AMERICAN UNIVERSITY OF BEIRUT

NATIONAL RENEWABLE ENERGY ACTION PLAN – LOCAL AND GLOBAL ASSESSMENT

by
LEA ISKANDAR YOUNES

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science
to the Department of Mechanical Engineering
of the Maroun Semaan Faculty of Engineering and Architecture
at the American University of Beirut

Beirut, Lebanon
December 2024

AMERICAN UNIVERSITY OF BEIRUT

NATIONAL RENEWABLE ENERGY ACTION PLAN – LOCAL AND GLOBAL ASSESSMENT

by

LEA ISKANDAR YOUNES

Approved by:

____

Dr. Farid Chaaban, Professor — Advisor
Department of Electrical and Computer Engineering

____

Dr. Nessreen Ghaddar, Professor — Member of Committee
Department of Mechanical Engineering

____

Dr. Riad Chedid, Professor — Member of Committee
Department of Electrical and Computer Engineering

Date of thesis defense: December 6, 2024

ACKNOWLEDGEMENTS

A particular thank you to my wonderful advisor, Dr. Farid Chaaban, for his patience, advice, and encouragement. I have profited significantly from his extensive expertise and meticulous editing. I am delighted that he has accepted me to work on this thesis. Likewise, I thank Ms. Amal Al Assaad for aiding me in collecting the data from the LCEC and helping me forecast the data.

Last but not least, I cannot forget my family's unconditional and loving support. They always made my day especially during all these unpreceded hard times the country and all of us are passing through. They always encouraged me to continue and were always there when I needed them.

ABSTRACT
OF THE THESIS OF

Lea Iskandar Younes for Master of Science
Major: Energy Studies

Title: National Renewable Energy Action Plan – Local and Global Assessment

Within the effects of global warming and climate change, there comes renewable energy, a solution for long-term growth and sustainability. Countries worldwide are experiencing the negative impacts of global warming and climate change which are caused by greenhouse gas (GHG) emissions. Moreover, the instability in oil prices and the talks about fossil fuel running out sometime in the future raises thoughts about finding other alternatives. Luckily, the burning of fossil fuels to produce energy can be replaced by greener and cleaner energy alternatives. Renewable energy is critical to long-term growth and sustainability. Clean technologies provide significant benefits in terms of economic growth, financial benefits, and environmental benefits, in addition to energy sector security, strengthening the sustainability of the energy sector and other key sectors globally and specifically in Lebanon. Furthermore, renewable energy is recognized as the primary component for mitigating the detrimental effects of the country's power sector crisis and due to the rise in fuel prices, electricity bill, and currency depreciation.

TABLE OF CONTENTS

ILLUSTRATIONS

Figure

TABLES

Table

ABBREVIATIONS

NREAP	National Renewable Energy Action Plan
PPA	Power Purchasing Agreement
RE	Renewable Energy
CO_2	Carbon Dioxide
kWh	Kilowatt-hour
GWh	Gigawatt-hour
GHGs	Greenhouse Gases
BAU	Business As Usual
NDC	Nationally Determined Contribution
IMF	International Monetary Fund
MEW	Ministry of Energy and Water
LCEC	Lebanese Center for Energy Conservation
EDL	Electricite Du Liban
SDGs	Sustainable Development Goals
COP	Conference of Parties

CHAPTER 1

INTRODUCTION

The United Nations approved the Sustainable Development Goals (SDGs), also known as the Global Goals, in 2015 as a global call to action to eradicate poverty, safeguard the environment, and guarantee that by 2030, all nations enjoy happiness and security. The 17 SDGs are interconnected, recognizing that actions in one area will have an impact on outcomes in others, and that progress must balance the needs of society, the economy, and sustainable development for the environment. Countries have agreed to emphasize improvement for those who are the most disadvantaged. The SDGs aim to eliminate poverty, hunger, AIDS, and gender discrimination regarding women and girls, and other goals. To fulfill the SDGs in whatever setting, technology, initiatives, and financial resources are required [1].

Goal 7, specifically, is about assuring access to clean and cheaper energy, which is critical for agricultural, economic, communications, education, healthcare, and transportation growth. Our daily lives rely on consistent and economical energy. Nonetheless, energy use is the most significant driver to climate change, representing over 60% of total world GHG emissions. To ensure universal access to inexpensive power by 2030, sustainable energy sources such as solar, wind, and thermal must be invested in. Developing infrastructure and improving technologies to offer clean energy in all emerging nations is a critical aim that may both support prosperity and benefit the environment [2].

All industries and sectors benefit from a well-established energy grid. Having access to power in developing nations has begun to accelerate, energy efficiency is improving, and renewable energy is gaining traction. For a number of years, fossil fuels such as coal, oil, and gas have been key sources of energy generation. However, burning carbon fuels emits enormous amounts of GHG, which cause climate change and have negative effects on people's health and the environment. Everyone is affected, not just a few. Furthermore, global power use is continuously increasing. In brief, countries will be unable to power their economy without a consistent electrical supply. To provide universal access to energy by 2030, electrification must be expedited, renewable energy investments must be expanded, energy efficiency must be enhanced, and appropriate laws and regulatory frameworks must be built [2].

Countries may speed up the transition to a more cheap, dependable, and sustainable energy framework by putting funds into renewable energy resources, promoting energy-efficient practices, and implementing clean energy technology and infrastructure. Businesses may preserve the environment by committing to procuring 100% of their operational electrical power from renewable sources. Employers may minimize internal transportation demand by prioritizing telecommunications and incentivizing less energy-intensive means of transportation such as rail travel over vehicle and plane travel. Investors may put more money into sustainable energy services, bringing innovative technology to market faster from a broad supply base [2].

1.1. Lebanon Energy Overview

The Ministry of Energy and Water (MEW) in Lebanon oversees the water, electricity, petroleum and gas sectors. Moreover, the production of electricity is carried out by the national power utility, Electricite Du Liban (EDL). The generation of electricity in Lebanon, in addition to transportation, manufacturing industries, and others, contributes to GHG emissions. Before the energy and economic crisis in the country, 98% of the electricity produced came from fossil fuels that are imported. The other 2% came from hydropower and biomass (wood, charcoal). Hydropower is Lebanon's primary form of renewable electricity generation. A total of five hydro-electric power plants are scattered from Lebanon's north to south. The Litani power plant is the main plant on the Litani River in southern Lebanon. The Litani River is the country's longest river, rising in the Beqaa valley and emptying into the Mediterranean Sea near Saida, with an annual flow of around 920 million cubic meters and serving as an efficient source of hydropower. By 2018, a total fixed capacity of 286MW, stemming from five major generating plants, was reported [3].

Solar power has become an increasingly attractive technology in Lebanon, efficiently bypassing institutional arrangements that are typically barriers by personal initiatives. Lebanon has tremendous solar power potential across a vast geographic area, mostly in the Baalbak and Bekaa governorates [4].

Large-scale wind projects in Lebanon have recently made sociotechnical and political inroads. In 2018, a partnership was formed between a private organization called Lebanon Wind Power SAL (the proponent) and the government of Lebanon to build three wind farms combining 200MW capacity using power purchasing agreements (PPAs) [4].

Several challenges were hindering the execution of renewable energy projects in Lebanon: legal and regulatory, institutional macro-fiscal and commercial, and technological. In addition to the social and environmental limitations. For the successful achievement of the targets, the previously mentioned challenges should be addressed.

1.2. Developed and Developing Countries Energy Overview and Targets

Like Lebanon, several other developed and developing countries have set certain renewable energy targets within their countries' NREAP. From the list of developed countries, Sweden achieved significant renewable energy targets. Sweden attained its 50% renewable energy target eight years ahead of plan in 2012. This puts them on schedule to meet their 2040 objective of producing 100% fossil-free renewable electricity. Sweden was able to achieve this target by utilizing their natural resources and combining wind, bioenergy, solar, and even body heat! Body heat from commuters going through Stockholm's central station, for instance, is used to heat a nearby building! [5] Moreover, in the list of developed countries comes the United Kingdom. The United Kingdom is currently the world leader in offshore wind energy. It has more installed capacity than any other country, with offshore wind powering over 7.5 million residences. With an aim to quadruple this by 2030, this will contribute significantly to the government's goal of decarbonizing its power grid by 2035 [5]. Iceland, for example, uses a combination of hydropower and geothermal energy. In 2015, a combination of hydropower and geothermal energy produced nearly all of Iceland's electricity. In fact, geothermal energy heats nine out of ten households, and Iceland is one of the top ten global producers of geothermal energy. The UN has even stated that their transition could serve as an example for other countries to follow [5]. During their first 100 days in authority in 2022, Germany's new government implemented the "biggest energy policy reform in decades." Renewables are in the forefront, with aims of 80% renewable energy by 2030 and nearly 100% by 2035. Renewables accounted for almost 47% of German power consumption in 2022 (a 4.9% increase from 2021) [5]. In 2016, renewables generated 98% of Norway's electricity, with hydropower leading the way. Since the late 1800s, Norway has been capturing power from rivers and waterfalls, so it's easy to understand how this natural resource has been an important component of Norway's power profile. They've also added thermal and wind energy to the mix over time [5]. Furthermore, renewable energy accounts for 84% of New Zealand's electricity consumption. New Zealand has established a target of 50% renewable energy consumption by 2035, and 100% renewable electricity by 2030 [5]. Its neighbor Australia has adopted the deployment of renewables. The success of rooftop solar, ambitious targets, and increased funding at the federal and state levels bode well for Australia's renewables adoption. Three million Australian houses, or one in every three, have solar PV installations, totaling 17GW of capacity. Power sector decarbonization efforts must be pushed up significantly, as Australia wants to boost the share of low-carbon power generation to 82% by 2030, up from 27% presently. This will necessitate a faster implementation of renewable energy zones, quicker permitting of grid-related projects, and more coal retirements [6]. The world's fifth-largest emitter, Japan, also plans to be carbon-neutral by 2050. Japan wants to reduce GHG emissions by 46% by 2030 compared to 2013 levels by increasing renewable energy in its electricity mix to 36%-38%, more than doubling current levels, and nuclear power to 20%-22%, up from 6% in 2019 [7]. Renewable energy sources accounted for 67% of Denmark’s electricity supply in 2021, with wind energy accounting for 46.8% and biomass accounting for 11.2%. The country intends to be completely independent from fossil fuels by 2050 [8]. Finally, in the list of developed countries comes Canada. Canada is a world leader in the development and use of renewable energy. Renewable energy sources currently account for approximately 18.9% of Canada's total primary energy supply. Hydropower is Canada's major renewable energy source, accounting for 59% of total electricity generation. With a long-term goal of 100%, Canada’s target is to ensure that 90% of electricity comes from renewable energy sources by 2030 [9].

Developing countries are also setting renewable energy targets. From the list of developing countries with significant renewable energy targets comes Kenya. Lake Turkana Wind Power Project, Africa's largest wind farm, is located in Kenya. With approximately 310 MW of capacity, it can power one million homes! Africa has enormous renewable energy potential, with 60% of the finest solar resources in the world; nonetheless, the region receives less than 3% of global energy investments. As the continent that has contributed the least to the climate problem while suffering enormous consequences now and in the future, the international community must work with Africa to invest in its sustainable energy future [5]. In Egypt, the economic development relies mainly on the energy sector. Based on increasing solar and wind deployment, the government has set a target for renewables to account for 42% of the country's electricity mix by 2035 [10]. In Thailand, the power sector contributes largely to the country’s emissions. Therefore, Thailand has significantly boosted its emission reduction targets, announcing net zero greenhouse gas emissions by 2065 and carbon neutrality by 2050 [11]. Talks about green hydrogen are emerging nowadays as an alternative to fossil fuels. One cannot mention hydrogen without talking about Oman’s potential in this field. Oman desires to generate at least one million tons of renewable hydrogen per year by 2030, up to 3.75 million tons by 2040, and up to 8.5 million tons by 2050, which would be more than Europe's total hydrogen need today. In energy equivalent definitions, the 2040 hydrogen aim would represent 80% of Oman's current LNG exports, while the 2050 target would nearly treble them. Oman's hydrogen projects will extract hydrogen from desalinated sea water using electrolysers driven by renewable electricity. Furthermore, in 2022, Oman established a target of net zero emissions by 2050 and began lowering the usage of fossil fuels in its domestic energy balance [12]. Expected to become the fourth largest economy in the world by 2050, Indonesia must set renewable energy targets in order to meet the growing demand. The government has a plan to reach zero emissions by no later than 2060. Indonesia has an abundance of natural resources as well as a large potential for renewables, particularly hydro, geothermal, and solar PV. The national electricity plan calls for a 23% renewables participation in the grid's power mix by 2025 compared to 14% in 2021[13]. In Sudan, most of the electricity generated comes from hydropower. Moreover, it is home to more than 50% of the Eastern African's total oil-based capability. Sudan is also considering expanding its solar power projects in the future years [14]. Albania, having a population of around 2.85 million, is nearly totally reliant on hydropower for electrical generation. This provides it with an edge in terms of decarbonizing its electrical industry, but it also leaves it extremely sensitive to climate change. Since 2017, Albania solely offered renewable energy subsidies for hydropower, leaving solar PV and wind undeveloped. Nevertheless, in late 2023, a 140 MW solar project was claimed to have gone operational. Albania is the only nation in the Western Balkans to have constructed big new hydropower facilities in the recent decade. As of the end of 2022, it has at least 25 operating hydroelectric plants of more than 10 MW, as well as several smaller ones [15]. Jordan is a regional leader in renewable energy adoption and clean energy growth. Solar and wind energy supply roughly 29% of the electrical system, and Jordan plans to achieve 50% renewable electricity by 2030 through electricity system developments and energy storage initiatives [16]. According to tender papers, the Jamaican government is looking for 100 MW of renewable energy to diversify its energy system. Independent power producers will create this capacity through wind, solar, and hydro projects proposed under power purchase agreements (PPAs) [17].

CHAPTER 2

ASSESSMENT METHODOLOGY

2.1. Project Objectives

The objective of this work is to assess the NREAP for Lebanon, and to project using different economy- related scenarios to examine the country's capability to achieve the 30% of electric power generated from renewable energy as the target for year 2030. The targets or scenarios cannot be achieved without addressing certain challenges and limitations. Moreover, and for comparison purposes, the work will discuss the reduction of CO_2 emissions/capita of 10 different developed and 10 different developing countries. Three scenarios will be used to map the evolution of renewable energy capacity and developments on a yearly timescale up to the year 2030, based on the trends over the past 5 years.

The first scenario (Full Recovery) is the most optimistic one. It assumes the full economic and political recovery of the country with international assistance. The market is assumed to be boosted by the availability of international money and the financial community's funding. As a result, the social and economic crisis will be alleviated. The country's financial status will dramatically improve. Moreover, key policy initiatives and changes are put in place. This scenario resembles an important comeback that will result in the execution of pipelined projects.

The second scenario (Partial Recovery) is the median one and it assumes that the country's condition is improving, that a new transparent administration is constituted with international assistance, and that the relevant executives implement the essential macro-fiscal changes, including sectorial reforms, particularly in the electrical sector. However, some obstacles have caused delays in the swift implementation of these measures. The potential availability of international finance and the lending community's backing gives a favorable overall signal, but such funds are not given right away due to delays in implementing the necessary changes. The previously mentioned assumptions would have a positive impact on the development of each renewable energy technology, but with some postponements.

The third and last scenario (Stagnation) is the pessimistic one which reflects the stagnation situation of the country. The country's economic status has deteriorated, and a lack of international support has resulted in additional macroeconomic and financial barriers and crisis. This scenario resembles the failure to implement changes and worsening financial and economic conditions. The absence of defined sectorial shifts, notably in the power sector, adds to the complexity. CEDRE funds have been suspended due to delays and a lack of change. Unfortunately, this scenario accurately depicts the current situation in Lebanon.

For the successful implementation of the above- mentioned scenarios, especially the first two of them, certain obstacles and challenges should be addressed. At the legal and regulatory level, regulatory authorities should be informed on how to improve access to finance and the process of issuing licenses. At the institutional and structural level, highly trained employees should be devoted to following up on projects and conducting feasibility studies. At the macro-fiscal and commercial level, improvements should be made. Moreover, the government or the MEW should commit to the IMF program; the funding sources for renewable energy projects should be guaranteed. At the technological level, in collaboration with the transportation industry, the power sector's infrastructure should be upgraded, shifting reserves should be introduced, and eventually storage units will be installed. At the social and environmental level, public acceptance propels renewable energy development. In addition to media campaigns, public hearings, and foreign entity ownership issues.

The results of Lebanon's scenarios will be compared to the other 20 case studies collected from developed as well as developing countries to come out with a more comprehensive assessment related to the achievements as well as challenges facing the efforts facing the deployment of successful measures to achieve the 2030 target on global scale. The data between 2018 and 2024 is collected from the LCEC databank, and then it was extrapolated till year 2030.

2.2. Full Recovery Scenario

As mentioned above, the Full Recovery scenario is the most optimistic one, as it assumes the full economic and political recovery of the country with international assistance, the market is boosted by the availability of international money and the financial community's funding. The country's financial status is dramatically improving, and key policy initiatives and reforms are put in place. Results of the projections up to the year 2030 are presented in Table 1.

Table 1: Full Recovery Scenario Projections

Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Wind (MW)	0	0	0	0	0	0	0	226	226	226	826	826	826
Wind (GWh)	0	0	0	0	0	0	0	615	615	615	2,247	2,247	2,247
Solar PV Centralized (MW)	0	0	0	0	0	15	165	265	265	565	565	865	865
Solar PV Centralized (GWh)	0	0	0	0	0	26	287	460	460	981	981	1,503	1,503
Solar PV Distributed (MW)	56	78	92	206	869	1,166	1,300	1500	1800	2100	2400	2700	3000
Solar PV Distributed (GWh)	85	112	133	309	1,262	1,924	2,145	2,475	2,971	3,465	3,960	4,454	4,950
CSP (MW)	0	0	0	0	0	0	0	100	100	100	300	300	300
CSP (GWh)	0	0	0	0	0	0	0	345	345	345	1,035	1,035	1,035
Hydro (MW)	286	286	286	286	286	286	286	386	416	446	476	506	536
Hydro (GWh)	347	347	347	347	347	347	347	563	628	692	757	822	887
Biogas (MW)	9	9	9	9	9	9	9	20	31	42	53	64	75
Biogas (GWh)	83	83	83	83	83	83	83	184	285	386	487	588	689
Total RE (MW)	351	373	387	501	1,164	1,476	1,760	2,497	2,838	3,479	4,620	5,261	5,602
Total RE (GWh)	515	542	563	739	1,693	2,380	2,862	4,642	5,303	6,484	9,468	10,649	11,310
T&D losses	17%	17%	17%	17%	17%	17%	13.30%	11.70%	9.5%	8%	8%	8%	8%
Generation (GWh)	26,770	27,573	28,400	25,560	17,687	17,687	17,641	17,914	18,088	18,375	19,294	20,259	21,272
Total Generated RE Share from Electricity Consumed (%)	2%	2%	2%	3%	10%	13%	16%	26%	29%	35%	49%	53%	53%

2.3. Partial Recovery Scenario

The Partial Recovery scenario assumes that the country's condition is improving, that a new transparent administration is constituted with international assistance, and that the relevant executives implement the essential macro-fiscal changes. However, some obstacles have caused delays in the swift implementation of these measures, and hence international finance and the lending community's backing are witnessing some delays.

Table 2: Partial Recovery Scenario Projections

Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Wind (MW)	0	0	0	0	0	0	0	0	226	226	226	226	826
Wind (GWh)	0	0	0	0	0	0	0	0	615	615	615	615	2,247
Solar PV - Centralized (MW)	0	0	0	0	0	0	105	105	105	405	405	405	705
Solar PV - Centralized (GWh)	0	0	0	0	0	0	182	182	182	704	704	704	1,225
Solar PV - Distributed (MW)	56	78	92	206	869	1,166	1342	1519	1695	1871	2047	2224	2400
Solar PV - Distributed (GWh)	85	112	133	309	1,262	1,924	2,215	2,506	2,797	3,087	3,378	3,669	3,960
CSP (MW)	0	0	0	0	0	0	0	0	0	100	100	100	100
CSP (GWh)	0	0	0	0	0	0	0	0	0	345	345	345	345
Hydro (MW)	286	286	286	286	286	286	286	286	286	286	386	386	386
Hydro (GWh)	347	347	347	347	347	347	347	347	347	347	563	563	563
Biogas (MW)	9	9	9	9	9	9	9	9	9	20	31	42	53
Biogas (GWh)	83	83	83	83	83	83	83	83	83	184	285	386	487
Total RE (MW)	351	373	387	501	1,164	1,461	1,742	1,919	2,321	2,908	3,195	3,383	4,470
Total RE (GWh)	515	542	563	739	1,693	2,354	2,827	3,118	4,024	5,282	5,889	6,281	8,826
T&D losses	17%	17%	17%	17%	17%	17%	13.30%	11.70 %	9.5%	8%	8%	8%	8%
Generation (GWh)	26,770	27,573	28,400	25,560	17,687	17,687	17,641	17,914	18,088	18,375	19,294	20,259	21,272
Total Generated RE Share from Electricity Consumed (%)	2%	2%	2%	3%	10%	13%	16%	17%	22%	29%	31%	31%	41%

2.4. Stagnation Scenario

The Stagnation scenario is the pessimistic one that reflects the lack of serious efforts to improve the economic situation in the country. The country's economic status has deteriorated, and a lack of international support has resulted in additional macroeconomic and financial barriers and crisis. The absence of defined sectorial shifts, notably in the power sector, adds to the complexity. Unfortunately, this scenario accurately depicts the current situation in Lebanon.

Table 3: Stagnation Scenario Projections

Year	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Wind (MW)	0	0	0	0	0	0	0	0	226	226	226	226	226
Wind (GWh)	0	0	0	0	0	0	0	0	615	615	615	615	615
Solar PV - Centralized (MW)	0	0	0	0	0	0	105	105	105	105	105	105	405
Solar PV - Centralized (GWh)	0	0	0	0	0	0	182	182	182	182	182	182	704
Solar PV - Distributed (MW)	56	78	92	206	869	1,166	1,257	1,347	1,438	1,528	1,619	1,709	1,800
Solar PV - Distributed (GWh)	85	112	133	309	1,262	1,924	2,073	2,223	2,372	2,522	2,671	2,821	2,970
CSP (MW)	0	0	0	0	0	0	0	0	0	0	0	0	0
CSP (GWh)	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydro (MW)	286	286	286	286	286	286	286	286	286	286	286	286	286
Hydro (GWh)	347	347	347	347	347	347	347	347	347	347	347	347	347
Biogas (MW)	9	9	9	9	9	9	9	9	9	20	20	20	20
Biogas (GWh)	83	83	83	83	83	83	83	83	83	184	184	184	184
Total RE (MW)	351	373	387	501	1,164	1,461	1,657	1,747	2,064	2,165	2,256	2,346	2,737
Total RE (GWh)	515	542	563	739	1,693	2,354	2,686	2,835	3,600	3,850	3,999	4,149	4,819
T&D losses	17%	17%	17%	17%	17%	17%	13.30%	11.70%	9.5%	8%	8%	8%	8%
Generation (GWh)	26,770	27,573	28,400	25,560	17,687	17,687	17,641	17,914	18,088	18,375	19,294	20,259	21,272
Total Generated RE Share from Electricity Consumed (%)	2%	2%	2%	3%	10%	13%	15%	16%	20%	21%	21%	21%	23%

CHAPTER 3

CARBON TAX AVOIDED
AND AMOUNT OF CO2 SAVED

3.1. Full Recovery Calculations

All renewable technologies emit a little amount of carbon dioxide as part of their production owing to emissions from manufacture and installation (upstream emissions) [18].

3.1.1. CO2 Emissions Reduction

The renewable energy technology in Wh in a certain year is equal to the renewable energy technology in the same year in W multiplied by the capacity factor of this technology and 8760 (365days/year * 24hours/day).

- **Wind Energy**

In the Full Recovery Scenario by 2030, wind energy will reach 2247GWh. Wind energy produces around 0.012kg of CO_2/kWh [19]. Hence, wind energy produces:

$$2.247 \times 10^9 kWh \times \frac{0.012kg}{kWh} = 26964 \; tons \; of \; CO2/year$$

- **Solar PV Centralized**

By 2030, centralized solar PV units will generate 1503GWh of energy. Solar energy produces around 0.048kg of CO_2/kWh [19].

Hence, solar PV centralized produces: $1.503 \times 10^9 kWh \times \frac{0.048kg}{kWh} =$

$72144 \; tons \; of \; CO2/year$

- **Solar PV Distributed**

By 2030, distributed solar PV units will generate 4950GWh of energy. Solar energy produces around 0.041kg of CO_2/kWh [20].

Hence, solar PV distributed produces: $4.95 \times 10^9 kWh \times \frac{0.041kg}{kWh} =$

$202950\ tons\ of\ CO2/year$

- **CSP**

By 2030, CSP will generate 1035GWh of energy. CSP produces around 0.038kg of CO_2/kWh [20].

Hence, CSP produces: $1.035 \times 10^9 kWh \times \frac{0.038kg}{kWh} = 39330\ tons\ of\ CO2/year$

- **Hydro**

By 2030, hydropower will generate 887GWh of energy. Hydropower produces around 0.004kg of CO_2/kWh [19].

Hence, hydropower produces: $0.887 \times 10^9 kWh \times \frac{0.004kg}{kWh} = 3548\ tons\ of\ CO2/year$

- **Biogas**

By 2030, Biogas will generate 689GWh of energy. Biogas produces around 0.018kg of CO_2/kWh [19].

Hence, Biogas produces: $0.689 \times 10^9 kWh \times \frac{0.018kg}{kWh} = 12402\ tons\ of\ CO2/year$

- **Thermal Power Generation**

Assuming that the energy demand in Lebanon is 18,000GWh such that a total of

5,000GWh is satisfied by EDL and the remaining 13,000GWh satisfied by private generators.

- **EDL**

EDL power plants emit 0.65kg of CO_2/kWh produced [21].

EDL: $5 \times 10^9 kWh \times \frac{0.65kg}{kWh} = 3{,}250{,}000\ tons\ of\ CO2$

- **Private Generators**

Private generators in Lebanon emit 0.86kg of CO_2 for each kWh produced [22].

Private Generators: $13 \times 10^9 kWh \times \frac{0{,}86kg}{kWh} = 11\ 180\ 000\ tons\ of\ CO2$

EDL and private generators combined will emit a total of 14,430,000 tons of CO_2.

Accordingly, the total amount of CO_2 saved per year = (the carbon footprint of EDL+ private generators) *100% – [(the carbon footprint of renewable energy technologies) *53% + (the carbon footprint of EDL+ private generators) *47%]

The total amount of CO_2 saved per year = 14,430,000*100% – [(26964 + 72144 + 202950 + 39330 + 3548 + 12402) *53% + 14,430,000*47%] = 14,430,000 - [189389+6782100] = 7,458,511 tons of CO2

Note: the 53% in the above equation is the total renewable energy share from generated electricity in the year 2030. So, the remaining 47% is satisfied by thermal power generation (EDL+ private generators).

3.1.2. Cost Reduction

For renewable technologies, taking a carbon tax of about \$84/tCO_2 into consideration [19]:

7458511 tons of CO_2 saved * $84/t = $626,514,924 saved/year.

- Reduction of CO2 emissions per capita:

Amount of CO_2 emissions (2020) = (amount of CO_2 emitted by RE) *2% + (amount of CO_2 emitted by thermal power generation) * 98% = (0+0+5453+0+1388+1494) *2% + (14430000) *98% = 14141567 tons

The 2% in the above equation is the total renewable energy share from generated electricity in year 2020.

Amount of CO_2 emissions (2030) = (amount of CO_2 emitted by RE) *53% + (amount of CO_2 emitted by thermal power generation) *47 % = (26964 + 72144 + 202950 + 39330 + 3548 + 12402) *53% + (14430000) * 47% = 6971489 tons

Reduction of CO_2 emissions =

Amount of CO_2 emissions (2020) - Amount of CO_2 emissions (2030) = 7170078 tons

$$Reduction\ of\ CO2\ emissions\ per\ capita = \frac{Reduction\ of\ CO2\ emissions}{Lebanese\ Population}$$

$$= \frac{7170078}{6,000,000} = 1.2\ tons\ of\ CO2\ per\ capita$$

Table 4 represents the renewable energy projections for the full recovery scenario from the year 2025 till year 2030. The table also includes the amount of CO_2 saved in million tons and the carbon tax avoided in million $. Moreover, some constants are included in this table. These constants helped in calculating the amount of CO_2 saved and carbon tax avoided.

Table 4: Full Recovery Scenario

Year	2025	2026	2027	2028	2029	2030
Wind (MW)	226	226	226	826	826	826
Wind (GWh)	615	615	615	2247	2247	2247
Amount of CO2 emitted by wind energy (tons)	7380	7380	7380	26964	26964	26964
Solar PV Centralized (MW)	265	265	565	565	865	865
Solar PV Centralized (GWh)	460	460	981	981	1503	1503
Amount of CO2 emitted by solar PV centralized (tons)	22080	22080	47088	47088	72144	72144
Solar PV Distributed (MW)	1500	1800	2100	2400	2700	3000
Solar PV Distributed (GWh)	2475	2971	3465	3960	4454	4950
Amount of CO2 emitted by solar PV distributed (tons)	94050	121811	142065	162360	182614	202950
CSP (MW)	100	100	100	300	300	300
CSP (GWh)	345	345	345	1035	1035	1035
Amount of CO2 emitted by CSP (tons)	13110	13110	13110	39330	39330	39330
Hydro (MW)	386	416	446	476	506	536
Hydro (GWh)	563	628	692	757	822	887
Amount of CO2 emitted by hydro (tons)	2252	2512	2768	3028	3288	3548
Biogas (MW)	20	31	42	53	64	75
Biogas (GWh)	184	285	386	487	588	689
Amount of CO2 emitted by biogas (tons)	3312	5130	6948	8766	10584	12402
Total RE (MW)	2,497	2838	3479	4620	5261	5602
Total RE (GWh)	4,642	5303	6484	9468	10649	11310
Generation (GWh)	17321	17841	18375	19294	20259	21272
Total RE Share from Generated Electricity (%)	26	29	35	49	53	53
Amount of CO2 saved (million tons)	3.71	4.13	4.97	6.93	7.47	7.47
Carbon tax avoided (million $)	312	347	418	582	628	628

In what follows is the list of constants, based on local, regional and international standards and guidelines, used in the calculations.

Constants

Wind Energy Carbon footprint (kg/kWh)	0.012
Solar Energy Centralized Carbon footprint (kg/kWh)	0.048
Solar Energy Distributed Carbon footprint (kg/kWh)	0.041
CSP Carbon footprint (kg/kWh)	0.038
Hydro Carbon footprint (kg/kWh)	0.004
Biogas Carbon footprint (kg/kWh)	0.018
Lebanon Demand (GWh)	18000
EDL Production (GWh)	5000
Private Gen Production (GWh)	13000
EDL Carbon footprint (kg/kWh)	0.650
Private Generators Carbon footprint (kg/kWh)	0.860
Carbon Tax ($/ton)	84
Amount of CO2 emitted by EDL in tons	3250000
Amount of CO2 emitted by private generators in tons	11180000
Amount of CO2 emitted by EDL+private generators in tons	14430000
Lebanese Population including refugees	6,000,000

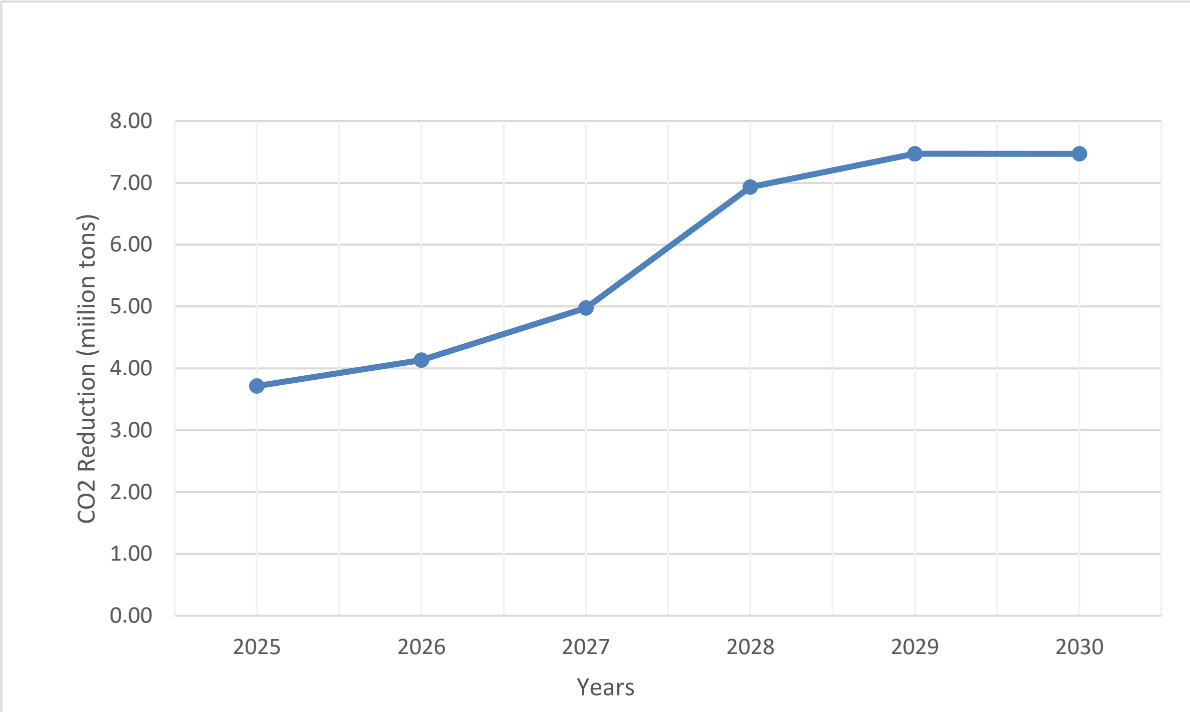

Figure 1: CO2 saved in Full Recovery Scenario from year 2025 till 2030.

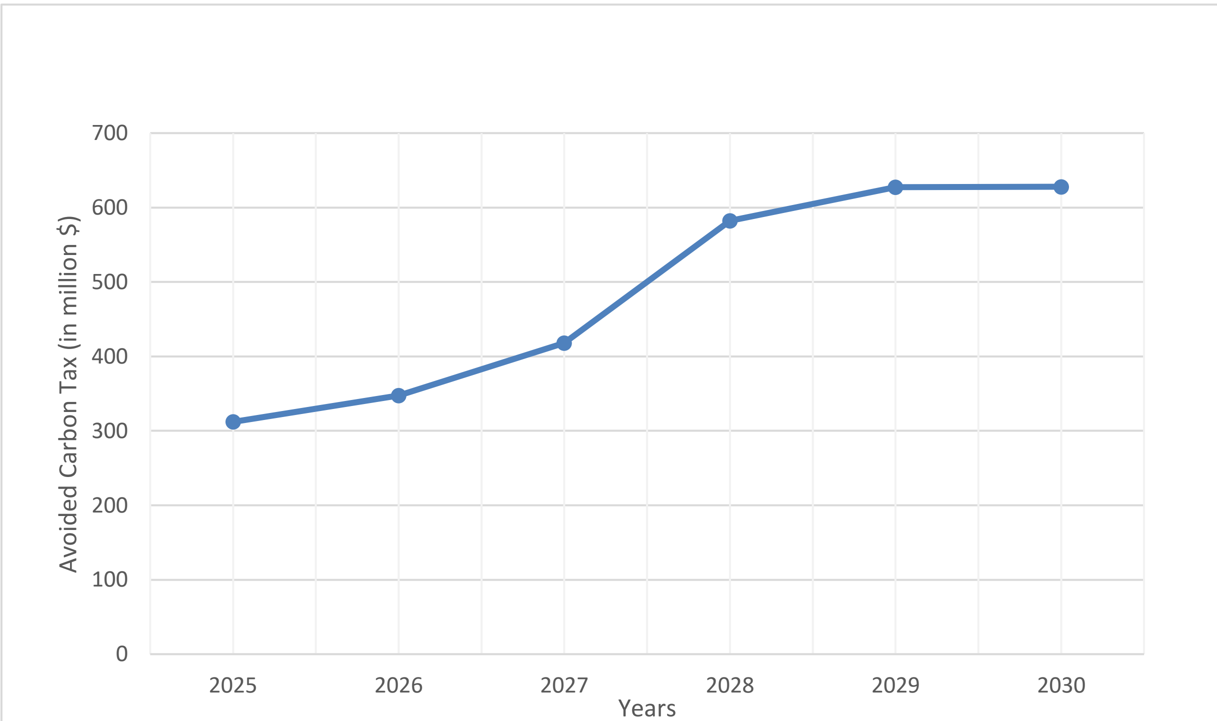

Figure 2: Carbon tax avoided in Full Recovery Scenario from year 2025 till 2030.

3.2. Partial Recovery Calculations

3.2.1. CO_2 Emissions Reduction

- **Wind Energy**

In the Partial Recovery Scenario and by 2030, wind energy will reach 2247GWh. Wind energy produces around 0.012kg of CO_2/kWh [19].

Hence, wind energy produces: : $2.247 \times 10^9 kWh \times \frac{0.012kg}{kWh} = 26964\ tons\ of\ CO2/year$

- **Solar PV Centralized**

By 2030, centralized solar PV units will generate 1225GWh of energy. Solar energy produces around 0.048kg of CO_2/kWh [19].

Hence, solar PV centralized produces: $1.225 \times 10^9 kWh \times \frac{0.048kg}{kWh} = 58800\ tons\ of\ CO2/year$

- **Solar PV Distributed**

By 2030, distributed solar PV units will generate 3960GWh of energy. Solar energy produces around 0.041kg of CO_2/kWh [20].

Hence, solar PV distributed produces: $3.96 \times 10^9 kWh \times \frac{0.041kg}{kWh} = 162360\ tons\ of\ CO2/year$

- **CSP**

By 2030, CSP will generate 345GWh of energy. CSP produces around 0.038kg of CO_2/kWh [20].

Hence, CSP produces: $0.345 \times 10^9 kWh \times \frac{0.038kg}{kWh} = 13110\ tons\ of\ CO2/year$

- **Hydro**

By 2030, hydropower will generate 563GWh of energy. Hydropower produces around 0.004kg of CO_2/kWh [19].

Hence, hydropower produces: $0.563 \times 10^9 kWh \times \frac{0.004kg}{kWh} = 2252\ tons\ of\ CO2/year$

- **Biogas**

By 2030, Biogas will generate 487GWh of energy. Biogas produces around 0.018kg of CO_2/kWh [19].

Hence, Biogas produces: $0.487 \times 10^9 kWh \times \frac{0.018kg}{kWh} = 8766\ tons\ of\ CO2/year$

- **Thermal Power Generation**

Assuming that the energy demand in Lebanon is 18,000GWh such that a total of 5,000GWh is satisfied by EDL and the remaining 13,000GWh satisfied by private generators.

- **EDL**

EDL power plants emit 0.65kg of CO_2/kWh produced [21].

EDL: $5 \times 10^9 kWh \times \frac{0.65kg}{kWh} = 3{,}250{,}000\ tons\ of\ CO2$

- **Private Generators**

Private generators in Lebanon emit 0.86kg of CO_2 for each kWh produced [22].

Private Generators: $13 \times 10^9 kWh \times \frac{0{,}86kg}{kWh} = 11\ 180\ 000\ tons\ of\ CO2$

EDL and private generators combined will emit a total of 14,430,000 tons of CO_2.

The amount of CO_2 saved per year = (the carbon footprint of EDL+ private generators) *100% – [(the carbon footprint of renewable energy technologies) *41% + (the carbon footprint of EDL+ private generators) *59%]

The amount of CO_2 saved per year =

14,430,000*100% - [(26964+58800+162360+13110+2252+8766) *41% + 14,430,000*59%] = 14,430,000 - [111623.32+ 8513700] = 5,804,677 tons of CO_2

Note: the 41% in the above equation is the total renewable energy share from generated electricity in the year 2030. So, the remaining 59% is satisfied by thermal power generation (EDL+ private generators).

3.2.2. Cost Reduction

For renewable technologies, taking a carbon tax of about 84$/t$CO_2$ into consideration [19]:

5804677 tons of CO_2 saved * \$84/t = \$487,592,868 saved/year

- Reduction of CO2 emissions per capita:

Amount of CO_2 emissions (2020) = (amount of CO_2 emitted by RE) *2% + (amount of CO_2 emitted by thermal power generation) * 98% = (0+0+5453+0+1388+1494) *2% + (14430000) *98% = 14,141,567 tons

Amount of CO_2 emissions (2030) = (amount of CO_2 emitted by RE) *41% + (amount of CO_2 emitted by thermal power generation) * 59% = (26964+58800+162360+13110+2252+8766) *41% + (14430000) *59% = 8,625,323 tons.

Reduction of CO_2 emissions =

Amount of CO_2 emissions (2020) - Amount of CO_2 emissions (2030) = 5,516,243 tons

$$Reduction\ of\ CO2\ emissions\ per\ capita = \frac{Reduction\ of\ CO2\ emissions}{Lebanese\ Population}$$

$$= \frac{5{,}516{,}243}{6{,}000{,}000} = 0.92\ tons\ of\ CO2\ per\ capita$$

Table 5 represents the renewable energy projections for the partial recovery scenario from the year 2025 till year 2030. The table also includes the amount of CO_2 saved in million tons and the carbon tax avoided in million $. Moreover, some constants are included in this table. These constants helped in calculating the amount of CO_2 saved and carbon tax avoided.

Table 5: Partial Recovery Scenario

Year	2025	2026	2027	2028	2029	2030
Wind (MW)	0	226	226	226	226	826
Wind (GWh)	0	615	615	615	615	2,247
Amount of CO2 emitted by wind energy (tons)	0	7380	7380	7380	7380	26964
Solar PV - Centralized (MW)	105	105	405	405	405	705
Solar PV - Centralized (GWh)	182	182	704	704	704	1,225
Amount of CO2 emitted by solar PV centralized (tons)	8736	8736	33792	33792	33792	58800
Solar PV - Distributed (MW)	1519	1695	1871	2047	2224	2400
Solar PV - Distributed (GWh)	2,506	2,797	3,087	3,378	3,669	3,960
Amount of CO2 emitted by solar PV distributed (tons)	95228	114677	126567	138498	150429	162360
CSP (MW)	0	0	100	100	100	100
CSP (GWh)	0	0	345	345	345	345
Amount of CO2 emitted by CSP (tons)	0	0	13110	13110	13110	13110
Hydro (MW)	286	286	286	386	386	386
Hydro (GWh)	347	347	347	563	563	563
Amount of CO2 emitted by hydro (tons)	1388	1388	1388	2252	2252	2252
Biogas (MW)	9	9	20	31	42	53
Biogas (GWh)	83	83	184	285	386	487
Amount of CO2 emitted by biogas (tons)	1494	1494	3312	5130	6948	8766
Total RE (MW)	1,919	2,321	2,908	3,195	3,383	4,470
Total RE (GWh)	3,118	4,024	5,282	5,889	6,281	8,826
T&D losses	11.70%	9.50%	8%	8%	8%	8%
Generation (GWh)	17,914	18,088	18,375	19,294	20,259	21,272
Total Generated RE Share from Electricity Consumed (%)	17%	22%	29%	31%	31%	41%
Amount of CO2 saved (million tons)	2.43	3.15	4.13	4.4	4.4	5.80
Carbon tax avoided (million $)	205	264	347	370	370	488
Constants						

Wind Energy Carbon footprint (kg/kWh)	0.012
Solar Energy Centralized Carbon footprint (kg/kWh)	0.048
Solar Energy Distributed Carbon footprint (kg/kWh)	0.041
CSP Carbon footprint (kg/kWh)	0.038
Hydro Carbon footprint (kg/kWh)	0.004
Biogas Carbon footprint (kg/kWh)	0.018
Lebanon Demand (GWh)	18000
EDL Production (GWh)	5000
Private Gen Production (GWh)	13000
EDL Carbon footprint (kg/kWh)	0.650
Private Generators Carbon footprint (kg/kWh)	0.860
Carbon Tax ($/ton)	84
Amount of CO2 emitted by EDL in tons	3250000
Amount of CO2 emitted by private generators in tons	11180000
Amount of CO2 emitted by EDL+private generators in tons	14430000
Lebanese Population including Refugees	6,000,000

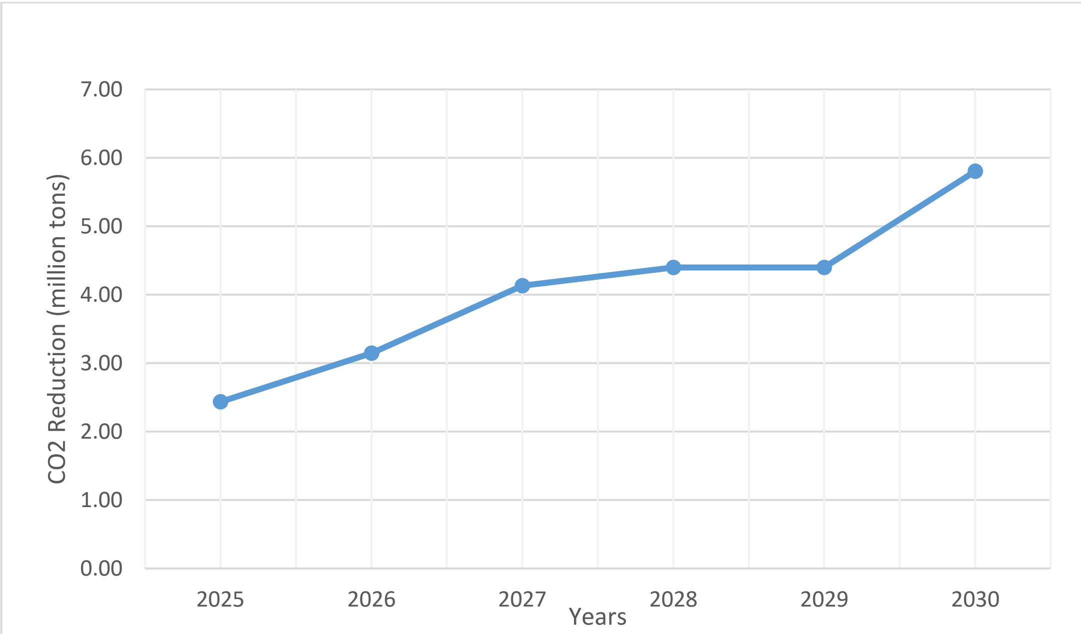

Figure 3:CO2 saved in Partial Recovery Scenario from year 2025 till 2030.

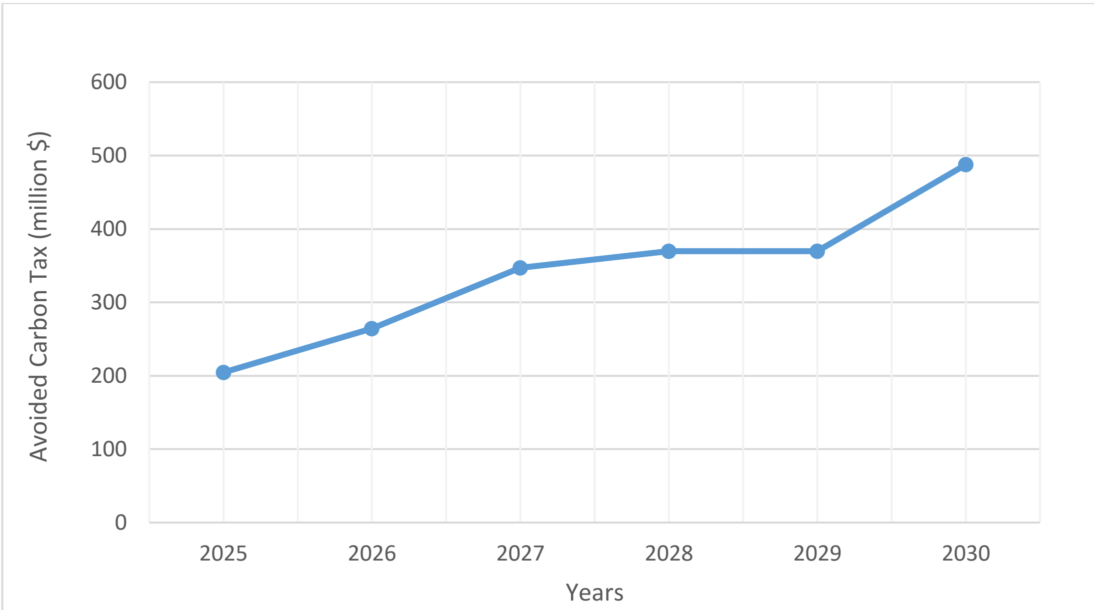

Figure 4: Carbon Tax avoided in Partial Recovery Scenario from year 2025 till 2030.

Table 6: Percentage Change in CO2 emissions/capita between the current year and year 2030

Technology	kW in 2024	kW in 2030	Load Factor (%)	CO2/kWh in 2030 (g/kWh)	CO2/capita now (g/capita)	CO2/capita in 2030 (g/capita)	% Change in installed capacity
Wind	0	826,000	31.05	12	0	4500	100
Solar PV- Centralized	105,000	705,000	19.83	48	1456	9800	85.14
Solar PV- Distributed	1,342,000	2,400,000	18.84	41	15200	27060	43.82
CSP	0	100,000	38.95	38	0	2185	100
Hydro	286,000	386,000	14.5	4	231	375	38.4
Biogas	9,000	53,000	104.86	18	250	1461	82.88
Thermal Power Plants	2,157,534	1,515,411	80	801.67	2020167	1418950	-29.76

As it can be seen from the above table, the power supplied by renewable technologies increased between the current year and year 2030. Whereas the power supplied by thermal power plants decreased between those two years. This came as a result of renewable technologies partially replacing thermal power plants to produce energy. Since the energy produced by thermal power plants decreased, the amount of CO_2 emitted by thermal power plants decreased as well. Hence, the amount of CO_2/capita decreased as well.

3.3. Stagnation Calculations

3.3.1. CO_2 Emissions Reduction

- **Wind Energy**

In the Stagnation Scenario by 2030, wind energy will reach 615GWh. Wind energy produces around 0.012kg of CO_2/kWh [19].

Hence, wind energy produces: : $0.615 \times 10^9 kWh \times \frac{0.012kg}{kWh} = 7380\ tons\ of\ CO2/year$

- **Solar PV Centralized**

By 2030, centralized solar PV units will generate 704GWh of energy. Solar energy produces around 0.048kg of CO_2/kWh [19].

Hence, solar PV centralized produces: $0.704 \times 10^9 kWh \times \frac{0.048kg}{kWh} =$

$33{,}792\ tons\ of\ CO2/year$

- **Solar PV Distributed**

By 2030, distributed solar PV units will generate 2970GWh of energy. Solar energy produces around 0.041kg of CO_2/kWh [20].

Hence, solar PV distributed produces: $2.97 \times 10^9 kWh \times \frac{0.041kg}{kWh} =$

$121{,}770\ tons\ of\ CO2/year$

- **CSP**

By 2030, CSP will generate 0GWh of energy. CSP produces around 0.038kg of CO_2/kWh [20].

Hence, CSP produces: $0 \times 10^9 kWh \times \frac{0.038kg}{kWh} = 0\ tons\ of\ CO2/year$

- **Hydro**

By 2030, hydropower will generate 347GWh of energy. Hydropower produces around 0.004kg of CO_2/kWh [19].

Hence, hydropower produces: $0.347 \times 10^9 kWh \times \frac{0.004kg}{kWh} = 1{,}388\ tons\ of\ CO2/year$

- **Biogas**

By 2030, Biogas will generate 184GWh of energy. Biogas produces around 0.018kg of CO_2/kWh [19].

Hence, Biogas produces: $0.184 \times 10^9 kWh \times \frac{0.018kg}{kWh} = 3{,}312\ tons\ of\ CO2/year$

- **Thermal Power Generation**

Assuming that the energy demand in Lebanon is 18,000GWh such that a total of 5,000GWh is satisfied by EDL and the remaining 13,000GWh satisfied by private generators.

- **EDL**

EDL power plants emit 0.65kg of CO_2/kWh produced [21].

EDL: $5 \times 10^9 kWh \times \frac{0.65kg}{kWh} = 3{,}250{,}000\ tons\ of\ CO2$

- **Private Generators**

Private generators in Lebanon emit 0.86kg of CO_2 for each kWh produced [22].

Private Generators: $13 \times 10^9 kWh \times \frac{0{,}86kg}{kWh} = 11\ 180\ 000\ tons\ of\ CO2$

EDL and private generators combined will emit a total of 14,430,000 tons of CO_2.

The amount of CO_2 saved = (the carbon footprint of EDL+ private generators) *100% – [(the carbon footprint of renewable energy technologies) *23% + (the carbon footprint of EDL+ private generators)*77%]

The amount of CO_2 saved = 14,430,000*100% - (7380+33792+121770+0+1388+3312) *23% + 14,430,000*77%] = 14,430,000 - [38557+11,111,100] = 3,280,342 tons of CO_2

Note: the 23% in the above equation is the total renewable energy share from generated electricity in the year 2030. So, the remaining 77% is satisfied by thermal power generation.

3.3.2. Cost Reduction

For renewable technologies, taking a carbon tax of about $84/tCO2 into consideration [19]:

3280342 tons of CO2 saved * $84/t = $275,548,728 saved/year.

- Reduction of CO2 emissions per capita:

Amount of CO_2 emissions (2020) = (amount of CO_2 emitted by RE) *2% + (amount of CO_2 emitted by thermal power generation) * 98% = (0+0+5453+0+1388+1494) *2% + (14430000) *98% = 14141567 tons

Amount of CO_2 emissions (2030) = (amount of CO_2 emitted by RE) *23% + (amount of CO_2 emitted by thermal power generation) * 77% =

(7380+33792+121770+0+1388+3312) *23% + (14430000) *77% = 11149658 tons

Reduction of CO_2 emissions =

Amount of CO_2 emissions (2020) - Amount of CO_2 emissions (2030) = 2991909 tons

$$Reduction\ of\ CO2\ emissions\ per\ capita = \frac{Reduction\ of\ CO2\ emissions}{Lebanese\ Population}$$

$$= \frac{2991909}{6000000} = 0.5\ tons\ of\ CO2\ \ per\ capita$$

Table 7 represents the renewable energy projections for the stagnation scenario from the year 2025 till year 2030. The table also includes the amount of CO_2 saved in million tons and the carbon tax avoided in million $. Moreover, some constants are included in this table. These constants helped in calculating the amount of CO_2 saved and carbon tax avoided.

Table 7: Stagnation Scenario

Year	2025	2026	2027	2028	2029	2030
Wind (MW)	0	226	226	226	226	226
Wind (GWh)	0	615	615	615	615	615
Amount of CO2 emitted by wind energy (tons)	0	7380	7380	7380	7380	7380
Solar PV - Centralized (MW)	105	105	105	105	105	405
Solar PV - Centralized (GWh)	182	182	182	182	182	704
Amount of CO2 emitted by solar PV centralized (tons)	8736	8736	8736	8736	8736	33792
Solar PV - Distributed (MW)	1,347	1,438	1,528	1,619	1,709	1,800
Solar PV - Distributed (GWh)	2,223	2,372	2,522	2,671	2,821	2,970
Amount of CO2 emitted by solar PV distributed (tons)	84474	97252	103402	109511	115661	121770
CSP (MW)	0	0	0	0	0	0
CSP (GWh)	0	0	0	0	0	0
Amount of CO2 emitted by CSP (tons)	0	0	0	0	0	0
Hydro (MW)	286	286	286	286	286	286
Hydro (GWh)	347	347	347	347	347	347
Amount of CO2 emitted by hydro (tons)	1388	1388	1388	1388	1388	1388
Biogas (MW)	9	9	20	20	20	20
Biogas (GWh)	83	83	184	184	184	184
Amount of CO2 emitted by biogas (tons)	1494	1494	3312	3312	3312	3312
Total RE (MW)	1,747	2,064	2,165	2,256	2,346	2,737
Total RE (GWh)	2,835	3,600	3,850	3,999	4,149	4,819
T&D losses	11.70%	9.50%	8%	8%	8%	8%
Generation (GWh)	17,914	18,088	18,375	19,294	20,128	21,272
Total Generated RE Share from Electricity Consumed (%)	16%	20%	21%	21%	21%	23%
Amount of CO2 saved (million tons)	2.29	2.86	3.00	3.00	3.00	3.28
Carbon tax avoided (million $)	193	240	252	252	252	276
Constants						

Wind Energy Carbon footprint (kg/kWh)	0.012
Solar Energy Centralized Carbon footprint (kg/kWh)	0.048
Solar Energy Distributed Carbon footprint (kg/kWh)	0.041
CSP Carbon footprint (kg/kWh)	0.038
Hydro Carbon footprint (kg/kWh)	0.004
Biogas Carbon footprint (kg/kWh)	0.018
Lebanon Demand (GWh)	18000
EDL Production (GWh)	5000
Private Gen Production (GWh)	13000
EDL Carbon footprint (kg/kWh)	0.650
Private Generators Carbon footprint (kg/kWh)	0.860
Carbon Tax ($/ton)	84
Amount of CO2 emitted by EDL in tons	3250000
Amount of CO2 emitted by private generators in tons	11180000
Amount of CO2 emitted by EDL+private generators in tons	14430000
Lebanese Population including Refugees	6,000,000

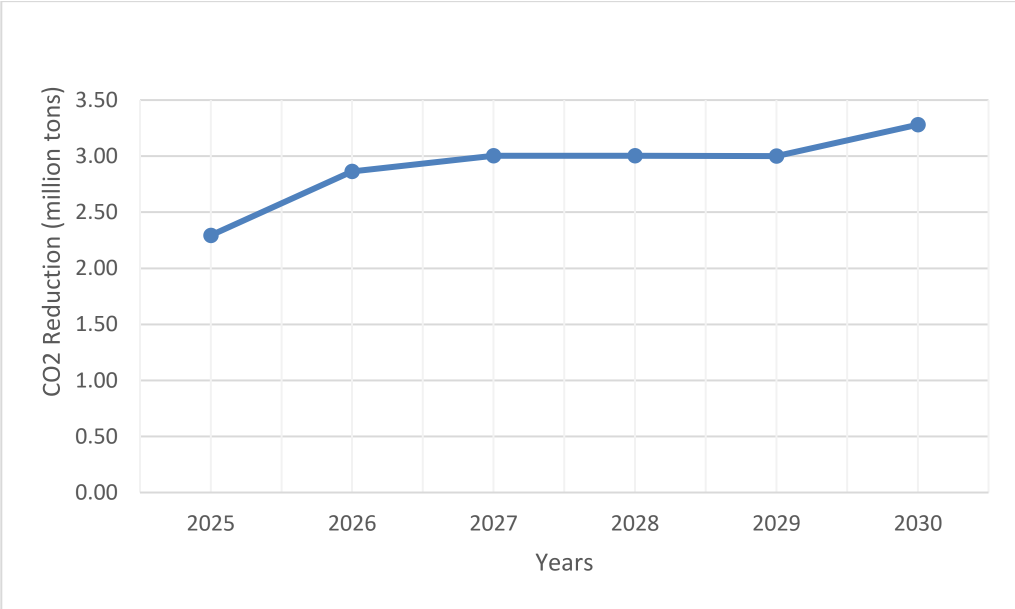

Figure 5: CO2 saved in Stagnation Scenario from year 2025 till 2030.

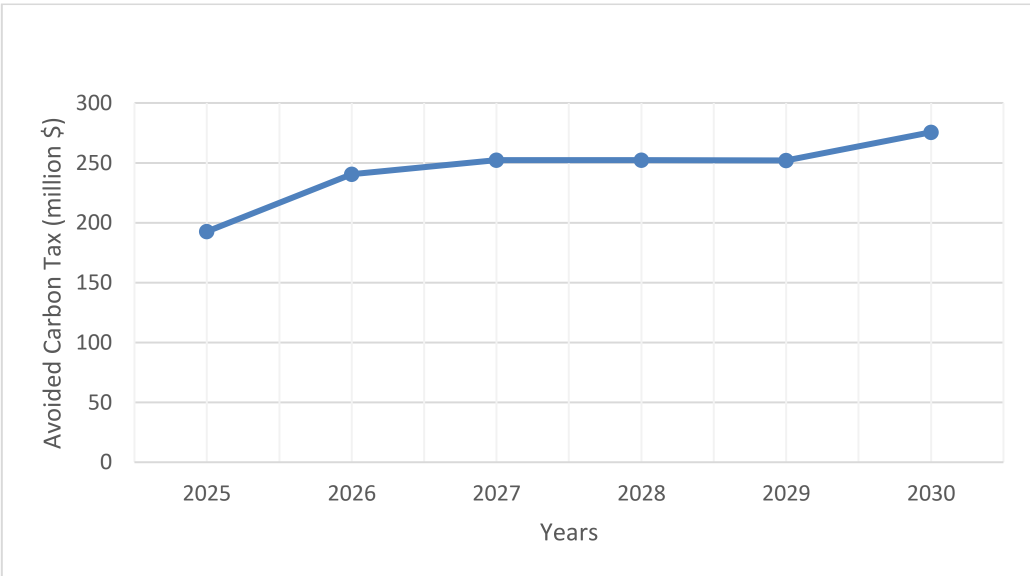

Figure 6: Carbon tax avoided in Stagnation Scenario from year 2025 till 2030.

3.4. Analysis of the Results

Table 8 summarizes the results of all 3 scenarios related to CO2 total reduction by year 2030, the monetary savings, and the per capita reductions.

Table 8: Results of the three Scenarios

Year 2030 Scenarios and Forecasts	Full Recovery	Partial Recovery	Stagnation
Amount of CO_2 saved/year (tons)	7,458,511	5,804,677	3,280,342
Cost of CO_2 saved/year ($)	626,514,924	487,592,868	275,548,728
Reduction of CO_2 emissions per capita (tons/capita)	1.2	0.92	0.5

The amount of CO_2 saved per year in tons, the cost of CO_2 saved per year in USD, and the reduction of CO_2 emissions per capita in tons/capita are the highest in the Full Recovery scenario. This is expected since the total renewable energy share from generated electricity (53%) is the highest in the Full Recovery scenario. As the total renewable energy share from generated electricity decreases to 41% in the Partial Recovery scenario, the amount of CO_2 saved per year in tons, the cost of CO_2 saved per year in USD, and the reduction of CO_2 emissions per capita in tons/capita decrease to reach 5,804,677 tons, $487,592,868, and 0.92 tons/capita respectively. In the Stagnation scenario, the total renewable energy share from generated electricity is the lowest among all three scenarios (23%). Hence, the amount of CO_2 saved per year in tons, the cost of CO_2 saved per year in USD, and the reduction of CO_2 emissions per capita in tons/capita are the lowest between all scenarios. It should be noted that considering the stagnation scenario, the country will not meet the set target of 30% RE by 2030.

CHAPTER 4

REDUCTION OF CO2 EMISSIONS/ CAPITA- GLOBAL PRESPECTIVE

In this chapter ten developed and ten developing countries were randomly selected to compare the committed/targeted reduction of CO_2 emissions/capita between them.

4.1. Reduction of CO_2 emissions/capita for developed countries

Table 9: Calculations of CO2 emissions/capita for developed countries.

	Amount of CO2 emissions in 2020 (tons)	Amount of CO2 emissions in 2030-target 2030 (tons)	Reduction of CO2 emissions (tons)	Population (2023-2024)	Reduction of CO2 emissions/capita (tons/capita)
Iceland	1447000	1168800	278200	378,000	0.74
Sweden	33576000	19,738,020	13,837,980	10,650,000	1.30
United Kingdom	308,650,000	179,768,000	128,882,000	67,962,000	1.90
Denmark	27,357,000	15,593,400	11,763,600	6,000,000	1.96
Japan	1,014,067,000	693,383,040	320,683,960	122,631,432	2.62
New Zealand	31,360,000	17,116,000	14,244,000	5,269,939	2.70
Germany	603,351,000	334,357,800	268,993,200	83,253,000	3.23
Norway	36,177,000	13,187,000	22,990,000	5,514,477	4.17
Canada	516,874,000	329,419,800	187,454,200	39,107,046	4.79
Australia	378,997,000	210,217,140	168,779,860	26,700,000	6.32

For the developed countries, the reduction of CO_2 emissions per capita in tons/capita are calculated using the amount of CO_2 emissions in 2020 and the targeted amount of CO_2 emissions in 2030. The reduction of CO_2 emissions/capita is calculated using the following equation:

$$Reduction\ of\ CO2\ emissions/capita = \frac{Reduction\ of\ CO2\ emissions\ (tons)}{Population}$$

The reduction of CO_2 emissions/capita start from a value of 0.74 which is attributed to Iceland and increases to a value of 6.32 tons/capita which is attributed to Australia. Hence, if Australia were to reach its 2030 target, each Australian individual will be reducing 6.32 tons of CO_2 compared to year 2020. Figure 7 presents the estimated reduction in selected developed countries.

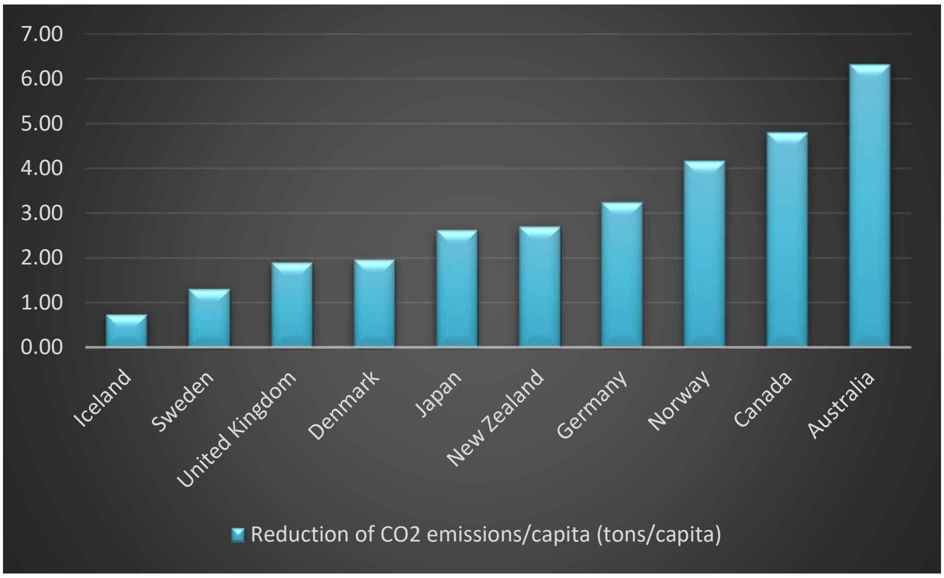

Figure 7: The reduction of CO2 emissions/capita in tons/capita of the developed countries.

4.2. Reduction of CO2 emissions/capita for developing countries

Table 10: Calculations of CO2 emissions/capita for developing countries.

	BAU CO2 emissions 2030 (tons)	NDC Target CO2 emissions 2030 (tons)	Reduction of CO2 emissions (tons)	Population (2023-2024)	Reduction of CO2 emissions/capita (tons/capita)
Sudan	69,027,406	41,906,330	27,121,076	49,359,000	0.55
Egypt	341,675,000	261,120,000	80,555,000	114,485,000	0.70
Jamaica	7,200,000	5,148,000	2,052,000	2,825,000	0.73
Kenya	143,000,000	97,240,000	45,760,000	56,203,000	0.81
Lebanon					0.92
Albania	15,148,000	11,978,000	3,170,000	2,827,000	1.12
Jordan	43,989,000	30,291,000	13,698,000	11,385,000	1.20
Oman	125,254,000	116,486,220	8,767,780	4,713,553	1.86
Thailand	555,000,000	388,500,000	166,500,000	71,886,000	2.32
Indonesia	2,869,000,000	1,954,075,900	914,924,100	279,800,000	3.27

The reduction of CO_2 emissions per capita in developing countries are calculated using the Business-As-Usual (BAU) scenario and the Nationally Determined Contribution (NDC) target. Hence, the reduction of CO_2 emissions is the difference between the amount of CO_2 emitted according to the BAU scenario and the amount of CO_2 emitted according to the NDC target. The reduction of CO_2 emissions/capita is calculated using the following equation:

$$Reduction\ of\ CO2\ emissions/capita = \frac{Reduction\ of\ CO2\ emissions\ (tons)}{Population}$$

The reduction of CO2 emissions/capita start from a value of 0.55 which is attributed to Sudan and increases up to 3.27 tons/capita which is attributed to Indonesia. For Lebanon, the reduction of CO_2 emissions/capita was calculated using the amount of CO_2 emitted according to the partial recovery scenario based on year 2020 and 2030. Figure 8 presents anticipated CO2 reductions for selected developing countries.

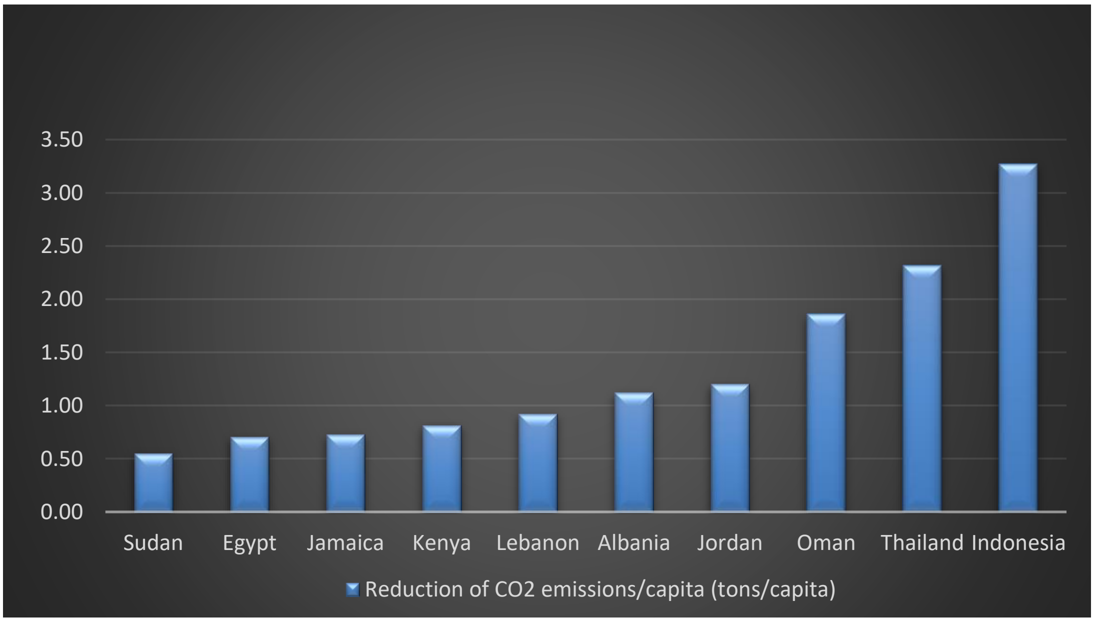

Figure 8: The reduction of CO2 emissions in tons/capita of the developing countries

4.3. Analysis of the Results

From the presented results, it can be noticed that in general developed countries have higher values of reduction of CO_2 emissions/ capita than developing countries. This is very logical since developed countries are committed to achieving higher CO_2 emissions reductions compared to developing countries. Developed countries or the wealthy nations with rich economies are contributing negatively to the environment more than developing countries. Hence, they are required to reduce the amount of CO_2 emissions more than developing countries. Developed nations have significant financial resources and infrastructure, making them better equipped for mitigating and adapting to climate change. Developing countries are still in the early stages of development, including adaptation to climate change. Developed countries' negotiating strength in the global economy significantly impacted poor countries. Some say that emerging countries have fewer financial resources compared to industrialized nations. This problem directly affects poor nations grappling with climate change impacts. Developing nations' agricultural production are impacted by limited money, human resources, and technology. In 1996, the Kyoto Protocol proposed that industrialized nations reduce their carbon emissions to mitigate the consequences of climate change [23].

As for Lebanon, the “full” and “partial” recovery scenarios would lead to achieving the set national target of 30% renewable energy share in the electricity production. The excessive percentage can be used to optimize the renewable energy mix, i.e. minimize the cost. The “stagnation” scenario, however, would stand short of achieving the target due to the lack of political and economic stability, and due to lack of any external funding.

Addressing climate change is a common responsibility. Early UN climate discussions acknowledged a shared responsibility for climate change, but—guided by the notion of "common but differentiated responsibilities"—relied on affluent nations, rather than poor countries, to reduce GHG emissions. Developed nations have released most emissions to date, dating back to the industrial revolution, and their sophisticated economies could better handle the expenses [24].

The 29th Conference of the Parties (COP29) of the UN Framework Convention on Climate Change (UNFCCC) in Baku, Azerbaijan, closed on November 24, 2024. The conference approved a new climate financing objective for poor nations and established regulations for implementing Article 6 of the Paris Agreement, which allows for national and worldwide carbon trading. The New Collective Quantified Goal (NCQG) for climate funding was agreed after extensive talks. The NCQG extends industrialized nations' pledge to raise US$100 billion in climate money for poor countries, which was completed in 2022 after a 2-year delay. The parties pledged to provide at least US$300 billion in climate funding annually by 2035, with industrialized nations leading the way. The Paris Agreement's Article 9.2 supports voluntary contributions from poor nations while protecting their position as recipients. The decision encourages all parties to increase funding from both public and private sources to at least US$1.3 trillion yearly by 2035 [25]. Discussions will resume during the UNFCCC intersessional meetings in Bonn, Germany in June 2025, with the goal of obtaining a settlement by COP30 in November 2025. The delay also applied to other mitigation-related tasks on the agenda, including building features for nations' new NDCs. Countries' subsequent set of NDCs, expected early next year, will define their emissions-reduction objectives for 2035 (ideally, alongside stronger targets for 2030) and emphasize steps they will adopt across certain sectors. Every nation must present new climate commitments ahead of COP30. The emphasis should be on significant emitters, which are expected to spearhead initiatives to significantly reduce emissions. This involves establishing strong near-term objectives that bring net-zero aspirations within reach. Importantly, nations should integrate climate initiatives into the foundation of their economic and sectoral plans (including in their NDCs) through decisive actions to swiftly shift away from fossil fuels and towards a zero-carbon, climate-resilient future [26].

CHAPTER 5

CONCLUSION

Renewable energy or green technologies offer an environmentally friendly approach to generate and consume power. However, the implementation of these technologies necessitates the presence of a clear regulatory framework with secured financial resources. Moreover, the country's economic situation should be stable enough to attract funds and investors. Some countries have the resources but lack the technical skills and funds to implement such kinds of technologies, other countries have technical competencies and capabilities but lack the resources or the regulatory framework to put the resources into use, and finally other countries lack all kinds of resources.

Two of the three scenarios adopted for Lebanon ("full" and "partial" recovery) would lead to achieving the set national target of 30% renewable energy share in the electricity production. The "stagnation" scenario, however, would stand short of achieving the target due to the lack of political and economic stability, and due to lack of any external funding.

Climate change and global warming have a greater impact in developing countries than in developed countries, highlighting the need for equal attention to climate change action globally, as emphasized in the Kyoto Protocol and Copenhagen Accords. Developed countries must help underdeveloped countries in addressing climate change impacts.

Finally, the reduction of CO2 emissions/capita can be extended to include other economic parameters such as the levelized cost of electricity (LCOE) in $/Wh.

REFERENCES

[1] Sustainable Development Goals | United Nations Development Programme. (n.d.). UNDP Sustainable Development Goals | United Nations Development Programme (undp.org)

[2] Martin. (2023, September 8). Energy - United Nations Sustainable Development. United Nations Sustainable Development. Energy - United Nations Sustainable Development

[3] Kinab, E., & Elkhoury, M. (2012). Renewable energy use in Lebanon: Barriers and solutions. Renewable & Sustainable Energy Reviews, 16(7), 4422–4431. Renewable energy use in Lebanon: Barriers and solutions - ScienceDirect

[4] Haddad. (2021, April 11). Current Barriers and Future Outlooks for Renewable Energy in Lebanon. Current Barriers and Future Outlooks for Renewable Energy in Lebanon (lebanesechamber.ca)

[5] Council, C. (2023b). 11 countries leading the charge on renewable energy. Climate Council. 11 countries leading the charge on renewable energy | Climate Council

[6] Australia has raised its climate targets and now needs to accelerate its clean energy transition, says new IEA review - News - IEA. (n.d.-b). IEA. Australia has raised its climate targets and now needs to accelerate its clean energy transition, says new IEA review - News - IEA

[7] Reuters. (2023, March 1). Japan can achieve 90% clean power share by 2035, US study finds. Reuters. Japan can achieve 90% clean power share by 2035, US study finds | Reuters

[8] Hope, B. (2022). Top 10: Nations that are leading the renewable energy charge. Sustainability Magazine. Top 10: Nations that are leading the renewable energy charge | Sustainability Magazine

[9] Canada, N. R. (2017, December 13). About renewable energy. About Renewable Energy (canada.ca)

[10] Renewable Energy Outlook: Egypt. (2018b, October 1). Renewable Energy Outlook: Egypt (irena.org)

[11] Thailand's Clean Electricity Transition – Analysis - IEA. (n.d.). IEA. Thailand's lean Electricity Transition – Analysis - IEA

[12] Oman's huge renewable hydrogen potential can bring multiple benefits in its journey to net zero emissions - News - IEA. (n.d.). IEA. Oman's huge renewable hydrogen potential can bring multiple benefits in its journey to net zero

emissions - News - IEA

[13] Executive summary – Enhancing Indonesia's Power System – Analysis - IEA. (n.d.). IEA. Executive summary – Enhancing Indonesia's Power System – Analysis - IEA

[14] Sudan - Countries & Regions - IEA. (n.d.). IEA. Sudan - Countries & Regions - IEA

[15] The energy sector in Albania - Bankwatch. (2024, January 11). Bankwatch. The energy sector in Albania - Bankwatch

[16] Jordan - Renewable energy. (2024, January 17). International Trade Administration | Trade.gov. Jordan - Renewable Energy (trade.gov)

[17] Skujins, A. (2023, September 19). Jamaica seeks proposals for 100 MW of renewables. Pv Magazine International. Jamaica seeks proposals for 100 MW of renewables – pv magazine International (pv-magazine.com)

[18] When 100% renewable energy doesn't mean zero carbon. (2019, May 23). Stanford Doerr School of Sustainability. https://sustainability.stanford.edu/news/when-100-renewable-energy-doesnt-mean-zero-carbon

[19] Wehbe, N. (2020). Optimization of Lebanon's power generation scenarios to meet the electricity demand by 2030. The Electricity Journal, 33(5), 106764. https://doi.org/10.1016/j.tej.2020.106764

[20] Smoot, G. (2023, July 19). What is the carbon footprint of solar energy? A Life-Cycle Assessment | Impactful Ninja. Impactful Ninja. https://impactful.ninja/the-carbon-footprint-of-solar-energy/

[21] Solar Photovoltaic: Electrify for your House! (2014, April 9) Solar Photovoltaic | United Nations Development Programme (undp.org)

[22] Azhari, K. (n.d.). A "Solar" Solution to the Energy Crisis in Lebanon. http://www.businessnews.com.lb/EnergyCrisis/Energycrisisreseachpaper-K.Azhari.pdf

[23] Wijaya, A. (2014). Climate Change, Global warming and Global inequity in developed and Developing Countries (Analytical Perspective, Issue, Problem and Solution). IOP Conference Series: Earth and Environmental Science, 19, 012008. https://doi.org/10.1088/1755-1315/19/1/012008

[24] Who is responsible for climate change? (n.d.). World101 From the Council on Foreign Relations. Who Is Responsible for Climate Change? | World101 (cfr.org)

[25] COP29 climate change conference: Outcomes | Think Tank | European Parliament. (n.d.).

https://www.europarl.europa.eu/thinktank/en/document/EPRS_ATA(2024)766266

[26] Waskow, D. (n.d.). Key Outcomes from COP29: Unpacking the New Global Climate Finance Goal and Beyond. World Resources Institute. https://www.wri.org/insights/cop29-outcomes-next-steps