An SDG-Based Design Evaluation of Supercritical Sahiwal Coal-Fired Power Plant

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***Abstract*—Energy is the basic necessity of modern living; however, its production has raised concerns about Earth's prosperity and sustainability, as almost 81% of energy is being produced from the burning of fossil fuels. This adds a major portion of carbon dioxide to the environment, resulting in global warming. Therefore, United Nations member states have devised 17 Sustainable Development Goals (SDGs) to move the world towards a sustainable future. On one side, it is important to replace non-renewable energy resources with renewable ones, and on the other side, we need to evaluate conventional power plants for their conformance with UN SDGs. In the same context, the Sahiwal coal-fired power plant (SCPP) is one of the flagship power-sector projects that has been completed under the China-Pakistan Economic Corridor (CPEC). SCPP serves as one of the main sources of electrical power generation in Pakistan. This paper evaluates the supercritical SCPP from the standpoint of assessing its conformance to UN's SDGs. Specifically, it focuses on SDG numbers 7, 11, and 13, which involve evaluating harmful emissions, performance, and operating parameters. The evaluation also includes thermodynamic cycle analysis, coal analysis, and plant economics of a 660MW supercritical cogeneration unit. The analysis and evaluation provided in this paper offer insights into the degree of compliance of SCPP with UN SDGs and propose measures for further improvements in this regard. Additionally, a comparative study has been included in this paper, comparing SCPP with two other supercritical coal-fired power plants.**

Keywords— UN SDGs, Sahiwal coal fired power plant, supercritical power plant, cycle analysis, cogeneration, plant economics, coal analysis.

I. INTRODUCTION

The prosperity of world populace depends on sustainable development. However, the industrial revolution, in the 17th century, mainly boosted the use of fossil fuel burning for energy production. On one hand, it helped the world in industrial development while on the other hand it raised major concerns regarding the sustainability of the Earth's environment. To address this issue, 195 countries agreed to work collectively to keep the global warming temperature to well below 2 degree centigrade [1]. In this context, United Nations member states adopted a 2030 agenda for sustainable development. The main gist of 2030 sustainable development agenda are the 17 United Nations Sustainable Development Goals (UN SDGs) are interconnected with each other and provide an outline for the global partnership between developed and developing nations to achieve global sustainability and prosperity by working for common goals. The Earth's environment does not influence only a single nation rather it has significant impact on the entire world which raises serious concerns about its prosperity. Off the many reasons that plague the usage of non-renewable fuels, the most central is the addition of carbon dioxide in our environment. However, despite the continuing efforts for reduction of greenhouse gases, still almost 81% of world's energy is being produced by burning of fossil fuels which is the major contributor of carbon dioxide in the atmosphere [2].

A major part of fossil fuel burning takes place in power plants for energy production. This makes them the major affecters of all SDGs. The situation in developing economies is even more paradoxical where provision of clean and green power production must be balanced with rising cost of energy. The situation is equally crucial, in Pakistan, which remains a full signatory of the UN SDGs with ever increasing energy costs. Therefore, the implementation of the UN agendas is as much applicable to Pakistan's energy sector as to any other country. In the same context, Sahiwal coal fired power plant (SCPP), which is considered to be one of the most cleaner of coal-fired power plant in the world [1], has been installed under CPEC. Its construction was started in July 2015 and was scheduled to be inaugurated in June 2017; however, the plant was inaugurated 22 days before its schedule. It was built in Punjab near the city of Sahiwal. An estimate of 1.912 billion dollars were invested to build this plant which was financed by two renowned companies of China: Huaneng Shandong and Shandong Ruyi Technology Group Ltd. The plant was installed with a total capacity of 1320MW which consists of 2 x 660 MW coal-fired units. It was the first ever plant of Pakistan that utilized advanced super-critical technology not only enhancing the plant's efficiency up to 45-47% but also generating 2-3% less carbon dioxide gas [2]. The plant uses imported coal to generate electricity. The South African imported bituminous coal and Indonesian sub-bituminous coal are blended in equal quantities. This high-quality imported coal produces less amount of ash; therefore, the fuel is burned far more efficiently compared to locally available sub-bituminous types, to generate heat that is exploited by the plant to generate electricity. An average of 11000 tons of coal is utilized daily by the plant which is delivered from port Qasim Karachi to Yousaf wala station of Pakistan through five railway freight wagons, each carrying 2500 tons of coal. The plant has two coal yards. One is inside the plant that has a storing capacity of 370,000 tons of coal which is enough for a month. Another coal yard is situated in Karachi with a storage capacity of 250,000 tons of coal [3]. Overall, the plant has the capability to generate 9 billion kWh of electricity yearly, which meets the demand of approximately ten million households.

In addition to consuming nonrenewable sources, the wastewater discharge by the plant is treated so that it can be reused by the plant itself. Tree plantation is another drive initiated during the construction of Sahiwal plant to optimize the ecological environment by planting thirty thousand trees. While being one of the cleaner coal-fired power plants in the world it still raises major concerns to environmental sustainability. Since this issue is of significant importance, it is inevitable to analyze the operating and performance characteristics of SCPP, to assess its viability from the standpoint of specific UN SDGs attainment. It has been identified that this evaluation is closely dependent on three SDGs that are SDG#7 (Affordable and Clean Energy), SDG#11 (Sustainable Cities and Communities), and SDG#13 (Climate Action). Where SDG#7 mainly refers to energy efficiency, universal access of energy, and enhancement of renewable energy contribution in energy production. This is the most important SDG on which our evaluation is based. Whereas SDG#11 targets sustainable, safe, and reliable communities. As energy is the most basic necessity for modern living, therefore it is substantially important to enhance its access and efficiency. Hence, the assessment of SCPP for this SDG is important. Finally, the SDG#13 requires the world to take actions to combat climate change and its impacts. As SCPP is a coal-fired power plant, it can have substantial impact on the environment unless sufficient remedial measures are in place, this makes it important to evaluate the plant against this SDG. In this paper the performance and operation of SCPP is thus evaluated from the standpoint of verifying the extent to which the plant is able to satisfy UN SDGs. Table I shows the assessment scheme of the plant against the selected UNSDGs.

II. Overview Of Coal-Fired Power Plants

As coal is one of the most important non-renewable fuels, it will continue to play a substantial role in electricity generation. Although burning of coal affects the environment, it can be overcome by enhancing the efficiency of the power plant. Pakistan is a developing country and with increasing population, electricity needs are climbing every day. Therefore, under the CPEC project Pakistan has installed several power plants in different regions of the country. SCPP is one of the crucial projects for meeting high energy demands while maintaining sustainable energy production. Analysis of such projects is pivotal for future commitments. Moreover, life cycle assessment (LCA) of plants plays an essential part for the promotion of a sustainable development [4]. Life cycle assessment of SCPP has been conducted which proves the relative efficiency of the plant with implementation of super critical technology [1, 5]. Climate change potential for the plant's operation stage accounts for 84% while coal transportation takes up 16%. Moreover, an assessment of a similar pulverized coal fired power plant depicted a 3% decrement of CO_2 for 1% increment in plant efficiency [6]. HoSoto & Vergara [7] has designed an ocean thermal energy conversion (OTEC) hybrid plant to enhance the efficiency of existing 740 MW coal-fired power plant. Authors have presented a thermodynamic cycle. The heat source of OTEC plant has been taken as the waste heat rejected by the existing power plant. It has been found that efficiency of coal-fired power plant increases by 1.3% when OTEC has been utilized. Xu et al. [8] has proposed that removing the moisture content of coal can enhance the energy efficiency of the power plant. It has been found that an increase of about 0.6-0.9% has been achieved, in net efficiency of the coal-fired power plant. Espatolero et al. [9] have utilized thermodynamic and economic approaches to enhance the efficiency of supercritical units in a power plant. Authors` have focused on strategy for flue gas heat recovery system and optimization of feedwater heaters network to enhance efficiency. Furthermore, sequential quadratic programming method has been used for optimization and Aspen Plus software for simulation. It has been concluded that there is an increase in the power plant efficiency and cost analysis has shown that this concept is profitable if applied. Maruf et al. [10] have studied the improvement in the efficiency and permanence in power production domain. While investigating various plant consuming different types of fuel for generating power in Bangladesh for the period of 2009-19, it has been revealed that the performance and efficiency parameters of plants are greatly influenced by lack of maintenance. Moreover, juxtapose of exergy parameters such as climate change impact potential and other parameters. It has been further concluded that hydro-power plants are extremely economical and ecologically friendly compared to conventional thermal plants. As coal-fired power plants add considerable amounts of carbon dioxide to the environment, carbon capturing techniques can be employed to solve this issue for production of energy through coal-fired power plants.

Olabi et al. [11] has evaluated the role of carbon capture before a combustion process to achieve sustained development goals. The study shows a substantial increase in the utilization of fossil fuel in today's world leading to a global environmental and greenhouse effect. Therefore, a detailed analysis and discussion is conducted on carbon capture technology (CCT) that can be seamlessly tailored with all 17 SDGs. Health issues including breathing problems are most common among developing countries. For this purpose, Goodarzi et al. [12] have conducted an investigation on the fine particles emitted from the stack of the coal power plants (CPP). To capture and subsidize this environmental as well as human respiratory hazard, an electrostatic precipitator (ESP) technique was planned to be adhered to the plant as a remedial solution in maintaining the atmosphere. To undertake the design evaluation of a functioning plant is a tedious process. However, for the purpose of assessing the attainment of SDGs, the computations as well as the schematics and thermodynamics T-s diagram can be appropriately simplified. There are several non-dimensional powerplant parameters that can be assumed beforehand for the purpose of evaluation of plant performance. Additionally, the published SCPP (powerplant) parameters have been acquired from open sources as well as research papers [2, 13-15].

TABLE I. ASSESSMENT SCHEME OF THE SCPP AGAINST THE SELECTED UN SDGS NUMBER 7,11, AND 13.

Sustainable Development Goal	**Goals**	**Evaluation Criteria**
SDG#7 (Affordable and clean energy)	Access to affordable, reliable, and modern energy services Increase substantially the share of renewable energy Improvement in energy efficiency	**Affordability:** Unit cost of electricity of selected power plant **Reliability:** Plant utility factor, operating factor, capacity factor **Availability**: Proportion of population with clean access to electricity **Renewability:** Analyze briefly the plant by selecting any alternative fuel and state the performance parameters **Efficiency:** Power plant efficiencies (Thermal, Plant, Cogeneration, Optimal degree of regeneration, etc.)
SDG#11 (Sustainable Cities and Communities)	Reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.	**Environmental Impact:** Mechanism for reduction of pollution (particulate matter) and emissions from the stack tube
SDG#13 (Climate Action)	Reduction of global CO_2 emissions emitted from electricity generation	**Emissions:** Measurement of emissions **Zero-carbon emissions:** Techniques for reduction of CO_2 emissions

III. EVALUATION OF SCPP ON SDG#7 (AFFORDABLE AND CLEAN ENERGY)

The SDG#7 primarily deals with the provision of affordable, reliable and clean energy production [16]. In the case of coal power plants, it is somewhat complicated to implement, as the operating fuel for generation of power mainly depends on non-renewable resources which has a devastating effect on the environment. Therefore, focus needs to be kept on the coal power plant to provide cost-efficient and green power solutions. Conventionally, subcritical technology is being implemented in most of the power plants in Pakistan. Being one of the largest coal producer in the world [1], it is much economical for Pakistan to meet the energy requirement by its own locally produced coal. Moreover, due to changing trends in setting up of new power plants, the usage of newer technologies such as supercritical power generation on the SCPP are found to be an effective way for generation of clean energy. Hence, the efficiency of modern plants is estimated to be 11% more as compared to traditional ones. In addition, while considering the emission of SCPP, it is well below the design value and far superior to the Punjab Environmental Quality Standards (PEQS), National Environmental Quality Standards NEQS, and World Bank standard. In general, those power plants that are equipped with pulverized coal system diminishes the CO_2 emissions by 3% for every 1% gain of optimization in the thermal efficiency [1]. Liang et al. [17] have also discussed that coal-fired power plants with subcritical technology shares high impact on climate change potential than supercritical plants. If we consider the emission standards of SOx, the limits established by NEQS Pakistan, World Bank Standard, EU Standard, and Japanese Standard are 1700 mg/Nm^3, 850 mg/Nm^3, 200 mg/Nm^3, 172 mg/Nm^3, respectively. However, the SOx emission of Sahiwal Power Plant is as low as 90 mg/Nm^3, which is far below the limits set by all of the standards. Furthermore, carbon capture and storage technology are found to be of great potential in reducing the emission of CO_2 in the environment. In the study, Asante-Okyere et al. [18] stated that supercritical plant, equipped with carbon capture and sequestration (CCS) technology, narrows down the environmental impact by 71 % than plant without it. Therefore, installing this technology on SCPP will allow it to utilize domestic coal rather than the imported one which enables it to be more economical and ecological. Cebrucean et al. [19] have examined both supercritical and subcritical coal power plant with the influence of biomass and capturing technology of CO_2 to enhance the efficiency of the plant. Addition of biomass is found to be of great potential in reducing the CO_2 emission without significantly reducing the plant efficiency. Nevertheless, with the rise to 30% for biomass co-firing subsidized the plant efficiency by 1% while lessening the emission of CO_2 by 28%. Moreover, the study also concluded that supercritical coal power plants were more suitable for the environment, as their efficiency is 2.9 % greater and emission of carbon content is 6% lesser than that of sub-critical one.

This section provides the basic plant analysis, cogeneration, coal analysis, and plant economics to evaluate the plant from the standpoint of UN SDG#7 as mentioned in Table I.

A. *Plant Analysis*

The Sahiwal coal power plant consists of two identical units of 660 MWe, thereby, being capable of generating a maximum 1320 MWe for the national grid. This paper mainly focusses on the analysis of a single unit of 660 MWe plant. Fig. 1 depicts the temperature-entropy (T-s) diagram of the power plant which presents both ideal and non-ideal behavior. While Fig. 2 illustrates the schematics of the SCPP. At First, the values of enthalpies at different streams are calculated by using thermodynamic parameters from Cengel [8] and NIST tables [9], followed by the calculation of work output and the efficiencies. The efficiencies of high pressure, intermediate, and low-pressure turbines are arbitrarily affixed at industrial value of 93.33%. Terminal temperature difference (TTD) for all bleeds, is taken to be no more than 3K (ºC). In case of low-pressure heaters, saturated bled steam is added to LP heaters, while maintaining a positive TTD. Whereas, when the bleeds are extracted from superheated region then the terminal temperature difference is negative. Additionally, the efficiency of the condensate pump is arbitrarily set to industrial values of 82.5% and that of main pump is taken as 85%. After finding the enthalpies, an energy balance is applied at each feed water heater to find mass flow rate in each bleed. The total mass flow rate of steam throughout the cycle is calculated to be 588.05 kg/s. Hence, the work of turbine and pump has been found to calculate the net-work output of the plant. The heat generated by the burning of pulverized coal in SCPP is transferred to the main cycle of the plant by plate type heat exchanger. The amount of total heat added to the plant is found to be 1465628.36 KW. Therefore, efficiency of the plant cycle comes out to be 41.72 %. The gross station efficiency has been evaluated by taking the ratio of the turbine heat rate to the gross plant heat rate is found to be 64.6. Similarly, station net power is defined as the power obtained by the rotation of turbine with the deduction of internal power required by the plant itself for its auxiliary units and is found out to be 38.86 %. Table II depicts all the other necessary performance parameters to access the performance of SCPP. These parameters have been determined using the conventional thermodynamics approaches of El-Wakil [20] and Nag [21].

B. *Cogeneration*

Cogeneration is the process of generating both electricity and processing heat from a single unit. Process heat is being desired by many industries along with electrical power. It is classified into two major categories i.e., Topping and Bottoming cycle. Topping cycle is mainly focused on the generation of electricity and loss of heat as a by-product. Whereas bottoming cycle is established to generate process heat, only. In this case study, we imply cogeneration on SCPP only if it is feasible to save energy in contrast to electricity production plant only. The temperature-entropy (T-s diagram) of the cogeneration plant has been shown in Fig. 3. It consists of three turbine stages along with a throttle to reduce pressure for extraction of process heat, representing both ideal and non-ideal behavior. Similarly, the schematic diagram of cogeneration has also been presented at Fig. 4, showing a general process of the powerplant cycle. A closely-related approach is applied in the cogeneration cycle as implemented above. The enthalpies at different points are calculated using Cengel [8] and NIST steam tables [9] steam tables.

In case of 50 % of the extraction of steam acquired by throttling effect, energy balance is applied on the feed water heater to calculate the amount of process heat. The mass flow rate of steam through the cycle is about 588.08 kg/s and mass flow rate through the bleed is 294.03 kg/s. Therefore, the amount of process heat Q_h is found to be 699.321 MW. Hence, the amount of power generated by the turbine is 699.783 MW while the amount of heat added to the plant is 1634.27MW. The total network done by the plant is 678.264 MW. Thermal efficiency of cogeneration plants is calculated by the formula as shown in Eq. 1.

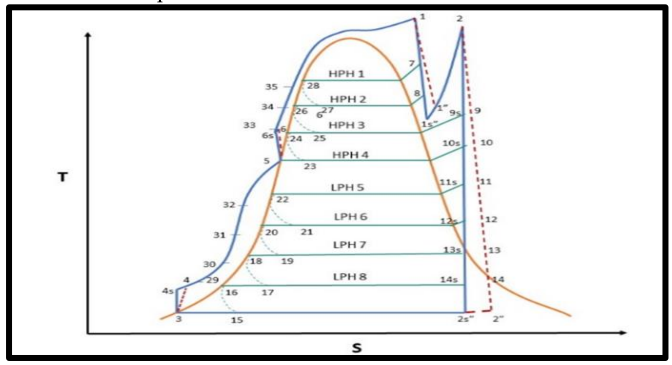

Fig. 1. Simplified T-S diagram of Sahiwal coal power plant.

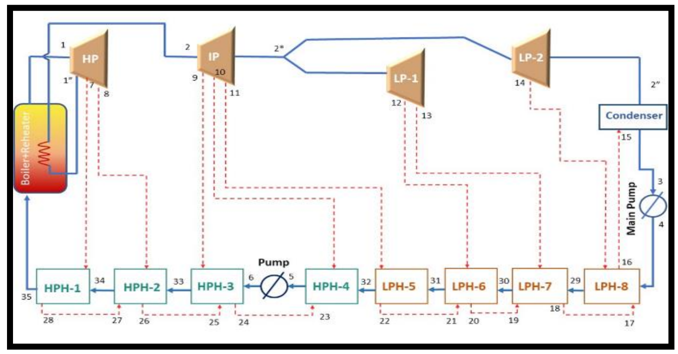

Fig. 2. Simplified plant schematics of Sahiwal coal power plant.

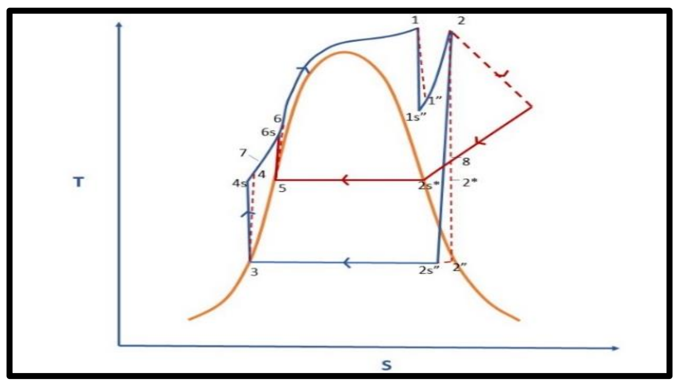

Fig. 3. Shows simplified T-S diagrams of cogeneration plant.

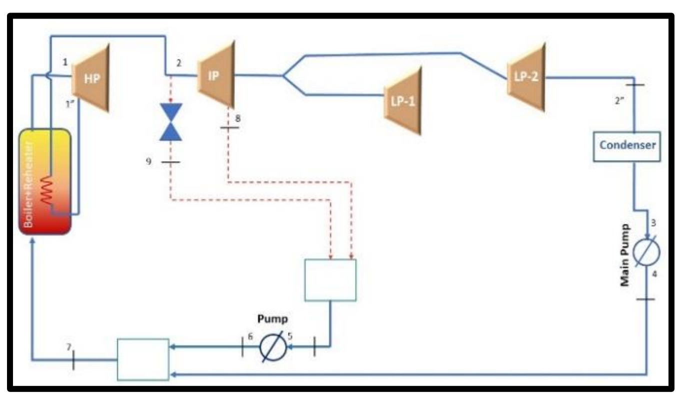

Fig. 4. Shows simplified T-S diagram of cogeneration plant.

TABLE II. ASSUMED DESIGN PARAMETERS OF SCPP

Parameters	Values
Gross station efficiency	64.6%
Cycle Efficiency	41.72%
Net station efficiency	38.86%
Net cycle efficiency	43.63%
Overall efficiency of plant	95.07%
Work of Condensate Pump	1.337 KJ/s
Work of Main Pump	30.56 KJ/s
HP Turbine work	338301.36 KJ/s
IP Turbine work	203940.37 KJ/s
LP-I Turbine work	57980.36 KJ/s
LP-II Turbine work	32723.6 KJ/s
Total Turbine work	632945.68 KJ/s
Net Work	611052.33 KJ/s
Heat Added	1464628.36 KJ/s
Steam Rate	0.00589
Work Ratio	0.9654
Heat Rate	8628.82
Rate of Coal burned	458333.33 Ibm/hr
Gross station HR	5278.364 Btu/KWh
Station net power output	601298.27 KJ/s
Net Station HR	8778.25 Btu/KWh
Net station cycle HR	7820.30 Btu/KWh

TABLE III. PLANT ANALYSIS PARAMETERS FOR COGENERATION.

Parameters	Values
Process Heat (50% of steam was used for process heat)	699321.54 KJ/s
Total Turbine work	699783.43 KJ/s
Net Work (50% of steam was used for process heat)	678264.98 KJ/s
Heat Added (50% of steam was used for process heat)	1634272.93 KJ/s
Cogeneration efficiency (50% of steam was used for process heat)	84.3%
Process Heat (100% of steam was used for process heat)	1398633.095KJ/s
Cogeneration efficiency (100% of steam was used for process heat)	85.58%

$$\eta = \frac{W_T + Q_A}{Q_A} \quad (1)$$

Where, W_T, Q_h, and Q_A represent the total work of turbine, the amount of extracted process heat, and the amount of heat added by the fuel (such as coal) in the plant, respectively. By solving Eq. 1, thermal efficiency of the cogeneration plant with 50% extraction of process heat is found to be 84.3%. Similarly in case of 100% extraction of process heat process heat is calculated to be 1398633.95 KW. Therefore, the overall efficiency of the cogeneration plant goes up to 85.58%. The important parameters have been listed in Table III. Process heat in general is mainly utilized by the garment industry for dying and other purposes. Therefore, an analysis is done on SCPP to utilize 50 % and 100% of its steam for process heat.

C. Coal Analysis

Fuel for SCPP is imported from Indonesia and South Africa. The coal from Indonesia is sub-bituminous coal, whereas the coal of South Africa is bituminous coal. Fuel is transported to Qadirabad via suppliers who transport coal to Karachi from where the Pakistan Railways transport it to the plant. The heating value of coal is classified as Higher Heating Value (HHV) and Lower Heating (LHV). Chemical reaction of coal with air is analysed under stoichiometric combustion of coal, complete combustion of coal with excess air, incomplete combustion of coal with excess air, conditions.

The stoichiometric reaction is given as:

$$(6.11\,C + 2.5125\,H_2 + 0.512\,O_2 + 0.0632\,N_2 + 0.036\,S) + 6.89O_2 + 25.91N_2 \rightarrow 6.11CO_2 + 2.5125H_2O + 0.036SO_2 + 25.97N_2$$

Whereas the complete combustion reaction with excess air is found to be:

$$(6.11\,C + 2.5125\,H_2 + 0.512\,O_2 + 0.0632\,N_2 + 0.036\,S) + 8.268O_2 + 31.092N_2 \rightarrow 6.11CO_2 + 2.5125H_2O + 0.036SO_2 + 31.1552N_2 + 1.38\,O_2$$

Moreover, the incomplete combustion reaction with excess air is found to be as:

Assumption: 90% of Carbon dioxide is converted into CO_2 and 10% is converted in CO

$$6.11 * 0.90 = 5.499$$

$$6.11 * 0.10 = 0.611$$

$$(6.11\,C + 2.5125\,H_2 + 0.512\,O_2 + 0.0632\,N_2 + 0.036\,S) + 8.268O_2 + 31.092N_2 \rightarrow 5.499CO_2 + 0.611C0 + 2.5125H_2O + 0.036SO_2 + 31.1552N_2 + 1.6835\,O_2$$

Two different methods used to calculate the adiabatic temperature of the coal in each type of reaction which are average (Cp) method (AM) and multiple iteration method (MIM). The summary of all calculations has been illustrated in Table IV, which demonstrates the higher and lower heating value of coal. It can also be found that adiabatic temperature value varies in each case either in stoichiometric condition or in lean condition with complete and incomplete combustion. Therefore, mean values are found in either case to eliminate the limitation of each method.

D. Economics:

The plant economics data has been taken from National Electric Power Regulatory Authority (NEPRA) report of 2019-2020 [22]. Table V depicts all the basic economic parameters that influence the working and running of SCPP. The table also portrays the amount of coal consumed, its cost, plant maximum power production capacity and real-life production of power by SCPP to fulfil the required amount of electricity in the national grid. Moreover, Fig 5. Shows the chronological load curves which elaborate the demand and production of power in a year. It can be depicted from the graph that SCPP generates maximum power of more than 800 MW in the month of January and frequent fluctuation in demand led the plant to generate electricity power accordingly. Similarly, Fig. 6. illustrates load duration curve of SCPP which demonstrates the generation of power to meet the public demand and load for a period of one year in gradually descending order from peak load to minimum load. The pictorial graph also depicts the peak load and minimum load of SCPP for the month of January and April, respectively.

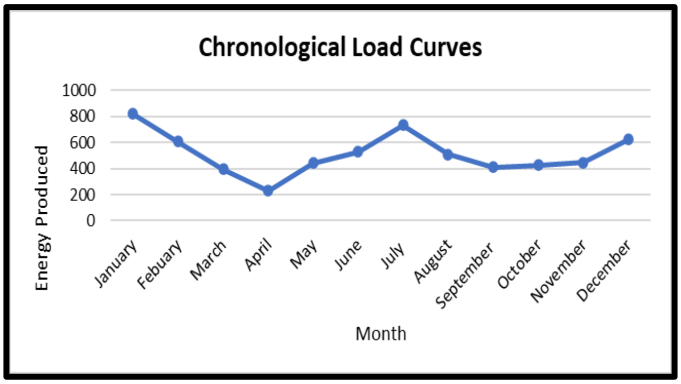

Fig. 5. Chronological load curve (courtesy NEPRA database [22]).

TABLE IV. COAL ANALYSIS.

Parameter	Value
HHV value of coal	12607.5325 Btu/Ibm
LHV value of coal	11516.43 Btu/Ibm
Tp by AM (Stoichiometric reaction)	2000 °C
Tp by MIM (Stoichiometric reaction of coal)	3000 °C
Tp, mean (Stoichiometric reaction of coal)	2500°C
Tp AM (Lean reaction with 20% excess air with complete combustion)	1600°C
Tp by MIM (Lean reaction with 20% excess air with complete combustion)	2700°C
Tp, mean (Lean reaction with 20% excess air with complete combustion)	2150°C
Tp by AM (Lean reaction with 20% excess air with incomplete combustion)	1500°C
Tp by MIM (Lean reaction with 20% excess air with incomplete combustion)	2550°C
Tp, mean (Lean reaction with 20% excess air with incomplete combustion)	2025°C

To sum up, most of the performance and economic parameters of SCPP are comparable with other similar coal fired power plants in the world. However, there is room for more improvement. Moreover, the involvement of supercritical technology in SCPP works best in maintaining the friendly environment and pursued the practical implementation of SDG 7 goals. However, a collectively incorporation the CCS technology in SCPP led a way for the plant to be more economical in the interest of the country.

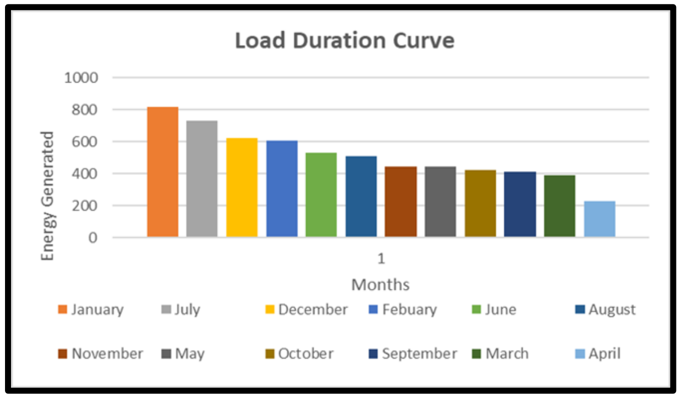

Fig. 6. Load duration curve (courtesy NEPRA database [22]).

IV. EVALUATION OF SCPP ON SDG#11 (SUSTAINABLE CITIES AND COMMUNITIES)

In the modern world of urbanization, a massive increase in the development of mega-cities is being observed. By the year 2050, an estimate of 6.5 billion of the world population will be residents of cities which led to the emission of 70% of carbon. Therefore, to meet the energy requirement, a number of plants are being established which are solely dependent on fossil fuel. Thereby affecting the environment and rising the temperature of the earth. Thus, a need to implement modern tools and techniques to diminish the emission of hazardous gases from the plant is required in optimizing a sustain production of energy. Thus, the use of the best quality of fossil fuel i.e., bituminous coal, in coal fired power plants to reduce the emission of ash and carbon content is recommended. Furthermore, installation of cyclone separator, which is being used in most of the modern plants to drain out the hazardous pollutant particle by the effect of centrifugal force. Similarly, Sulphur content is one of the toxic pollutant particles emitted from the flue gases that worsen the natural environment and caused acid rain. Therefore, flue gases desulfurization (FGD) technology is to be implemented in plant to remove Sulfur dioxide from the flue gases [23]. Ihsan et al. [24] highlighted another major emission which is not pre-dominantly studied, ash flying out from the SCPP also contains radioactive contents like radium and potassium, which adversely affects the environment as well as the human life, nearby the plant area. An investigation is performed around the surrounding soil up to a radius of 4 km. A vital decline in the content of radioactive is found far away from the plant. However, these contents are still beyond the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) standards, leading to the potential of cancer for the workers and the population living thereabout. In addition to that, combined cycle plants are considered to be more beneficial for the environment as such plants are equipped with heat recovery systems. Therefore, high temperature exhaust gases from the engines in thermal power plants are fed into the boilers to utilize the excessive amount of heat to generate electricity from the steam generator. Thus, lessen the amount of heat being emitted from the plant. Hence, by acquiring these techniques, an eco-friendly production of energy can be achieved and the requirement of united nation sustainable development goal for the sustainable cities and communities can be accomplished [25].

To summarize, although SCPP is one of the cleanest coal power plants in the world, much attention is required to minimize the harmful emissions for green power production to pave way for sustainable societies. The efficiency of the power plant can be enhanced further to meet the targets of SDG#11

TABLE V. BASIC ECONOMIC PARAMETERS.

Parameter	Value
Fixed cost	1.92 billion dollars
Coal consumption	0.375 Kg/KWh
Annual load time	6720 hours/Annum
Cost of coal/ton	120 $
Utilization factor	53.33 (2019-2020)
Fuel cost	7.69170 Rs/KWh
Actual power generation	6167.81 GWh / year
Maximum possible power generation	11563.20 GWh / year
Rated power	660*2=1320 MW
Rated capacity	776 MVA
Operation and management cost	0.17980 Rs/KWh
Specific cost	7.87150 Rs/KWh
Average monthly electricity production	513.9325 GWh
De-rated capacity	1250 MW
Load factor	0.628 MW
Utility factor	0.54MW
Plant capacity factor	0.533 MW
Plant operating factor	0.715MW
Annual plant capacity factor	0.533MW
Plant use capacity factor	0.695 MW
Demand factor	0.683MW
Base load	228.53 MW

V. EVALUATION OF SCPP ON SDG#13 (CLIMATE ACTION)

Improper execution of energy production yields adverse outcomes leading to international environmental concerns such as global warming. Due to this, entire biological and geological ecosystems are affected by climate change. The average global temperature has risen by almost 1 degree Celsius since 1880 and is likely to increase up to 4 degrees Celsius by the end of the 21st century [26]. Moreover, climate change is also affecting crop production. China's rice production may suffer by 13.5% in 2060 [27]. The increasing population is contributing to the already high food demand. On the other hand, Ocean levels are rising due to increased glacier meltdowns. Based on Atmospheric and Oceanic General Circulation Models (AOGCMs), sea levels are projected to rise by 18-59cm in 2100 [28]. Therefore, it has caused extreme flooding in some areas while prolonged droughts in others. Carbon dioxide emissions are one of the main causes of global warming. Especially in urban areas it accounted for 70% in 2008 and is expected to increase up to 76% by 2030.

As a remedial measure, the member states of the European Union (EU) have started to design and implement National Adaptation Strategies (NASs) to control climate change since 2005. The adaptation practices are planned at national, regional, and community levels as well [29]. Some of the factors which motivate member countries to develop NASs are White Paper Adaption and EU Green policies [30]. Similarly, specialized organizations such as UK Climate Impacts Programme have been developed to formulate policies and bridge them with the states' governing policies [31]. Climate research has evolved from the start of the 21st century. Research and awareness regarding climate change is a major part of SDG 13. To control greenhouse gas emissions, UNFCCC has devised Kyoto Protocol. Much research-oriented programs including the German Klimzug program, and Dutch 'Knowledge for Climate' have been initiated to get a deep insight into climate change. Pakistan on the other hand has a mixed reputation in terms of policies and strategies. Being a signatory of UNFCCC, Pakistan has developed four emission inventories in 1994, 2008, 2012, and 2015. These inventories covered five sectors in terms of emissions namely, industrial processes, energy, waste, agriculture, and land use. A report exhibiting 405.06 tons of CO_2 released per year was published in 2015. However, no further reports are published since then which poses a serious concern among other members of UNFCCC. Furthermore, none of the combine power plants (CPPs) signed under CPEC were integrated with ultra-supercritical technology being more efficient than supercritical. In the design process, all CPPs of CPEC project were to be equipped with baghouse filters or electrostatic precipitators (ESP) which were meant to remove dust and smoke from flue gases. Moreover, CCS technology was also part of the plan [2]. However, they were not deployed as well. Thus, an increase in tropospheric ozone was witnessed in 2017 when SCPP started its operation [32]. CPPs are the major contributors towards greenhouse gases (GHGs) such as NOx, CO, CO_2, O_3, and SO_2 etc. There are many harmful gases which are contributing toward climate change thus making the Earth suffer.

If we talk about SCPP, it uses an equal blend of imported bituminous and sub-bituminous coal which has less Sulphur and ash content than lignite [33]. To cater to GHG concerns, new and improved "supercritical cycle power plants" are deployed which prove to be more efficient [1]. As SCPP runs on a supercritical cycle, it produces more kilowatt per ton of coal, thus reducing the amount of SO_2 proactively.

To control the emissions produced by SCPP, both active and passive protocols are needed to be implemented. Baghouse filters or electrostatic precipitators (ESP) can be used which provide 99.9% efficiency to remove dust and smoke [34]. Low NOx burner (LNBT) offers 40-60% efficiency [35]. As fuel of SCPP has a specific carbon content of 0.2426 $\frac{\text{kgCO}_2}{\text{kwh}}$. Therefore, carbon dioxide emission rate comes out to 348.694 CO_2 tons per day, approximately.

Dealing with CO_2 reduction actively, an air separator is used to convert coal into a clean gas usually called "syngas" thereby, removing CO_2 before combustion [36]. When coal is burnt, it is converted into ash and hot flue gases. These products are harmful to the environment. To reduce the devastative effects, these products are passed through a particle removal chamber. It splits ash from the smoke making it free of Sulphur [34]. The flue gas is then fed to a CO_2 absorption unit where Amine-based solution absorbs carbon dioxide. It is then heated to release pure CO_2 which is further compressed, stored, and utilized in other processes [37]. Another technique called chemical looping combustion (CLC) can be used where an oxidizer usually a metal oxide serves as an oxygen source for combustion, thus, eliminating oxygen consumption from the air [38].

To sum up, power plants are major producers of GHGs because of fossil fuels especially coal and same is the case with SCPP. NOx, CO, CO_2 , O_3 , and SO_2 are the biproducts of coal combustion which contribute towards global warming and pollution. However, coal is cheap and readily available making it an inevitable solution for developing countries to meet their energy needs. Pakistan has one of greatest coal reserves in the world, but the main hurdle is their high Sulphur content which is a major pollutant. A solution to this problem is coal washing which can reduce the pollution rate. Hence, it will not only reduce imports of coal but also contribute towards economy of the country. As Pakistan is an agricultural country with decent livestock capacity, traditional plants can be fitted with biogas technology to reduce dependence on coal and other fossil fuels. This not only helps with the economy but also utilize the waste, thereby, reducing CO_2 emissions by 11-25%.

VI. COMPARATIVE ASSESMENT

SCPP has been compared with two other power plants of similar capacity. Hereinafter, these power plants are referred to as Plants "A" and "B" in accordance with data provided by Adibhatla & Kaushik [44] and Akash et al. [45]. Both plants are specifically selected from South Asian region to establish better comparative assessment. The Plant A is a 660 MWe supercritical coal-fired power plant in India, which runs on Indian bituminous coal and is based on modified Rankine cycle. Whereas plant B is also a 660 MWe supercritical coal-fired power plant in India, which runs on Singrauli coal. All three powerplants have several commonalities, such as these use super-critical technology and have a power rating of approximately 660MW capacity. In SCPP, a blend of bituminous and sub-bituminous coal is used to keep the running cost within the feasible range while producing less Sulphur based post combustion pollutants. Although, it has more carbon content for producing high temperature, SCPP fuel still has more Sulphur than the bituminous coal used by the plant A [44] closely followed by plant B [45]. Furthermore, three thousand trees are also planted to make up for industrialization at SCPP, whereas no such efforts surfaced regarding plant A and plant B. In addition, SCPP is equipped with pulverized coal system reducing CO2 emissions by 3% for every 1% gain in thermal efficiency. SCPP has a net station efficiency of 38.86% making it more efficient due to high carbon content resulting in high peak steam temperature of 571ºC. Adding to that, high hydrogen, high carbon, and low moisture content (7.215 %) of SCPP fuel has increased the temperature of steam. This is in comparison to the 12 and 8.28 percent moisture content in fuel of other two power plants, respectively. The loss in power production is due to irreversibilities and lack of exact data, which makes it difficult to reach a rated power of 660MW.

SCPP was supposed to be equipped with CCS technology, baghouse filters, and electrostatic precipitators (ESP). However, none of these have been installed yet. Along with the aforementioned systems, low NOx burners technology (LNBT), chemical looping combustion (CLC) as well as biogas systems are proposed as a part of evaluation under SDG 13 to control climate change. Plant A [44] is located in India where sometimes energy supply-demand is quite inconsistent. This varying demand forces the generators to limit their station loads to much lower capacities than the rated values, thereby compromising the plant's efficiency. Therefore, the plant incorporates sliding pressure operation to deal with rapid and unpredictable inconsistent energy demands. As a 100, 80, and 60 percent of Normal Continuous Rating (NCR) under pure sliding pressure operation, the net power output are 660MW, 528.1MW, and 396MW, respectively while maintaining station efficiency at 38.94, 38.75, and 37.86 percent, respectively. Recommendations have been made for plant B [45] to mitigate GHG emissions, particularly carbon dioxide. CCS technology is an effective way to sequestrate CO2. For plant B, three different methods of CCS were simulated and studied by the authors using software [45]. Although CO2 emission rate decreased from 0.92 kg/kWh to 0.14 kg/kWh and remained consistent across three derivates, CCS technology with Amine-based capture proved to be more effective in terms of electricity cost followed by Ammonia and Membrane, respectively. The summary of comparative assessment has been added at Table VI.

VII. CONCLUSIONS

The United Nations has devised sustainable development goals which are mutually agreed by member states of United Nations for the sustainability and prosperity of the world. All the UN SDGs are interconnected and each one needs special attention. However, if we consider power, then a major part of energy is being produced from fossil fuels. The main disadvantage of fossil fuels is their depletion and the emission of carbon dioxide when they are burned. Therefore, the existing power plants need to be updated with carbon capturing technologies and alternative eco-friendly fuels. UN SDG numbers 7, 11, and 13 address these issues very well. In the same context, this paper evaluates the Sahiwal coal power plant, which is a flagship power-sector project and situated in Sahiwal, with the standpoint of SDG#7 (Affordable and Clean Energy), SDG#11 (Sustainable Cities and Communities), and SDG#13 (Climate Action).

Based on the analysis conducted, it can be concluded that: -

- Most of the performance and economic parameters satisfies the goals specified under SDG#7. Moreover, the involvement of supercritical technology in SCPP works best in maintaining the friendly environment and pursued the practical implementation of SDG 7 goals.
- Insofar as SDG#11 is concerned, significant attention needs to be given toward minimizing the harmful emissions for greener power production. The efficiency of the power plant can be enhanced further to meet the targets of SDG#11.
- In case of SDG#13, the reduction of NOx, CO, CO_2, O_3, and SO_2 gases are paramount. These gases are the biproducts of coal combustion which contribute towards global warming and pollution. Pakistan has substantial amount coal reserves, but the main hurdle is their high Sulphur content which is a major pollutant. Incorporation of processes for coal washing prior to feeding into the SCPP can greatly reduce the pollution rate. This can reduce the cost of energy production emanating from the import of expensive high-quality coal from external sources.

- The comparative assessment of SCPP with two other 660 MW_e plants. The performance of SCPP is quite acceptable as compared to the other two power plants.
- Overall, the SCPP can be regarded as a power plant which is evaluated to be closely achieving the targets of the UN SDGs. However, serious steps are required to restrict the emission of harmful gases to control global warming.

VIII. RECOMMENDATIONS

Following recommendations can improve the plant efficiency while reducing the carbon emissions from SCPP at the same time.

1. A collective incorporation of CCS technology with supercritical technology in SCPP may lead a way for the plant to be more economical in the interest of the country.
2. Removing the moisture content of coal can enhance power plant's efficiency.
3. Baghouse filters or electrostatic precipitators can be used to remove dust and smoke.
4. Syngas, an air separator can be used to convert coal into a clean gas before combustion.
5. Chemical Looping Combustion can be used for controlling emissions from the power plant.
6. Cyclone separator may be used to separate hazardous gases.
7. Flue gases desulfurization technology can be used to remove Sulfur dioxide from the flue gases.

TABLE VI. COMPARATIVE ASSESSMENT OF THREE 660 MWE COAL-FIRED POWER PLANTS.

Parameters		SCPP	Plant A [39]	Plant B [40]
Performance Parameters	$\eta_{net\ Station}$ (%)	38.86	38.75	35.04
	T_{max} (ºC)	571	540	528
	P_{output} (MW)	601.3	659.9	660
	Net Station heat rate (KJ/KWh)	9261.5	No information has been provided.	10270
	HHV(KJ/Kg)	29320	No information has been provided.	16210
	P_{max} (MPa)	28	24.8	No information has been provided.
	Turbine Output (MW)	632.9	669.3	No information has been provided.
	Coal Cost per ton ($)	120	No information has been provided.	40
	Coal Consumption per hour (ton)	208	No information has been provided.	418.3
Technologies		Pulverized fluid bed, Blended bituminous and sub-bituminous coal, Supercritical technology	Bituminous coal, Supercritical technology	Blended sub-bituminous local and imported coal, Supercritical technology
Coal Quality	Sulphur (%)	1.165	0.45	0.55
	Ash (%)	10.625	43	39
	Carbon	48.95	34.46	39.27
	Hydrogen	5.025	2.43	2.8
	Moisture	7.215	12	8.28
Recommendations for improvements		CCS ESP Baghouse filters LNBT Biogas	Sliding pressure Operation	Amine based CCS Ammonia based CCS Membrane based CCS

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