Comparing the Global Warming Impact from Wind, Solar Energy, and Other Electricity Generating Systems through Life Cycle Assessment Methods (A Survey)

Abdullah Marashli *, Al-Mothana Gasaymeh‡, Mohammad Shalby*

*Mechanical Engineering Department, Al-Hussein Bin Talal University, PO box 20, Maan, Jordan

(a.marachli@ahu.edu.jo, mothana777@yahoo.com, mohammad.shalby@ahu.edu.jo)

‡ Corresponding Author; Al-Mothana Gasaymeh, PO box 20, Maan, Jordan, Tel: +962772155238,

Fax: + +962 32179050,mothana777@yahoo.com

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Abstract- This study compares Greenhouse Gases (GHGs) emissions as CO2 equivalent per one kilowatt-hour of two types of renewable power generation technologies (solar and wind) compared to other traditional power generation technologies through life cycle assessment methods. Related to Global Warming Potential (GWP), the produced quantities of GHGs of each generation method vary through the lifecycle. For wind and solar power, the release of GHGs reached between 70 and 98% during manufacturing (including raw materials) and decommissioning. The recycling stage may play a crucial role in decreasing the impact of GHGs by up to 40%. -Adopting emissions calculated by the Life Cycle Approach (LCA) with electrical generation from solar and wind ways allows a fair comparison per (CO2) eq/ KWh basis and factors affecting each LCA stage. For the two studied systems, wind power emits the least amount of (CO2) eq/ KWh, with average values of 13.91 and 12.7 g CO2eq/kWh for offshore and onshore farms, respectively. While photovoltaic has the highest contribution to GHGs emissions, with a mean value of 23.39 g for CdTe, it is followed by 33.14, 39.93, 43.84,49.33, 50.76 for a-Si, m-Si, CIGs, CIS and sc-Si g (CO2) eq/ KWh, respectively. Concentrated Solar Power (CSP) occupied the medium contribution of 35.6 g for the tower and 30.94 g (CO2) eq/ KWh for the trough. Compared to fossil fuel-fired systems, the average (CO2) eq/ KWh is 936 g for coal-fired, 730 g for oil, and 502 for gas-fired power systems. Replacing one kilowatt-hour of coal or oil-generated electricity with one kilowatt-hour of wind power can save up to 923 or 716 g (CO2) eq/ kWh.

Keywords Global Warming Impact, Wind, Solar Energy, Life Cycle Assessment, Survey

1. Introduction

The issue of global warming is one of the challenges facing humanity in the coming decades. Mainly, conventional energy sources, which constitute 84.3% of primary energy sources (i.e., 33.1% from oil; 27% from coal; and 24.3% from gas), are responsible for releasing these gases into the surrounding environment. Carbon dioxide produced during fuel combustion is the cause of global warming, as its quantities increase with the increasing demand for energy, especially electrical energy, as one of the final forms of energy use. The amount of electrical energy generated during 2020 reached approximately 25.85 TWh, more than 60% of which comes from burning fuel, and it is responsible for putting more than 70% of CO_2 into the atmosphere [1].

According to the reference [2] about CO_2 status, global energy consumption climbed at over twice the average rate since 2010, led by natural gas, despite double-digit growth from solar and wind energy sources. CO_2 emissions released from the energy sector increased by 1.7 percent to a new level of 33.1 Gt CO_2, almost coming from 83.1% of fossil fuels as primary energy resource [3]. While GWP from all conventional fuels has grown, approximately two-thirds of the rise was attributed to the electricity sector. Coal use in electricity generation alone exceeded 10 Gt CO_2, primarily in Asia. China, India, and the United States are responsible for the net increase in emissions, accounting for 85 percent of the total [2].

As reference [4] noted and confirmed by reference [1] on the published assessment in the executive summary and is that, in the first quarter of the year 2020 compared with the first quarter of year2019, worldwide energy demand was dropped by 5%, with CO_2 emissions related to energy generation falling by 6-7%, depending on fuel type, throughout the pandemic Covid-19. Emissions from coal fell by 8%, oil by 4.5 %, and natural gas emissions by 2.3 %. The drop in annual CO_2 1 rate by 2.1- 2.4 Gt is similar to ten years ago. In the next decade, CO_2 emissions will exceed 2019 levels under the Stated Policies Scenario (STEPS), reaching 36 Gt, which will cause global warming of 1.65 degrees Celsius. However, the IEA reported in its Global Energy Review on April 20, 2021 [5] shows that global carbon emissions will grow by 1.5 billion tones, representing 5 percent, in 2021, to reach more than 33 billion tones due to the comeback of coal use in the power sector. Such a percentage of CO_2 concentration represents the second-largest increase in history

To reach a very low GWP by 2050, CO2 emissions-related energy fields would have to be cut by about 3.5 percent yearly from 2021 until 2050. Such reduction accounts for 70% compared to current levels [6], [3]. Most mitigation scenarios until 2050 are based on large-scale and accelerated deployment of so-called low-carbon energy technologies, which emit less CO2 than the conventional fossil-fuel power generating counterparts. Overall, it remains far below the levels required to reach the Glasgow Agreement Commitments (COP26) in 2021.

The goal of net-zero emissions by 2050 would require substantial additional efforts over the next ten years. For instance, joint to the Paris Climate Action and abide by the pledges [1] that require replacing coal-fired technologies with less GHG impact. Reliable and trustworthy outputs are needed to assist leaders and decision-makers in making the right energy policies. These data can be obtained by continually reviewing published research that uses the latest relevant data and software.

2. Objectives and Methodology

The goal of this study is to collect and analyze data to compare the life cycle of GHG emissions of wind energy (onshore and offshore), photovoltaic power (rooftop and utility), and Concentrated Solar Power (CSP) used for electricity generation based on a survey of the literature. In addition, obtained results are compared to some other traditional energy sources such as Coal, Natural gas, Hydro, Biomass, Oil, and Nuclear power.

The current literature review seeks to answer the following research questions:

- Which power generation technology has the most influence on total GWP?
- Which is the highest and which is the lowest?
- Where do the emissions fall throughout a lifecycle?
- Explain what reasons generate variability in overall Greenhouse gases in the literature.

The current study is a literature review research study. This study aimed to present a survey of research related to the global warming impact of wind, solar energy, and other electricity-generating systems through life cycle assessment methods. For the study, a group of research databases in English languages were selected to be searched for studies that related to the global warming impact of various electricity-generating systems. The examined scientific studies were collected from different sources that include Organizations such as (IEA), World Energy Council (WEC), Our World in Data Website, BP, World Nuclear Association (WNA), IRENA, IPCC, NREL, Ostfold Research, as well as Science Direct, Wiley Online Library, Taylor and Francis, Elsevier, and Google Scholar. Furthermore, a snowballing technique has been used to find additional papers from the list of references for the identified research papers.

To accomplish the goal of the current study, the following keywords were used in the searching process in the previously mentioned sources: Life Cycle Assessment (LCA), GHG emissions, GWP, carbon dioxide, renewable, concentrated solar power, the nuclear, wind, offshore, onshore, photovoltaic, hydropower, geothermal, biomass, non-renewable, fossil fuel, coal, oil, natural gas, energy, power, electricity, combined-cycle. The search was bounded from 2005 until the completion of writing this research in 2022.

The previous studies have been processed and categorized. Thus, only factual, accurate, and relevant data were used in this study. On the other hand, some related studies were excluded due to the lack of recentness, relevance, completeness, and originality. The reference evaluation unit used in this study gCO2equivalent per kWh power generated is equivalent to GWP unit.

3. Literature review

Due to the uniqueness of lifecycle analysis assumptions for each power generation system, the consequences also should be different according to input data. The choice of global warming potential value is important to understand, for example, which global warming potential coefficient is used for methane. Depending on the choice of GWP for CH4, the natural gas LC emissions could result in either 31% more or 40% less than coal LCI due to the high leakage rate of CH4. A research study by reference [7] claimed that greenhouse gas (GHG) emissions from natural gas could be twice that of coal, mostly due to fugitive emissions by leakage from hydraulic fracturing. "100-yr value is estimated to be 25 (times higher than CO2) by IPCC; the 20-yr value is estimated to be 72". Technology improvements, energy efficiency (EE), electricity supply mix, and other conditions should be included more accurately, from the extraction stage of raw material, including processing, transmission, storage, and end-use. If the opposite, emissions data are sparse and uncertain, which means the tremendous need for improvement to obtain actual values that mimic reality.

The current study used LCA, a methodology for analyzing environmental consequences associated with all phases of the life cycle of the commercial products, to give a full comparison across power generating systems in terms of their global warming impact. The examined power generating systems include wind, photovoltaic, concentrating solar power, and other power generating systems other traditional energy sources such as Coal, Natural gas, Hydro, Biomass, Oil, and Nuclear power.

3.1 Wind power

The literature review includes studies that evaluated wind turbines from a life cycle perspective, covering onshore and offshore farms. Furthermore, studies that compiled average wind power results from earlier research were considered. The analysis includes 58 studies published between 2005 and 2020, as given in Table (1). Generally, the wind power life cycle is divided into four phases: 1) wind turbine fabrication, which involves mining, processing materials, and manufacturing; 2) wind turbine construction, which includes transporting components, constructing foundations and substations, and assembling structural supporting; 3) operation and maintenance; and 4) decommissioning, which includes deconstruction, disposal, and recycling [8, 9, 10, 11, 12].

Two wind turbine systems, 4.5MW and 250W, were chosen by reference [13] in south France to evaluate their GHG emissions for all life cycle phases. The mean values for the 4.5W and 250W wind turbines were 15.8 g and 46.4 g CO2eq/kWh, respectively, illustrating that as power increases, the rate of GHG emission value decreases significantly. Furthermore, employing trains instead of vehicles as transportation reduces climate change emissions for 250 W from 23% to 2% and can minimize the impact on 4.5MW turbines by up to 20%.

Reference [14] conducted a review of 63 LCAs covering the period between 1990 and 2010 and concluded that GHG emissions from wind power differed from 4.6 to 55.4 g CO2eq/kWh. The lower value was for a higher capacity turbine (3 MW) and the maximum for 30 kW. This average value dropped as turbine capacity increased from 45.0 to 10.4 g CO2eq/kWh. Infrastructure related to steel production was the main contributor to the overall GHG emissions. Furthermore, 44 studies analyzed by reference [15], ranging from large to small turbines, concluded an average GWP unite of 19 g CO2eq/kWh. Reference [16] established GHG emissions of 7–10 g CO2eq/kWh, including end-of-life that contributes around 30%. The manufacturing stage contributes of 94.7% with foundations (10 %), tower (25– 30 %), cabling (20 %), nacelle (15 %) and blades (10–15 %), where the plant setup 1.75% and operation 3.5% of total global warming potential. The transportation share of GHG emissions during the total life cycle was 8%. Reference [17] observed that avoiding the shipment of some components overseas and substituting them with locally manufactured components might reduce transportation GHG emissions by 22%.

The comprehensive review was conducted by reference [18] for 19 studies covering Wind Energy Technologies (WETs), including 14 studies for onshore and 5 studies for offshore turbines. These studies revealed that the lowest mean values ranged from 5.3–13 g CO2eq/kWh between minimum and maximum of 8–124 GWP units for both types of wind turbines. The extraction of raw materials (30 %), turbine production (25 %), transportation (10 %), and emissions-related with installation on organic-rich soils (30 %), where these soils were removed and transported, are the primary contributions to the overall carbon footprint.

A study conducted by reference [8], screening 153 lifecycle studies, found that 22 studies are mainly linked to and liable for GHG emissions from the wind. The mean value reported was 34.1 g CO2eq/kWh, for low and high values was 0.4 & 364.8 g CO2eq/kWh over life span turbine between 20-30years. The first phase contributed to almost 71 % of GWP, followed by installation (24 %), operation (slightly less than 24 %), decommissioning, and recycling (19.1 %). Offshore estimations also revealed a decreased mean intensity.

Five types of wind systems utilized for generating electricity, included in 29 studies, represented 74 wind system cases designated to estimate the life cycle (GHG) emissions by reference [19]. Three case studies of onshore horizontal axis machines with a small capacity of fewer than 0.1 megawatts (MW); 4 case studies of onshore horizontal axis machines with a capacity is between 0.1 and 0.25 MW; 58 case studies of onshore horizontal axis machines with a large capacity is between 0.25 and 5 MW; 8 case studies of offshore horizontal axis machine with large capacity; and finally one case study of onshore vertical axis machine with small capacity. The mean life cycle GHG emissions resulting were 38.67, 11.75, 15.98, 12.9, and 46.4 gCO2e/kWh, respectively. Onshore turbines had higher GHG emissions (15.98 ±17.12 gCO2eq/kWh) than offshore ones (12.9 ± 7.61 gCO2eq/kWh) for turbines capacity greater than 0.25 MW.

At three different sites, deep-water, shallow-water, and onshore, in Texas, USA, the proportional sharing of individual steps to life cycle impacts were studied [20]. The comparison analysis results show that the extraction of material and related processes would be the leading phase for GHG emission, reaching (82 %) for deep-water, 72 % for onshore, and 58 % for shallow water. The other stage for onshore was followed by maintenance and operation (13.8 %) and fabrication (9 %). Steel recycling could result in a 20% reduction in average environmental impact. (GHG) values for the onshore location varied from 5–7 gCO2eq/kWh, 6–9 gCO2eq/kWh for the shallow-water, and 6–8 gCO2eq/kWh for the deep-water location. For the same categories, 2 MW on offshore and onshore occupied 9.3 and 7 gCO2eq/kWh, respectively. Relative values of the same class have been obtained by two studies [9, 21].

Table 1. Summery of the analysis of 58 studies published between 2005 and 2020 realted to the generation power from wind**.**

Reference	Total estimate (g CO2eq/kWh)	Life (years)	height (m) xRotor diameter (m)	Onshore/ offshore	System/turbine capacity	Location	Other assumptions
Reference [22]	14.8	20	55x 50	On	11 x 660 kW turbines	Italy	Min/max 8.8 /18.5
Reference [23]	7.65	20	55x 31	On	24 x 1.25 MW turbines	Guangxi,	
Reference [24]	15 12	20		On Off		Global survey	25% capacity factor (44)case studies Min/Max 1.7/81
Reference [25]	3.9	20		On	Enercon E40-600 kW Vestas V66-1.75 MW Vestas V-47-660 kW	China Mailiao, Jhongtun, Chunfong	
Reference [26]	39.6	20		On	33x1.5 MW	Mongolia	
Reference [27]	29.2 468	20		On Off	2.0 MW 2.0 MW	China	Fixed-floating platform
Reference [28]	2.4-7.0	20		On	2 MW	Spain	Repowering
Reference [21]	25.5	25	90X116 m 100X126	Off	27x3.6 MW 5MW	China	10 deep 8.5. m/s. 7.5
Reference [29]	12.5	20		On	50 MW	China	
Reference [30]	15-29	20		On	1.5 MW	Canada	based hydrogen production
Reference [9]	7	20 20		On	2.3 MW 3.2 MW	Denmark	
	11	25 20		Off	6 MW 4 MW	Denmark	
Reference [31]	10.42	20		On	37x1.65 MW M. Torres	Libya	
Reference [13]	15.8 46.4	20	124x113	On On	4.5 MW 250W-micro	France	Min/max (12.1 / 21.2) 35.8 / 58.8
Reference [32]	15.35	20		off	All farms	USA	floating wind energy
Reference [33]	8.82	20		On	2 MW	Global (German, Chinese, Denmark manufacturing)	gearless turbine
Reference [34]	13.4	30		Offshore	2 MW farm	UK	30%capacity factor
Reference [35]	10.69	20		Onshore		Ontario, Canada	Canadian electricity mix (210 g CO2-eq/kWh)
Reference	138–220	20	2x10	Onshore	1.5 kW turbines	New Zealand	electricity mix (224 g CO2-

[36]					roof		eq/kWh),
Reference [37]	7.1	20	80	Onshore	14 x 1.5 MW turbines	Brazil	electricity mix (64 g CO2-eq/kWh)
Reference 38]	7.9-12.5	20	84-108x80	Onshore	2.3 MW system	Germany	avg. wind speed 7.5-8.57
Reference [20]	7.35- 7.09-5.84 9.49 6.49 8.2 7.28	20		Onshore Offshore(sh) Offshore(D	1 MW 2 MW 2.3 MW 2 MW 2.3 MW 2.3 MW 5 MW	USA Texas	electricity mixes Cp 35% for onshore, 45% for shallow-water, and 47% for deep-water
Reference [19]	38.67 11.75 15.98 12.9 46.4	20	25 75)x(30-80)	Onshore Onshore Onshore Offshore Onshore	less than 0.1MW 0.1 and 0.25 MW 0.25 and 5 MW 0.25 and 5 MW less than 0.1MW	Global(Sweden, Canada, German, Italy, Taiwan Denmark, Japan, Spain USA, France	
Reference [10]	7.3	20	155x150	Onshore	24x4.2 MW	German	7.0 m/s (low wind)
Reference [39]	9.7 9.99	20		Onshore offshore	> 2 2 MW	Global	Wide range capacity factor
Reference [11]	4 to 45 7 to 23	20		Onshore offshore	0.66-4.5 MW	UK	Cp 19-40% onshore 26-54% offshore
Reference [40]	8.37 11.4 11.1	25 30 30		Onshore Offshore Offshore	2.5X60=150 MW 5X70=350 5X70=350	Global	- Shallow steel Shallow gravity
Reference [41]	14.4 18.4	25 30		Onshore Offshore		Survey (global)	
Reference [8]	3 4			Onshore Offshore		Survey (global)	
Reference [42]	5.27 4.22 3.53	20 25 30	78 x(83 - 87) m	Onshore	2x200 =400 MW, G83 G87	USA (Texas)	5.3 (average)m/s (recycling not including)
Reference [43]	10-16.6	20	65X 70 m,	Onshore	1.5x76 =114 MW, Enercon E-66	UK	Cp 21-22 % different turbine design variations
Reference [16]	7 to 10	20		Onshore	2x25=50-MW V100 Grid Streamer	Denmark	V=7-9.25 m/s , electricity mixes

					V90 V80		Recycling included
Reference [44]	8.65	20 20	65x77 m 50x50m	Onshore Onshore	1.5x18 =27 MW GW77 0.75x30= 22.5 MW Gold wind S50	China	8.3 m/s CF = 30%
Reference [45]	13.4	30		Onshore	20 MW	Italy	-

Reference [43] concluded that for all scenarios for Technology Improvement Opportunities (TIO) studied, the main contribution of all stages of lifecycle were construction (88.6-95.5) %, operation (6.8-1.8) % and decommissioning (5-2.7) % according to different turbine design variations. Reference [44] has estimated an average global warming value of 8.6 gCO2e/kWh without recycling. 90% due to the manufacture of turbines and their accessories with the manufacture of towers (41.0%), cables (30.0%), and rotors (19. %), while transformers and wiring made up only 9.6% and 0.4%, respectively.

Reference [41] comprise 54 studies. Their results were presented by minimum, maximum, and mean values. Mean in GHG emissions g CO2eq/kWh for onshore was 14.4 and 18.4 for offshore, respectively. Variations in GHG emissions 4.6-40.0 for onshore and 5.2-32 for offshore were found. Reference [46] concluded that replacing 1.23 GW onshore and 0.59 GW offshore and new installations 0.61+1.31 GW (total 3.74GW) to fulfill the capacity objectives between 2017 and 2030 in the Danish system decreases CO2eq/kWh from 40 to 13 g between 1980 and 2030. In 1980, the gCO2eq/kWh values of onshore wind turbines ranged from 20 to 90, whereas in 2010, the majority of them had indicator values ranging from 10 to 30 gCO2eq/kWh. The range of such indicators for offshore wind turbine fleet is slightly lower, ranging from 7 to 20 g CO2eq/kWh, which was referred by another study [8].

Reference [32] studied the GWP impact of floating offshore in California, United State. The model predicted ~15.35 g CO2eq/kWh with an uncertainty range of 8.58 - 30.17 g CO2eq/kWh. At the same time, the results are in accordance with other wind energy LCA research (3.0 to 45 CO2eq g/kWh for large-scale wind farms). During life cycle phases, first stage provides the most 40.6 % (18.3 g CO2eq/kWh). Meanwhile, the end-of-life phase contributes the least 20.4 % (-9.2 gCO2eq/kWh). During the fabrication phase, the turbine and substructure were the most critical contributors to CO2 emission, accounting for 77 % of manufacturing stage emissions. Steel was the most important material and energy contributor (49 %), while diesel and coal were about (27 %).

In another study, reference [47], a comparison between the vertical axis and horizontal axis wind turbine for low capacity (300-500) W in Thailand over 20 years life time concluded that the mean values of GWP unit are 12 gCO2eq/kWh and 5 gCO2eq/kWh, respectively. Other studies examined the effect of a location wind farm in particular countries. In a study conducted by reference [13], they reported 16 GWP units for a turbine capacity 4.5 MW. Reference [37] found 7.1 GWP unit for 141.5 MW of power in Brazil, reference [17] observed GHG of 16.9 gCO2-eq/kWh for turbines capacity of 1.8 MW in the United States. Reference [9] found 7 GWP units for 2.3 MW onshore in Denmark. Reference [27] obtained 29.2 GWP unit for 2 MW, reference [43] found 25.5 GWP unit for 5MW offshore in China.

The value of (GWP) from [10] accomplished 7.3 gCO2eq/kWh with recycling. The impact of each main life cycle phase was: all manufacturing steps 11.3 gCO2eq/kWh (98.2%), Plant setup 0.1, Operation 0.2 and End-of-life -4.4 (-38%). Whereas manufacturing includes all raw material extraction from mining to the site; plant set-up includes onsite assembly components and roads (e.g. cranes, generators, etc.); maintenance, service, and transportation are all part of the operating stage; and end of life involves disassembling recycling, and garbage disposal. The manufacturing stage commanded the life cycle impact, where the tower fabrication occupied (42 %), nacelle frame (8 %), gearbox (7 %), tower foundations (15 %), rotor blades (10 %), and wiring (3 %) being the major determinants contributing to this phase. The end-of-life phase also contributes significantly (-38 percent) by offering environmental credits for avoiding material processing such as copper and steel and so on.

Reference [39] presented an updated evaluation LCAs of onshore and offshore wind turbine electricity generation for 58 case studies relevant to GHG emissions. By new simplified LCA models, Global Warming Potential (GWP) was obtained for onshore (0.001–5. MW) and offshore (0. 5–8. MW). For Onshore and offshore large scale, median values of GWP are 9.7 and 9.99 gCO2eq/kWh, respectively. Furthermore, the median values decline as the nominal WT capacity and capacity factors increase. The GWP has a broad range of variability for onshore applications, ranging from 4.8 to 560.0 GWP units with a wide range (between 0.02 and 0.56) for onshore applications. This fact is particularly for micro turbine applications where various basic assumptions lead to widely disparate estimates, what means that turbine capacity between 0.2 -1000 KW still requires further investigation.

The role of each life cycle stage on CO2eq was done by reference [42], they showed that the mean value was 5.27 gCO2eq/KWh for 20 years life span, distributed as follows, 90.1% for raw material acquisition/manufacturing, 1.9% transportation 7.1% installation, and 0.9%o operation and maintenance. The most significant maintenance effects are created by replacing some control system components, followed by the replacement of the lubricant. If the end-of-life were included, the mean value would be declined by -65.8% to still equal to 1.82 g CO2eq/kWh. Extending the life cycle to 30 years, the overall GHG impact would be decreased by 33% to 3.53 g CO2eq/kWh. The highest impacts of each major component of the turbine come from the manufacturing of the tower contributing > 40% of the overall impact. The processing of steel needed for manufacturing the tower contributed to 95% of the greenhouse gases. Replacing the steel tower with a steel-reinforced concrete tower reduces CO2 emissions by 6.4% overall.

According to reference [25], the average CO2 emission factor of the three systems investigated was 3.9 g CO2eq/kWh over the life span. All raw materials had an average intensity of 1.35 kgCO2/kg. Manufacturing accounted for 44% of CO2 emissions, decommissioning for 40%, and construction for 16%. The overall CO2 emission rate was 1.98 kg CO2/kg for all steel materials.

Reference [48] studied the GWP impact of tall towers onshore turbine (76.16-m hub height): a lattice and a tubular one over a 20-year lifetime. As the results show, the 82 % responsibility of the manufacturing phase of the overall equivalent CO2 emissions of the tubular tower, whereas the lattice one accounted for 75 %. The second contribution comes from the transportation step, accounting for 9% for tubular and 14% for lattice. Related to CO2 emissions per structural component, it was 62% for the tubular tower, 27%foundation, 9% nacelle, and 2% rotor.

3.2 Solar Energy

One of the most common methods for generating electricity directly from solar energy is to use Photovoltaic Cells (PVs). Another way to generate electricity indirectly from solar energy involves focusing the sun rays through a Concentrated Solar Power (CSP) system to convert it into thermal energy and electrical energy. Furthermore, Concentrated Photovoltaic (CPV) can be used to generate electricity. The design of Photovoltaic Cells (PVs) is varied and these cells can be affected by several variables [49, 50, 51, 52, 53]In (CPV), where sunlight is focused on as hybrid technology, it was developed to overcome weaknesses and highlight the advantages of PV systems [54]. CPVs are still in their adolescence compared to conventional PV systems. Consequently, they play a limited role in solar electricity generation, with a relatively small number of research studies related to operation and installations [55]. In 2021 meantime, conventional PV and CSP systems represent the main part of the renewable energy market. Therefore, the scope of the current study is limited to the most widespread technology, but sometime the data related to the third generation may be used for comparison purposes [56, 57, 58].

3.2.1 Photovoltaic (PV)

PV system produced electricity consists mainly of three parts a) multiple modules connected to create an array, b) Balance Of System (BOS), c) storage system typically used for stand-alone systems. Communally BOS includes inverters that the device usually replaced at least once during the life span of a PV array, and support systems fabricated from stable and durable materials such as aluminium alloys, combiner boxes, cables, and connectors. Additional equipment and facilities such as land and grid connections should be needed for large-scale ground-mounted PV construction [58, 59].

PV systems are distinguished by fabrication techniques, shapes, sizes, and used materials. Various semi-conductive materials were used in manufacturing PV: about 85–90% of the solar cells are composed of single-crystalline silicon (sc-Si) or multi-crystalline silicon (mc-Si). The single-crystalline silicon (sc-Si) and multi-crystalline silicon (mc-Si) are called first-generation PV cells. The scope research areas for PV technologies are the first-generation and second generation of PV cells, based on the thin-film solar cells, which include (a-Si, lc-Si, GaAs, C.I.S., CdTe, CdS, CIGS). PV systems are categorized as grid-connected, stand-alone systems. In addition, PV systems can be categorized according to their configurations: fixed PV or tracking systems that include single and double axis tracking.

The third-generation PV cells include organic or semi-Organic PV panels (OPV), Perovskite cells (PC), Dye-Sensitized Solar Cells (DSSC), and Quantum Dot (QD) cells, as well as CSP systems, which are considered: still under development [58, 60]. Photovoltaic (PV) power facilities, as mentioned by reference [61], have carbon footprints that can range from 12g per kWh for a facility employing First Solar's thin-film modules to as high as 24g per kWh for one using multi-crystalline silicon panels over its entire lifecycle. The reviewed literature regarding the Photovoltaic (PV) includes 78 studies published after 2005 related to most used PV technologies and covered its LCA, as follows: 22, 23, 15, 8, 7,3 studies for sc-Si, mc-Si, CdTe, CIGS, a-Si, CIS respectively. The reviewed studies are presented in Table (2).

The life cycle of a PV power system may divide into four stages [8, 31, 62, 63, 64]: 1) acquisition of raw materials, processing of materials, and manufacturing; 2) installation and construction of electrical and electronic parts, wiring, and land-used and structural support; 3) operational and maintenance phase; and 4) PV component end-of-life (decommissioning, recovery, disposal, or recycling). According to reference [65], all parts of the BOS components' analyzed system should be characterized. The End-Of-Life (EoL) should be integrated into the study and thoroughly specified, given their significant impact on the results. A more thorough impact assessment technique should be employed when updating data due to new parameter upgrades to avoid such a negative effect. Reference [66] estimated GHG emissions in 15.6– 50, 44–280, and 9.4–104 for amorphous, mono-crystalline, and poly-crystalline solar PV systems.

The median value of GHG emissions from 42 case studies obtained by reference [67] was between 40-47

GWP units for ground or roof mount related to all types of PVs cells studied. Results presented by reference [68] were less twice than the results in reference [67]. It is close to the results of reference [69], as the life span was considered 17 instead of 30 years

Reference [70] examined five types of photovoltaic (PV) systems-based electricity generation: sc-Si, mc-Si, a-Si, CdTe, and CIS thin film (CIS). The mean GHG emission rates were 37, 33.5, 34.5, 25.5, and 28.25 GWP units. For its high conversion efficiency and low energy consumption across the lifecycle, the CdTe PV system has the lowest greenhouse gas (GHG) emission rate value. In contrast, the mono-Si PV system has the highest value due to the high energy intensity during the PV cell production process.

Table 2. Summery of the analysis of 20 studies published between 2005 and 2020 related to the generation power from Photovoltaic (PV)

Source (20) studies	Total (g CO2 eq/kWh)	Life (years)	Irradiance (kWh/m2)	Technology	Mounting	Location	Other assumptions
Reference [71]	53.5	30	1700	ms-Si	30º tilt, fixed aluminum mount	Virtual	5 MWp, module η=0.14
	42.8				30º tilt, dual-axis tracking		
	38				30º tilt, fixed wood mount		
	37.5				30º tilt, single-axis tracking		
Reference [70]	23 22.9 32 33	17 17 17 17	2096 1834 1228 1834	mc-Si mc-Si CdTe CdTe	Calculated per produced kWh without recycling	Brazil China Germany China	η=0.141 =0.129 =0.09 =009
Reference [72]	32 62 142	20	1700	CdTe CIS mc-Si	actual production systems	Europe	η= 0.08 η=0. 10 η=0.14
Reference [73]	44	30	1000	sc-Si	tilt of 35º, fixed 125m2,wall mounted 32 rows	UK	14.4 kWp η=0.115
Reference [74]	61 13 29 30	30	1700	sc-Si CdTe mc-(Si) sc-Si	153.5m2 Solaire building integrated photovoltaic Without integration	USA	11.3kWDC η=0.14 η=0.109 η=0.132 η=0.142
Reference [57]	10.7 24.6	15 30	1600	Perovskite-silicon tandem Mono-(SI)	simulation	USA	η=0.252 0.231 0.276
Reference [75]	29.2	25		Poly-(SI) 315-320Wp (cell)	246MWp $3.64x10^6$m2	Chile	0.165-0.162
Reference [60]	47.9	30	1600–	sc-Si	30º tilt, ground	Italy	η=0.1385

			1800		mounted single-axis tracking		2 MWp
Reference [76]	37 21 30 45	30	1700	mc-si CdTe Ribbon-Si sc-Si	On-roof mount	Europe	european electricity mix η=0.132 european electricity mix η=0.08
Reference [77]	12.75	30	1700	CdTe	-	USA	η=0.109 electricity mix (750 g CO_2-eq/kWh)
Reference [67]	45 40 47 48 44	30	1700	c-Si sc-Si mc Si c-Si c-Si	- - - Ground mount Roof mount	Global	- η=0.14 η=0.132 - -
Reference [68]	20 16 26 21 14 27	30	2400	a-Si CdTe CIGs a-Si CdTe CIGs	Ground mount Ground mount Ground mount On-roof mount On-roof mount On-roof mount	Global	η=0.063 η=0.109 η=0.115 η=0.063 η=0.109 η=0.115
Reference [78]	92	30	1204	sc-Si	45 degree fixed mount	Global	-
Reference [79]	5	30	1700	CdSe QDPV	Ground mount	Europe	η=0.14
Reference [41]	52.5 61.5 35.5	25-30		mc-si (sc-si) Thin Film (CdTe)(CIS)((CIGS)	Survey	Global	
Reference [8]	49.9	-25-30	1204-2400	a-Si GIS ms-Si sc-Si	Survey	Global	η=0.06-0.14% 17.5 to 110 g
Reference [80]	43.5 39.5 44.3 52.4	30	1700	a-Si (amorphous) GIS ms-Si sc-Si	3 kW On-roof mount area 49.2 m2 28.2m2 24.5m2 17.7m2	Greece	η=0.061 CF =21.8% η=0.106 CF =20.2% η=0.123 CF

							=20.6% η=0.17 CF =20.6%
Reference [82]	41.8 31.5 27.5 25.2	30	1700	sc-Si; mc-Si sc-Si mc-Si.	100 kWp Ground fixed mounted 1,59 m2 panel area	Korea	sc-Si η=0.159; mc-Si η=0.149 sc-Si η=0.276 mc-Siη=0.204
Reference [83]	30.2 29.2 20.9	25 25 30	1580	multi-Si PV technologies (cell or module)	Roof-integrated one 60-cell silicon PV module.	Singapore	Aluminum back surface field η=0.159 Passivated emitter and rear cellη=0.167 Solar cells with the frameless double-glass module structure η=0.162
Reference [84]	60.1 80.5 65 87.3	25	1600 1200 1600 1200	LS-PV ms-Si Distributed ms-Si LS-PV sc-Si Distributed sc-Si	performance ratio 0.75 1.12 m2 1kWh 0.7 0.75 0. 70	China	sc-Si cell η=0.17 mc-Si cell η=0.15 grid-connected photovoltaic
Reference [45]	26.6	30	1600	sc-Si	Ground mount	Italy	
Reference [85]	85.33 73.67 23.22 50.5 39.2 57.49	30		sc-Si ms-Si CdTe CIS CIGs a-Si	Survey	Global	

The GWP includes recycling for two types of c-Si panels (sc-Si and mc-Si) evaluated by reference [82]. This evaluation was built according to two scenarios related to the PV efficiency: a base one with efficiency: of 15.9% for sc-Si and 14.9% for mc-Si and the other scenario with higher efficiency: of 27.6% for sc-Si and 20.4 for mc-Si. As a result, the sc-Si and mc-Si panels release 41.8 and 31.5 g CO2eq/kWh in the base case, and with the higher efficiency case, those values are reduced by 34.3% and 20.0%, respectively. Further analyses of the lifecycle lineal on the basic case for both the sc-Si and mc-Si module show that pre-manufacturing, manufacturing processes, and end life contributed 12%,88%,-20%, and 19%,81%,-12% for sc-Si, mc-Si modules of total respectively. The highest share comes from ingot (38% for the sc-Si base scenario and the lowest 11% for the mc-Si module in both scenarios). Reference [86] evaluated the carbon footprint of a large-scale grid-connected PV system over its entire life cycle, including extraction of raw material, module fabrication, and operation, excluding the end-of-life stage. GHG emissions ranged from 12.28 to 58.81 g COeq/kWh, with cell efficiency ranging from 14 to 20% considering four alternative manufacturing scenarios of a multi-crystalline panel. Reference [8] examined 21 studies that were directly related to GHG emissions from PVs. The mean value reported was 17.5 - 110 g CO2eq/kWh, with an average of 49.9 g CO2eq/kWh. The majority of the footprint CO2 has been related to the first stage, which was expected to contribute about 71% of the lifetime GWP. For construction 19%, operational stage about 13% (6.15 g CO2eq/kWh), decommissioning and recycling -3.3 % for PVs.

In China, reference [87] conducted an LCA for mc-Si modules PVs. The cells had a life span of 25 years and a cell efficiency of 16 percent. A PV system's GWP was 50.9 gCO2eq/kWh, with CO2 (83.6%) and CH4 (13.6%) dominating (11.2 %). Solar-grade multi-Si (SoG-Si) production, ingot casting, wafer slicing, cell processing, and module assembly were all part of the manufacturing process for PV modules in China. Because of its high energy use, the manufacture of SoG-Si was a significant stage, accounting for around half of the GHG. Because of its high electricity use, cell manufacturing contributed significantly to GWP (20.5 %). This factor is related to the that electricity was mainly generated in china by coal-fired power plants.

Data adopted by reference [64] related to installation rooftop-mounted under Southern European irradiation of 1700 kWh/m2/yr and performance ratio of 0.75, indicated that the mean values of GHG emissions were 29, 28, and 18 g CO2eq/kWh with an efficiency of 10.9,13.2, 14% and life span 30 years for sc-Si, mc-Si and CdTe respectively. The contribution of GWP unit of BOS, frame, laminate, and cell is about 60% for c-Si technology, while 3% and 67% for BOS and laminate related to CdTe type.

Reference [84] examined the environmental effects of grid-connected c-Si PV generation. Depending on the installation methods, GHG emissions range from 60.1 for LS-PV ms-Si to 87.3 gCO2eq/kWh for distributed sc-Si systems. Approximately 84 percent or possibly more of total GHG emissions occur during the PV manufacturing process, with SoG-Si creation accounting for 36 % of total Carbon footprint over the lifecycle. Reference [88] investigated the LCA implications of an mc-Si panel system in China, with an operational life of 25 years and a cell efficiency of 16%. The study did not include the transportation or use phases in its research, instead focused on the decommissioning and recycling stage. 90% of the climate change impact was due to the share production process. When comparing landfill and recycling scenarios, the most important GHG impact processes were mc-Si fabrication, processing of cells, and panel assembly. The recycling scenario of the end-of-life (EoL) stage showed fewer consequences on the environment than the disposal scenario.

Reference [85] reviewed 31 LCA studies connected to PV electrical generating systems. They concluded that the calculated mean values of GWP impact for sc-Si (24 case studies), mc-Si (35 case studies), CdTe (21case studies), a-Si (16 case studies), CIS (3case studies), and CIGS (one case study) were to be 85.33, 73.68, 23.22, 57.49, 50.5, 39.2 gCO2eq/kWh respectively. It should be noted here that these high values of CO2 rates came as a result of the authors' reliance on almost references before 2010, where the end-of-life excluded. In addition, the following should be noted from all previous studies that CdTe cells are the least effective in global warming than other photovoltaic cells.

Report by reference [89] described energy intensities needed for recycling of crystalline silicon (c-Si) and cadmium telluride (CdTe) PV modules over a 30year lifespan. Compared to the impacts created by the manufacture of a 3 kWp, the climate change impacts of recycling efforts of c-Si PV modules are quite minimal, accounting for a maximum of 1.1 percent. In contrast, it is about 4.8% for CdTe PV module recycling, but still the minor GHG impact. Recycling resources like silicon, copper, aluminum, and glass has a constructive effect on climate change. Global warming may have contributed -15 % of the total impact by using an advanced recycling approach for 1000 kg waste (c-Si) panels [90].

CdTe technology uses less energy and material resources than Si technology, according to reference [63], resulting in a reduction in all gaseous emissions repercussions. They also highlight the importance of the end-of-life recycling process, which involves raw material recovery. Adoption recycling innovation methods can cut the GWP by 24.14 % in multi- silicon and 4,71 %t in CdTe technologies. When a 1 m2 polycrystalline panel is recycled, 0.889 m2 (89%) are produced due to this procedure. In contrast, if a 1 m2 CdTe solar panel is reprocessed, 0.0412 kilogram CdTe (94.9 %) is obtained instead of the 0.0434 kg required for a new solar panel.

A comparative LCA of various p-type multi-crystalline silicon (multi-Si) photovoltaics investigated by reference [83] installed for electricity generation in Singapore (Table 2) starts with the extraction of silica sand and ends with the installation phase. The GHG emissions were 30.2 gCO2eq/kWh for the aluminum back surface field η=0.159; 29.2 for passivated emitter and rear cell η=0.167 and finally 20.9 gCO2eq/kWh for cells with the frameless double-glass module structure. This study shows that shifting from the conventional first to the third case reduced the GHG emission by 50%. The relative contribution of the carbon footprint from various manufacturing stages was roughly 41.5 percent for wafer products (including casting and wafering); 26.1 percent for silicon feedstock production (solar grade); and 15.7 percent for the balance of system BOS including installation, etc. 0.9% for cell processing and 7.5% for module assembly for all modules. It should be noticed here that share module assembly for 1&2 cases reached 16.5%, while a share of silicon feedstock slightly increased.

The survey results carried out by reference [41] of 45 case studies showed the average value of CO2 footprint in the range of 50.9 5 g CO2eq/kWh. The maximum value was 126, and the minimum was 12.5 g CO2eq/kWh. The average value for sc-Si, mc-Si, and thin-film was 61.8, 52.2, and 35.5 g CO2eq/kWh, respectively. The principal reason for such fluctuation is cell and module manufacturing energy requirements. Thin-film technology, on the other hand, offers substantially reduced energy requirements. GWP range from 12.5 to 95.0 g CO2eq / kWh, with thin-film a-Si technology releasing the lowest and CIGS emitting the most. The location of large-scale constructions may also play an animated role in CO2 quantities related to land use or electricity production mixes in the production phase [45].

Four types of PV cells (a-Si, GIS, mc-Si, and sc-Si) were investigated by reference [80]. They found that the mean higher carbon footprint value was 52.4 for sc-Si and the lower 39.5 g CO2eq/kWh for GIS. This contradicts the survey results the results of the previous study [41]. Reference [91] showed that more than 75 % of GWP is due to multi-crystalline cell processing and module assembly. It also noticed the direct relation between consumption of energy and climate change impact, where it two steps have the highest consumption rate and non-positive environmental impacts. On the contrary, the second generation is less energy-intensive than first-generation models through manufacturing processes (purification and crystallization). This should lead to a lower GWP impact [58, 82].

Using varied evaluation approaches, a lack of or missing data at some stages of LCAs, and selecting different functional units result in a wide range of outcomes, complicating the comparison between studies [58, 65]. The low number of panels that reached the decommissioning phase is the key reason for the end-of-life stage [90].

Table 2 summarizes the research's significant parameters that studied GHG emissions based on panel energy generation capacity, type of solar panel, orientation, and angle. Other criteria such as durability, irradiance (kWh/m2), mounting, efficiency, location, technology, system, and the electricity mix of that country and year of study are all considered as possible. Another cause for the gap in data for major greenhouse gas emissions could be one of the factors outlined above [66, 70].

3.2.2 *Concentrating Solar Power (CSP.)*

Concentrated Solar Power Plants (CSPs) are thermal systems using a thermodynamic cycle such as the Rankin cycle to generate electricity. This technique can function at two temperature levels either high temperatures (about 1000 oC) or intermediate temperatures (about 400–500 oC). Solar arrays must be focused on tiny surfaces using reflecting mirrors of various shapes to achieve such high temperatures. Its primary characteristics are high efficiencies, the utilization of mainly the direct component of solar energy, and the requirement of high Direct Normal Irradiation (DNI), which makes the implementation of small plants problematic. A central tower can capture the concentrated solar radiation, parabolic trough, dish, or linear fresnel reflectors. The life cycle phases of CSP technologies also include the four stages mentioned earlier for PV cells and wind systems, taking into account the specifics of each technology [41, 89, 92, 93].

According to reference [94], following the full harmonization of 125 research studies, 10 generated 36 case studies with independent GWP estimates that passed quality and relevance screening: 19 for trough and 17 for tower systems. The Inter Quartile Range (IQR) of published estimates for troughs and towers was 83 and 20 g CO2eq/kWh, respectively, whereas the median values were 26 and 38 (g CO2eq/kWh).

Reference [93] assessed the life cycle for a dry-cooled, 106 MWnet power tower facility in the USA. The estimated GWP was 37 g CO2eq/kWh. The highest contribution of GHG through life span was for O&M 17 g CO2eq/kWh (46%), whereas 14 (37.8%) ,4(10.8%), 2.4(6.48%), 0.38, for manufacturing, disposal, construction, dismantling respectively. Using synthetic salts as storage agents, estimated GHG emissions increased by 12%.

A comparison of CSP cells and PV cells was made by reference [60]. In this work, the obtained GWP was 29.9 gCO2eq/kWh for the CSP plant and 47.9 g CO2eq/kWh for a PV power plant. Decommissioning of the plants was considered but did not involve component transportation. A commercial wet-cooled 50 MWe CSP plant with thermal efficiency (30-35% based on parabolic troughs operating with different Natural Gas (NG) inputs (from 0 to 35 % of mix generation of electricity) was investigated [95]. Using solar energy, only produced GWP 26.6 g CO2eq/KWh. Higher impact values were observed for GWP that accounted for 311 g CO2eq/KWh when using 35 % NG.

More than 100 reviewed case studies engaging with life cycle assessment of renewable energy systems are included in reference [96], such as (C.S.P.s, P.V.s), wind, hydro, and geothermal energies. The results obtained after harmonization of 15 case studies for CSPs (9 for parabolic trough and 6 for tower) between the lowest and highest values for GWP were respectively equal to 10 and 71 g CO2eq/kWh, for a mean value equal to 33 while for wind 11.84 and for PV 31.6 g CO2eq/ kWh. Previous research [97] indicated that GHG emissions from PV plants are 34.4 gCO2eq/kWh, while trough and tower CSPs emit 20.6 gCO2eq/kWh and 14.2 gCO2eq/kWh, respectively. Values related to other technologies are listed in Table 3.

Reference [40] Supporting Information (SI) obtained other 95-33g CO2eq/kWh results. The midpoint values were 22.7 and 33 g CO2eq/kWh for troughs and towers, respectively. Another survey comparing three types of CSP systems used for producing electrical power was done by reference [85]. This study reviewed 10 case studies for trough receivers, 9 case studies for central towers, and 2 case studies for the parabolic dish. The highest contribution had tower systems with average GHG emissions of 85.67 gCO2eq/kWh and the lowest average of 41 gCO2e/kWh for the parabolic dish, whereas 79.8 gCO2e/kWh for the parabolic trough.

Reference [41] surveyed two types of concentrated systems (troughs and towers) within three capacity ranges: less than 50 MW, Between 50 MW and100 MW, and more than 100 MW. For CSP technologies, a minimum value of 10.0 g CO2eq/kWh and a maximum value of 56.0 g CO2eq/kWh displayed a considerable variance. The mean values were 33.2, 30.3, and 24 g CO2eq/kWh. It was also discovered that power tower receivers contribute more than 31.9 g to GHG emissions than parabolic trough receivers 23.6 gCO2eq/kWh.

Three case studies considered by reference [45] represented three geothermal power plant scenarios, one wind farm, and one CSP plant in Italy. The assessment employed the ReCiPe 2016 and the ILCD 2011 Midpoint+ LCIA methods widely used in Europe to perform comparing potential impact at the midpoint level. The investigated plants had similar nominal capacity (about 20 MWe), assuming a lifetime of 30 years. The system boundaries consisted of the whole life cycle of the system (including the replacement of main parts). The impact of climate change at the mid-point was 13.4, 26.6, 415, and 484 GWP units for wind, solar, geothermal, and national energy mix), respectively.

Table 3. Summery of the analysis of 11 studies published between 2005 and 2020 related to the generated power from Concentrating Solar Power (CSP)

Source	**Total estimate (g CO2eq/kWh). Type**	**Life (years)**	**Capacity**	**Location**	**Tower height or aperture area**	**Other assumptions**
Reference 92]	31 tower	20	110 MW	Global	140m x0. .457 km2	manufacturing + operational, without storage
	9.8 tower	20	110 MW		240 m1.469 km2	with storage
Reference [95]	26.6 troughs	25	50 MW	Spain	510.12km2	parabolic troughs desert land
Reference [98]	24.3 tower	30	101 MW	South Africa	1.4375 km2 Heliostat size 25 m² Tower height 230 M DNI kWh/m²/a 2,900	Tower with heliostats 12 hour heat storage and no supplementary fuel electricity grid mix
Reference [94]	26 trough 38 tower 38 parabolic	30	1-400 kW	Survey		utility-scale CSP
Reference [40]	22.7 trough 33 tower	30	net 103MW 106 MW	(lca)	4.1 km2 6.3km2	CF=0.47 CF=0.42
Reference (2019) [41]	23.6 trough 31.9 tower	25-40	< 50 MW to > 100 MW	Survey		
Reference [99]	6.5HCPV 53.7 107.7	30 25	FULLSUM 1.008MWp 7.5 kW CPV	Chile Moroco Japan	0.27 m2, CR=625X 3600 m2 CR=520x 34.56 m2 CR=476x	DNI 3322,η=0.34 1834 η= 0.282 909 η=0.3
Reference [100]	13.6 Paraboloidal dish	30	1MW	Italy		
Reference [101]	202 Central tower 196 Parabolic trough	25 25	1.7 MW 50 MW	Spain Spain		
Reference [93]	37 tower	30	a dry-cooled, 106 MWnet	USA	No of heliostats 6,682 total aperture area 964,712 m2 tower height 172 total land area	DNI 2600 kWh/m2 capacity factor 41.7%

					6,345,471 m2	
Reference [85]	85.87 tower 79.8 trough 41.24 parabolic dish	30		Survey		

Reference [99] reviewed issues related to CPV with High Concentration Photovoltaics (HCPV) and Low Concentration Photovoltaics (LCPV). GWP impact of the system could be decreased by 23–31% by extending the life span of the HCPV plants 10 years from 20 to 30 years. Reference [102] explored HCPV prototypes based on LCA analysis of modules: mirror-based, Fresnel lens, and Achromalens. GHG emissions for the mirror-based optical design module were roughly 10% less than the Achromalens modules. Moreover, a contribution in the carbon footprint of 50% comes from optics, tracking systems, and metals of the frame.

Reference [92] carried out and compared CO_2eq/MWh of a tower-type CSP utilizing molten salts as a storage agent with a reference CSP plant without storage in a baseload pattern. Without storage, the impact was 67% (31 gCO_2eq/kWh) larger than with storage (9.8 gCO_2eq/kWh). The GWP was presented by reference [98] linked to CSP plant-generated electricity shows that the GHG impact of the assessed plant is 24.3 g CO_2eq /kWh. The plant's construction phase releases 12.0 g CO_2eq/kWh (44 %), while the other produces 15.2 g CO_2eq/kWh (55 percent). By recovering and replacing virgin material at the end of life, 2.9 g CO_2eq/kWh (10 %) of CO_2 emissions are prevented. The solar field contributes 30% of the GWP, followed by molten salt storage and transportation expenditures, which contribute 25%, and building on site, which contributes 9%. Table 3 summarizes the results of the survey for CSP technologies

4. Compression GWP of Wind and Solar Technologies Versus Other Electricity Generation Systems.

The finding of GWP impact studies linked to electricity generation systems are tabulated in Table (4). The GWP of traditional power systems conducted only fossil fuel combustion and related activities and is based on the IPCC's 'Default CO_2 Emissions Factors for Combustion' listed in its Guidelines for National Greenhouse Gas Inventories (IPCC) [103] and AR 5 Climate Change 2014: Mitigation of Climate Change 2014.

Table 4. The findings of studies related to the GWP impact linked to electricity generation systems

Options	Min/Mean/Max Silva and Raadal, (2019) [41]	Min/Mean/Max Reference [104]	Min/Median/Max Reference [105]	Min/mean/Max Reference [8]	Min/ /Max Reference [106]	Mean Reference [104]	Mean Reference [107]	Min/Median/Max Reference [96]
Lignite		1054/790/1372(6)			800/1300 (7)	1133	1504	
Coal—PC	692/948.9/1250(42)	756/888/1310(10)	740/820/910	960-1050 1005	600/1050 (36) 825	921	888	
Oil		547/733/935(5)			530/900(10)	731	733	
Gas—Combined Cycle			410/490/650					
Natural Gas	259.6/446.7/539.3 (20)	362/499/891 (12)		443 for conv,492 fracking 611 LNG	380/1000 (23) 545	506	499	
Geothermal flash steam and binary cycle power plants	15/38.1/56(13)		6.0/38/79	38			38	16.9/33.6/142(20)
Hydropower	2.4/21.4/90 for reservoir 1.2/19.1/4	2/26/237(7)	1.0/24/2200	10(resv) and 13 run river	2/20(12)	27	26	2.2/11.6/74.8(15)

	8.2 for run Run-of-river,(94)							
Nuclear		2/29/130(14)	3.7/12/110	66	3/35(10)	14		
Biomass		10/45/101(5)		14/41	8.5/130(25)	52	26	
Concentrated Solar Power	10/27.9/56 (29)		8.8/27/63	13				14.2/30.9/203(15)
Solar PV—rooftop	1.5/50.9/126 (45)	13/85/731(13) (both)	26/41/60			97	23	9.4/29.2/46(36)
Solar PV—utility			18/48/180	17.5/50/110	13/190(22)			
Wind onshore	4.6/14.4/40 (54)	6/26/124(11)(both)	7.0/11/56	34	3/41(22)	30	10	6.2/9.4/46(20)
Wind offshore	5.2/18.4/32 (54)		8.0/12/35					

Note: The number in the () refers to number of studies.

Table 4 continoued. The findings of studies related to the GWP impact linked to electricity generation systems

Options	Mean value					
	Reference [18]	Reference [108]	Reference [45]	Reference [101]	Reference [63]	The current study
Lignite		790-1372				
Coal—PC		675-1639 1157		975		936
Oil				742		730
Gas—Combined Cycle		245-930 587	484	607	478	
Natural Gas						502
Geothermal flash steam and binary cycle power plants	11–78 (4)40	6.-76 36	415 mid			37.4
Hydropower	2–75 (11)	3-12 run ri 0.-165 resv		3.7-237		22.7
Nuclear		1-220		24.2	18.5	26.9
Biomass	25-550(14)	75-635		35-178		62.4
Concentrated Solar Power	30–150 (6)	7-89		13.6-202		28
Solar PV—rooftop	9–300 (19)	5-217		53.6-250		48
Solar PV—utility			26.6			
Wind onshore	8–124 (14)	2-81	13.4	9.7-123.7	10.5	13.2
Wind offshore	5–24(5)					

Note: the number in the () refers to the number of studies.

Conventional power plants are mainly responsible for emitting the most significant amounts of carbon dioxide, while more than 75% are released through fuel combustion and related activities. The average value of a GWP unit for a coal-fired system is 936 g CO2eq/ kWh, 730 g CO2eq/ kWh for oil, and 502 g CO2eq/ kWh for gas-fired power systems. Figure 1 shows the concentration of GWP units for investigated renewable and non-renewable energy systems.

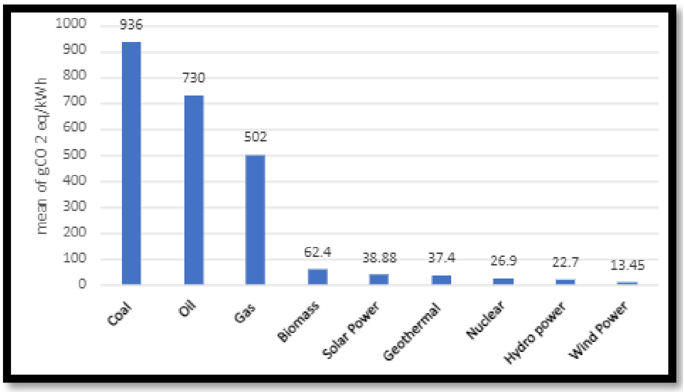

Fig. 1: The concentration of GWP units for investigated renewable and nonrenewable energy systems.

According to IRENA 2019, the total renewable energy installed capacity until 2020 was 2799. 094 GW distributed as Hydropower 1331. 9 GW; Pure pumped-storage 121.273 GW, Marine energy 527 MW, Wind energy 733. 276 GW (Onshore 698. 909 GW, Offshore 34 .367 GW.) Solar energy 713. 970 GW (photovoltaic 707. 495 GW, Concentrated solar power 6. 475 GW); Bioenergy 126. 557 GW; Solid biofuels and renewable waste 102. 852 GW; Bagasse 19. 908 GW; Renewable municipal waste 15. 355 GW; Other solid biofuels 67. 588 GW; Liquid biofuels 3. 555 GW; Biogas 20. 150 GW; Geothermal energy 14. 050 GW. Renewable energy share of electricity capacity reached 36% of global electricity generation in 2020. As predicted by bp Statistical Review may climb to 45 percent by 2040.

The overall electricity made up 25,850 TWh by the end of 2020 share each sector in detail is 15,757 fossil fuel (8,736 TWh from coal. 5,892 gas. oil 1,128) 10,109 low carbon sources (hydro 4,355 TWh nuclear 2,616 wind 1,59. solar 0.844 other renewable 0.702 TWh. It is responsible for releasing around 12 Gt of carbon dioxide (67.7 % are coming from coal, 24 % from gas, and 6.7% from oil), whereas less than 2% from low carbon sources. Replacing one kilowatt-hour of coal or oil-generated electricity with one kilowatt-hour of wind can save 923 or 717 of gram carbon dioxide equivalent

According to the BLUE Map (IEA) scenario, the combined contribution of renewable energy resources such as solar, wind, and hydropower should rise from 16.5 percent of total electricity output in 2010 to 39 percent in 2050. Reference [40] indicate that the large-scale implementation of wind, PV, and CSP has the potential to minimize GHG emissions impacts on power production. Furthermore, it would have a more minor environmental impact than a system with a high proportion of CO2 capture systems.

5. The Results

According to the findings of the studies, the manufacturing stage accounts for between 90 and 98 percent of the overall GWP of an onshore wind farm not built on peat lands [10, 11, 13, 14, 16, 47, 25, 22 ,33], while a 70% of an offshore farm [21, 109, 110], with most of these impact occurring during material extraction and component manufacturing. The higher contribution (up to 42%) was coming from towers, 30% for nacelle and 20% for rotor blades [10, 16, 44]. Typically, transportation and installation contribute only about 6% of GWP for an onshore wind farm if carbon impacts of land-use change, such as construction on peatlands are not included [44]. For offshore, the ratio would be higher as a result of extensive use of ships, although there is no study clearly estimating the division between fabrication and installation effects [111]. The operational and maintenance phases account for 1.6 to 6% of the total life cycle GWP impacts of onshore plants [10, 43] and around 20% of offshore (due to the installation site being more difficult to access) [20], with decommissioning accounting for the remaining 6% includes disposal. If the end-of-life comprised recycling stage is included in the calculation, then the total GWP declined up to 40% thanks to the recovery of metals [10, 20, 25, 32,], The plant setup occupied less than 1% of the total GWP impact. In absolute values, the GHG emissions corresponding with the operational phase were estimated at 0.74 gCO2eq/kWh (less than 5% on land) within [35] and 0.49 gCO2eq/kWh within [63]. The total GHG impact of onshore wind was 12.7 gCO2eq/kWh, for offshore 13.91gCO2eq/kWh and meanly 13.45gCO2eq/kWh for wind energy technologies.

Table 5. Summery the analysis of examined studies published between 2005 and 2020 related to the generation power from wind power, photovoltaic power, and Concentrating Solar Power (CSP)

Parameters	Wind power		Photovoltaic power						CSP	
	Onshore	Offshore	Sc-Si	m-Si	CdTe	CIGs	a-Si	CIS	Tower	Trough
Number of studies	45	27	22	23	15	8	7	3	11	7
Variations in GWP unite [g CO2eq/kWh]	3-138	4.6-81	22.5-115	20.9-80.5	5-48	26-93	12-57.5	35.5-62.	9.8-85.7	20.6-79.9

Average in GWP unite [g CO2-eq./kWh]	13.91	12.7	50.76	39.92	23.39	43.83	33.14	49.3	35.60	30.94
Most contributing Stage	Manufacturing + foundation		Manufacturing						Materials	
Variations in contribution %	86-98	70-90	75-96						52-70	
The majority of the contributing activity %	Tower (41)% steel +concrete		Contractual material +glazing 30% for ingot , 50% for SoG-Si						O&M+ solar field	
Transport %	10		6							
O+M %	1.6-6		13						24	
Recycling %	-40		-20						-10	

The obtained mean values from this review were arranged between 50.76 GWP unit for sc-Si and 23.4 for CdTe panels, whereas 33.14 for a-Si, 39.9 for mc-Si, 49.3 for CIS, and 43.8 for CIGs, respectively. In general, the studies indicate that a major CO2 impact is coming from the manufacture (structural materials and glazing) (75-90%) as presented in [8, 64, 87, 84, 88, 89, 90, 83, 91]. The current silicon technology modules, notwithstanding the development of thin-film manufacturing, [58, 91]. The recycling stage can be declined GWP up to 20% depending on innovative technologies [82, 90] while operational step up to 13%. The most effective element of GHG impact was ingot about 38% or SoG-Si about 50% of the manufacturing stage [87]. The results also showed that with raising the efficiency of the cell, the value of the GHG emission effect decreases [67, 68, 82, 69]. Also, the installation effect on the ground is less affected than those cells were installed on the roof-mounted [67, 69].

The calculated average GWP impact related to CSP technologies (11 for the tower, 7 for the trough, 3 for the parabolic) were 35.6, 30.94, and 25.8 gCO2eq/kWh, respectively. The overall GHG impact of solar system technologies was 38.88 gCO2eq/kWh. Figure 2 represents the average, maximum, and minimum GHG emission values for solar and wind energy systems.

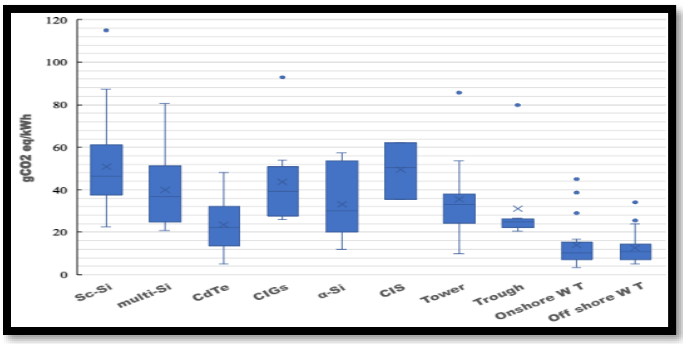

Fig. 2: The average, maximum, and minimum GHG emission values for solar and wind energy systems.

These conclusions do not contradict the findings of other researchers. The overall finding is tabulated in Table (5).

6. Discussion and Conclusion

1. Comparing the ranking of wind and solar technologies in terms of overall GWP for this study indicated the impact of the height sc-Si PV, while the lowest for onshore wind farms.
2. The findings indicate that raw material acquisition/manufacturing for wind and solar technologies has the most significant contribution to total GWP impacts, accounting for up to 98 % of the life cycle stage, followed by installation, operation, and maintenance.
3. The findings show that GWP may demonstrate considerable differences within the same technology. As noted throughout this study, such changes may be related to differences based on "actual variables," such as regional surroundings (e.g., wind speed and solar radiation), percent energy mixes used in raw material acquisition, etc. However, variation may be exacerbated by changing methodological supposition, which needed to consider recommendations and suggestions from the previous practices, involving recycling and transportation at the end-of-life stage. It is important to obtain more accurate results for further studies.
4. Imbalances between studies are likely to be explained by a combination of actual differences in the studied systems (e.g., turbine size), key assumptions (e.g., capacity factors, wind speed life span), and data contradiction (e.g., material emission rates), and variations in methodologies and approaches. The causes of variation in LCA are extensively documented in previous studies, e.g. [11].
5. Solar and wind farms require more mass of materials (silicon, cement, steel, copper, and aluminum) than

fossil fuel-powered power plants. However, the materials share reached 20–50% of the total footprint for renewables, with CSP tower and offshore wind technologies exhibiting the highest shares. However, the impact was still minimal in absolute terms compared to the impact of fossil fuel from mining to combustion in power plants. CSP and ground-mounted PV power facilities have high land-use requirements. Wind and roof-mounted PV have the lowest land usage requirements. Because the land is already in use as a structure, roof-mounted PV is considered to have zero direct land usage. Analyzed the entire power plant for ground-mounted solar electricity since the modules or mirrors are so closely spaced that cultivation and other uses are unfeasible in the unoccupied areas.

6. The initial need for silicon, copper, and cadmium is primarily related to PV systems, whereas additional iron and cement demand is primarily driven by wind and CSP installations.
7. With increasing efficiency, capacity, power factor, implement innovation recycling methods, and an expended lifetime of all systems, footprint declined significantly.
8. Differences in the electricity mix impact not only the emissions for each phase but also the total emissions for a given power generation scenario. Changes in grid energy may have the largest influence on supply chain manufacturing and materials and consumables for power plant construction, including activities linked with the wind power scenario's construction phase.
9. Analysis data from the literature suggest that the GHG emissions associated with the life cycle of solar power systems and wind power systems have decreased significantly during the past two decades, reaching 38.88 g CO_2e/kWh and 13.45 gCO_2e/kWh in 2020, respectively. In terms of other electricity generation technologies, the total value of GHG emissions is 936 gCO_2e/kWh for coal-fired and 730,502,62.4,37.4,26.9,22.7 for oil, gas, bio-energy, geothermal, nuclear, and hydropower, respectively.

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