Carbon Footprint Study on Renewable Power Plants: Case Study on Egypt's Benban Solar Park

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***Abstract*— Some recent human activities have negatively affected the environment through the production of toxic substances. Carbon footprint (CFP) refers to the total amount of greenhouse gases generated, i.e., disaggregated by categories of equivalent carbon dioxide compounds. It plays a major role in global environmental degradation, causing global warming. The direct emission of the CFP is determined by the fossil fuels used to generate electricity traditionally and the use of different means of transportation. The use of renewable energy sources (RESs) is a long-term investment aimed at obtaining clean energy, reducing CFP, and replacing fossil fuels for electricity production, thus contributing to the conservation of energy resources for future generations. This paper discusses the most important ways to reduce the CFP by treating toxic gases in the atmosphere and switching to the use of RESs. The results obtained show that the more use of RESs, the less carbon it is because it is clean energy. Furthermore, this paper has studied the case of the Benban solar power plant, Aswan, Egypt which is considered one of the world's biggest solar photovoltaic stations. It was found that this plant reduces carbon emissions by 2 million tons of heat emissions, the equivalent of 400,000 cars.**

Keywords—Carbon footprint- Renewable energy sources (RESs) Greenhouse gas- Benban solar park.

I. INTRODUCTION

The carbon footprint (CFP) reflects the amount of carbon dioxide released into the Earth's atmosphere by the daily activities of humanity, both locally and commercially. Carbon dioxide can be emitted directly or indirectly by organizations, events, producers, or individuals. Recently, carbon unit programs have spread widely throughout the world as the issuance of certified carbon units has been made available. The American chemistry center (ACC) helps international companies and institutions offset the inescapable carbon emissions during its operations. At the same time, it supports the development of several projects to reduce the CFP and combat climate change [1].

The global CFP Council (GCC) is one of the initiatives of the gulf research and development organization (GRDO), the first voluntary greenhouse gas (GHG) balancing program in the Middle East and North Africa region, established in 2016 and operational in 2019. The regulatory framework of the global CFP board includes all elements that ensure a real and lasting reduction in carbon emissions from projects registered by the board. It should also be noted that the GCC in Qatar is one of two approved international programs in developing countries [2]. The GCC, launched in the Middle East and North Africa region, aims to provide a carbon production program for stakeholders committed to a carbon-free world. The World Council has received several applications for project registration for the CFP reduction from countries such as Turkey and India.

The list of registration applications also includes several projects from other states, including but not limited to Qatar, Oman, Serbia, Saudi Arabia, Egypt, Jordan, Spain, Belgium, Canada, and the United States of America. A negative aspect of the CFP is the damage to the ozone layer, increasing atmospheric temperature. The carbon stamp varies according to people, location, habits, and personal choice, and each of us contributes to GHG emissions through our travel, the food that is eaten, the amount of electricity that uses, etc. For example, when a person drives a car, which burns fuel, it generates a certain amount of carbon dioxide in the atmosphere, and when people heat their homes, it also generates carbon dioxide on the assumption that electricity comes from charcoal plants. Humans account for about 50-65% of total global methane emissions in 2000 (IPCC 2013) [3]. This research contributes to ways to reduce the CFP

ISSN: 2636 - 3712 (Printed Version)
ISSN: 2636 - 3720 (Online Version)

in the atmosphere, and it will apply this process to the station of the Benban solar park.

II. STEPS OF IMPROVEMENT OF CARBON FOOTPRINT

The process of improving the CFP is divided into three stages (plan, develop, and manage), as shown in Fig. 1.

A. The improvement steps of CFP are illustrated as follows:

- Assign resources (i.e., secure management support, establish a team, and prepare a budget).
- Design GHG inventory (i.e., define inventory boundary, determine sources of emissions, and select base year).
- Collect data (i.e., design an efficient data management system, obtain appropriate data, and ensure data quality).
- Calculate emission (i.e., apply calculation tools and guard against calculation errors).
- Set target (i.e., identify emission opportunities, decide on target type and level).
- Reduce emissions (i.e., implement emission reduction activities).
- Report results(i.e., publicly report complete inventory information).

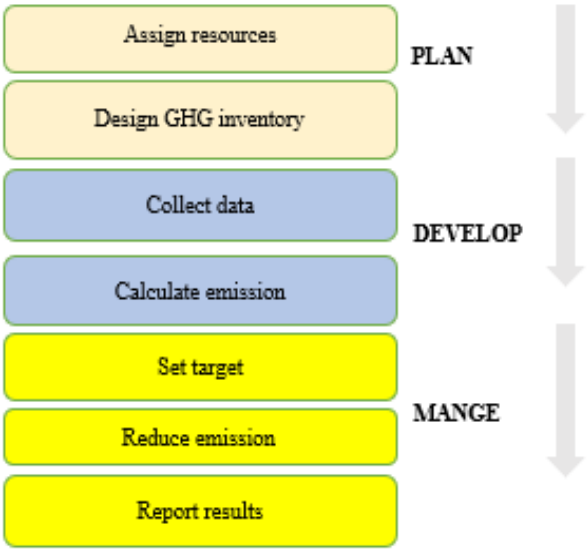

Fig. 1. *Steps of improvement of the CFP.*

B. Main Sources of CFP Emissions

- Electricity production, especially fossil fuel production. Transport exhaust (cars, trains, aircraft, motorcycles, etc…).
- Industry, especially industries that work with industrial waste, human waste, and others.
- Chemical reactions, especially those that produce toxic gases such as Carbon (C) and Carbon-Methane (CH4). Fluorinated gases are emitted from a variety of industrial processes, saturated carbon (PFCS), sulfur hexafluoride (SF6), and hydrofluorocarbons (HFCS).
- Consumption of foodstuffs, manufacturing goods, materials, timber, buildings, transport, and roads.

III. LITERATURE SURVEY

The previous studies involved the importance of smart grids, RESs, and schemes for implementing solar power plants in electric grids. The characteristics and limitations are discussed for two types of available solar power plants. The modifications required to make the solar plant into a smart or intelligent solar plant [4]. The study is based on a new strategy of frequency control and also in the virtual inertia control based on the virtual synchronous generator, which simulates the behavior of conventional generators in large power systems. Maintaining the dynamic security of renewable energy systems is the main challenge for integrating more renewable energy sources [5]. The growth of renewable energy generation is greatly reducing the inertia levels of renewable energy grids, which can lead to frequency instability and power system degradation. To handle this problem, electric vehicles can be relied upon. To mimic the inertial force needed in low-inertia smart hybrid power systems, thus regulating system frequency and avoiding system instability [6]. A study of automatic generation control for future multi-source energy systems has been introduced in [7]. In this previous study, RESs included PV plants, wind power plants, concentrated solar power plants, and hydroelectric power plants. Also, it has investigated the effect of the participation of EVs in enhancing frequency stability [7].

The global community has pledged to reduce GHG emissions through the ongoing work of renewable sources such as solar energy, causing an environmental cost to produce photovoltaic systems [8]. Scientists and researchers have confirmed that the rate of carbon emissions in the atmosphere will rise by the end of 2020 to 20%, and is constantly increasing due to the difficult challenges facing the environment [9]. Carbon dioxide emissions from solid waste processes in China are estimated at 46.46 million tons, which is much more expensive compared to 2.72 million tons in Japan [10]. Mitigate the negative environmental impacts of photovoltaic systems using the best design of solar power plants, select the site carefully, develop new materials, reduce the use of hazardous materials and recycle them whenever possible. The CFP of the photovoltaic system can be reduced by using new materials that can reduce GHS emissions by recycling solar cell materials by up to 42% [11].

Increased generation of electricity to meet consumer demands results in carbon emissions if only generation is taken into account, the control of emissions from the demand side will not be achieved [11]. Reduce carbon emissions by 1.3 to 1.6 tons per year for a standard UK home with a solar system, depending on where it lives in the UK, and this is estimated by Energy Travel Trust (EST) [13]. Industrial processes account for more than one-fifth of global emissions and increase as infrastructure develops and the middle class expands worldwide. The average CFP of energy used in aluminum production increased by 38% and silicon by 43%. This is from 2000 to 2019 [14]. The crashing car (CS) plays a key role in environmental improvements as an innovation in low-carbon transport to mitigate the CFP

associated with transport [15]. Car transport in the city of Biggar in Scotland represents half of carbon dioxide emissions, 24% of natural gas, and 12% of electricity consumption, and air travel represents 10% of these emissions, so the city of Biggar aims to plant trees to compensate for these emissions [16]. Wheat cultivation and bread consumption (cooled storage and roasting) increase the CFP by 35% and 25% of the total, respectively, in some countries (e.g., the United Kingdom, France, and Spain), the CFP can be reduced by 25% by avoiding roasting and cooling and further reductions of (5-10) % by reducing the amount of bread waste disposed of by consumers [17]. A new method has been studied to know the best capacities of PV systems, diesel generator units, and battery banks according to less cost to system reliability and CO2 emissions [18]. The main goal reducing annual energy to A given customer Taking into consideration(PV cost, maintenance cost, and reducing CFP emission [19].

IV. CARBON FOOTPRINT CALCULATE

A. Fuel Combustion

The CFP of fuel combustion can be measured by using the following equations [20].

$$CF_{FC} = \sum[\,(A_i + e_i + C_i - S_i) * O_i * \frac{44}{12}] \quad (1)$$

where CF_{FC} is the CFP from fuel combustion, when driving a certain distance, the amount of fuel used is measured, which is called fuel consumption. A_i is the apparent consumption of the ith fuel and e_i is the heat conversion factor of the ith fuel, which is the amount of heat energy emitted from burning or treating fuels. C_i is the average carbon content of the ith fuel and refers to carbon produced by the combustion of gasoline, coal, diesel, propane, natural gas, and distilled heating fuels. S_i is the carbon sequestration of fossil fuels used by the ith non-fuel and aims to change the global climate by reducing the amount of carbon in the atmosphere. O_i is the carbon oxidation factor of the ith fuel. The oxidation factor employees to determine the quantity of the fuel that helps to carbon dioxide emissions. The carbon (S_i) can be calculated using (2).

$$S_i = P * PC * m \quad (2)$$

where P is the output of carbon sequestration products, PC is carbon content per unit of the product of the fuels, and m is the rate of carbon sequestration of fuels. The apparent consumption (A_i) is calculated according to (3).

$$A_i = A_1 + A_2 + A_3 - A_4 \quad (3)$$

where A_1 is the final consumption of fuels, i.e., the total final consumption of energy used in the provision of energy services. A_2 is the thermal power consumption of fuels, i.e., it is the rate of heat production from the fuel. A_3 is the heating consumption of fuels, which is a chemical process or reaction between a fuel (hydrocarbon) and oxygen. A_4 is the non-fuel consumption.

B. Power Transportation

Power transportation for the CFP can be calculated using the following equations (4) – (5), [20].

$$Cf_{power\ impot} = w_1 * q \quad (4)$$

$$Cf_{power\ export} = w_2 * q \quad (5)$$

where w_1 is the power imported from other provinces, regions, or cities; w_2 is the power exported from local provinces, regions, or cities; q is the average emission.

The carbon emission from power import is considered a positive value, and the export is a negative value. Therefore, the net carbon footprint of power transportation can be calculated according to (6)

$$Cf_{power\ transportation} = Cf_{power\ import} + Cf_{power\ export} \quad (6)$$

by integrating (1) and (6), the total CFP can be calculated from energy utilization using (7):

$$Cf_{energy} = Cf_{fc} + Cf_{power\ transportation} \quad (7)$$

C. Industrial Production

In industrial production, carbon emissions are produced from chemical reactions that include the process of producing steel, cement, calcium carbide, and soda ash. It could be calculated using the equation [20].

$$Cf_{industrial} = K_{cem} + D_{cem}K_{ste} * D_{ste} * K_{cac2} * D_{cac2} * K_{sod} * D_{sod} \quad (8)$$

where $Cf_{industrial}$ is the industrial production CFP, $K_{cem}, K_{ste}, K_{cac2}, and\ K_{sod}$ are the carbon emission factors of cement. Greenhouse gas emissions are produced directly and indirectly when cement is produced, which leads to the release of carbon dioxide into the atmosphere. The quantity of CO2 emissions from steel production is approximal double the quantity of steel created 1.85 tons of carbon per 1 ton of steel. Calcium carbide is a chemical composed of the formula of CaC2. Carbon emissions can be accounted for by multiplying the quantity of consumed soda ash by the default coefficient for sodium carbonate. $D_{cem}, D_{ste}, D_{cac2}$, and D_{sod} are the outputs of cement, steel, calcium carbide, and soda ash, respectively.

V. GENERAL REASONS FOR REDUCING THE CARBON FOOTPRINT

Searching for clean renewable energy sources and exploiting them as an alternative to fossil fuels. Reducing all types of waste, especially gaseous waste. Controlling all waste emanating from industrial activities and obligating factories to treat their waste. Monitoring agricultural activities and obligating them to switch to environmentally friendly organic crops. Exploitation and development of mass transportation to reduce the use of individual means of transportation that emit millions of liters of harmful gases daily. Rationalization in consuming electricity and water and using them more effectively. Recycling and reusing recyclable materials in production processes. Adoption and use of high-efficiency and environmentally friendly machines, devices, equipment, and projects. Expanding the planting of trees and forests and re-cultivating the natural vegetation cover. Adopting green buildings that are environmentally friendly in construction operations. Moreover,

reducing clothing waste and meat and food consumption. Additionally, it is not recommended to use single-use plastic.

TABLE I. ENERGY SOURCES HEAT CONVERSION FACTOR, CARBON EMISSION FACTOR, AND CARBON OXIDATION FACTOR [20].

Energy type	The heat conversion (e_i)	Carbon emission factor (c_i)	Carbon oxidation factor (o_i)
Raw coal	20.52	24.74	0.98
Diesel	43.33	20.20	0.98
Other cleaned coal	20.52	24.74	0.98
coke	28.20	29.50	0.97
Cleaned coal	20.52	24.74	0.90
Crude oil	42.62	20.00	0.98
Gasoline	44.80	18.90	0.98
Biquette	20.52	24.74	0.90
Natural gas	48.00	15.30	0.99
Kerosene	44.67	19.55	0.98
Fuel oil	40.19	21.10	0.98
Liquefied petroleum gas	47.31	17.20	0.98

TABLE II. CARBON EMISSION FACTORS IN THE PRODUCTION PROCESS OF MAJOR INDUSTRIAL PRODUCTS [20].

Major industrial product	Cement	steel	Calcium carbide	Soda ash
Carbon emission factor	0.427	1.060	2.190	0.138

A. Reduction of Garment Waste

The clothing sector generates approximately 2 to 10% of the world's total carbon emissions and uses about 70 million barrels of oil annually to manufacture polyester fibers, one of the most widely used fibers in the rapid erosion industry [21]. The steps on how to reduce the CFP are shown in Fig. 2. Where the first step reduces the amount of waste product, the second ruse is using materials repeatedly, the third step is recycling is using the material to make the new product, the fourth step is the recovery of energy from waste, and the fifth step landfill is safe disposal of waste to landfill.

B. Reduction of Meat and Food Consumption

Livestock and its by-products emit at least 32000 million tons of carbon dioxide annually, or 51% of all global GHG emissions and are likely to increase in livestock by about 80% years until 2050 unless more sustainable food production systems are built on a large scale [22]. As shown in Fig. 3, the CFP of eating mutton is the largest carbon dioxide (kg) since tomatoes have the least carbon dioxide.

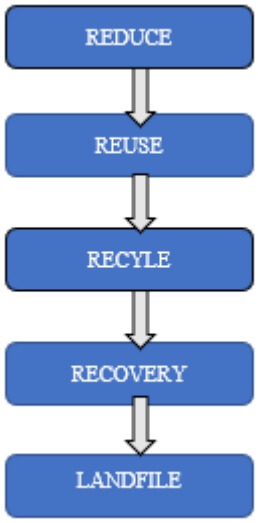

Fig.2. *Steps for CFP reduction.*

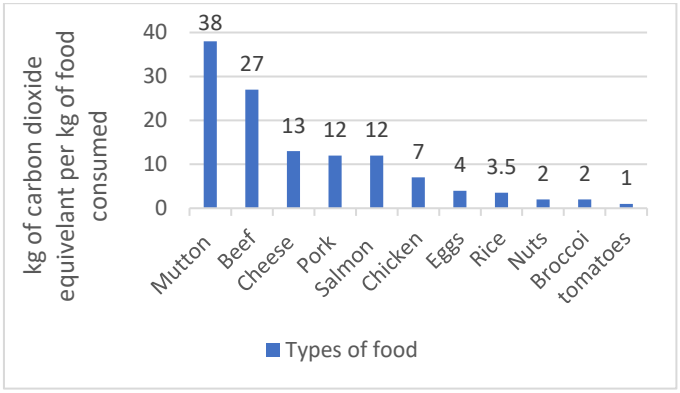

Fig. 3. *The CFP of what you eat.*

C. Non-Use of Single-Use Plastic

The days when the reuse of food cans and recycling of tin cans were enough to save the Earth, brought about have passed. It's time for all of us to start living without plastic.

D. Lower Driving Rates

The simplest way to reduce a car's CFP is to drive less. In addition, one can accompany others to reduce the amount of gas used and carbon emitted by each person. Figure 4 shows the amount of carbon dioxide in grams per kilometer (g CO2 e/Km). The electric car (by using solar) represents the lowest emission from driving less than 100 g co2 e / km compare with other cars.

E. Electricity Provision

More efficient lighting sources such as compact fluorescent lamps (CFL) and light-emitting diodes (LED) can replace the old incandescent lamps, especially since the old lamps are now gone in most markets.

F. Home Heating and Cooling Efficiency

Keep systems tuned, insulate the house, and shut down any air leaks. Also, set the thermostat higher in some grades in summer and lower in winter.

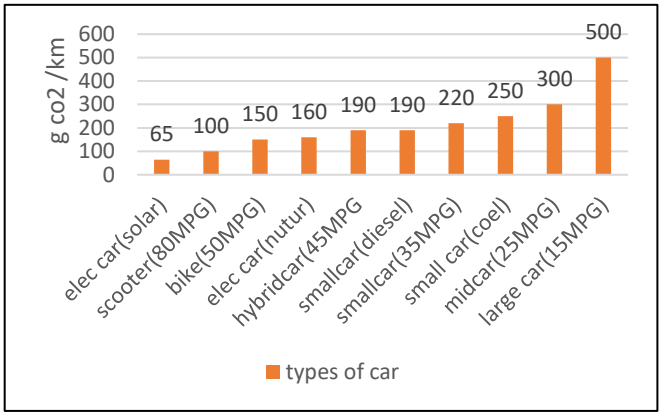

Fig.4 . Emissions from driving alone.

G. Lower Flight

Air travel is one of the most carbon-laden activities. Some flights can be reduced by traveling by train instead or by combining several flights in one trip. When travel is the only option, nonstop flights are sought, as they produce fewer gas emissions than split flights.

H. GHG emissions (tons CO2 e/ GWh) for each type of energy

The GHG emission is different according to different methods of generating electricity, which is represented in coal, oil, natural gas, solar photovoltaic (PV), hydroelectric, and wind. As shown in Fig. 5, coal represents the highest GHG emissions for electric generation whereas the wind is the least GHG for electric generation.

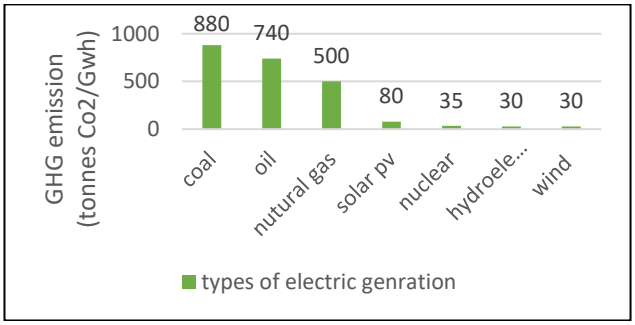

Fig.5 . *GHG emissions for each type of energy*.

VII. Benban Solar Park Egypt

Figure 6 shows the largest and most recent global project in the field of solar PV, the Benban solar power plant, targeting Egypt for 37% of clean energy by 2035. The Benban solar power plant is about to achieve its target of having 20% of clean energy by 2022. The project involved 40 specialized companies, including 10 global and Arab companies. The investment cost of the project is 3.4 billion euros, estimated at 40 billion pounds. The project site was selected based on NASA studies and reports, selected as the World Bank's best project for 2019, producing 90% of the high energy produced from the dam. It provides 200 direct and indirect employment opportunities and the project has contributed to avoiding 2 million tons of CO2 emissions [23].

Fig.6. *Benban solar park in Egypt.*

VIII. Reduction of the CFP using Benban Solar Park

Solar energy has seen a rise in world adoption for decades now. It is the ideal sustainable, clean and cheap energy source. Renewable energy such as photovoltaic and wind energy has a much lower carbon footprint than conventional electricity production and this is due to emissions generated during equipment production during manufacturing. Now more than ever there is a need for large-scale use of solar energy for industries, to stem the evolution of carbon dioxide emissions and the rise of greenhouse gases, and to create a safer planet for its inhabitants. With solar projects, there are no emissions. This allows for clean air and a safe energy solution for the environment and for those who work in solar power plant companies. Furthermore, there is also a focus on reducing emissions as much as possible during the production and manufacturing phase of solar power plants. This makes solar net pollution much lower than other energy solutions, even at the production stage. This means that even if you exclude the green benefits of solar energy.

During the first years of operation of the solar energy system, about 50 gm of carbon dioxide is produced per k/h. There is no doubt that solar energy generates CFPs, but it may be non-existent compared to coal. Where power plants operated with coal and natural gas generate 18 times more than solar power plants, while conventional power plants operated with coal generate 13 times that of solar energy. Reducing the CFP of Benban solar plants is due to the solar panels installed in the station. Collected the energy from the sun and it converted to usable electricity. There is no energy waste because it can be stored in various energy storage units. Also, solar PV power plants don't produce greenhouse gases due to the electrons taken from the sun's energy to generate energy. furthermore, the Benban solar park is limited by water pollution because the PV panel does not need water to work such as manufacturing processes. Sunlight is converted into electricity without a needed local water supply. Solar energy doesn't pollute the waterway as it happens with using fossil fuels.

With the increasing demand for solar energy, the impacts on reducing the CFP have also increased, as each KW/H of the solar plant in Banban reduces about one ton of global warming annually. Tons of global warming annually, so the plant camp

reduces about 2 million tons of global warming. This reduction depends on several factors, including methods of electricity generation, where the percentage of the CFP varies if it is generated by traditional methods such as fossil fuels or natural gas. Or if it is generated from renewable energy such as solar energy. Reducing the CFP of solar energy depends on the solar panels, how to obtain the material used to produce the solar panels, how to manufacture it, and the expected life span. It also depends on the type of solar panel and the material from which the solar panel is made. It is the most important type of silicon that achieves an efficiency of 29%, while there is another type called perovskites, which theoretically achieves efficiencies in a single layer of 33%, which can achieve these efficiencies in reducing the CFP of the solar energy system even more.

IX. CONCLUSION

With solar projects, there are no carbon emissions in large quantities. The Benban solar park reduced its carbon footprint by using clean sources and renewable energy. This allows for clean air and a safe energy solution for the environment and those working in solar plant companies. Solar power produced by solar power plants is entirely green. This research addressed how to reduce the CFP in different ways such as; reducing garment waste, preventing the use of plastics, preventing the use of fossil fuels in industry, reducing emissions from the production of cars, trains, and aircraft, reducing chemical reactions that produce toxic substances such as carbon, methane, etc., and relying on renewable energy such as wind, bioenergy and solar energy to meet consumers' needs. As in the case study, it was clear that each station from the Benban solar park reduces 50000 tones annually from global warming, hence all stations of this power plant reduce 2 million tons of thermal emissions, equivalent to 400 thousand cars. A report issued by the United Nations stressed the importance of taking rapid and large-scale action to address greenhouse gas emissions from the most energy-intensive countries, which account for about 25 percent of total carbon dioxide emissions globally and 66 percent in the industrial sector.

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