarizes the results of 900 MW Lakvijaya coal power plant for without (base) and with different CCS technologies.

Table 6 : Results of Lakvijaya coal power plant (900 MW) with and without CCS technology

	Base	Amine	Ammonia	Membrane	Oxy-fuel
Coal	0.359	0.42	0.46	0.46	0.45
Sorbent	0	1.195×10^{-4}	4.52×10^{-4}	0	0
Activated Carbon	0	10.34×10^{-3}	0	0	0
Bottom Ash Disposed	4.83×10^{-2}	8.21×10^{-2}	8.52×10^{-3}	7.32×10^{-2}	9.13×10^{-2}
Fly Ash Disposed	0.3	0.38	0.38	0.4	0.4
Scrubber Solids Disposed	0	1.49×10^{-3}	7.02×10^{-3}	0	0
Particulate Emissions to Air	8.17×10^{-3}	9.41×10^{-4}	0	0	0.8×10^{-4}
CO_2 emission	0.9832	0.01	0.01	0.01	0.02
SO_2 emission	10.1×10^{-3}	6.56×10^{-7}	6.15×10^{-5}	6.02×10^{-7}	6.16×10^{-2}
NO emission	2.12×10^{-3}	1.15×10^{-3}	1.04×10^{-3}	1.01×10^{-3}	1.16×10^{-3}
NO_2 emission	1.25×10^{-4}	2.12×10^{-4}	2.07×10^{-3}	2.07×10^{-6}	2.15×10^{-4}
HCl generated	0.56×10^{-4}	2.00×10^{-5}	2.01×10^{-3}	2.06×10^{-6}	2.06×10^{-4}
					All in kg/kWh

4.1.2.1 Water usage

In thermal power plants, the heat is expelled from the thermal cycle by passing through a condenser. The heat of used steam passed through the condenser is cooled by water. This cooling water is normally released to a stream, a repository or to sea. Change of total water requirement of different thermal power plants for different CCS technologies compared with base plant is shown in Figure 9.

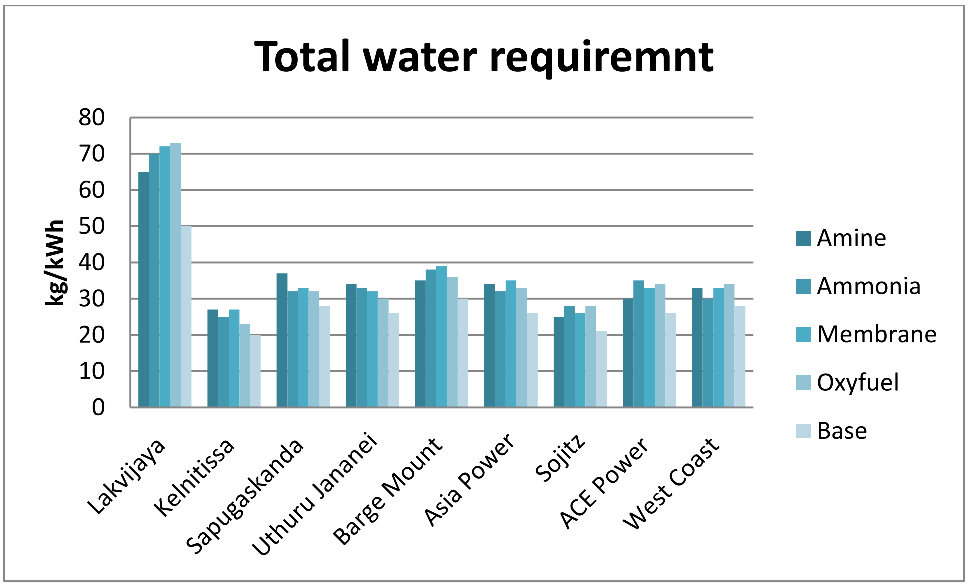

Figure 9 : Total water discharge of different thermal power plants for different CCS technologies

As shown in the figure, there is a considerable increase of cooling water consumption for different capture technologies compared with base plants, notably in coal power plant. Water requirement will increase by implementing CCS technologies, because it requires additional amounts of water for chemical and physical processes to capture and separate large volumes of CO_2. The water used by the power plant depend on the internal factors in the power plant such as boiler efficiency, turbine efficiency, fuel type and the fuel medium as well.

If we consider Lakvijaya power plant, the total requirement of water is higher for all amine,ammonia,oxy-fuel and membrane-based capture. It shows the lowest increase of water consumption ~30% for the amine based capture and the highest increase of ~46% for the oxy-fuel based capture. As Lakvijaya power plant uses sea water for cooling, increase of water consumption will increase the sea water purification cost as well. Therefore, in the case of total water consumption, amine based CCS technology is most suitable for the Lakvijaya coal power plant. For all other power plants too we can select the most economical CCS technology by considering cooling water requirement. References [7 and 21] will show that water use is almost doubled when CCS technology is implemented, however, in our case it's bit lower, that may be attributed to the differences in technology of plants, the fuel quality, and some other internal factors as well.

4.1.2.2 Fuel consumption

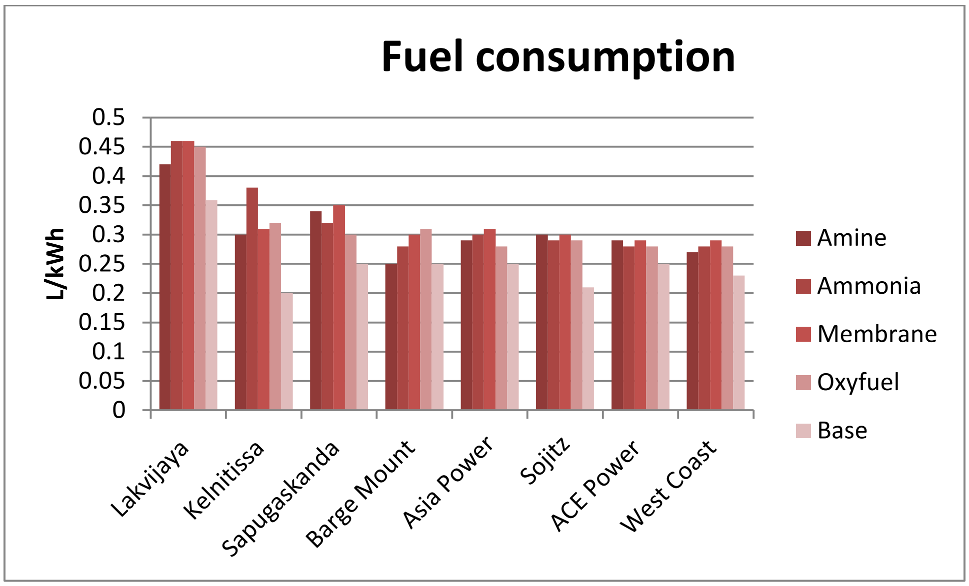

Figure 10 :Fuel consumption of different thermal power plants for different CCS technologies

Figure 10 shows the fuel consumption of different thermal power plants for without CCS technology and for different CCS technologies. We can see fuel consumption has been increased by a very large margin for all technologies. For coal power plant there is an increase of about 16-28%. Highest fuel consumption there is for ammonia based capture. Our results indicate that the fuel consumption is getting increased considerably for all the CCS technologies. The increase in coal or other thermal fuel not only results in higher cost but also for the faster exploitation of non-renewable sources. In the reference [7], the increase of coal requirement with implementing CCS technology is around 40 - 50%. But in our results it's bit lower, may be due to the differences of technology, fuel quality and some other internal factors as well.

4.1.2.3 CO_2 emission

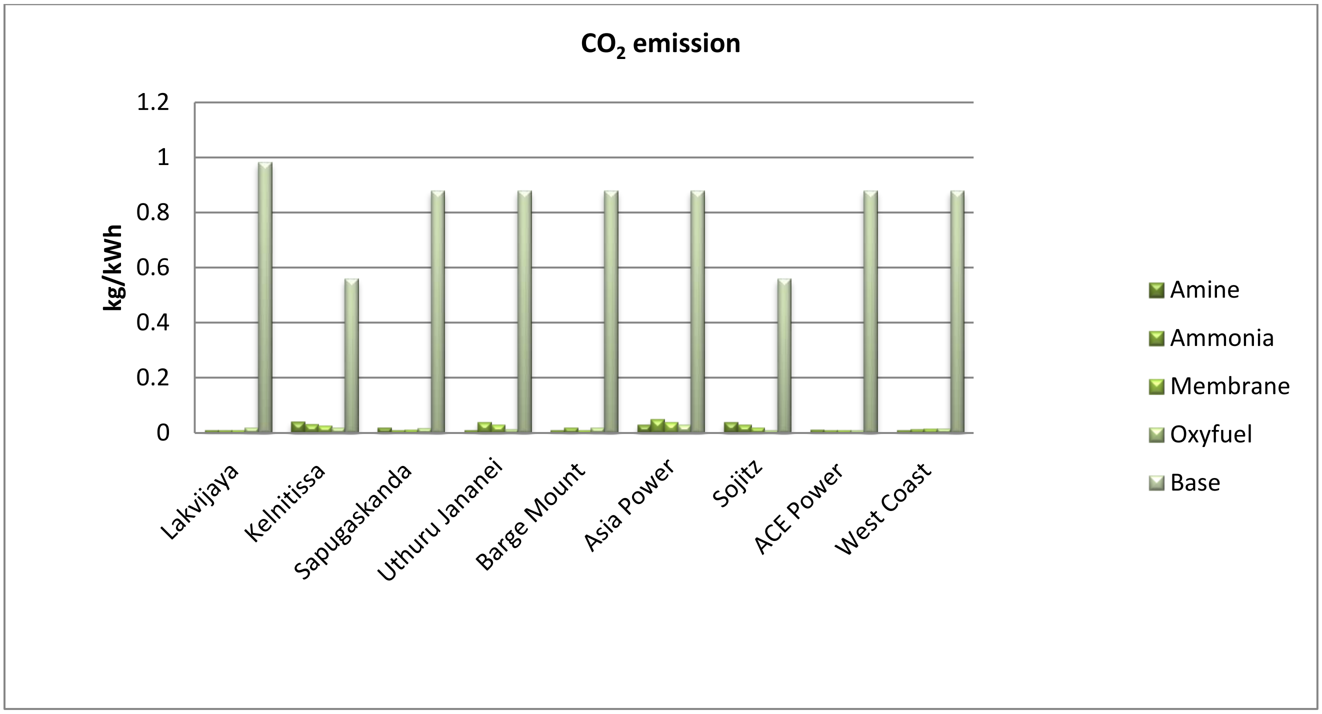

Figure 11 : CO_2 emission of different thermal power plants for different technologies

CO_2 emission in the Lakvijaya coal power plant is nearly 1 kg/kWh. For other thermal power plants, it is bit lower as shown in Figure 11. According to the simulation results, emission is varying from ~ 98% for all different CCS technologies implemented in the coal power plant. For all other power plants, emission figures are varying from ~90-97% for different technologies as shown in the Table 7. Therefore, it is clear that, with the best selected method it is possible to reduce CO_2 emission to > 90% up to near 100% in all of the thermal power plants.

The capture efficiency is considered almost equal in all capture technologies. But there can be small difference due to the power plant internal factors such as coal quality, plant factor, fuel quality and so on.

4.1.2.4 Other emissions and particulate production

The base debris and fly debris are increased pretty much as the expansion in coal utilization, which is normal as they are resulted by the coal ignition and in this manner their outflows are straightforwardly corresponding to the coal usage. The sorbent and scrubber solids arrangements are irrelevant for the dissolvable based procedures. Nonetheless, it may have a business task to carry out if the waste transfer cost of the zone is high. Particulate discharges are lower than base case. Layer and smelling salts based catch produces zero particulate outflows because of the channels put in. Amine based catch lessens around 25-30% discharges while oxy-fuel diminishes these by around 77%.Some key variables which can influence the exhibition of CCS are heater effectiveness, coal quality, CO_2 item weight and catch productivity. In this examination those parameters were not considered.

4.1.3 Most suitable CCS technology

Table 7: Summary of all different power plants

Power plant	CO_2 emission reduction (%)	Coal or Oil consumption Increase (%)	Total water req. increase (%)
Coal			
Lakvijaya	97-98	16-28	30-46
Oil			
Kelanitissa	95-96	50-90	15-35
Sapugaskanda	97-98	20-40	14-32
Uthuru Janani	98	14-25	15-30
Barge Mounted	97-98	2-24	16-30
Asia Power	98	10-24	23-34
SojitzKelanitissa	92-98	38-42	19-33
ACE power	98	12-16	15-34
West coast	98	17-26	11-26

We can propose the most suitable CCS technology by analyzing above simulation results. For that we rely on highest reduction of CO_2 emission and lowest increase of requirements of environmental resources, fuel and water. Table 7 summarizes the reduction of CO_2emission, increase of fuel consumption and increase of total water requirement for all thermal power plants considering four CCS technologies, amine, ammonia, membrane and oxy-fuel based carbon capture.

Figures of three parameters, decrease of CO_2emission, increase of fuel consumption and increase of total water requirement, are varying among power plants. Therefore, we can propose most suitable technology for different power plants individually considering most critical parameter on each plant. As CO_2emissionsare almost same for all CCS technologies, we can only rely on two parameters, increase of water and fuel requirement for different technologies, at this analysis. Most critical parameter/s were decided by estimating the economic value of two parameters, the water increment and fuel increment. This was done with referring to CEB statistical report [20] and USA Environmental report [18]. Based on those references, 0.24 LKR/Liter was used as the cost of waste water treatment in my calculations.

Table 8 summarizes the most suitable technology that we propose based on our analysis for different thermal power plants in Sri Lanka.

Table 8 : Suitable technology for different thermal power plants in Sri Lanka

Power Plant Name	**Economical value of fuel increment LKR/kWh**	**Economical value of water increment LKR/kWh**	**Selected Technology**
Lakvijaya	2.1	5.52	Amine
Kelanitissa	17.7	1.68	Oxy-fuel
Sapugaskanda	12.4	2.16	Ammonia
Uthuru Janani	11.5	1.92	Oxy-fuel
Barge Mounted	10.6	2.16	Amine
Asia Power Ltd	7.1	1.92	Ammonia
Sojitz Kelanitissa	18.6	1.68	Amine
ACE Power Embilipitiya	5.3	2.16	Amine
West Coast	11.5	1.44	Ammonia

Chapter 5

5. 0 Cost Analysis

5.1Technology implementation, transportation & storage cost

CCS holds extraordinary guarantee that it can catch ~ 90% of the carbon outflows created from non-renewable energy sources. Whenever conveyed with inexhaustible biomass, the technique is additionally one of only a handful not many carbon decrease advancements that can be carbon negative, attempting to separate carbon dioxide from the air. While expenses of various CCS ventures differ contingent upon the wellspring of the carbon caught, the separation to the capacity site, and the idea of the capacity site itself, capture is regularly the costliest piece of the CCS procedure. In that capacity, a significant part of the present CCS improvement is worried about bringing down the expense of this component.

The Carbon Capture and Storage Association (CCSA) assessed that the prior CCS extends in the plant area would cost between \$60–\$90 per ton of carbon dioxide lessened, the likeness around per ton. The affiliation likewise anticipated that these costs will decrease to \$35–\$50 in the mid-2020s, thanks to the technology advancement.

Table 9 : Technology implementation cost and transportation & storage cost

Option	Technology Cost (million USD)	Storage and Transportation Cost (million USD)
Lakvijaya	1303	5.04
Kelanitissa	432	0.34
Sapugaskanda	192	0.92
Uthuru Janani	29	2.75
Barge Mounted Plant	72	0.002
Asia Power Ltd	60	0.46
SojitzKelanitissa	204	0.002
ACE Power Embilipitiya	120	0.009
West Coast	360	0.002
Total	2772	9.68

Table 9 shows the costs for technology implementation, and transportation and storage for different power plants. These cost figures were estimated based on reference [19].Therefore, the total cost to implement CCS technology in Sri Lankan thermal power sector would be around 2800 million USD and transport and storage cost would be ~10 million USD per year.

5.2The economic benefit by reducing CO_2 emission to the environment

There is no direct method to calculate economic benefit by reducing CO_2 emission. Therefore, to calculate the economic benefit to the environment through the reduction of carbon emission, the values obtained on the reduction of CO_2emissions are converted into values of ‘carbon credits’. Therefore ‘carbon pricing’ has been evolved as a market based strategy for lowering global warming emissions.

A carbon price is a cost applied to carbon pollution to encourage polluters to reduce the amount of greenhouse gases they emit into the atmosphere. Economists widely agree that introducing a carbon price is the single most effective way for countries to reduce their emissions. The costs of climate impacts and the opportunities for low carbon energy options are better reflected in our production and consumption choices through that.

According to the World Bank refreshed the appraisals of the welfare estimation of passing from surrounding air contamination to 2013 utilizing the GBD 2013. Since the assessed worldwide passing from encompassing air contamination announced in GBD 2013 added up to 2.8 million (inferable from the advancement of the hidden information and strategies for estimation), the low-end appraisals for 2010 detailed here are generally equivalent to the focal evaluations of the World Bank.

To put the potential maintained a strategic distance from harms from air contamination into point of view it is helpful to think about the latest gauge of the social expense of carbon by the US Interagency Working Group, which was given as US$36 per tCO_2 in 2015.

In the event that legislatures presented a carbon assessment of $50 per tCO_2, at that point the negligible expense of lessening 1 tCO_2 over the economy would approach this figure (and normal expenses would be lower). The lower bound of the normal maintained a strategic distance from PM2.5 harms per tCO_2 decreased is easily above $36 in everything except two of the enormous producers. They prescribed that a carbon cost of $50-$100 by 2030, is steady with the center goal of the Paris Agreement of keeping temperature ascend beneath 2 degrees. The investigation in the multiple advantages report of co-profits by ozone depleting substance relief in 2030, in light of the demonstrating writing, exhibits a comparable picture. The worldwide air contamination co-benefits in 2030 of relief situations focusing on 2°–2.4°C warming before the century's over lie in the scope of $49–214 for every tCO_2-proportional subsided.

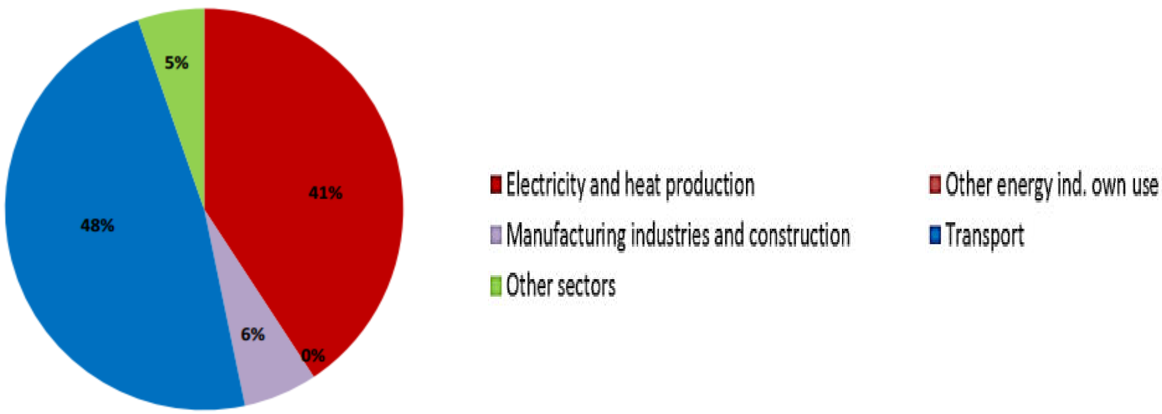

Figure 12 : CO_2 emission from fuel combustion [9]

The total annual CO_2 emission in Sri Lanka is ~ 16.7 Million tons, which is approximately 0.05 % of the total CO_2 emissions generated in the World. According to Figure 12 contribution of electricity sector for carbon emission is ~ 41%. That is ~ 6.85 million tons of CO_2 are annually adding to the environment from the electricity sector. It is to be noted that even though electricity sector is the major contributor for emissions in the world, the transport sector shows the highest emissions in Sri Lanka.

To calculate economic value of carbon reduction, we take 50 USD [17] as the carbon value per one ton of carbon according to the current world market.

Sri Lankan annual CO_2 Emissions (2016) = 16.74 (Million tons)

→ CO_2 Emissions due to Electricity and heat production = 16.74* 0.41 = 6.8634 (Million tons)

→ Other CO_2 Emissions = 9.9 Million tons

CO_2 reduction per year = 6.4 (Million tons)

(Considering average carbon emission reduction of 93 %)

Carbon tax = 50USD per Ton

Total environmental economic benefit = 320 Million USD per year

Therefore, by implementing CCS technology in the Sri Lankan thermal power sector, it results an environmental economic benefit value of 320 million USD per year.

5.3 Increase of generation cost with implemented CCS technology

Here we are going to address the effect of implementation of CCS technology on the unit price of electricity.

Source: *CEB long term generation plan 2018-2037*

Table 10 : Generation price of electricity without CCS technology [11]

Technology	Fuel Cost Rs. Million	Spare & Other Maintains Cost Rs. Million	Other Operation Cost Rs. Million	Total Generation Cost Rs. Million	Units GWh	Average Cost of Generation per unit Rs/kWh
Thermal Oil	49,516	1,677	6,406	57,598	2,360	24.40
Thermal Coal	20,762	762	11,977	33,502	5,067	6.61
Total	**70,278**	**2,439**	**18,383**	**91,100**	**7,427**	**12.26**

Generation Price of the Electricity = 12.26 LKR/kWh

Table 11 : Generation cost of electricity considering CCS technology implementation, transportation and storage cost

Technology	CCS technology Cost Rs. Million	Fuel Cost Rs. Million	Spare & Other Maintains Cost Rs. Million	Other Operation Cost Rs. Million	Total Generation Cost Rs. Million	Units GWh	Average Cost of Generation per unit Rs/kWh
Thermal Oil	264,420	63,380.5	1,677	6,406	86,228	2,360	36.5
Thermal Coal	234,540	26,990.6	762	11,977	50,018	5,067	9.8
Total	**498,960**	**91,371.1**	**2,803**	**26,363**	**618,497.1**	**7,427**	**83.3**

Generation Price of the Electricity with CCS = 83LKR/kWh

Table 12 : Generation cost of electricity considering only CO_2 transportation and storage cost

Technology	CCS technology storage and transmission Rs.Million	Fuel Cost Rs. Million	Spare & Other Maintains Cost Rs. Million	Other Operation Cost Rs. Million	Total Generation Cost Rs. Million	Units GWh	Average Cost of Generation per unit Rs/kWh
Thermal Oil	858.4	63,380.5	1677	6,406	70,836.4	2,360	30.01
Thermal Coal	932.4	26,990.6	762	11,977	41,700.4	5,067	8.2
Total	**1,790.8**	**91,371.1**	**2,803**	**26,363**	**122,327.9**	**7,427**	**16.47**

Generation Price of the Electricity with CCS = 16.47 Rs/kWh

According to CEB annual report, the generation cost of electricity in Sri Lanka is 12.26 LKR/kWh, as shown in Table 10.

Next we calculated the unit price of electricity considering CCS implementation, transportation and storage cost. Then unit price will increase up to 83LKR/kWh. However, the technology implementation cost is only once in lifetime cost.

Finally, we calculated the unit cost by considering only CO_2transportation and storage cost, after implementing the CCS technology. Then the unit price is 16.47 LKR/kWh as shown in Table 12.

Economic benefit due to reduction of CO_2 emission was not considered in these calculations. If it is considered, the unit cost will reduce considerably.

Here we considered 1 USD = 185 Rs in all of these calculations.

5.4 Cost analysis using project management theory

According to above calculations, it is clear that a big capital investment is required to implement CCS technology in Sri Lankan electricity sector to change it to a carbon free clean sector. As there would be no capital to invest directly, we did an IRR (internal rate of return) analysis to identify most suitable financial options for this project.

Comparison between project IRR and equity IRR helps to understand the project feasibility. Generally, Equity IRR is more than project IRR. However, the equity IRR will be lower than the project IRR whenever the cost of debt exceeds the project IRR. The option with the most noteworthy IRR would likely be viewed as the best and be embraced one.

Therefore, to determine the most suitable loan option, we compared different possible loan options as shown in Table 13. The project IRR takes as its inflows the full amount(s) of money that are needed in the project. The calculation assumes that no debt is used for the project. Equity IRR assumes that we use debt for the project, so the inflows are the cash flows required minus any debt that was raised for the project.

Table 13 Properties of different loan options to cover the implementation cost of CCS technology

Case Number	Project IRR	Equity IRR	Description
1	-6.12 %	5.35%	10 years loan period (Debt to equity ratio =75 : 25) , Interest rate = 4%
2	-6.07%	6.33%	5 years loan period(Debt to equity ratio =75 : 25) Interest rate = 4%
3	-6.62%	3.18%	10 years loan period (Debt to equity ratio =50 : 50) Interest rate = 4%
4	-6.53%	5.11%	5 years loan period (Debt to equity ratio =50: 50) Interest rate = 4%
5	-6.72%	5.63%	20 years loan period (Debt to equity ratio =75 : 25) Interest rate = 4%

As shown in Table 13, we considered 5 options. Case 1 is 10 years loan period with 75:25 debt to equity ratio and case 2 is 5 years loan period with 75:25 debt to equity ratio and so on. Calculated project IRR and Equity IRR values are given in each case. Highest Equity IRR and lowest project IRR represents most economic project. Therefore, from our case study, the best suitable option is the Case 2, that is 5 years loan period with 75:25 debt to equity ratio.

Discussion

In this study we tried to analyze the feasibility of implementing CCS technology in the Sri Lankan thermal power sector. This technology is being evolved in many countries to capture CO_2 to reduce the greenhouse gas emissions to the environment. However, this is highly resource intensive and therefore needed to study the impacts beforehand. Therefore, to the best of our knowledge, as the first study about CCS technology in Sri Lanka, we tried to address some key factors related to the implementation.

First we obtained the base plant CO_2 emission data using IECM software that used in this study for all power plant simulations, and validated using CEB data as shown in Table 5 under 4.1.1.

As there is no any prior work in Sri Lanka, we don't have data to validate other results. So we use similar capacity CCS projects that have been done in some other countries. Although some of the factors are different than us, we can approximately validate the Sri Lankan power plants with CCS technology using data of studies in some other countries and TransAlta Corporation (TransAlta), a Global CCS Institute as a Knowledge Sharing Partner [22].

Task Pioneer was being proposed to catch 1 million tons of carbon dioxide (CO_2) every year from a coal terminated power plant and to ship the CO_2 by pipeline to a sequestration site or to be used for improved oil recuperation (EOR) in a drained oil/gas field. In Sri Lanka our annual carbon emission due to electricity is around 7 million tons. In their project they would be able to decrease their emission around 90%.According to our simulation results also, CCS technology allows to reduce our power plant emission to more than 90% .

As indicated by International Energy Agency request, CCS should lead some way or another one fifth of outflows decreases, crosswise over both power and modern divisions, so CCS has a significant job as influence of a monetarily manageable approach to meet atmosphere moderation objectives inside the 2050 time period, that simultaneously guaranteeing worldwide and provincial vitality security.

Industrial point sources of CO_2 emissions in Sri Lanka

Sri Lanka's complete yearly CO_2emissions are assessed to have been 16.74 Mt in 2016 .The complete yearly emissions of CO_2 from huge point sources in Sri Lanka are extremely little, and assessed to be around 2.6 Mt. They get for the most part from 6 oil-terminated power plants, a processing plant and a cement plant. They will be expanded by the activity of new coal-terminated power plant, yet national emissions will even now be exceptionally little in worldwide terms.

Potential geographical CO_2 stockpiling locales in Sri Lanka

The greater part of inland Sri Lanka is comprised of Precambrian crystalline rocks with no CO_2 stockpiling potential. The main noteworthy advancement of sedimentary shakes inland is along the NW coast, where Miocene limestone overlies the Precambrian storm cellar. There are no critical coal stores known in Sri Lanka. No oil fields or gas fields have been found to date, yet there is oil and gas potential in the Sri Lankan side of the Cauvery Basin, seaward toward the north of the island, in Palk Bay and the Gulf of Mannar. There might be some saline spring CO_2 stockpiling limit here also, yet it can't be evaluated at present.

Coordinating CO_2 sources and potential geographical CO_2 stockpiling locales in Sri Lanka

The main potential topographical CO_2 stockpiling destinations are seaward to the N and W of the island. The capacity limit around there can't be measured at present, so no gauge of the capacity potential comparative with national outflows from huge point sources can be made. Notwithstanding, the new coal-terminated power plant under development at Norochcholai is moderately very much set as for the surmised $_{CO2}$ stockpiling potential in the Cauvery Basin.

Appropriate innovation for control plants

IECM programming gave the most reasonable CCS innovation that can actualize in the diverse power plants in Sri Lanka. To actualize the above innovation there various sorts of realities that need to consider. In the wake of considering each one of those components above reproduction results were taken.

Conclusion

A worldwide temperature alteration is the consequence of increment in the world's normal surface temperature because of ozone depleting substances like carbon dioxide and methane. It is continually bringing about extraordinary high temperature of the surface, decrease of snow spread, and ascends in the water level and the expanding human exercises are significantly adding to the reason for an unnatural weather change.

This research mainly concerned about how to reduce the carbon emission in electricity sector in Sri Lanka. To achieve this there are several ways that we can think. Reduction in coal and oil usage and implementation of carbon capture technology are some of the available technologies in nowadays. CCS technology is considered globally as a better way to lessen carbon emission. However, this is a costly technique and resource usages are also increasing considerably, that vary from country to county. Therefore, here we have attempted to analyze the feasibility of CCS technology to thermal power sector in Sri Lanka in terms of technology and cost.

I used IECM free software to analyze thermal power plants in this study. All thermal power plants were analyzed using the simulation software for different CCS capture technologies and by analyzing reduction of carbon emission and least increase of resource usage (fuel consumption and water requirement) We proposed most suitable technology for Sri Lanka. But for different power plants different factors are critically affected and therefore based on that different capture technologies were proposed for different power pants. As to our simulation results > 90% carbon capture is possible with those different technologies.

After technological analysis, my focus was on cost analysis. According to estimated calculations the total implementation cost of CCS technology in thermal power sector in Sri Lanka was estimated to about 2800 million USD. Transportation and storage cost was estimated to ~10 million USD per year.

Annual carbon emission in Sri Lankan thermal power sector is estimated to about 6.9 Mtonnes. By assuming 93% carbon reduction due to CCS technology, we calculated environmental economic benefit value. Here a carbon value of 50 USD per ton was assumed according to the current world market. Then the economic benefit value is 320 miliion USD per year due to implementation of the CCS technology. That means the total capital expenses of technology is recovered by less than 9 years by considering environmental benefits.

I also focused on the effect on unit generation cost of electricity due to technology implementation. Not only the technology cost, but also increase of resources usage with the technology is also affecting it. According to CEB data, the unit cost of generation is 12.26 LKR/kWh. When consider CCS technology implementation cost, CO_2 transportation and storage cost, and resource increase cost due to CCS technology, without taking effect the environmental benefit value, the unit cost of generation increased to ~83 LKR/kWh.

However, as the implementation cost is only once cost, then we calculated the unit generation cost by considering only resource increase and the cost of CO_2transportation and storage only. If environmental benefit is not considered, then unit cost is ~16.47 LKR/kWh in this consideration. Consideration of the environmental benefit value will considerably lower the cost than the general unit cost.

Finally, we did a project analysis to propose a funding method to implement the CCS technology in Sri Lankan thermal power sector. By analyzing project IRR and equity IRR for different funding options, the best suitable option was identified as a 5 years loan period with 75:25 debt to equity ratio.

As a conclusion, as the first study about CCS technology in the Sri Lankan scale, we proposed most suitable CCS technologies for different thermal power plants. We also did cost estimation for technology implementation and environmental benefit to the society by stopping the release of carbon to the environment. From our study we would propose CCS technology as a viable technology to Sri Lanka, but more detailed analysis is required before hand.

Through its Intended Nationally Determined Contribution (INDC), Sri Lanka communicates its intent to reduce GHG emissions unconditionally by 7% by 2030 compared to a business-as-usual scenario (with 2010 as a base year), achieving 4% from energy and 3% from other sectors. It commits to a more ambitious, conditional reduction of 23% that would increase reductions from energy to 16%, and 7% from other sectors. The unconditional energy target could be met through the implementation of non-conventional renewable energy sources projects including mini and micro hydro, wind and solar farms. The conditional target would require future support for the non-conventional renewable. Reductions from other sectors would consist of activities in the transport, waste, industrial, and forestry sectors, with detailed plans yet to be completed.

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