UNIVERSITY OF TURKISH AERONAUTICAL ASSOCIATION
INSTITUTE OF SCIENCE AND TECHNOLOGY

TECHNICAL AND FINANCIAL EVALUATION OF A 110 MW SOLAR THERMAL POWER STATION IN IRAQ

Master Thesis

Hasanain MUSAFER

Institute of Science and Technology

Mechanical and Aeronautical Engineering Department

July, 2017

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Thesis Supervisor: Assist. Prof. Dr. Munir ELFARRA

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Hasanain MUSAFER

11.07.2017

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I wish to dedicate this humble work for my lovely Iraq. I have tried to collect characters to write a word for him. A word says how much I miss him, but the characters become midgets when I try to. Even the letter is crying you Iraq. I hope he will recover soon. To the candle that lit the path of my life. At whom I realize how nostalgia is a killer. For my parents, who built me to be as I am. I would like to pay my life to see their face again, to kiss their blessed hands. Last, but not least, I would like to thank my wife for her understanding and love during the past few years. Her support and encouragement was in the end what made this dissertation possible. Thanks to my daughters Noor and the twins (Ward and Yasmeen) whom always courage me to study. Thanks to my brothers and sisters.

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Iraq, until today, has not found itself on the renewable energy map in spite of the fact that it has huge sources of renewable energy, most notably solar energy. Iraq is located between latitudes 20ºN and 40ºN with 5 to 8 $kW/m^2/d$ of solar radiation, as seen from the land spacing and the available data from DNI Map, the SWERA Report and NASA.

For this thesis, the concentrated solar power (CSP) technologies were selected to construct the first solar power station in Iraq as a result of our evaluation of this technology. A plant capacity of 110 MW was selected as the optimum capacity for a power plant from the information about the development of concentrated solar power (CSP) as presented in Chapter 2. Baghdad was the location selected for several reasons, the most important of which is the solar radiation there and other reasons, as mentioned in Chapter 3.

The concentrated solar power collectors used in this study include the parabolic trough collector (PTC), the linear Fresnel reflector (LFR) and the solar power tower (SPT). These kinds of collectors can be used with thermal energy storage (TES) and backup fossil (BF).

For the technical evaluation, the annual energy that was produced, capacity factors and the total areas were calculated for each project. All of these factors were calculated using the System Advisor Model (SAM) software. In addition, greenhouse gases (GHG) reduction was obtained by using the RETScreen software.

For the financial evaluation, two scenarios were applied to determine the best tariffs. Scenario One gave grants to the project for different hours of thermal energy storage (TES) and profit indicators. At TES 0 hours, with grants or without grants, the best technology was found to be the parabolic trough collector (PTC) and the most suitable tariff was found to be between $75/MWh and $240/MWh, whereas 3 hour and 9 hour TES will have us use the solar power tower (SPT) when the grant is zero and with grants giving us a tariff between $110/MWh and $225/MWh.

Scenario Two gives the project between $10 and $30 for each ton of greenhouse gases (GHG) reduction ($/t$CO_2$). At 0 hours TES, the best technology was found to be PTC, with tariffs of $230/MWh and $215/MWh, respectively, and at 3 hours and 9 hours TES, SPT was used, which gives a tariff of $215/MWh and $180/MWh.

Keywords: Concentrate Solar Power, Thermal Energy Storage TES, RETScreen, Net Present Value.

ÖZET

IRAK’TAKİ 110 MW GÜNEŞ TERMAL GÜÇ İSTASYONUNUN TEKNİK VE MALİ DEĞERLENDİRİLMESİ

MUSAFER, Hasanain
Fen bilimleri yüksek lisans,Makine mühendisliği
Danışman:Yardımcı Prof.Dr. Munir ELFARRA
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Irak; en önemli solar enerji olan büyük yenilenebilir enerji kaynaklarına sahip olmasına rağmen günümüze kadar yenilenebilir enerji haritasında yerini bulamamıştır. Ülkenin kapladığı alan, DNI haritasından alınan veriler,SWERA raporu ve NASA verilerinden de anlaşıldığı üzere Irak 20º ve 40º kuzey enlemleri arasında 5 ila 8 kW/m^2/d güneş ışınımı değerlerine sahiptir.

Bu teknolojinin tarafımızca değerlendirilmesi sonucu;Irak’ta ilk güneş enerjisi istasyonu kurmak için odaklanmış güneş enerjisini (CSP) seçtik.bölüm 2’de sunulduğu gibi odaklanmış güneş enerjisinin (CSP) gelişimi hakkında alınan bilgiye dayanarak optimum santral kapasitesi olarak 110 MWh tesis kapasitesini seçtik.Birçok sebepten dolayı yer olarak seçilmiştir.Bu sebeplerin en önemlisi oradaki güneş ışınımı olup,diğer sebepler ise 3.bölümde açıklanmıştır.

Bu çalışmada kullanılan odaklanmış güneş enerjisi kolektörleri;parabolik oluk tipi güneş kolektörü (PTC),doğrusal Fresnel reflektör (LFR) ve güneş enerji kulesi (SPT)’dir.Bu tür kolektörler termal enerji depolama (TES) ve fosil yedekleme(BF) için kullanılabilmektedir.

Teknik değerlendirme bakımından;üretilen yıllık enerjiyi,kapasite etkenini,her bir proje için toplam alanları hesapladık.Sistem danışman modeli (SAM) veritabanını kullanarak tüm bu etkenler hesaplanmıştır.Bunun yanında,sera gazları (GHG)

indirgenimi temiz enerji yönetim yazılımı (RetScreen) yazılımı kullanılarak sağlanmıştır.

Ekonomik değerlendirme bakımından; en iyi tarifeleri belirlemek için iki senaryo kullandık.1.Senaryo,farklı saatlerde termal enerji depolama(TES) ve kar göstergeleri için düzenlenen projeye bağışların verilmesidir. Bağışlı veya bağışsız 0 saatlik termal enerji depolamada(TES) en iyi teknoloji parabolik oluk tipi güneş kolektörü(PTC) ve en uygun tarife ise 80/MWh $ ve 240 /MWh $ dir, Hibenin sıfır olması durumunda 3 saat ve 9 saatlik TES bize güneş enerjisi kulesi (SPT) kullanacak ve bize 110 $ / MWh ile 225 $ / MWh arasında bir tarife verilecektir.

2.Senaryo ise ; her ton sera gazı(GHG) indirgenimi ($/t$CO_2$) için 10 $ ile 30 $ arası meblağ vermektedir.0 saatliktermal enerji depolamada(TES),en iyi teknoloji; 230 /MWh $ ve 215/MWh $ tarife parabolik oluk tipi güneş kolektörü (PTC) olarak görülmüştür.3 saatlik ve9 saatlik termal enerji depolama(TES)da bize 215/MWh $ 180 /MWh $ tarifeyi veren güneş enerji kulesini (SPT) kullandık.

Anahtar kelimeler: odaklanmış güneş enerjisi, termal enerji depolaması TES, temiz enerji yönetim yazılımı RETScreen, Net bugünkü değer.

LIST OF SYMBOLS

C	:	Capital initial cost of the project
IG	:	Grants
C_{ener}	:	Annual energy savings of income
C_{capa}	:	Annual capacity savings or income
C_{RE}	:	Annual renewable energy production credit income
C_{GHG}	:	Greenhouse gases reduction income
$C_{O\&M}$	:	Yearly operation and maintenance costs
C_{fuel}	:	Annual cost of fuel or electricity
I	:	The discount rate
n	:	The time of cash flow
$\lambda\, prop$	:	Fraction of electricity lost in transmission and distribution for proposed
e_{cr}	:	GHG emission reduction credit transaction fee

LIST OF ABBREVIATIONS

AEP	:	Annul Energy Production
ALCS	:	Annul life saving
BF	:	Backup fuel
CF	:	Capacity factor
CSP	:	Concentrated Solar power
DNI	:	Direct Normal Insolation
ESTELA	:	European Solar Thermal Electricity Association
GHG	:	greenhouse gases
GW	:	Gigawatt
GW_e	:	Gigawatt-electric
HTF	:	Heat Transfer Fluid
IEA	:	International energy agency
IRENA	:	International Renewable energy agency
LFR	:	Linear Fresnel Reflector
MENA	:	Middle East and North Africa
MWh	:	Megawatt-hour
NASA	:	National Aeronautics and Space Administration
NPV	:	Net Present Value
NREL	:	National Renewable Energy Laboratory
RES	:	Renewable energies
PDS	:	Stirlingdish system
PTC	:	Parabolic trough collector
PV	:	Photovoltaic
SEGS	:	Solar Energy Generating System
SPB	:	Simple Payback Period
SPT	:	Solar Power Tower
STP	:	Solar Thermal power
SNL	:	Sandia National Laboratories
S&L	:	Sargent & Lundy Consulting Group
SWERA	:	Solar and Wind Energy Resource Assessment
tCO_2	:	tonnes of CO2
TES	:	Thermal Energy Storage
TMY	:	Typical Meteorological Year

CHAPTER ONE

INTRODUCTION

Solar energy is the energy obtained from the sun radiation and transform into electricity by employ one of solar technologies, either directly using photovoltaic (PV) or indirectly using concentrated solar power (CSP) [1]. PV technology use both direct and diffuse irradiances, whereas that CSP can using only the direct solar irradiance concentrated by concentrating solar collector like trough collector and central receivers. Therefore, full exploitation of the CSP is limited to those geographical regions where the annual direct irradiation levels are high, this region latitude (20^o-40^o) North -South called Sun-Belt area which include: Middle East and the north Africa MENA region, South Africa, Southern Europe, southern-west USA and Mexico, part of India and Pakistan, Australia, part of Brazil and Chile [2].

"Within 6 hours, deserts receive more energy from the sun than humankind consumes within a year," calculated by Dr. Gerhard Knies1 [3]. The world's highest potential for solar energy is located in the (MENA) region with 45% of the world's potential [4]. Iraq, which is located between latitudes (29^o-37^oN), and has much desert and flat land, receives 3,000 hours per year of solar radiation, Figure 1.1 [5]. This makes Iraq suitable to produce electricity from solar energy in huge quantities. The benefits of solar energy production include GHG reduction, many social benefits and an increase in the national income due to the export of oil that would be consumed in conventional stations.

Global consciousness about climate change has led the world to embrace different greenhouse gases (GHG) policies and reduction targets. Renewable energies (RES) utilization has become most important, consequently prompting the foundation and focus of RES use in numerous countries. Therefore, many key questions emerge: What are the sources of RES found in this area? Which RES would be preferable to produce energy? How can one choose between them? What are the preference tools? What criteria are used? Additionally, there are other questions. Generally, the methodologies for choosing the best source of renewable energy can be divided into two approaches: economic methodologies and methodologies focusing on technical performance. When optimizing an RES in a system from a technical viewpoint, the approaches typically use the following variables as an optimization standard: data needed for the source of the RES, annual energy production, areas needed to construct a plant, GHG reductions and fuel savings in addition to economics, profit indicators, rate impacts, marginal costs, levelized unit electricity costs and building costs [6].

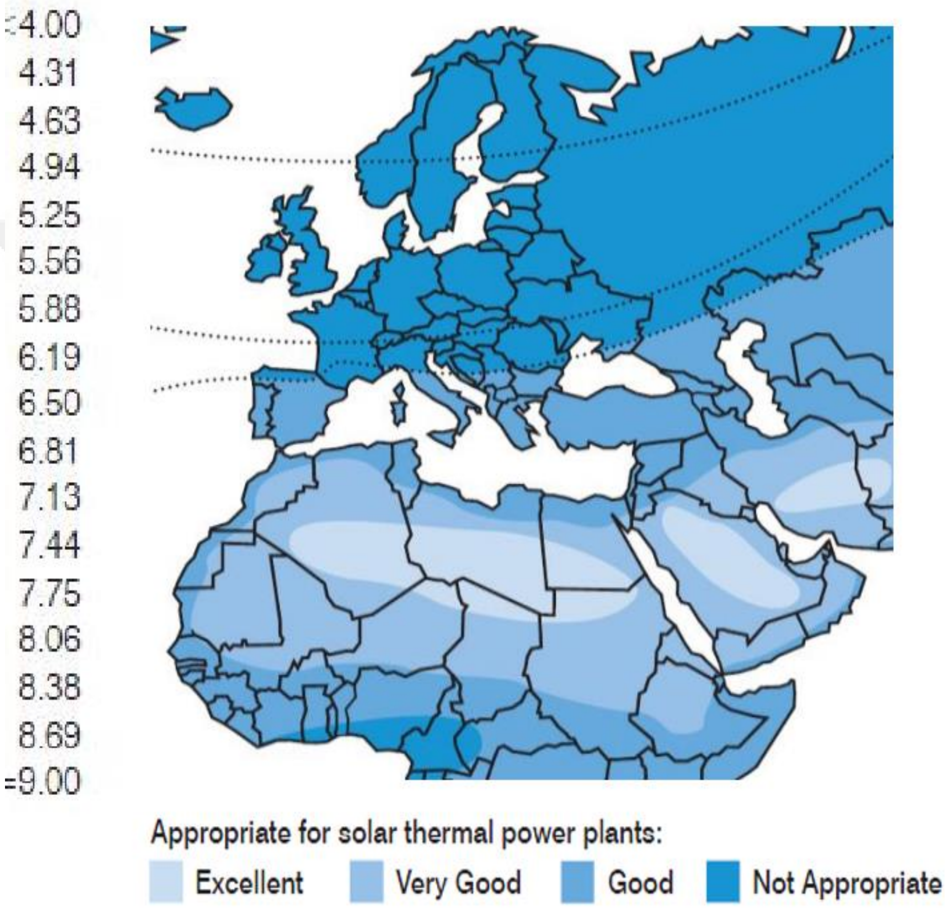


Figure 1.1 : Location of Iraq and solar radiation.

1.1 Demand and supply of electricity

Approximately 80% of electricity production in Iraq is from fossil fuels with the remaining production from hydropower. Figure 1.2 shows the estimated percentage of fuel burn. This year’s demand of electricity reached 15,000 MW, while the production of about 7000 MWh, did not meet this demand [7]. Iraq now needs to create many electrical power generation plants to fill the shortfall. The construction of power stations, especially those that depended on fossil fuels, will lead to increasing environmental pollution, more so in the future than now. The highest levels of pollution have been recorded even in recent years. This serves as motivation to find alternatives for the production of electrical energy. One of these solutions is to take advantage of the concentration of solar energy.

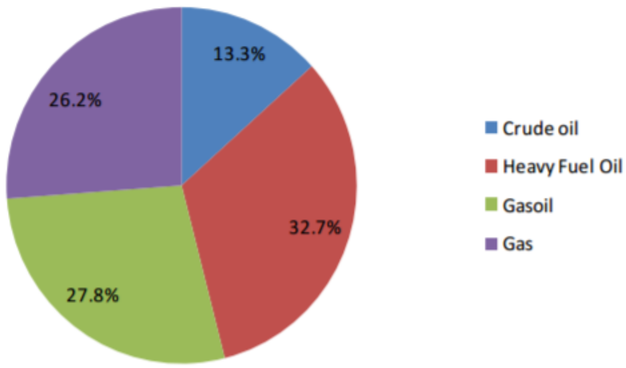


Figure 1.2 : Burning of fossil fuels for electricity production [4].

1.2 Concentrated Solar Power CSP

In this study, CSP will be analyzed because of the possibility of using thermal energy storage (TES). The energy potential of CSP for different districts in the MENA region is shown in Figure 1.3.

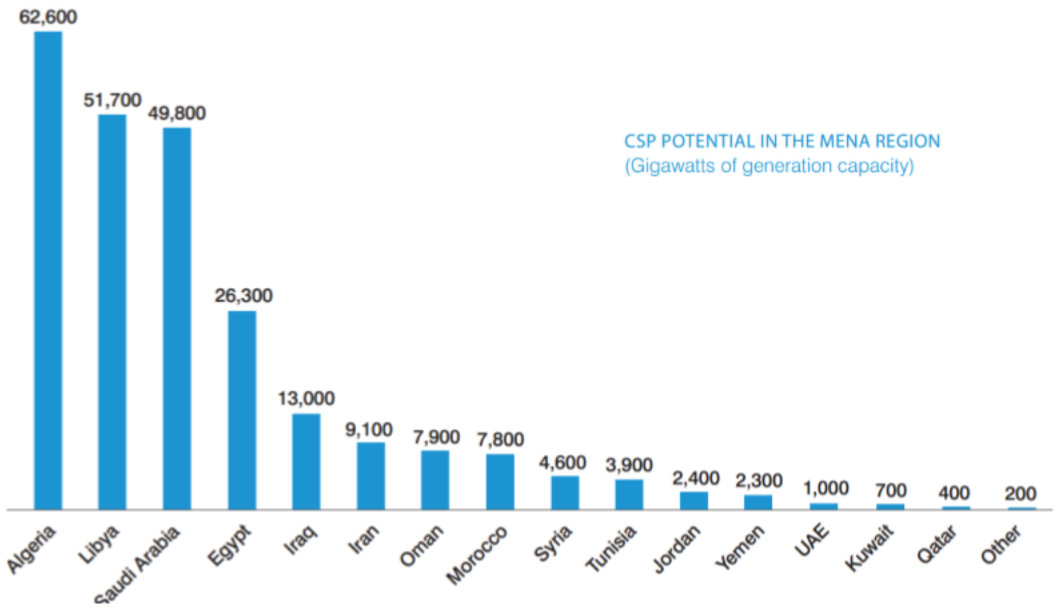


Figure 1.3 :CSP power potential (GW) in the MENA countries [2].

CSP technologies concentrate sunlight and direct its normal irradiance onto a small area by using mirrors in order to produce thermal energy. Thermal energy is used to produce steam to operate turbines, which drive an electrical power generator [8]. The four leading CSP technologies are the Parabolic trough Collector, the Solar power Tower, the Linear Fresnel Reflector and the Stirling dish.

CSP plants are adapted mainly to the focus power system and large capacity to produce electricity. Table 1.1 shows a brief comparison between the four above mentioned CSP technologies [9].

Table 1.1 : Comparison of state of the art CSP technologies.

	Parabolic trough	**Central tower**	**Fresnel collector**	**Stirling dish**
Figure[3]				
Capacity	**10-200 MW**	**10-150 MW**	**10-200 MW**	**0.01-0.4 MW**
Focusing Type	**Linear**	**Point**	**Linear**	**Point**
Thermal Efficiency	**30-40%**	**30-40 %**	**30-55%**	**20-40%**
Max solar efficiency	**21%**	**20-35%**	**20%**	**29%**
Land use $m^2MWh^{-1}y^{-1}$	**6-8**	**8-12**	**4-6**	**8-12**

1.3 Thesis Objectives

The main aim of the research is to carry out an extensive technical and financial assessment of using different CSP technologies for Baghdad region. The technical and financial evaluations would be helpful to the decision makers in the selection of the appropriate technologies through financial and analytical indicators of profit. The specific objectives include:

- Determining which areas with the highest concentrations of solar radiation are the most suitable to establish a thermal power plant.
- Technical and financial analyses of CSP technologies to know the features of each of them.
- Calculations of thermal energy storage (TES) for each technology and the impact on the annual energy production.

- Knowing how lower tariffs achieve the best profit indicators (SPB, NPV, ALCS).
- Calculating the amount of reduction of greenhouse gases (GHG) for each technology.

1.4 Thesis Methodology

The road map of the research is divided into three parts, the first section being the software used in research and comparisons among themselves and data collection. The second section includes a technical study of each CSP technology with the use of TES for different numbers of hours. The third section includes a study analyzing the financial indicators.

1.4.1 Software

- System advisor model (SAM)

SAM will be used to calculate the capacity factors, the actual annual energy outputs of a plant, the initial costs and the total area of the station. All these calculations will be applied to zero hours TES. This is followed by increasing the TES to three hours and then nine hours with re-calculations of the above variables. Moreover, it will be used to conduct a technical evaluation of the plant.

- RETScreen

RETScreen analysis would have been used for the selected sites to generate the various performance indicators. Since the RETScreen software does not have certain algorithms for the estimation of capacity factor C_f for CSP technologies, the SAM software will be used to estimate C_f depending on meteorological data and technical specifications.

1.4.2 Technology evaluation

In this section, the technical evaluations of CSP technology and special focuses on each type are presented. Sites for construction of new power plants are selected such that the sites have the highest levels of solar radiation. In this section, the parabolic dish collector (PDC) is excluded from this study as this technique cannot be used with TES.

1.4.3 Financial evaluation

The RETScreen software will be used to perform analyses on the financial viability of the project. It will also be used to determine the total investment costs and financial performance indicators (SPB, NPV, and ALCS). The figure below shows the map of the methodology.

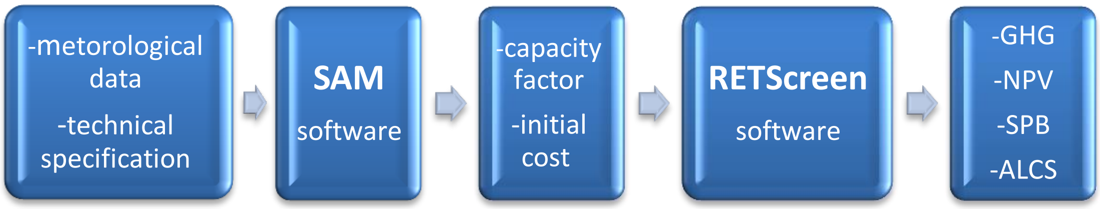


Figure 1.4 : The methodology of study.

1.5 Structure of thesis

- Chapter 1 "Introduction"

  This chapter provides a brief overview of renewable energy in the region with a discussion of the objectives and methodology, a graphic representation of the methodology and a presentation of the structure of this thesis.

- Chapter 2 "Literature Survey"

  The literature survey provides an overview of CSP technologies and their future, CSP plants around the world, a brief presentation of the software used in the study, Iraq in the map of CSP and the challenges, opportunities and the inevitabilities.

- Chapter 3 "Technical Evaluation"

  This chapter contains the technical specifications of CSP technologies (PTC, LFR, and SPT) and meteorological data. It provides the calculation of plant areas, GHG reduction income and annual energy production.

- Chapter 4 "Financial Evaluation"

  This chapter presents financial accounts indicators for profit and different numbers for TES. Profit indicators for investment projects are NPV, SPB, and ALCS.

- Chapter 5 "Conclusions and Recommendations"

  This chapter concludes the research and presents the final recommendations.

CHAPTER TWO

LITERATURE SURVEY

"Power generation from solar energy is one of the most interesting options in reducing fossil fuel consumption and related CO_2 emissions. Nowadays, one of the most effective solutions for power generation from solar energy is represented by Concentrating Solar Power (CSP) systems" [10]. Concentrating Solar Power (CSP) plants use mirrors to concentrate the energy from the Sun to drive traditional steam turbines or engines that create electricity [11]. Figure 2.1 shows the principle of operation of CSP plants. A CSP plant consists of a solar field, thermal energy storage and a power block.

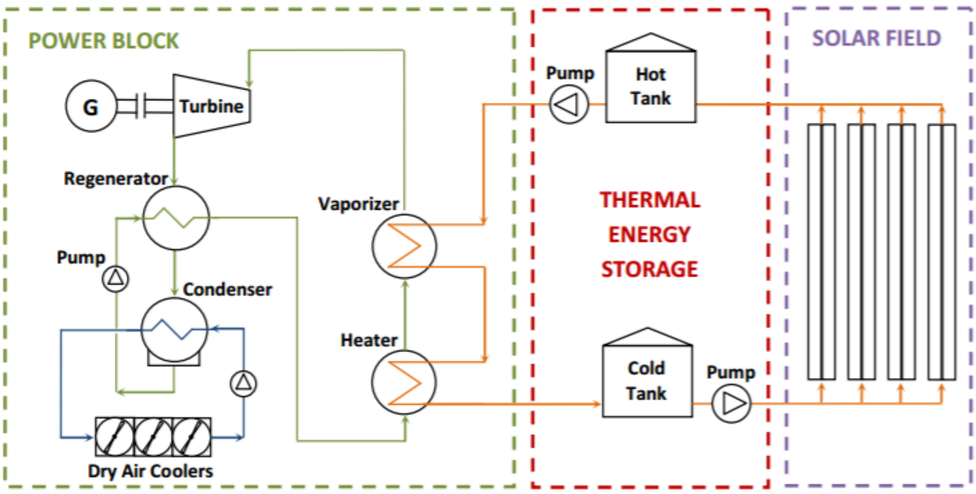


Figure 2.1 : Principle of operation of CSP plants [10**].**

At present, there are four available CSP technologies.Figure2.2 shows the leading types of CSP: the parabolic trough collector (PTC),solar power tower (SPT),linear Fresnel reflector (LFR) and parabolic dish systems (PDS) [12].

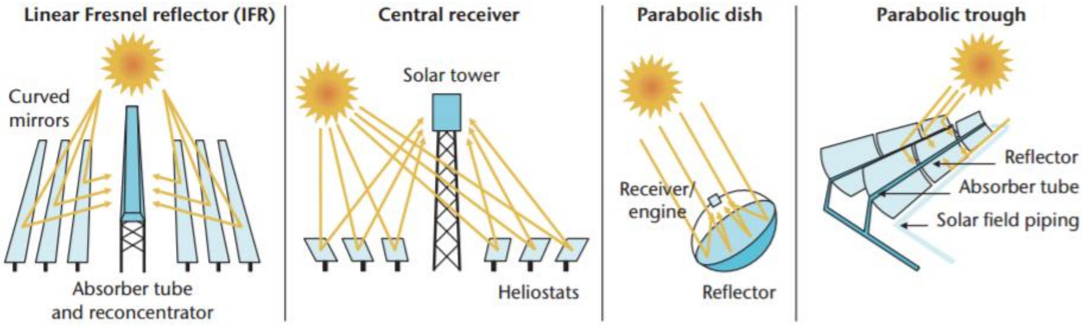


Figure 2.2 : Leading types of CSP technologies [12].

The first CSP plant was a PTC built in the 1980s when it was constructed at a small Solar Power Systems Project Collector System in Spain in 1981 [13, 14]. In 1984, the LUZ corporation established the world's first commercial PTC named SEGS I in California, USA [13, 15].

Parabolic trough technology was utilized in the world's first nine solar power plants and the technology has succeeded in proving the economic feasibility of its usage. The SEGS I–IX 354 (MW) is still commercially profitable since they started operation and have since increased their efficiency and output as the operators improved their procedures. SEGS in California, with a common capacity from three separate locations at 662 and 542 MWh, is now the world's second largest solar thermal energy [16]. The Ivanpah Solar Electric Generating System, the largest solar thermal energy generator in the world (gross) 392 (MW), is a CSP plant in the Mojave Desert and is located at the base of Clark Mountain in California. It consists of three solar thermal power plants on an area of 14 km^2. Figure 2.3 shows this plant [17].

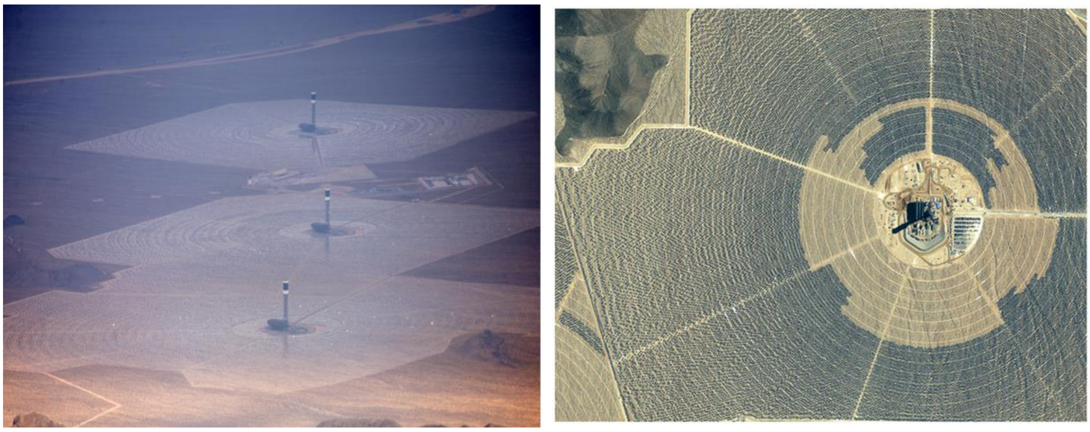


Figure 2.3 : The largest solar thermal energy generating in the world.

The facility consists of fields of heliostat mirrors focusing sunlight on receivers located on centralized solar power towers. The continuous increase in the efficiency of CPS technologies has encouraged many countries, especially Spain, to utilize this technology to generate clean, reliable energy by constructing small or large-scale solar plants. CSP capacity is now growing in India, the Middle East, North Africa, Australia, South Africa, Chile and China [18]. Figure 2.4 shows how the capacity of installed CSP has grown over 10-fold from 2004 to the end of 2014 [19].

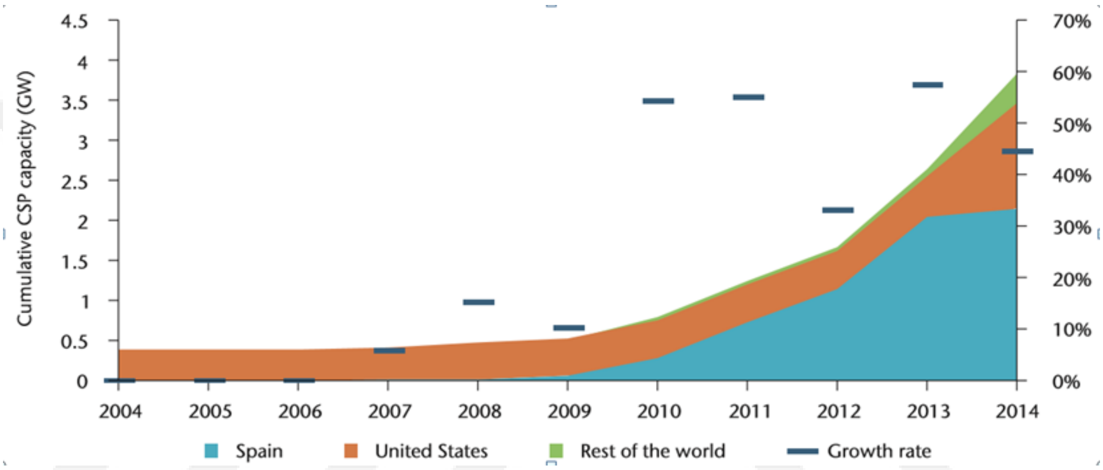


Figure 2.4 : Capacity of installed CSP growing from 2004 to the end of 2014.

Currently, CSP presents only a portion of the consumed total primary energy supply. There was 4.4 GW of installed CSP capacity around the world, as shown in Figure 2.5 The installed CSP capacity is about 0.07% of the world's installed power generation capacity [20], and approximately 40 times less than the installed capacity of PV, which was 177 GW at the end of 2014 [21]. The low point of CSP is mainly due to a gradual learning curve of using the technology [22], high costs of the technology and the current economic and financial crisis[23].

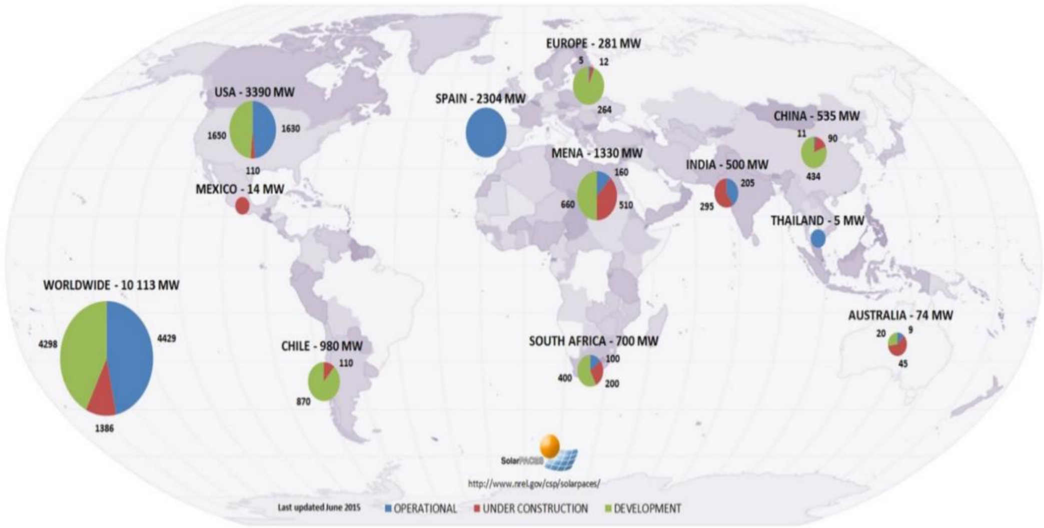


Figure 2.5 : Installed CSP capacity around the world.

In the second quarter of 2016,approximately 1.1 GWe of CSP has been contracted. Table 2.1 shows the share of CSP plant capacity under construction with the technology [24].

Table 2.1 : Share of CSP plant capacity under construction.

CSP technology	Share
Parabolic trough collector (PTC)	53%
Linear Fresnel Reflector (LFR)	0%
Solar Power Tower (SPT)	47%
Parabolic Dish Collector (PDC)	0%

2.1 Concentrated Solar Power projects around the world

Below are the important CSP projects classified according to technology. The tables shows power plant configuration data for the solar field, power block, and thermal energy storage for PTC, LFR and SPT. These projects are either operational, under construction, or under development. The United States of America has produced over 1800 MW of CSP plants [25]. There is no review of PDC because it does not use TES. Table 2.2 shows the percentage share of each technology installed from all CSPs around the world.

Table 2.2 : Share of CSP Installed Capacity per technology [26].

CSP technology	Share
Parabolic trough collector (PTC)	84%
Linear Fresnel Reflector (LFR)	4%
Solar Power Tower (SPT)	12%
Parabolic Dish Collector (PDC)	<1%

2.1.1 Parabolic Trough Collector (PTC) projects

There are (98) PTC projects around the world [25]. Table 2.3 shows the technical specifications of several projects of the largest in capacity and annual energy generation. Parabolic trough systems consist of curved mirrors along one dimension in a parabolic shape to focus the Sun’s rays onto a receiver tube that is mounted at the focal line of the parabola. In the receiver tube, a high-temperature heat transfer fluid (such as synthetic oil) absorbs the heat from the Sun’s radiation. The temperature of the fluid reaches 398°C or higher, and flows onto a heat exchanger to produce steam from heated water. The steam runs a conventional steam turbine to produce electricity. A typical solar collector field contains hundreds of parallel rows of troughs connected as a series of loops, which move in tandem with the Sun during the day as it crosses the sky from sunrise to sunset [9, 26].

Table 2.3 : Technical specifications of several projects of PTC around the world.

Country	Project name	Capacity MW	AEG MWh/year	Status	Cost $/million	STE h	Tariff $/MWh	Land area m^2
India	Godavari	50	118,000	2013	----	----	177	1,500,000
Spain	Andosol	50	175,000	2011	340	7.5	291	2,000,000
S. Africa	Bokpoort	50	230,000	2016	565	9.3 bf	----	1,000,000
India	Diwaker	100	----	2013	----	4	148	----
Spain	Enerstar	50	100,000	2013	----	----	291	2,140,000
USA	Genesis	250	580,000	2014	----	----	----	7,891,377
Spain	Ebersol	50	103,000	2009	216	----	----	1,500,000
S. Africa	Kaxu	100	330,000	2015	860	2.5	----	----
USA	Martin	75	155,000	2010	476	----	----	2,023,430
USA	Mojave	250	600,000	----	1,600	----	----	7,082,005
Morocco	Noor I	160	----	2015	795	3	162	----

2.1.2 Linear Fresnel Reflector projects (LFR) projects

There are 15 LFR projects around the world [27]. The highest capacity is 125 MW in India, four are 50-megawatt projects, four are1-megawatt projects and the remaining projects are 3, 5, 9, 14, 30, and 44 MW in one project. Table 2.4 shows the largest LFR plants. It approximates the principles of the curved mirror of trough systems by using long rows of flat mirrors of lower-cost. These modular reflectors concentrate the Sun's rays onto elevated receivers, which consist of tubes through which water or another fluid flows. The LFR is characterized as a simple design and it facilitates direct steam generation. The weakness of LFR in converting solar energy is that it is less efficient than another CSP technologies in addition to it being more difficult to mix storage capacities with it [28].

Table 2.4 :LFR projects around the world**.**

Country	Project name	Capacity MW	AEG MWh/year	Status	STE h	Tariff $/MWh	Land area m^2
India	Dhursar	125	280,000	2014	----	163	3,400,000
Australia	Kogan	44	44,000	----	----	----	300,000
Spain	Puerto 2	30	49,000	2012	0.5	289	700,000

2.1.3 Solar Power Tower (SPT) projects

There are 30 SPT projects around the world [29], and most of them are under construction. Table 2.5 shows their details. Power tower systems use a central receiver system which permits higher operating temperatures and thus maximum efficiency. Computer controlled heliostats (flat mirrors) track the Sun along two axes and concentrate solar direct radiation onto a receiver at the top of a high tower. The focused radiation is used to increase the temperature of a transfer fluid (to over 537.78°C) to produce steam and run a turbine in the power block and generate electricity. When using molten salt as an HTF, energy storage can be used for 24 hours [9].

Table 2.5 :SPT projects around the world.

Country	Project name	Capacity MW	AEP MWh/year	Status	Cost /million	STE h	Tariff $/MW h	Land area/m^2
USA	Crescent	110	500,000*	2015	$737	10	135	6,474,976
Spain	Gemasolar	19.9	80,000	2011	230 €	15	----	1,950,000
China	Golmud	200	1,120,000	2018	$778.029	15	----	25,000,000
China	Huanghe	135	628,448	2017	----	3.7	----	13,000,000
S. Africa	Khisolar one	50	180,000	2016	----	2	----	----
Morocco	Noor III	150	----	2017	----	8	142.7	----
S. Africa	Redstone	100	480,000	2018	----	12	124	----
China/	Sun Can	100	----	Un c	----	11	----	----
China	Supcon	50	120,000	Un c	----	6	108.4	3,300,000
China	yumen	100	----	Un c	----	10	----	----

2.2 The future of CSP

The International Energy Agency (IEA) is an international organization dealing in research, development and marketing of energy and its uses. The IEA expects cost reductions in CSP plants because of the advantage of being able to combine TES systems. This is leading to cost-competitive dispatchable renewable technology for countries in the Sunbelt. IEA presents three scenarios for the global electricity mix outlook by 2050 [30]. The first scenario, 6DS, which means the global mean temperature, will increase by 6°C and CSP projects will increase to 1% of the global electricity mix. The second scenario, 2DS, is the global mean temperature increasingby 2°C and CSP projects sharing 7% of the global electricity mix. The last scenario, hi-Ren, considers the 2^{o}C with a larger share of renewable energy in which the CSP will reach 11%. Figure 2.6 shows the three scenarios [31].

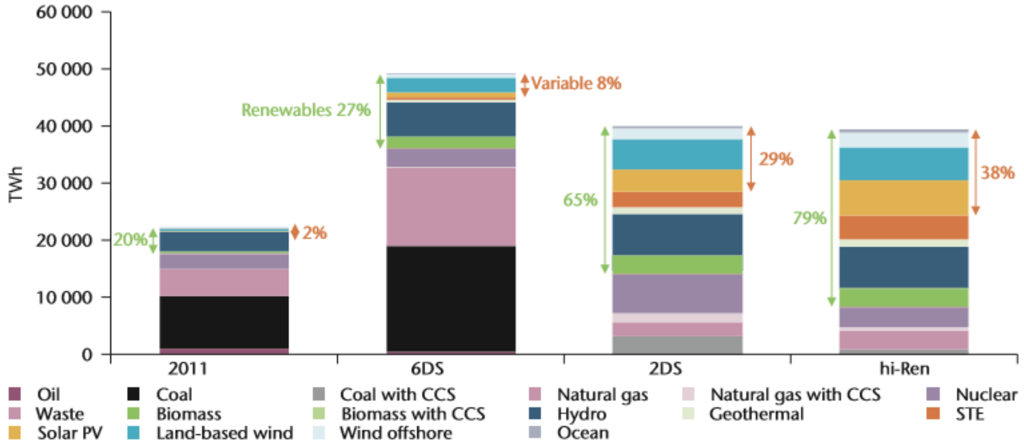


Figure 2.6 : Global electricity mix in 2011 and in 2050 in three IEA 2014 scenarios [25].

The IEA expects that CSP under the hi-Ren scenario capacity will be able to reach near to 230 GWe by 2030 and 980 GWe by 2050.While these numbers might seem too high, they are a clear index that CSP technology confirms a rapid increase in the coming years, even when considering that only one-tenth of such targets are reached (230 GWe and 980 GWe by 2030 and 2050, respectively) [32]. Another side focused on by the IEA is that CSP is predicted to play an important role in markets such as the Middle East, Africa and the USA. Figure 2.7 shows the projected generations mix by technology and region under the IEA's hi-Ren scenario. Specifically, in terms of annual generation, IEA's hi-Ren scenario expects that CSP will act as the largest source of electricity in Africa and in the Middle Eastern countries [31].

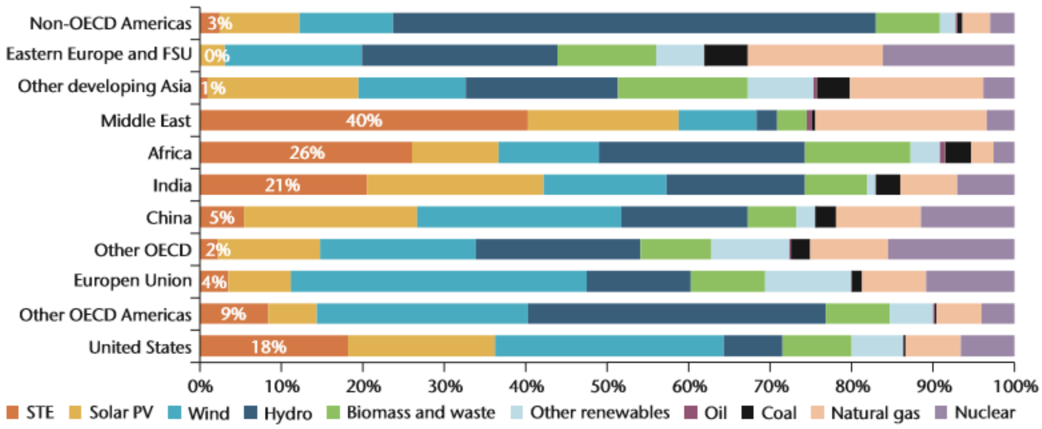


Figure 2.7 : Generation mix by 2050 in the hi-Ren Scenario by region [25].

The International Renewable Energy Agency (IRENA) is an intergovernmental organization that supports countries in their transition to a sustainable energy future.

Another perspective of a CSP future, in a study titled the REmap 2030 published in 2014, suggests a roadmap to double the share of renewables by up to 36% by 2030 [33]. One of the key findings from such a study can be seen in Figure 2.8, which compares the total cumulative installed renewable capacity by the end of 2013 (left) to the projections of the REmap 2030 scenario (right). Concerning CSP, one of the key findings from the study is that it is projected to show the fastest growth rate among all technologies in terms of cumulative capacity. Specifically, IRENA's estimates suggest that CSP capacity will increase up to 83 GWe by 2030. The study highlights that a key reason for this is the ability to integrate low-cost TES in order to provide dispatchable electricity to the grid and to capture peak market prices. The study also highlights that with the technology being in its infancy by the end of 2014, in terms of deployment, the potential for cost reduction is vast and that CSP with TES seem to become the most competitive [33].

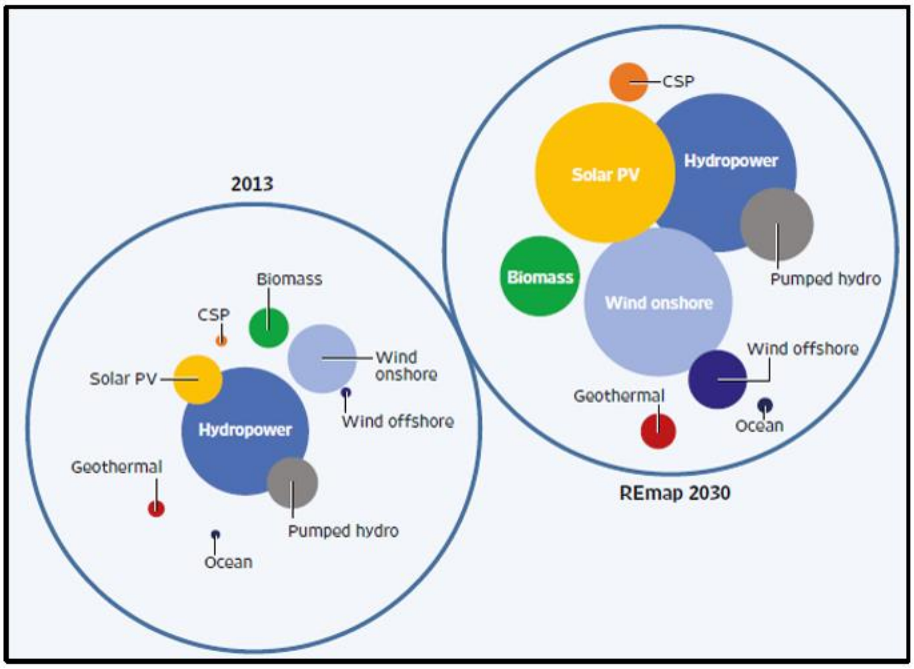


Figure 2.8 : Total cumulative installed renewable capacity by 2013 and in RE map 2030.

Other studies of organizations in support of CSP expansion tend to show even more optimistic scenarios. In their 2016 outlook, the European Solar Thermal Electricity Association (ESTELA) and Solar PACES (power and chemical energy systems) estimate that CSP will reach the milestone of 11 GWe of installed capacity by 2020 to supply 0.1% of the world's annual electricity demands. Furthermore, they predict that under current development trends, CSP will produce 21 GWe in the year 2030 and 42 GWe in the year 2050. Moreover, in their moderate scenario, they project that CSP will reach 22 GWe in 2020, 131 GWein2030 and 781 GWe in 2050 of installed capacity. Their projections are even more aggressive in their ‘advanced’ scenario, where the world’s total fleet of CSP capacity is expected to reach 1600 GWe by 2050 [34].

2.3 Comparison of CSP technologies

2.3.1 Technical comparison

In terms of the land needed on which to construct the CSP plant, PTC and LFR require less land than SPT [35]. Water requirements are very important for the location of CSP plants. As in other thermal power plants, CSP requires water for cooling, cleaning and condensing processes. The need for water is relatively high: for example, approximately 3000 L/MWh for PTC and LFR plants (similar to a nuclear reactor) compared to approximately 2000 L/MWh for a coal-fired power plant and only 800 L/MWh for a combined-cycle natural gas power plant. SPT plants need less water than PTC (which require 1500 L/MWh) [36].

When dry cooling systems are used on PTC plants existing in hot deserts, the decrease of annual energy production is 7%, and the increase in the cost of the produced electricity is approximately 10% [47]. However, dry cooling systems on SPT plants decrease the efficiency and will have lower efficiency than PTC. The installation of hybrid water and dry cooling systems reduces water consumption while reducing the performance penalty. As water cooling is more effective, operators of hybrid systems use only dry cooling in the winter when cooling needs are lower; during the summer, they then switch to collective wet and dry cooling. Increasing the concentrating ratio of the Sun can increase the possibility of reaching higher active temperatures and the best thermodynamic efficiencies. On SPT collectors, it can reflect the large amount of radiation focused on a single receiver (200-1000 kW/m^2) and reduce heat losses, thereby simplifying heat transport and minimizing costs [37].

In terms of the future of the technology, SPT shows hopeful advances with a version of a heat transfer fluid being developed that achieves high temperature to progress power cycle efficiencies. Moreover, higher efficiencies decrease the consumption of cooling water, and higher temperatures can reduce TES costs. Additionally, in SPT plants, the entire piping system is fixed in the focal area of the plant, which minimizes the size of the piping system, thereby reducing energy losses, material costs and maintenance [36,38]. SPT with molten salt technology may be better than the PTC plants.

2.3.2 Financial comparison

Commercial CSP technologies, (PTC) plants are the most used of all commercially operating plant [39]. SPT and PDC are now more expensive. In terms of cost related to plant development, SPT improvements will change levelized costs of energy, as offered by Sandia National Laboratories (SNL) and by the Sargent & Lundy Consulting Group (S&L). SPT will be the lower cost CSP technology in 2020. Table 2.6 shows comparisons between the technologies on the basis of different parameters such as relative cost, land occupancy, cooling water, thermo-dynamic efficiency, operating temperature range, solar concentration ratio and outlook for improvement [40].

Table 2.6: Comparison between leading CSP technologies [40].

Type	**Relati-ve cost**	**Land occupancy**	**Cooling water (L/MWh)**	**Thermo-dynamic efficiency**	**Operating T range (˚C)**	**Solar concentration ratio**	**Outlook for improvement**
PTC	Low	Medium	3000 or dry	Low	20-400	15-45	Limited
LFR	Very low	Medium	3000 or dry	Low	50-300	10-40	Significant
SPT	high	large	1500 or dry	High	300-565	150-1500	Very significant

2.4 Instrument software for technical and financial evaluation

2.4.1 SAM

To date, there exist several simulation software packages commercially accessible to assess the performances of CSP stations. The most commonly used software packages are mentioned below, including key advantages and considerations. First, and the most common tool for the pre-design of CSP plants is the System Advisor Model (SAM) from the US-based National Renewable Energy Laboratory (NREL). This tool incorporates financial and active hourly simulations of CSP plants and numerous other renewable energy technologies. The key preferred standpoint of SAM is that it is made freely accessible on the Internet and records an extremely point by point control of plant cost . Another important advantage is its integrated graphical user interface, which makes it very easy to use. Additionally, SAM coordinates an affectability investigation tool kit and simultaneously performs affectability while considering numerous outline parameters [41].

2.4.2 RETScreen

Another tool used for the analysis of CSP plants is the Green Energy System Analyses Tool (RETScreen) developed by the Clean Energy Solutions Center in partnership with Canmet Energy (Government of Canada)).The RETScreen Clean Energy Management Software is the world’s leading clean energy decision-making software. It is provided completely free-of-charge by the Government of Canada as part of Canada’s recognition of the need to take an integrated approach in addressing climate change and in reducing pollution. RETScreen is a proven enabler of clean energy projects worldwide and allows decision-makers and professionals to determine whether or not a proposed renewable energy, energy efficiency, or cogeneration project makes financial sense. Moreover, it evaluates the performance of the project. If a project is viable – or if it is not – RETScreen will assist the decision-maker to understand this quickly in a user-friendly format, and at relatively minimal cost [42].

2.5 Iraq in the map of CSP Plants

In all that has been mentioned about one of the oldest CSP stations and with the evolution of the stations and the future of CSP in the world, Iraq is not found in any place in the map of CSP projects [43]. Figure 2.9 shows all the countries in the MENA concentrated plants area, or future plans for the production of electricity from solar energy.

Figure 2.9 :CSP projects in the countries around Iraq [44].

2.6 Solar in Iraq

In this study, the site in Baghdad is chosen, which received >3000 hours per year of solar radiation. Hourly Sun-oriented power differs between 4,836 MJ/m^2 in January and 9,686 MJ/m^2 in June. Many studies have been conducted to determine the amount of solar radiation in Iraq, especially in Baghdad. The beginning of these studies was practical, and the theoretical studies were about the solar heaters and domestic concerns, which were solar-powered [45]. Experimental examinations of Trombe dividers have affirmed the capability of Sun-based vitality in the winter in Iraq [46]. Data concerning the practicality of the solar energy based radiation are pivotal for illuminating the monetary case for sunlight based vitality innovations. Figure 2.10 shows a yearly and monthly solar radiation map for the radiation periods of stations throughout the Iraqi territories. It is important to gather these data in all areas to evaluate fully the potential advantages of solar energy [47]. In the past decade, solar panels have been used for street lighting in Iraq; however, this did not succeed due to the dust which lowered the efficiency of the street lighting.

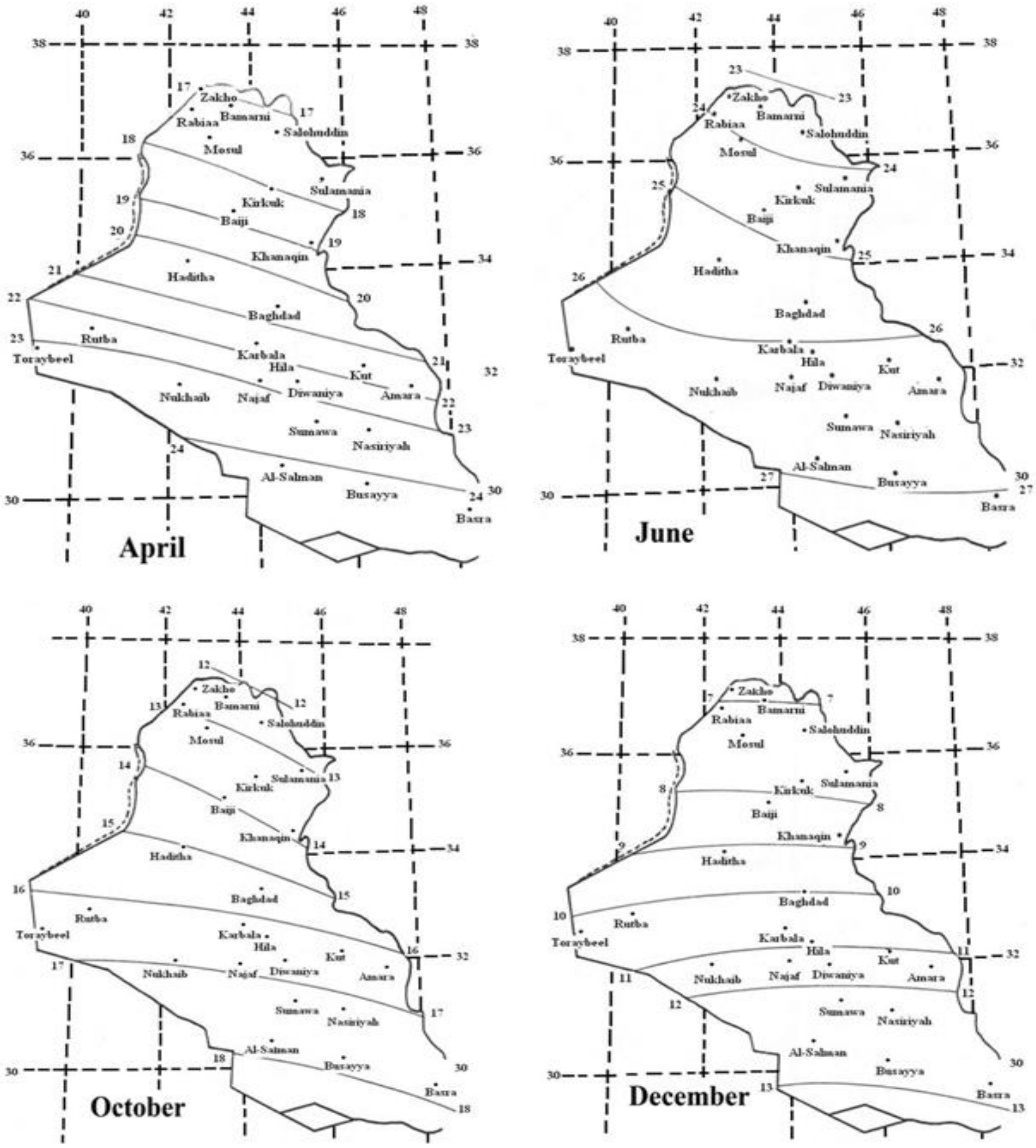


Figure 2.10 : Solar radiation lines for other months in Iraq.

These factors minimize the range of uses for PV cells although they did find limited application in individual home rooftop systems, community water-pumping stations, and areas where the terrain makes power grid access difficult [48]. The characteristics of solar radiation in Iraq are summarized as follows:

- In the northern regions, the yearly changes differed by approximately 300%,shifting from 7 MJ/m^2 in December and January to 23 MJ/m^2 in June. In the southern regions, the yearly changes differed by around 200%,shifting from 13 MJ/m^2 in December and January to 27 MJ/m^2 in June and July. In the focal regions, the yearly changes shifted by roughly 250% and can be considered to be normal yearly changes between the northern and southern regions.

- Solar radiation plummets from north to south and declines in the winter and in increments in summer. There is considerably more uniform appropriation of Sun-based radiation through every region in Iraqi during the summer (from June to August).
- Solar radiation appraisal depends on relationships derived from data that were measured by meteorology stations in cities and large towns. These locations receive less radiation than the surrounding areas due to pollution, thus the actual levels of radiation are higher than the measured value.

2.7 The opportunities, inevitable and challenges uses of renewable energy

2.7.1 The opportunities

Opportunities are now available to Iraq to progress in the use of solar energy in electricity production. These opportunities are materialized as follows:

- Iraq's location between latitudes (20-40º) where solar radiation is concentrated
- Iraq's financial resources from the export of oil
- Electrical energy production costs from the Sun costs tending to fall
- Changes in the direction of the interests of large companies regarding the establishment of traditional stations around solar plants
- There being large areas of land helping to establish solar power plants that require vast tracts of land
- The presence of water sources being very important in solar power stations, which are used in the cooling and cleaning of solar panels

2.7.2 The inevitable

There are two main reasons to push for the inevitable trend in renewable energy sources as well as push for opportunities for Iraq to use solar energy in particular.

- Future national income can increase because any electricity produced by solar power stations will allow Iraq's crude oil to be exported for extra income rather than being burned for electricity production in thermal power plants..
- The international community has begun an orderly retreat from the many uses of oil in the remaining decades of this century.

- There are three reasons for this thinking: the risk, size, and scope[49].

2.7.3 The challenges of using solar energy

There are numerous limitations and difficulties encountered in the use of CSP plants in Iraq. The lack of solid political support has remained aloof from CSP improvement in Iraq, with the exception of the as yet existing sponsorship framework for fossil power. Some of the main barriers are listed below [50]:

2.7.3.1 Financial and economic challenges

- High initial investment costs
- State support for traditional sources of energy (gas and electricity)
- Lack of financing mechanisms that encourage investment in renewable energy as compared to other countries

2.7.3.2 Institutional challenges

The implementation of renewable energy projects of technical assistance for the preparation of the project is required, in addition to providing support to rely on any appropriate regulatory frameworks. Moreover, should these regulatory frameworks be decisive, studies to attract investment in the renewable energy sector would be necessary.

2.7.3.3 Technical challenges

The effect of dust and dirt on solar energy devices, where ongoing research on this subject has demonstrated that more than 50% of the solar energy effectively is lost if the dust and dirt are not cleaned from receiving devices for a month.

Storage of solar energy and making use of it during the night or on cloudy days; solar energy storage depends on the nature and amount of solar energy.

Other challenges:-

- Lack of information campaigns directed at publicizing the importance of the use of solar energy
- Political challenges: The present circumstance of Iraq experiencing political instability and progressive developments toward a majority-rule system are the fundamental obstructions to renewable energy usage.
- Social and cultural challenges: Social improvements and advancing mindfulness toward renewable energy is not very high in terms of the end goals to accomplish social acknowledgment in Iraq.

CHAPTER THREE

TECHNICAL EVALUATION

This chapter contains the technical evaluation which will provide us with the methodology of selecting the location of a power plant, the technical specifications of the three types of CSP and the software that will be used. Moreover, the annual energy production, the total area required for each kind of plant and greenhouse gases GHG reduction emissions will be calculated for each type under the various thermal energy storages.

3.1 Software

The United States National Renewable Energy Laboratory NREL has a System Advisor Model (SAM) which was utilized as a starting point for this thesis. Data were used as the input into the SAM, which included costs, materials, capacities and other useful parameters. SAM will be used to determine the capacity factors, annual energy produced and total area of the plants for the three kinds of concentrating solar power plants, namely the parabolic trough collector (PTC), the solar power tower (SPT), and the linear Fresnel reflector (LFR). The results were evaluated on a technical basis.

3.2 Data Sources of solar irradiance

The location of Iraq in the region latitude (20^o-40^o)North -South called Sun-Belt area. Available insolation data uses a map of Direct Normal Irradiation (DNI), temperature and wind velocity. More climate parameters for the selected locations of concentrated solar power plants in Iraq are taken from the SWERA Report and NASA Data. Figure 3.1 shows the solar map of Iraq.

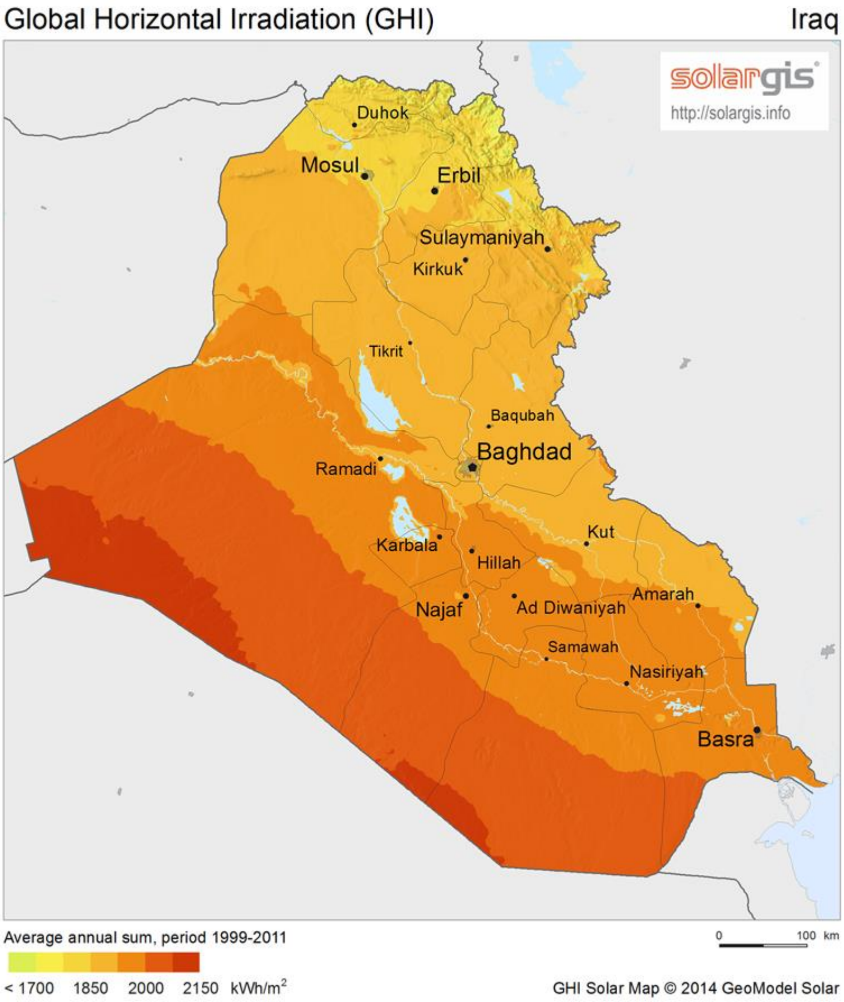


Figure 3.1 : The solar mapof Iraq [51].

The radiation and diffuse data for Baghdad site were obtained based on personal contact.

3.3 Location selection

The selection of locations for the CSP plant was carried out considering several parameters such as solar irradiation, the presence of water, grid accessibility, transports routs, distance to consumption centers and topography. Figure 3.2 shows the amount of radiation for the four locations in the middle and north of Iraq (Baghdad, Haditha, Samawah, and Najaf) for one year. From this figure, it can be observed that the levels of solar radiation in middle and north of Iraq is very convergent. As for the other criteria (grid accessibility, roads, ..etc), Baghdad is the first. This reason gives motivation to choose Baghdad to construct the first power plant.

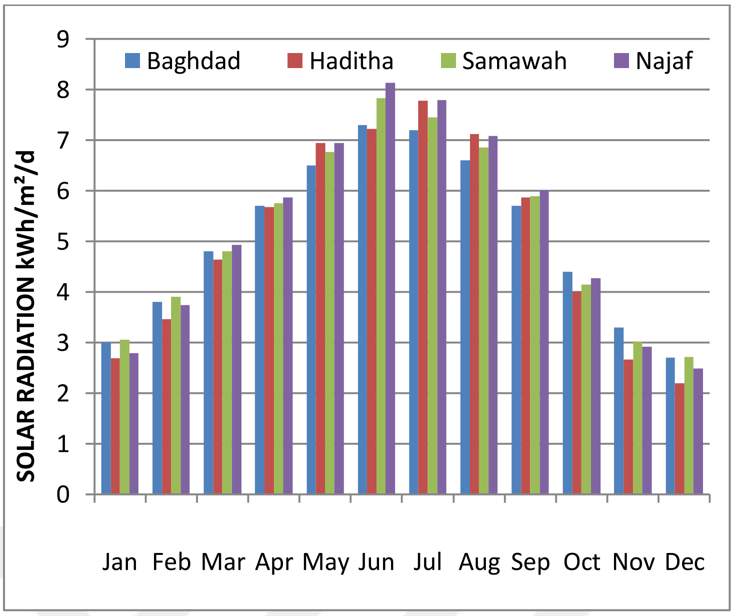


Figure 3.2 : Solar radiation for four locations in the middle and south of Iraq.

Table3.1 shows the amount of radiation for four locations in Iraq (data from NASA)

Table 3.1 : Solar radiation for four sites in Iraq(kWh/m²/d).

	Haditha	**Baghdad**	**Samawah**	**Najaf**
Jan	2.69	3.	3.06	2.79
Feb	3.46	3.8	3.9	3.74
Mar	4.64	4.8	4.8	4.93
Apr	5.68	5.7	5.75	5.87
May	6.95	6.5	6.77	6.94
Jun	7.22	7.3	7.83	8.13
Jul	7.78	7.2	7.45	7.79
Aug	7.12	6.6	6.85	7.09
Sep	5.87	5.7	5.89	6.01
Oct	4	4.4	4.14	4.27
Nov	2.66	3.3	3.02	2.92
Dec	219	2.7	2.71	2.49

3.4 Greenhouse Gases Emission Reduction Analysis

The annual GHG emissions reductions will be calculated and compared with GHGs produced by conventional power stations. Results are offered in terms of the tons of carbon dioxide per year that would be equivalent to the emissions reduction.

Methane CH4 and nitrous N2O oxide emissions are turned into the equivalent carbon dioxide emissions in terms of their global warming potential.
The reduction ΔGHG is calculated as follows(RETScreen International, 2004)[52]:

$$\Delta_{GHG} = (e_{base} - e_{prop})E_{prop}(1 - \lambda_{prop})(1 - e_{cr})$$

where $e_{base}$is the base case GHG emission factor, $e_{prop}$is the proposed case GHG emission factor, $E_{prop}$is the proposed case annual electricity produced, Base and for the suggested use of all types of fossil fuels in Iraq (natural gas, crude oil, diesel and heavy oil) as a reference case,$\lambda\ prop$ is the fraction of electricity lost in transmission and distribution (T&D) for the proposed case, and e_{cr} the GHG emission reduction credit transaction fee.

3.5 Technical specification:

3.5.1 Parabolic trough collector (PTC)

- Collector: solar Genix SGX-1
- Receivers: heat collection elements (HCEs) /2008Schott PTR 70 vacuum.
- Power block: NEXANT 500C HTF
- Thermal storage: molten salt
- Parasitic: SEGS V111 reference

3.5.2 Linear Fresnel reflector (LFR)

- Heat transfer fluid: Molten salt
- Receiver model type: Evacuated tube model
- Absorber flow pattern: Tube flow
- Absorber material type: 216L

3.5.3 Solar power tower (SPT)

- HTF: 60% Na No3 40% KNo3
- Receiver height: 21.7812 m
- Receiver diameter: 18.5107 m
- Tower height: 192.409 m

- Heliostat count: 8322
- Heliostat: Abengoa company ASUP 140i

3.6 Annual Energy Production

Table 3.2 illustrates the annual production of three kinds of CSP with different TES (0, 3, and 9 hours). From the table, it can be observed that SPT has the highest production for all hours of TES. The C_f of SPT increases significantly at multiples of TES of approximately 10%. Figure 3.3 and table 3.2 show the production of CSP technologies for different hours of TES. Table 3.3 shows the percentage of AEP increase from 0h to 3h and from 3h to 9h.

Table 3.2 : Annual energy production with different TES**.**

Types	**Storage 0 h**		**Storage 3 h**		**Storage 9 h**	
	C_f (%)	**AEP MWh**	**C_f (%)**	**AEP MWh**	**C_f (%)**	**AEP MWh**
PTC	29	251.1	30.8	266.7	31.5	273.53
LFR	25.6	221.6	29.6	256.7	30.3	263
SPT	30.3	262.7	40.9	354.9	47.1	408.4

Table 3.3 : Percentage of AEP increase versus storage hours.

Types	**Increase of AEP from 0h to 3h (%)**	**Increase of AEP from 3h to 9h (%)**
PTC	6.2	2.56
LFR	15	2.45
SPT	35	15

- For parabolic trough collector (PTC)

The electricity exported to the grid is 251.1 MWh with a capacity factor of 29% at storage 0 h. The increase in annual energy production versus storage hours is low. The annual energy production increases at an average of 4% as the storage hours increase.

- For Linear Fresnel Reflector (LFR)

When using 3 h storage with LFR, the annual electricity production increases from 221.6 MWh to 256.8 MWh, which is a great increase. However, when using 9 h storage, the percentage increase is 2%, which is not as great an increase as is 0 h to 3 h storage. This means that storage of over 3 h will not impact the production of the plants.

- Solar power tower (SPT)

The electricity exported to the grid per year without TES is the highest by using SPT technology reaching 262.7 MWh with a capacity factor of 30.3% at storage (0 h).The production for 9 h storage increases to approximately 55%, reaching 408.4 MWh with a capacity factor of 47.1%.

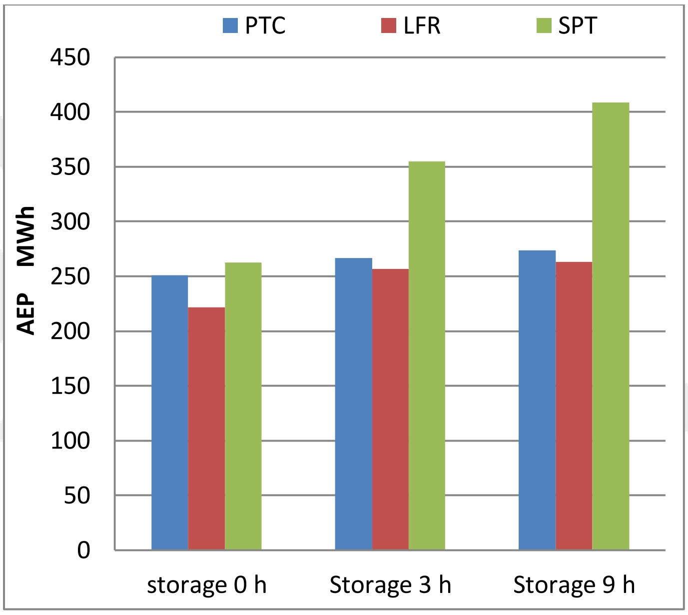


Figure 3.3 **:**Comparison of annual electricity production with different storages.

3.7 Greenhouse gases Emission for all types of Baghdad sites

The annual reduction of GHG depends on annual energy production. LFR has lower production, then GHG reduction is 222,257 tCO_2 at 0 h. SPT has the highest annual production and GHG reduction is 409,725 tCO_2 at 9 h. Figure 3.4 shows the higher and lower GHG reductions.

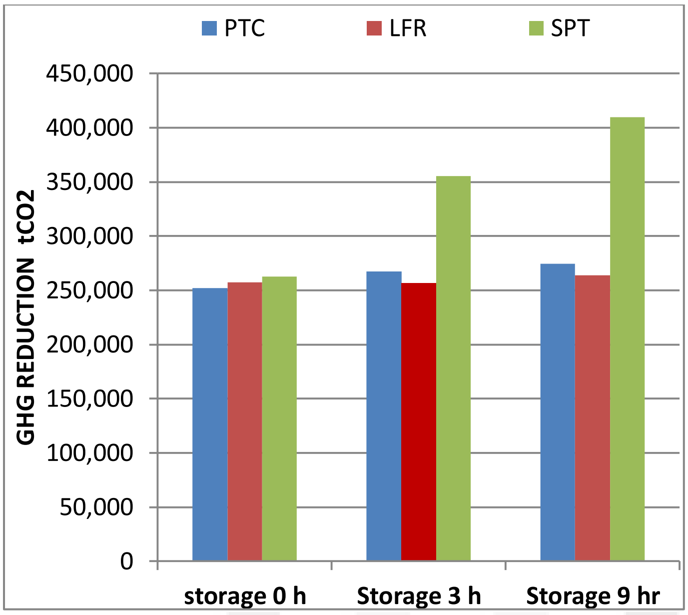


Figure 3.4 : Higher and lower GHG reduction for three kinds of CSP.

Table 3.4 shows the GHG reduction for PTC, LFR and SPT. The GHG reduction calculation is carried out by the RETScreen software and the equivalent tCO_2 by cars and light trucks not used or barrels of oil or other.

Table 3.4 :GHG reduction of tCO2 of all types of CSP and with equivalents.

Types	Storage 0 h		Storage 3 h		Storage 9 h	
	Net annual GHG reduction tCO_2	**Equivalent to cars and light trucks not used**	**Net annual GHG reduction tCO_2**	**Equivalent to cars and light trucks not used**	**Net annual GHG reduction tCO_2**	**Equivalent to cars and light trucks not used**
PTC	252,213	46,193	267,674	49,025	274,439	50,264
LFR	222,257	40,706	257,045	47,078	263,809	48,317
SPT	262,843	48,140	355,611	65,130	409,725	75,041

3.8 Plant design

From the SAM software (the Solar Field page), the occupied area for power stations of all types at the Baghdad site is calculated. The solar power tower (SPT) requires the largest area of 7 km^2while the linear Fresnel reflector (LFR) requires the smallest area of 1.8 $km^2$and the parabolic trough collector (PTC)requires an area of 3.3 km^2.Figure 3.5 shows the areas needed for each type of CSP plant.

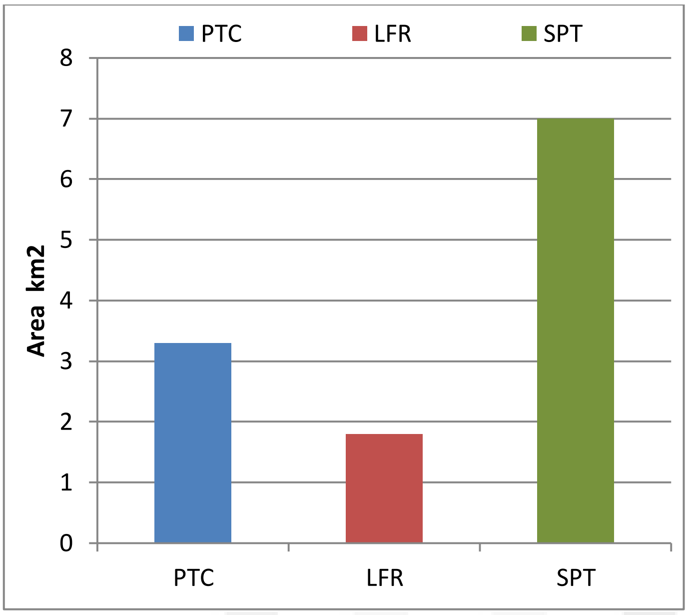


Figure 3.5 : Distribution areas for kinds of CSP.

CHAPTER FOUR

FINANCIAL EVALUATION

This chapter presents the approach of the plan to evaluate the financial analysis of this thesis. It shows two scenarios for this study, why this software is used and how the data are acquired. It contains four main parts: explanations of the scenarios, the cost evaluations of three kinds of CSP, evaluations of the three indicators of profit(financial indicators) with tariff through the impact of different grants and evaluating them with tariffs showing the impact on the GHG reduction income.

4.1 Approach of the scenarios

In this study, two scenarios were adopted to evaluate the three financial indicators with tariff showing the impact of the different grants and different GHG reduction incomes.

- **Scenario 1:** This scenario is divided into three parts according to hours of thermal energy storage TES(0 h, 3 h, 9 h), followed by presenting different grants(capital injection)for the project and without any other income (such as GHG reduction income). The influence of the change of grants is observed on the simple payback, net present value and annual life cycle savings and financial analyses and charts are produced.
- **Scenario 2:** In this scenario, grants or any sum of money are cut and the initial capital cost of a project is only produced from the money coming from GHG reduction. The GHG reduction income is a global system award for renewable projects which reduce CO_2 (dollars for each ton of carbon dioxide). In this scenario, the GHG reduction will use \$10/tCO_2 and \$30/tCO_2,this value chosen according to P. Luckow et al [53], and the impact of this award on the simple payback SPB, net present value NPV and annual life cycle saving ALCS is presented.

4.2 Financial Indicators

4.2.1 Simple payback period SPB

The SPB is the time needed to recoup all the money invested in the project through the revenue expected from the project. Moreover, it calculates the time period for the cash inflow to equal the capital cost. It is clear that the fewer the number of years for payback is better than a longer payback period in order to recoup the money invested in the project. In this study, our preference is 35 years (project life). One criticism of the payback period is that it does not account properly for the time value of money, risk or other important considerations, such as the opportunity cost.

The equation used to calculate the SPB is[52] :

$$SPB = \frac{C - IG}{\left(C_{ener} + C_{capa} + C_{re} + C_{GHG}\right) - (C_{O\&M} + C_{fuel})}$$

SPB = simple payback

C = capital initial cost of the project

IG = grants

C_{ener} = annual energy savings of income

C_{capa} = annual capacity savings or income

C_{RE} = annual renewable energy (RE) production credit income

C_{GHG} = GHG reduction income

$C_{O\&M}$ = yearly operation and maintenance costs

C_{fuel} = annual cost of fuel or electricity

4.2.2 Net Present Value NPV

Net present value (NPV) is one tool used to evaluate investment projects. This depends on when the project is assessed and achieves cash flow increase of the capital cost. In other words, it is the difference between the capital cost and the present value for net cash flow expected for the project. Net cash flow is the difference between cash inflow and cash outflow.

The equation used to calculate the NPV is [52]:

$$NPV = -C + \sum_{n=1}^{N} \frac{C_n}{(1+i)^n}$$

where

C = capital initial cost of the project

C_n = net cash flow for each period of the project

i = the discount rate (The return that could be earned per unit of time on an investment with similar risk.)

n = the time of cash flow

The rule used in the NPV is such that the NPV must be positive for the project to be acceptable. As NPV increases, the feasibility of the project increases too. This represents an advantage in the return of a company that invests in the project.

4.2.3 Annual Life Cycle Saving ALCS

RETScreen calculates the ALCS which are the levelized nominal yearly savings having exactly the same life and net present value as the project. The annual life cycle savings are calculated using the NPV, the discount rate and the project life.

$$ALCS = \frac{NPV}{\frac{1}{i}\left[1 - \frac{1}{(1+i)^N}\right]}$$

4.3 Tariff

An electricity tariff is a schedule of fees or prices that relate to the reception of electricity from a particular supplier. Sometimes tariff is known simply as electricity pricing. The construction of this type of schedule will vary from one country to another. In this study, the target tariff as \$80/MWh and different tariffs that achieve the best results for Financial Indicators are considered.

4.4 Initial capital cost

It was awarded the initial value of the projects from the SAM program and for the various thermal energy storages (TES), in which those values are closer to reality by comparing them with the newly executed projects. The initial cost is very important to calculate the financial indicators

4.5 Financial Evaluation

The RETScreen software was used to evaluate financial indicators. The discussed indicators of profit are applied to each scenario mentioned previously. The following procedures will be implemented:

1- Support the project with cash lump-sum grants and make GHG reduction income equal to zero for different tariffs.

2- Keep track of every result down to the best financial indicators.

3- Give the project GHG reduction income for each ton of carbon dioxide for 20 years of the life of the project without using any grant.

4.6 Cost evaluation

Table 4.1 and Figure 4.1 show the initial costs of the main kinds of CSP with different TES (0 h, 3 h, and 9 h). For TES (0 h), the PTC is less expensive than other types $487.5MM compared to SPT, which is equal to $648MM and is still the cheapest at TES (3 h) at a price of $569.2MM. At TES (9 h), the LFR is less expensive than other types $700.7MM compared to SPT.

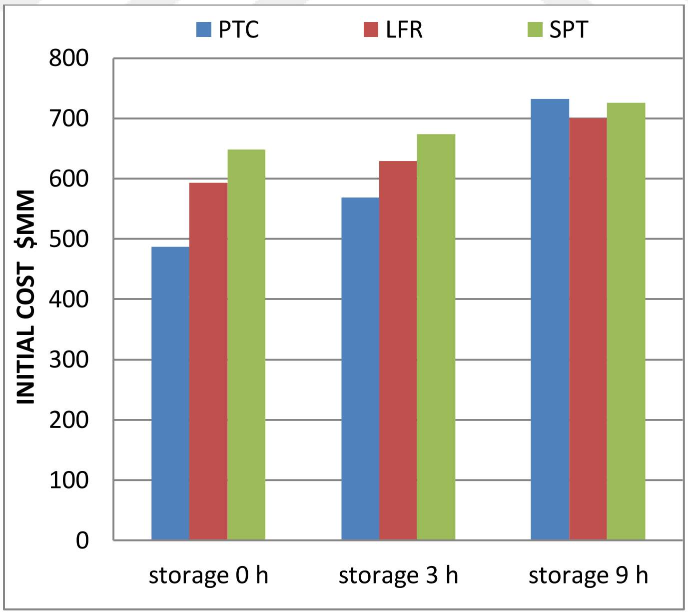


Figure 4.1 : Initial cost of CSP projects for different TES.

Table 4.1 : Initial capital costs for different CSP projects and different TES.

Types	**Initial Cost ($MM)**		
	Storage (0 h)	**Storage (3 h)**	**Storage (9 h)**
PTC	487.5	569.2	732
LFR	593.3	629.2	700.8
SPT	648	674.4	726 .9

4.7 Scenario 1:Financial Evaluation with grants and without GHG income for different TES

Grants are capital subsidies which are granted to the project to reduce the initial capital cost and hence to support the profitability and financial feasibility of a CSP plant. In this study the grants take to the different TES is constant:

Grant 1 = $0 for the 110 MW project and 0,3,9 h TES.

Grant 2 =$200MM for the 110 MW project and 0,3,9 h TES.

Grant 3 =$400MM for the 110 MW project and 0,3,9 h TES

4.7.1 With storage (0 h) for all types

- **Impact of grants on simple payback under different tariff condition**

For Parabolic Trough Collector (PTC), a target tariff ($80/MWh) at grant 1 gave an SPB of 40 years; at grant 2, it gave 25 years; and at a grant 3, it gave a SPB of under 10 years.

Table 4.2 illustrates the impact of grants on SPB under different tariffs for the studied CSP.

Table 4.2 : Impact of grants on the simple payback under different tariff conditions.

TARIFF $/MWh	SPB yrs.								
	PTC /without storage			LFR/without storage			SPT/without storage		
	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3
50	87.5	51.6	15.7	145	96.4	47.4	106.1	73.4	40.6
80	40	25	6.6	60	40	20	56	40	22
130	19	11.2	3.4	27.2	18	8.9	23.9	16.5	9.2
170	13.6	8	2.4	19.3	12.8	6.3	17.3	11.9	6.6
210	10.6	6.3	1.9	15	10	4.9	13.5	9.3	5.2
250	8.9	5.1	1.6	12	8.1	4	11.1	7.7	4.2
300	7.1	4.2	1.3	9.1	6.6	3.3	7.6	6.3	3.5

For linear Fresnel Reflector**,** in this kind at grant 1 and target tariff gave a SPB of 60 years, grant 2 gave 40 years and grant 3 gave 20 years. For Solar Power Tower (SPT), this technology at the target tariff giving the SPB for all grants is 56, 40, and 22 years, respectively. For grant 1 and grant 2 the SPB is not attractive then increases the tariff to obtain the best SPB. The results of Table 4.2 are plotted in Figures 4.2.

Table 4.3 shows the minimum tariff which is required to achieve SPB under 35 years for all types of CSP.

Table 4.3 : The best tariff give SPB below 35 years under different grants and TES 0h.

Types	**Minimum Tariff ($/MWh)**		
	Grant 1	**Grant 2**	**Grant 3**
PTC	90	70	Below 50
LFR	130	85	60
SPT	100	85	60

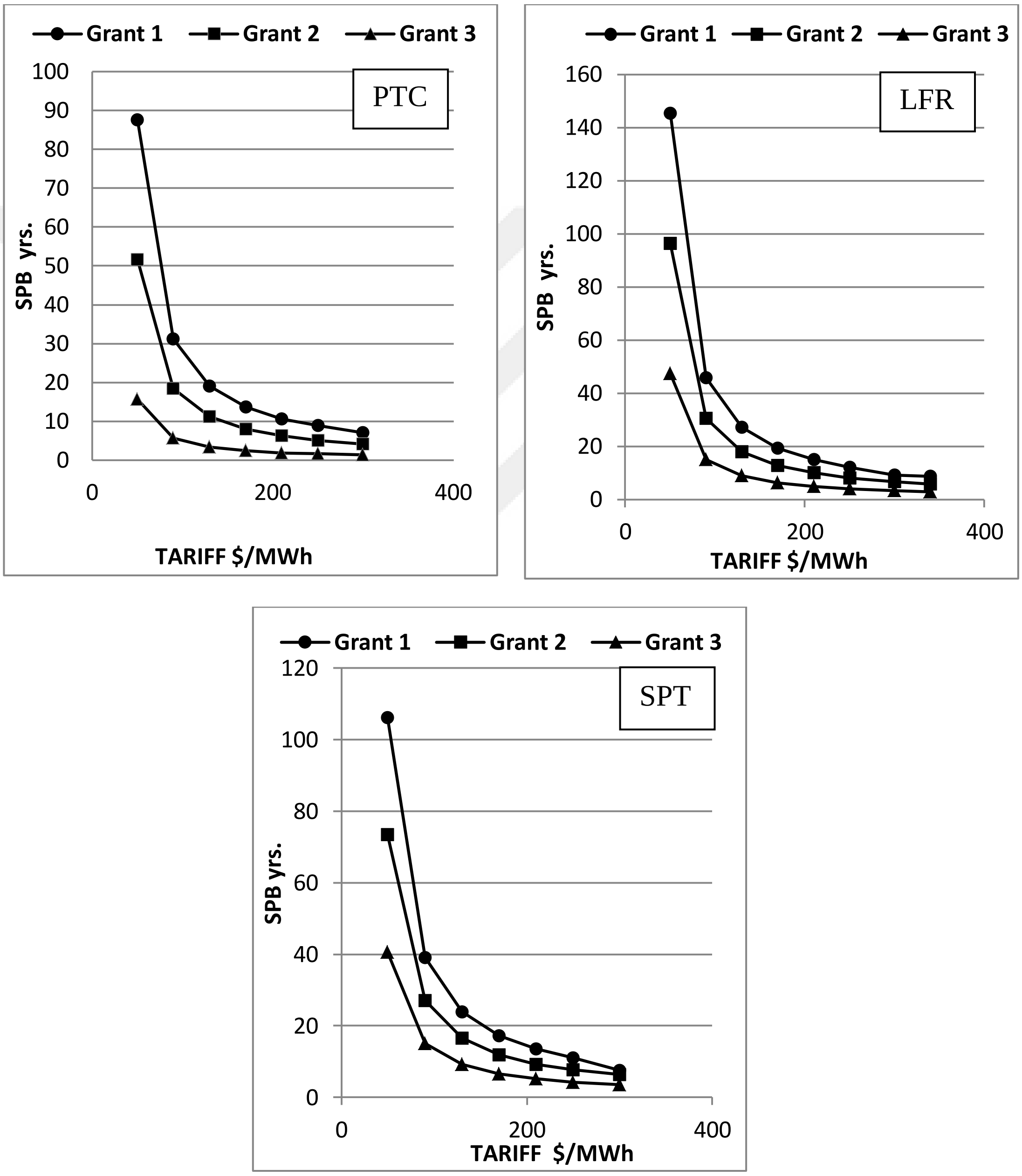


Figure 4.2 : Impact of grants on SPB for the different types under storage of 0h.

- **Impact of grants on Net Present Value under different tariff condition**

For PTC, the attractive positive NPV of the project at a grant 1 is for a tariff of $240/MWh, and at grant 2, the tariff is $160/MWh. At a grant 3, the tariff is $75/MWh. Figure 4.3 (PTC)show that**.**

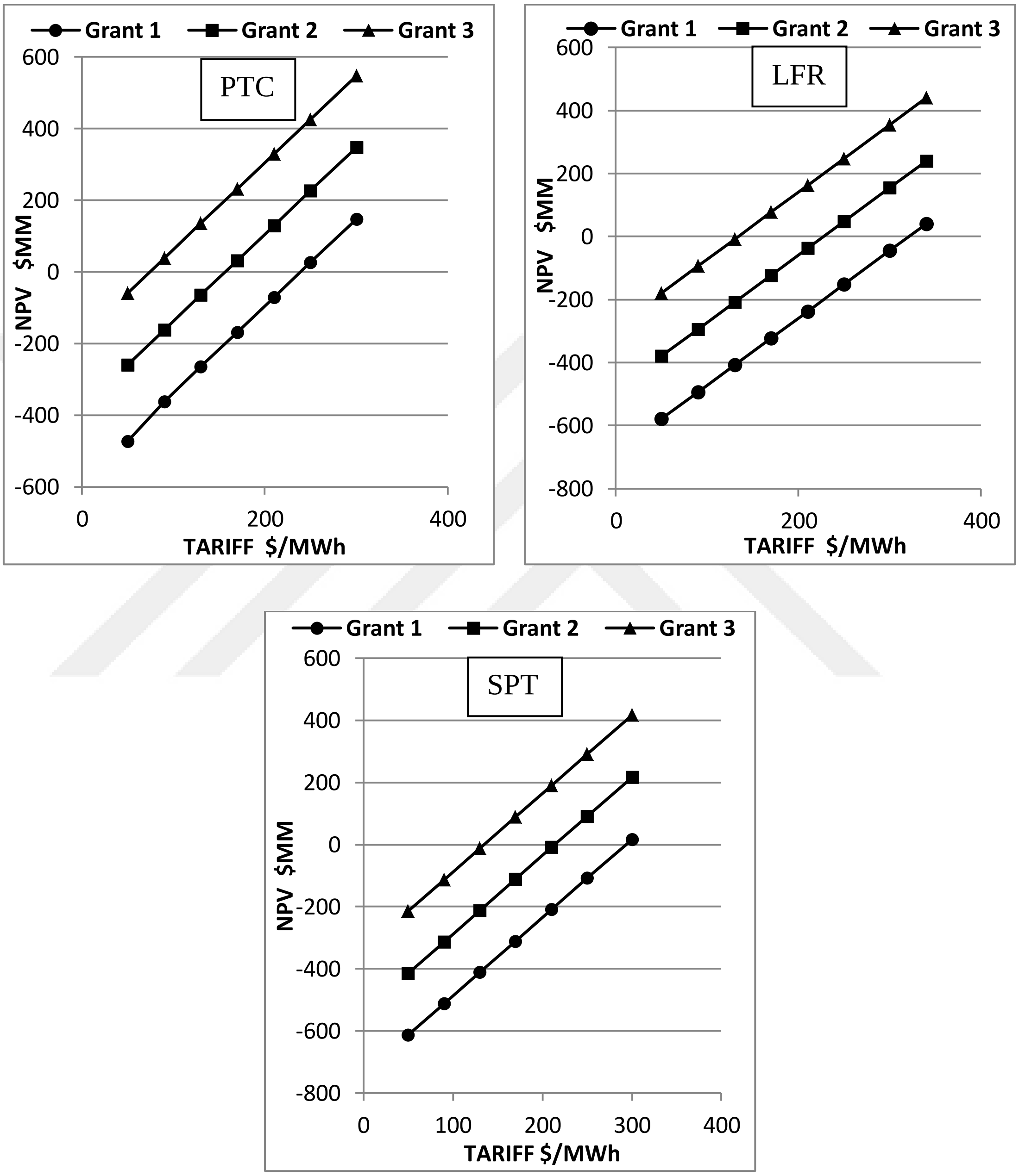


Figure 4.3 : Impact of grants on NPV for the different types under storage of 0h.

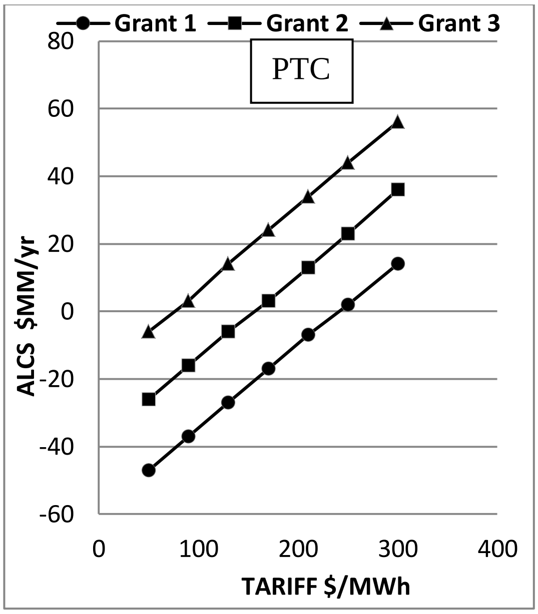
For LFR, the positive NPV found at grant 3 and at a lower tariff of $135/MWh. The tariff increases with a decrease in the grant to obtain a positive NPV. At grant 2, the tariff is $215/MWh and at grant1, the tariff is $330/MWh. For SPT, in this CSP technology, the positive NPV at grant 1 achieves a tariff of $295/MWh. The tariff decreases to $215/MWh with an increase of the grant 2, and with a grant 3, the tariff is $135/MWh. Table 4.4 illustrate the impact of grants on NPV of different tariff for three kinds of CSP.

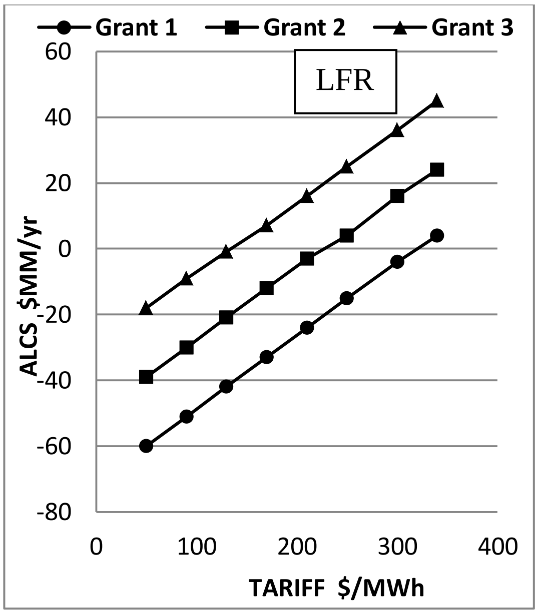
Table 4.4 : Impact of grants on NPV under different tariff conditions.

TARIFF $/MWh	**NPV($MM)**								
	PTC /without storage			**LFR/without storage**			**SPT /without storage**		
	Grant 1	**Grant 2**	**Grant 3**	**Grant 1**	**Grant 2**	**Grant 3**	**Grant 1**	**Grant 2**	**Grant 3**
50	–458.9	–258	–58	–579.3	–379	–179	–614	–414	–214
90	–361	–161	38	–493.8	–293	–93	–513	–313	–113
130	–264	–64	13	–408	–208	–8	–412	–212	–12
170	–167	32	23	–322	–122	77	–311	–111	88
210	–70	129	329	–237	–37	162	–209	–9	190
250	26.1	226.1	426.1	–151	48	248	–108	91	291
300	147.4	347.3	547.3	–45	154	354	17	217	417
340				40.4	240	440			

- **Impact of grants on Annual life Cycle Saving under different tariff condition**

For PTC, at a tariff of $50/MWh, the ALCS becomes negative value at grant 1. The ALCS at this grant is still negative until a tariff of $240/MWh, when it changes to positive. At a grant 2, the ALCS becomes positive at a tariff of $160/MWh, and the tariff decreases to $75/MWh at a grant 3 figure 4.4(PTC) show that. This result is the same of NPV but per year.





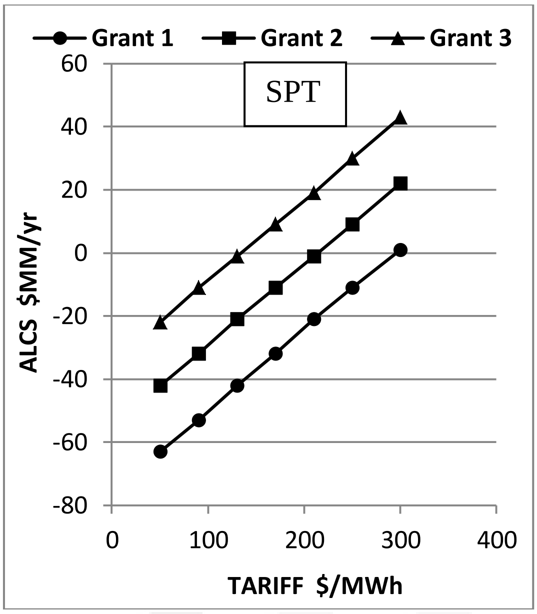


Figure 4.4 : Impact of grants on ALCS for the different types under storage of 0h.

For LFR, at a tariff of $50/MWh, the ALCS has a negative value(–$60MM) at grant 1. The ALCS at this grant is still negative until a tariff of $320/MWh, when it changes to positive. At a grant 2, the ALCS becomes positive at a tariff of $225/MWh, and the tariff decreases to $140/MWh at grant 3 as shown in Figure 4.4(LFR).

At tariff of $50/MWh for SPT, the ALCS has a negative value(–$63MM) at grant 1. The ALCS at this grant is still negative until the tariff of $300/MWh is reached, when it changes to positive. At grant 2, the ALCS becomes positive at a tariff of $215/MWh, and the tariff decreases to $130/MWh at grant 3 as shown in Figure4.4 (SPT).Table 4.5 illustrates the impact of grants on ALCS of different tariff for three kinds of CSP.

Table 4.5 : Impact of grants on ALCS under different tariff conditions.

TARIFF $/MWh	ALCS ($MM/year)								
	PTC/without storage			LFR/without storage			SPT/without storage		
	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3
50	–47	–26	–6	–60	–39	–18	–63	–42	–22
90	–37	–16	3	–51	–30	–9	–53	–32	–11
130	–27	–6	14	–42	–21	–8	–42	–21	–1
170	–17	3	24	–33	–12	7	–32	–11	9
210	–7	13	34	–24	–3	16	–21	–1	19
250	2	23	44	–15	4	25	–11	9	30
300	15	36	56	–4	16	36	1	22	43
340				4	24	45			

4.7.2 With storage (3 h) for all types

- **Impact of grants on simple payback under different tariff conditions**

Similar to the previous analyses for 0 h storage. Figures 4.5 shows impact of grants on SPB for different tariffs and for all types. Table 4.6 shows the best tariff achieving SPB equal to, or below, 35 years for all CSP types.

Table 4.6 : The best tariff for all CSP types at 3 h TES.

Types	Minimum Tariff ($/MWh)		
	Grant 1	Grant 2	Grant 3
PTC	85	75	BELOW 50
LFR	100	85	55
SPT	80	65	BELOW 50

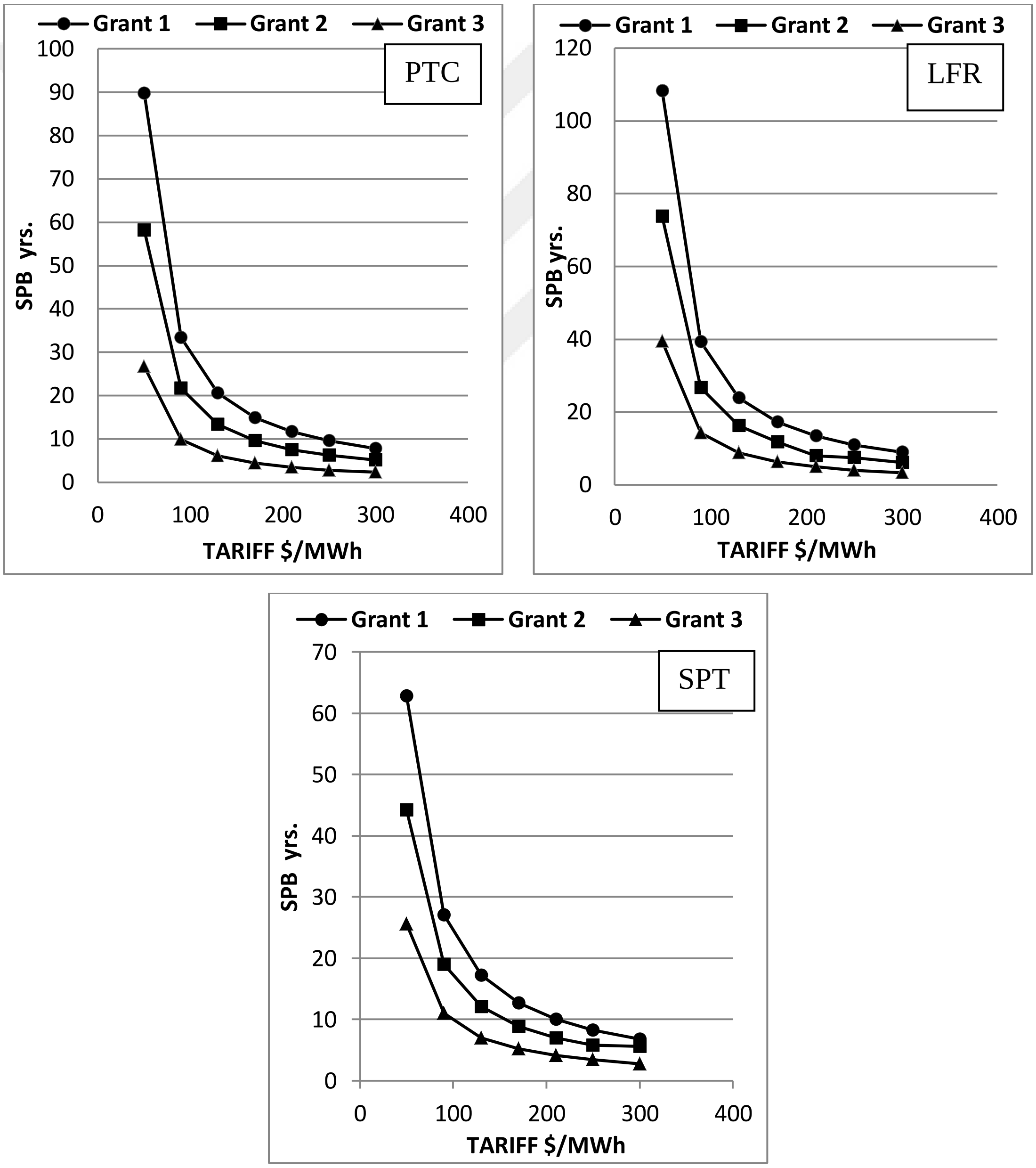


Figure 4.5 : Impact of grants on SPB for the different types under storage of 3h.

Table 4.7 shows RETScreen analysis to obtain the SPB under different grants and for different tariffs.

Table 4.7 : Impact of grants on the SPB under different tariff condition.

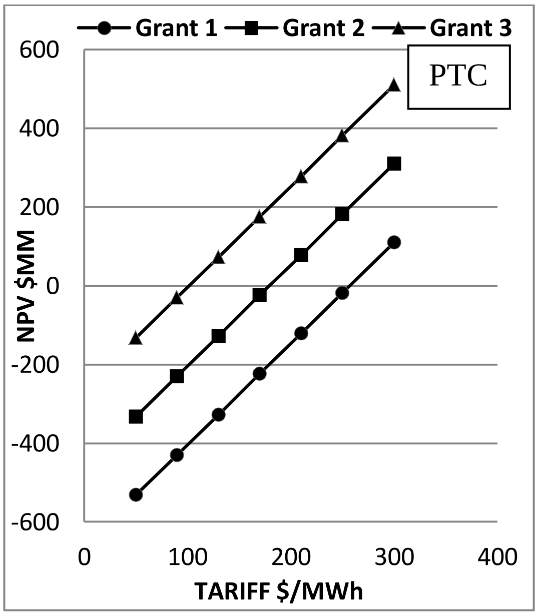
TARIFF $/MWh	SPB (yrs.)								
	PTC/storage (3 h)			LFR/storage (3 h)			SPT/storage (3 h)		
	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3
50	89.7	58.2	26.7	108.2	73.8	39.4	62.9	44.2	25.6
80	44	30	14	56	36	20	32	22	12
130	20.5	13.3	6.1	23.9	16.3	8.7	17.2	12.1	7
170	14.8	9.6	4.4	17.2	11.7	6.3	12.7	8.9	5.2
210	11.6	7.5	3.4	13.4	7.9	4.9	10	7	4.1
250	9.5	6.2	2.8	11	7.5	4	8.3	5.8	3.4
300	7.8	5.1	2.3	9	6.1	3.3	6.8	5.6	2.8

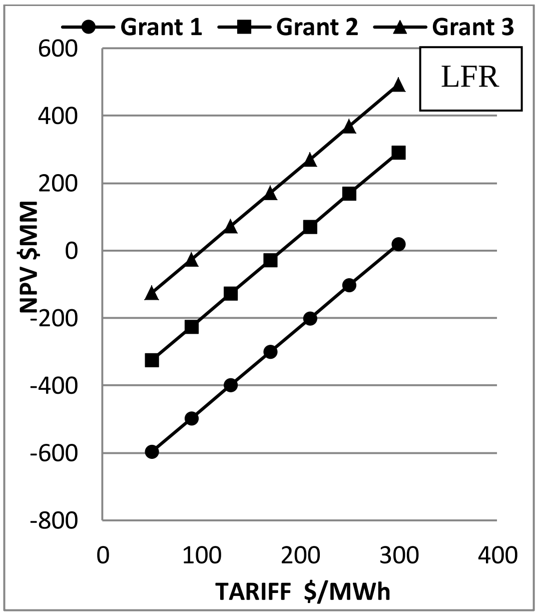
- **Impact of grants on net present value NPV under different tariff conditions**

Similar to the previous analyses for 0 h storage. Figures 4.6 show the impact of grants on NPV for different tariffs and for all types. Table 4.8 shows the best tariff achieving a positive value for NPV positive for all CSP types.

Table 4.8: The best tariff achieve positive NPV at 3 h TES.

Types	Minimum Tariff ($/MWh)		
	Grant 1	Grant 2	Grant 3
PTC	260	180	90
LFR	290	180	100
SPT	225	165	105





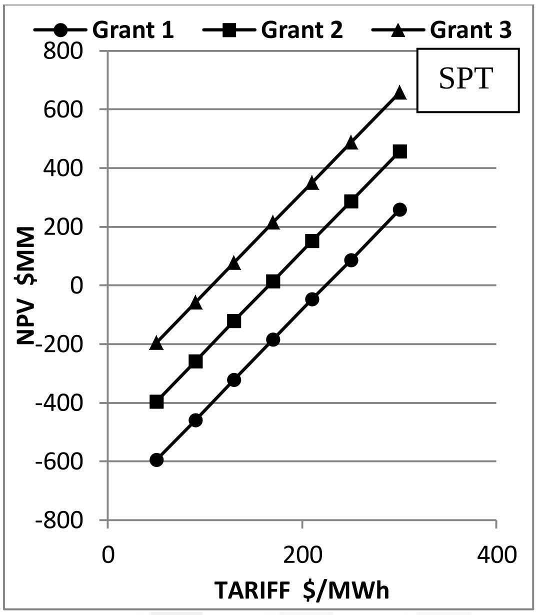


Figure 4.6 : Impact of grants on NPV for the different types under storage of 3h.

Table 4.9 shows RETScreen analysis to obtain NPV under different grants and for different tariffs.

Table 4.9 : Impact of grants on the NPV under different tariff condition.

TARIFF $/MWh	NPV($MM)								
	PTC /storage 3 h			LFR /storage 3 h			SPT/storage 3 h		
	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3
50	–531	–333	–133	–598	–326	–198,	–596	–396	–196
90	–430	–230	–30	–499	–227	–99	–459	–259	–59
130	–327	–127	72	–400	–128	–50	–322	–122	77
170	–224	–24	175	–301	–101	98	–185	14	214
210	–121	78	278	–202	–2	197	–48	151	351
250	–18	181	381	–103	96	296	87	287	487
300	110	310	510	19	219	419	258	458	658

- **Impact of grants on Annual Life Cycle Saving under different tariff conditions**

Similar to the previous analyses for 0 h storage. Figures 4.7 show the impact of grants on ALCS for different tariffs and for all types. Table 4.10 shows the best tariff achieving ALCS positive value for all CSP types.

Table 4.10 : The best tariff achieve positive ALCS.

Types	Minimum Tariff ($/MWh)		
	Grant 1	Grant 2	Grant 3
PTC	260	180	100
LFR	290	180	100
SPT	225	165	105

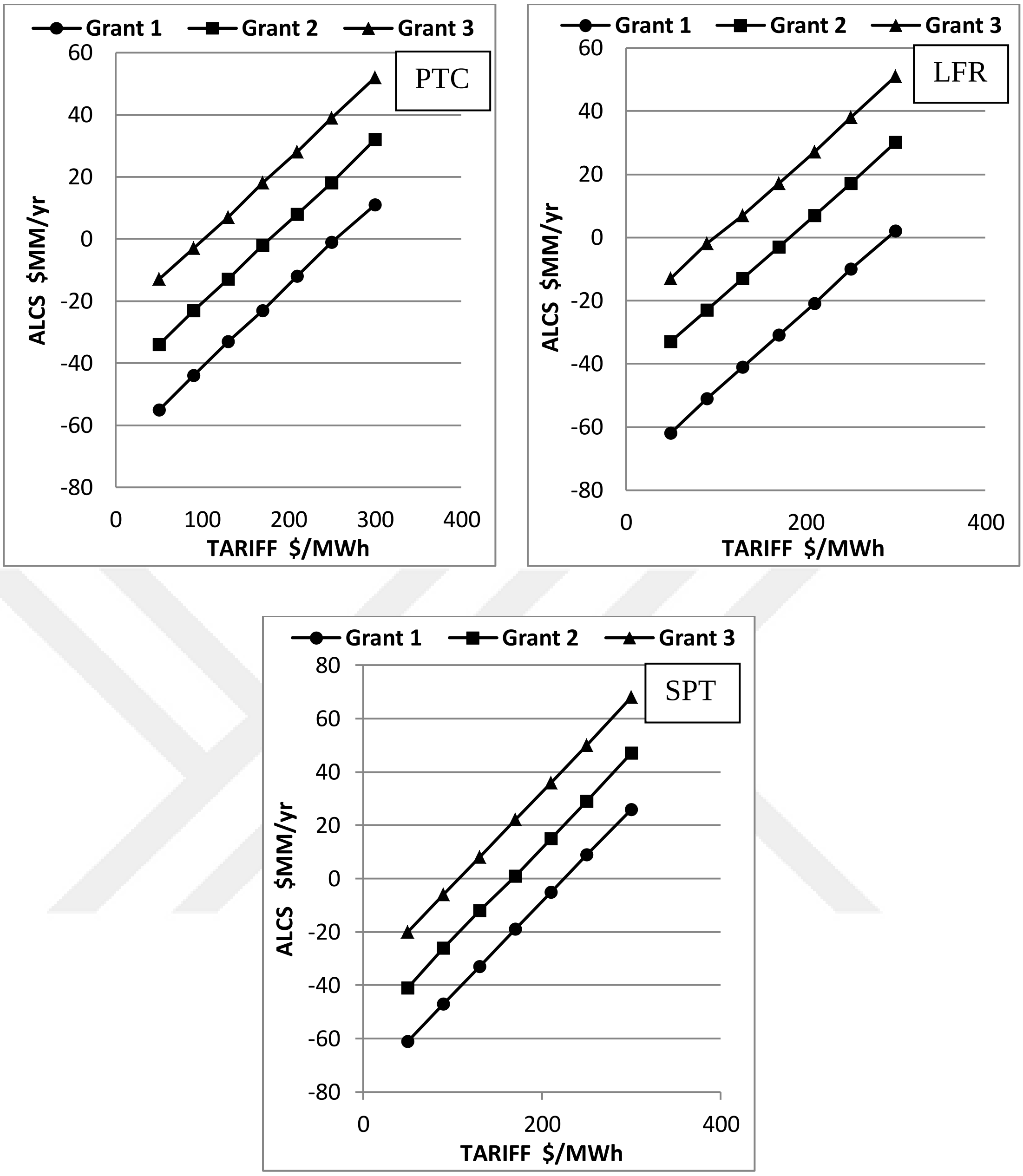


Figure 4.7 : Impact of grants on ALCS for the different types under storage of 3h.

Table 4.11 show RETScreen analysis to obtain ALCS under different grants and for different tariffs.

Table 4.11: Impact of grants on the ALCS under different tariff conditions.

TARIFF $/MWh	ALCS $MM/yr.								
	PTC /storage 3 h			LFR /storage 3 h			SPT/storage 3 h		
	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3
50	–55	–34	–13	–62	–33	–13	–61	–41	–20
90	–44	–23	–3	–51	–23	–2	–47	–26	–6
130	–33	–13	7	–41	–13	7	–33	–12	8
170	–23	–2	18	–31	–3	17	–19	1	22
210	–12	8	28	–21	7	27	–5	15	36
250	–1	18	39	–10	17	38	9	29	50
300	11	32	52	2	30	51	26	47	68

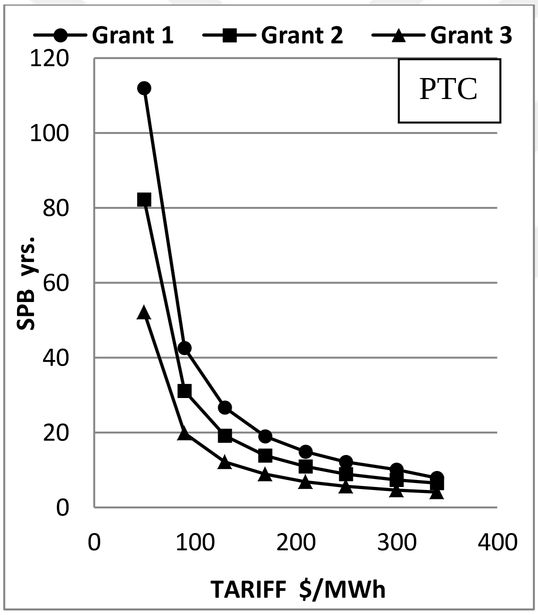
4.7.3 With storage (9 h) for all types

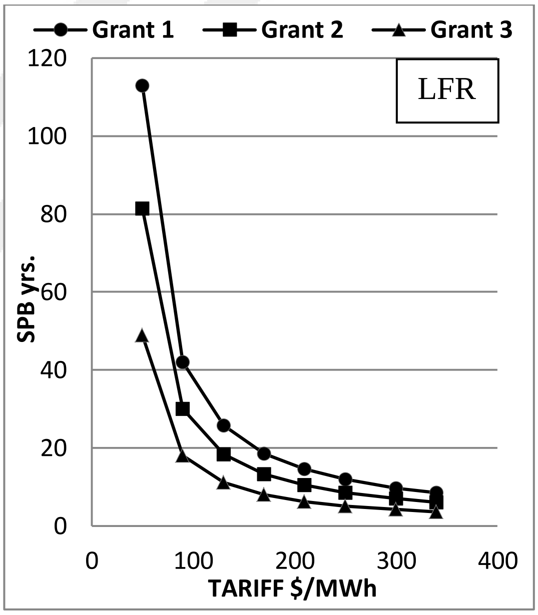
- **Impact of grants on simple payback under different tariff condition**

Similar to the previous analyses for 0 h storage. Figures 4.8 show impact of grants on SPB for different tariffs and for all types. Table 4.12 shows the best tariff achieving SPB equal to, or below, 35 years for all CSP types.

Table 4.12: The best tariff for all CSP types at 9 h TES.

Types	Minimum Tariff ($/MWh)		
	Grant 1	Grant 2	Grant 3
PTC	110	85	70
LFR	105	85	70
SPT	75	55	BELOW 50





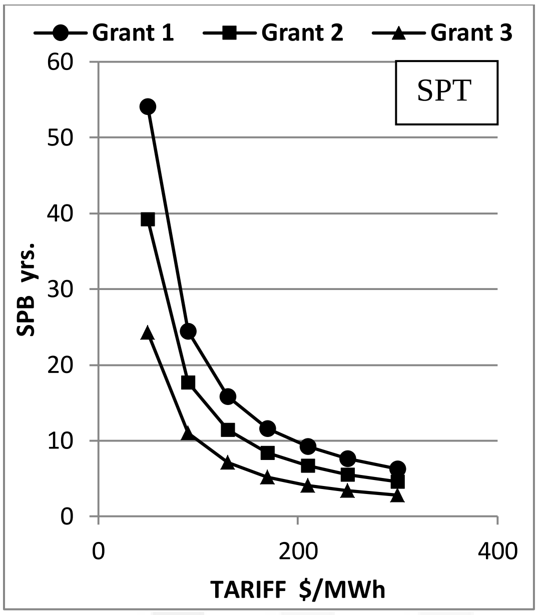


Figure 4.8: Impact of grants on ALCS for the different types under storage of 9 h.

Table 4.13 shows RETScreen analysis to obtain SPB under different grants and for different tariffs.

Table 4.13 : Impact of grants on the SPB under different tariff conditions.

TARIFF $/MWh	**SPB (yrs.)**								
	PTC/storage(9 h)			**LFR/storage(9 h)**			**SPT/storage(9 h)**		
	Grant 1	**Grant 2**	**Grant 3**	**Grant 1**	**Grant 2**	**Grant 3**	**Grant 1**	**Grant 2**	**Grant 3**
50	112	82.2	52.2	113	81.4	48.9	54.1	39.2	24.3
90	42.5	31.1	19.8	42	30	18	24.4	17.7	11
130	26.6	19.2	12.2	25.8	18.4	11.1	15.8	11.4	7.1
170	19	13.9	8.8	18.6	13.3	8	11.6	8.4	5.2
210	14.8	10.9	6.9	14.5	10.4	6.2	9.2	6.7	4.1
250	12.2	8.9	5.7	11.9	8.5	5.1	7.6	5.5	3.4
300	10	7.3	4.6	9.7	7	4.2	6.3	4.6	2.8
340	7.9	6.4	4.1	8.5	6.1	3.6			

- **Impact of grants on Net Present Value under different tariff condition**

Similar to the previous analyses for 0 h storage. Figures 4.9 show the impact of grants on NPV for different tariffs and for all types. Table 4.14 shows the best tariff achieving NPV positive value for all CSP types.

Table 4.14: The best tariff achieve positive NPV at 9 h TES.

Types	**Minimum Tariff ($/MWh)**		
	Grant 1	**Grant 2**	**Grant 3**
PTC	320	240	150
LFR	315	230	150
SPT	210	160	110

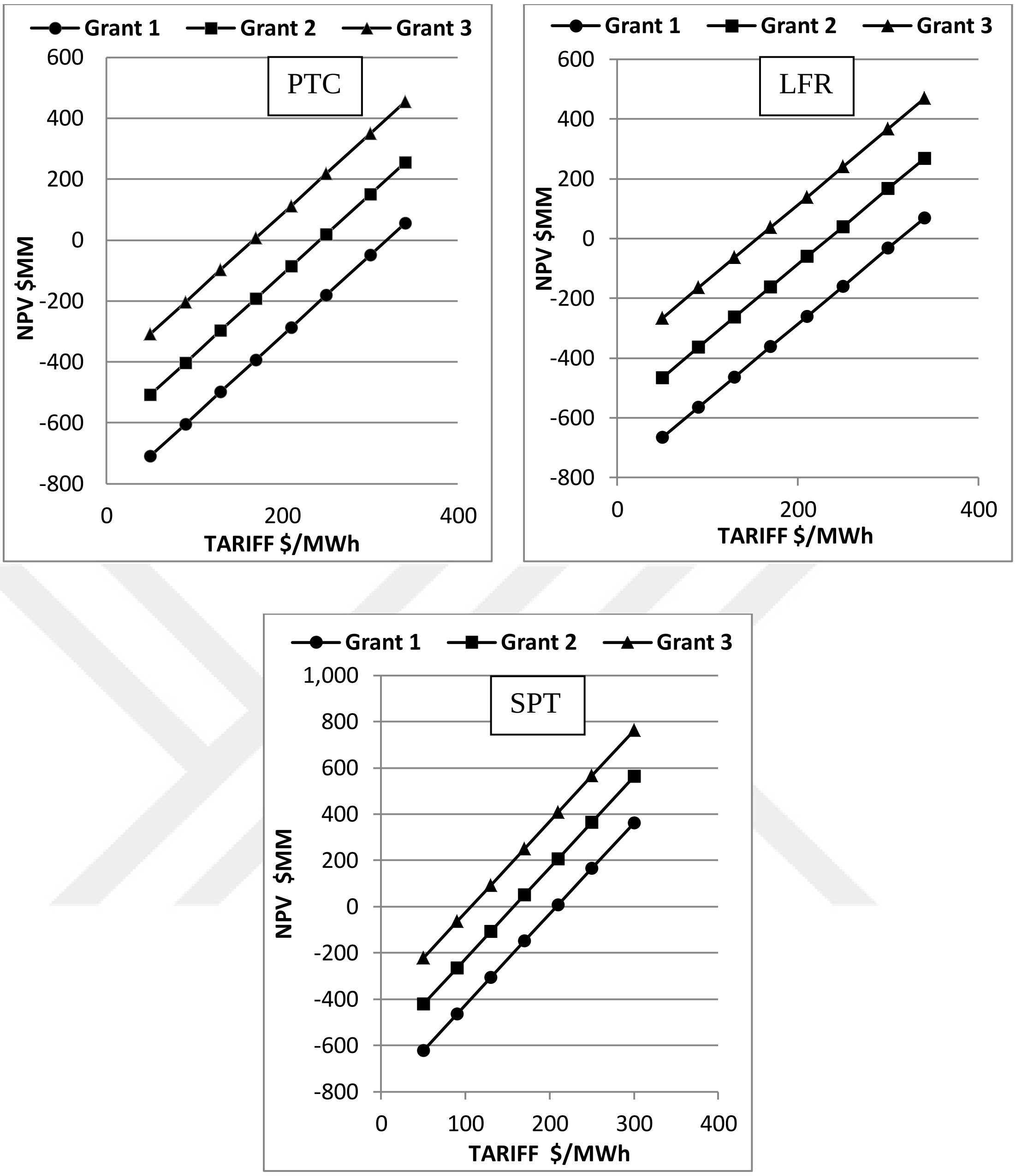


Figure 4.9 : Impact of grants on NPV for the different types under storage of 9h.

Table 4.15 shows RETScreen analysis to obtain NPV under different grants and for different tariffs for PTC, LFR and SPT.

Table 4.15: Impact of grants on the NPV under different tariff conditions.

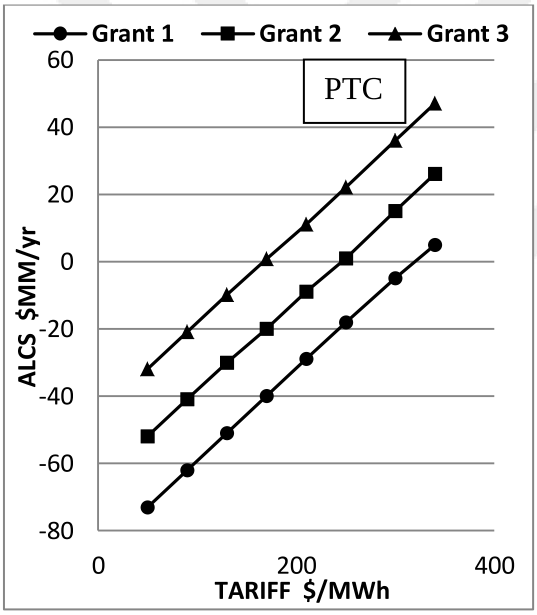
TARIFF $/MWh	**NPV($MM)**								
	PTC /storage 9 h			**LFR /storage 9 h**			**SPT/storage 9 h**		
	Grant 1	**Grant 2**	**Grant 3**	**Grant 1**	**Grant 2**	**Grant 3**	**Grant 1**	**Grant 2**	**Grant 3**
50	–709	–509	–309	–666	–466	–266	–622	–422	–222
90	–604	–404	–204	–564	–364	–164	–464	–264	–64
130	–498	–298	–98	–463	–263	–63	–307	–107	92
170	–393	–193	6	–361	–161	38	–149	50	250
210	–287	–87	112	–260	–60	139	7	207	407
250	–181	–18	218	–159	40	240	165	365	565
300	–49	–15	350	–32	167	367	362	562	762
340	55	255	455	69	269	469			

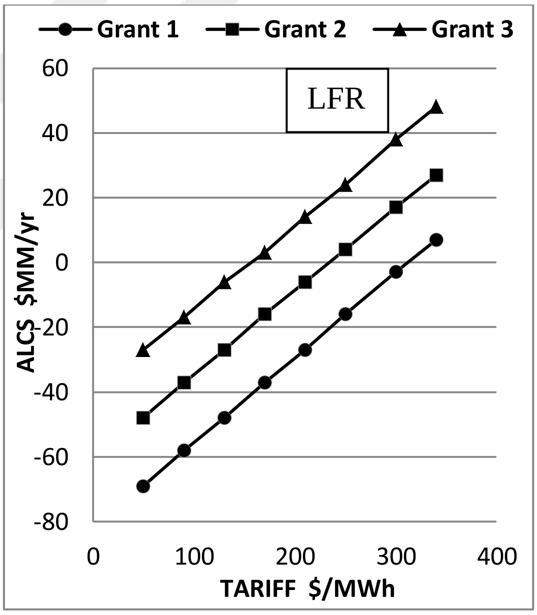
- **Impact of grants on Annual Life Cycle Saving under different tariff condition**

Similar to the previous analyses for 0 h storage. Figures 4.10 show the impact of grants on ALCS for different tariffs and for all types. Table 4.16 shows the best tariff achieving ALCS positive value for all CSP types.

Table 4.16: The best tariff achieve positive ALCS at 9 h TES**.**

Types	Minimum Tariff ($/MWh)		
	Grant 1	Grant 2	Grant 3
PTC	320	240	140
LFR	315	240	150
SPT	210	160	110





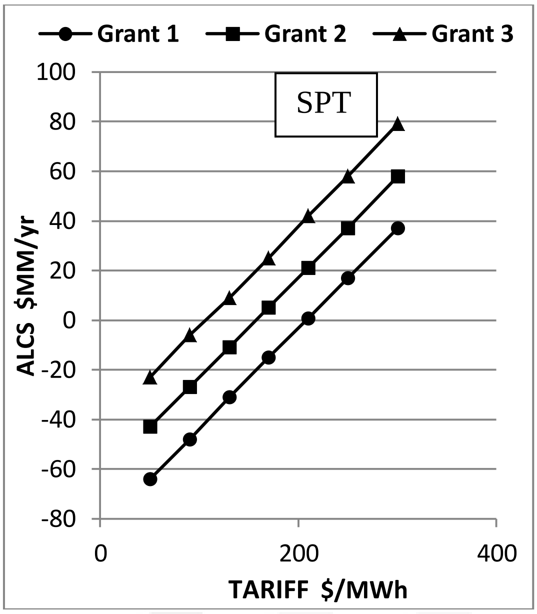


Figure 4.10 : Impact of grants on ALCS for the different types under storage of 9h**.**

Table 4.17 shows RETScreen analysis to obtain NPV under different grants and for different tariffs and for PTC, LFR and SPT

Table 4.17: Impact of grants on the ALCS under different tariff conditions**.**

TARIFF $/MWh	ALCS $MM/yr								
	PTC /storage 9 h			LFR /storage 9 h			SPT/storage 9 h		
	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3	Grant 1	Grant 2	Grant 3
50	-73	-52	-32	-69	-48	-27	-64	-43	-23
90	-62	-41	-21	-58	-37	-17	-48	-27	-6
130	-51	-30	-10	-48	-27	-6	-31	-11	9
170	-40	-20	718	-37	-16	3	-15	5	25
210	-29	-9	11	-27	-6	14	820	21	42
250	-18	1	22	-16	4	24	17	37	58
300	-5	15	36	-3	17	38	37	58	79

Table 4.18 :The summery of scenario 1 which achieve best tariff by using NPV indicators.

Table 4.18 : Minimum Tariff for positive NPV

Storage	Grants	TARIFF $/MWh		
		PTC	LFR	SPT
0 h TES	Grant 1	240	330	295
	Grant 2	160	215	215
	Grant 3	75	140	135
3 h TES	Grant 1	260	290	225
	Grant 2	180	180	165
	Grant 3	105	100	110
9 h TES	Grant 1	320	315	210
	Grant 2	240	230	160
	Grant 3	150	150	110

4.8 Scenario 2: Financial Evaluation with greenhouse gases GHG reduction income and without grants for different TES

4.8.1 With storage (0 h) for all types

- **Impact of GHG income on simple payback under different tariffs**

For all types of CSP, greenhouse gases (GHG) reduction income gives the project additional cash flow in the RETScreen analysis. Table 4.19 shows the impact of GHG income on the SPB for different tariff at 0 h TES and table 4.20 shows the minimum tariff that achieves SPB below 35 years. This table is obtained from figures 4.11.

Table 4.19: Impact of GHG reduction income on the SPB under different tariff conditions.

Tariff $/MWh	SPB yrs.					
	PTC with storage 0 h		LFR with storage 0 h		SPT with storage 0 h	
	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$
50	60.8	37.1	94.2	55.2	74.2	46.3
80	32	24	50	35	43	31
130	17.3	14.7	24.7	20.8	21.8	18.5
170	12.7	11.3	18	15.9	16.1	14.3
210	10.1	9.1	5.3	12.8	12.8	11.6
250	8.3	7.7	14.2	10.8	10.6	9.8
300	6.9	6.4	9.6	9	8.7	8.1

Table 4.20 : The best tariff give SPB below 35 years under the effect of GHG income.

Types	Minimum Tariff ($/MWh)	
	GHG reduction income ($10/tCO2)	GHG reduction income ($30/tCO2)
PTC	80	60
LFR	100	80
SPT	88	75

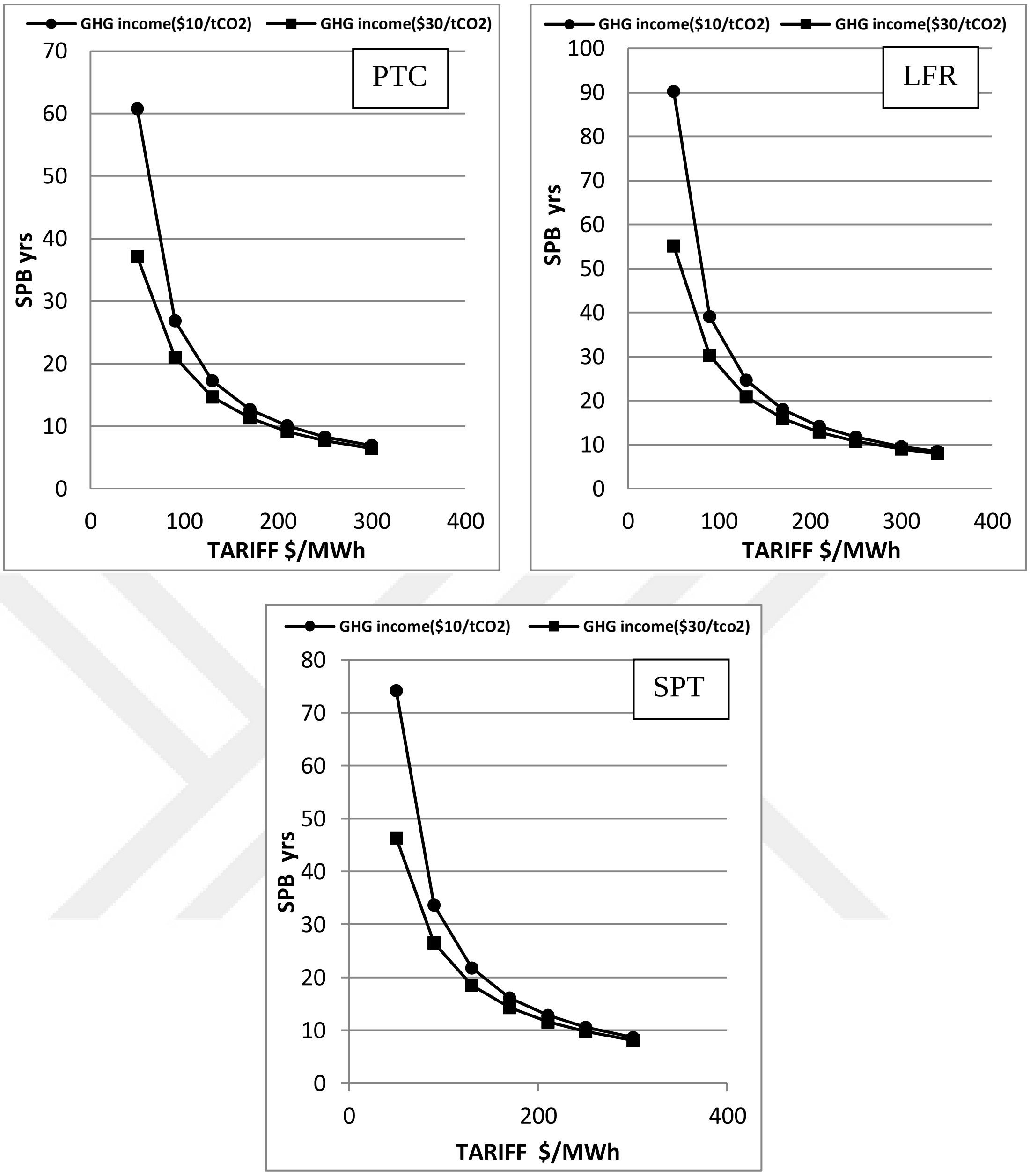


Figure 4.11 : Impact of GHG income on SPB for the different types under storage of 0 h.

- **Impact of GHG income on Net Present Value under different tariffs**

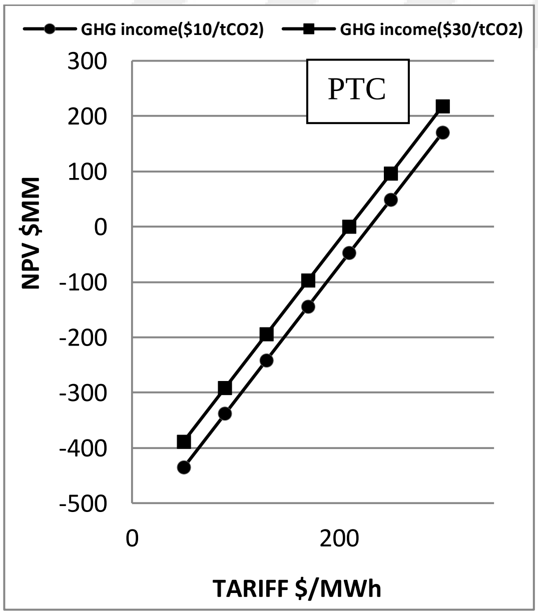
Table 4.21 shows the impact of GHG reduction income on NPV for all types of CSP at a GHG income reduction of \$10/tCO_2 and \$30/tCO_2. From figure 4.12 PTC, the best tariff obtaining positive NPV is \$215/MWh, for LFR, it is \$290/MWh and for SPT, it is \$265/MWh all this for GHG income \$30/tCO_2. Table 4.22 gives the minimum tariffs for GHG income reduction of \$10/tCO_2 and \$30/tCO_2.

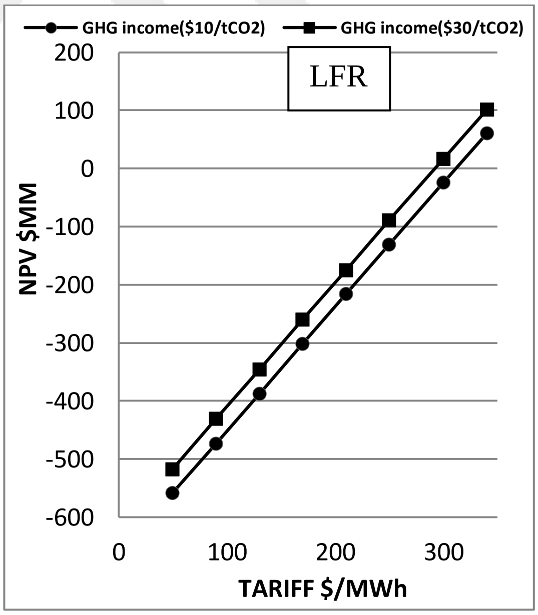
Table 4.21: Impact GHG reduction income on the NPV under different tariff conditions.

Tariff $/MWh	NPV $MM					
	PTC with storage 0 h		LFR with storage 0 h		SPT with storage 0 h	
	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$
50	–435	–388	–558	–517	–589	–540
90	–338	–291	–473	–431	–488	–439
130	–241	–194	–387	–346	–387	–338
170	–144	–97	–302	–260	–286	–237
210	–47	–14	–216	–175	–185	–136
250	49	96	–131	–89	–84	–35
300	170	218	–24	17	42	91

Table 4.22: Minimum tariffs for positive NPV under the effect of GHG income.

Types	Minimum Tariff ($/MWh)	
	GHG reduction income ($10/tCO2)	GHG reduction income ($30/tCO2)
PTC	230	215
LFR	320	290
SPT	280	265





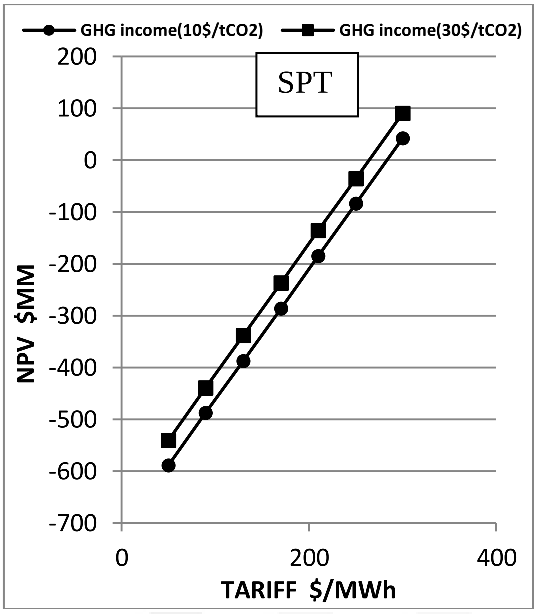


Figure 4.12 : Impact of GHG income on NPV for the different types under storage of 0h.

- **Impact of GHG income on Annual Life Cycle Saving under different tariff**

Table 4.23 and figures4.13 show the impact of GHG reduction income on ALCS for all types of CSP at a GHG income reduction of $10/tCO_2$ and $30/tCO_2$.

Table 4.23: Impact GHG reduction income on the ALCS under different tariff conditions.

Tariff $/MWh	ALCS $MM/yr					
	PTC with storage 0 h		LFR with storage 0 h		SPT with storage 0 h	
	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$
50	–45	–40	–57	–53	–61	–56
90	–35	–30	–49	–44	–50	–45
130	–25	–20	–40	–35	–40	–35
170	–14	–10	–31	–27	–29	–24
210	–4	–15	–22	–18	–19	–14
250	5	10	–13	–9	–8	–3
300	17	22	–2	1	4	9

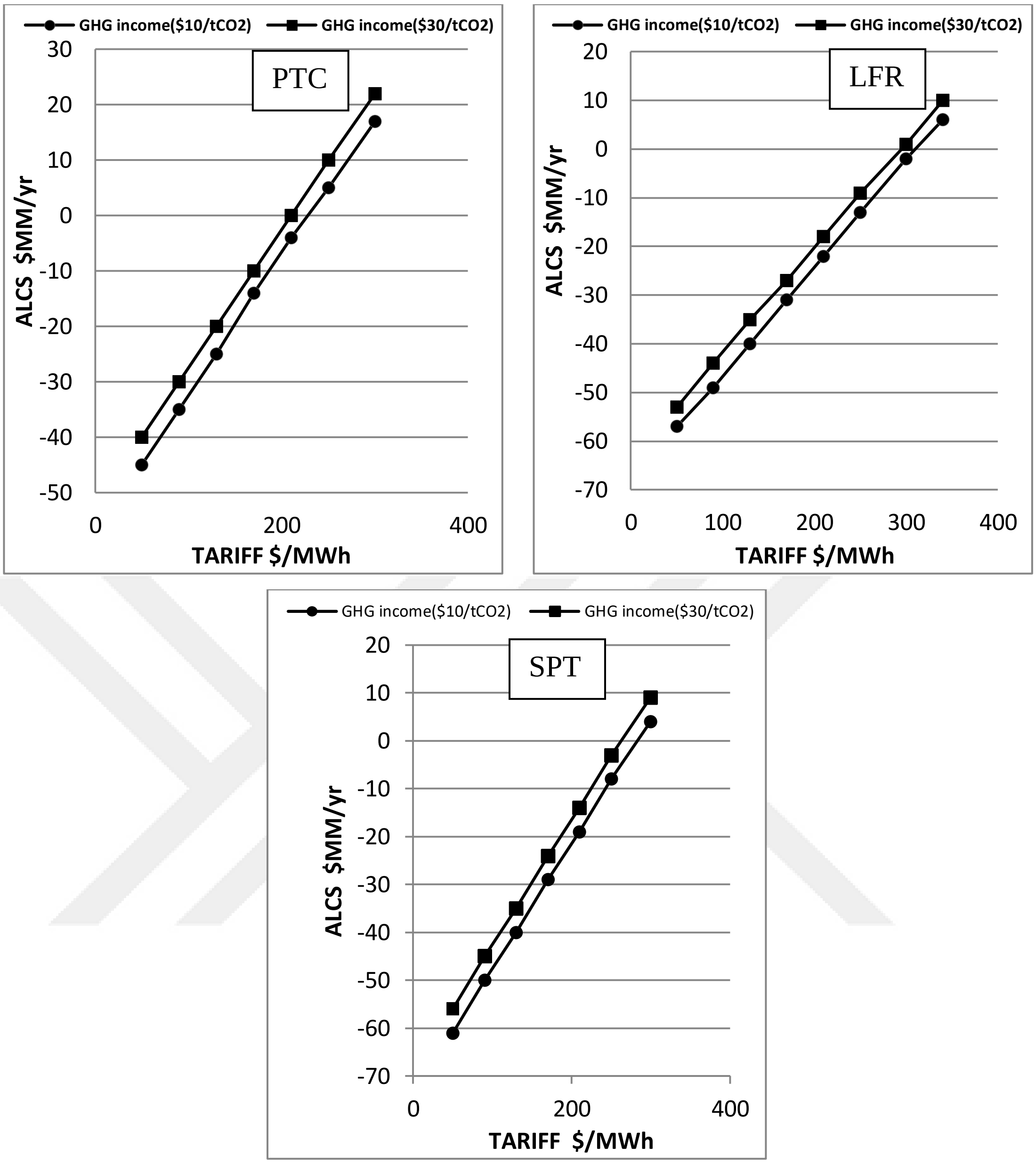


Figure 4.13: Impact of GHG income on ALCS for the different types under storage of 0 h.

4.8.2 With storage (3 h) for all types

- **Impact of GHG income on simple payback under different tariff**

For TES (3 h), the impact of GHG reduction income is obvious. From Figure 4.14 can obtain the table 4.24 which show the minimum tariff achieve SPB below 35 years. Table 4.25 shows the impact of GHG reduction income on SPB for all types of CSP at a GHG income reduction of $10/tCO_2$ and $30/tCO_2$.

Table 4.24 : The best tariff give SPB below 35 years under the effect of GHG income.

Types	Minimum Tariff ($/MWh)	
	GHG reduction income ($10/tCO2)	**GHG reduction income ($30/tCO2)**
PTC	80	50
LFR	88	70
SPT	70	Below 50

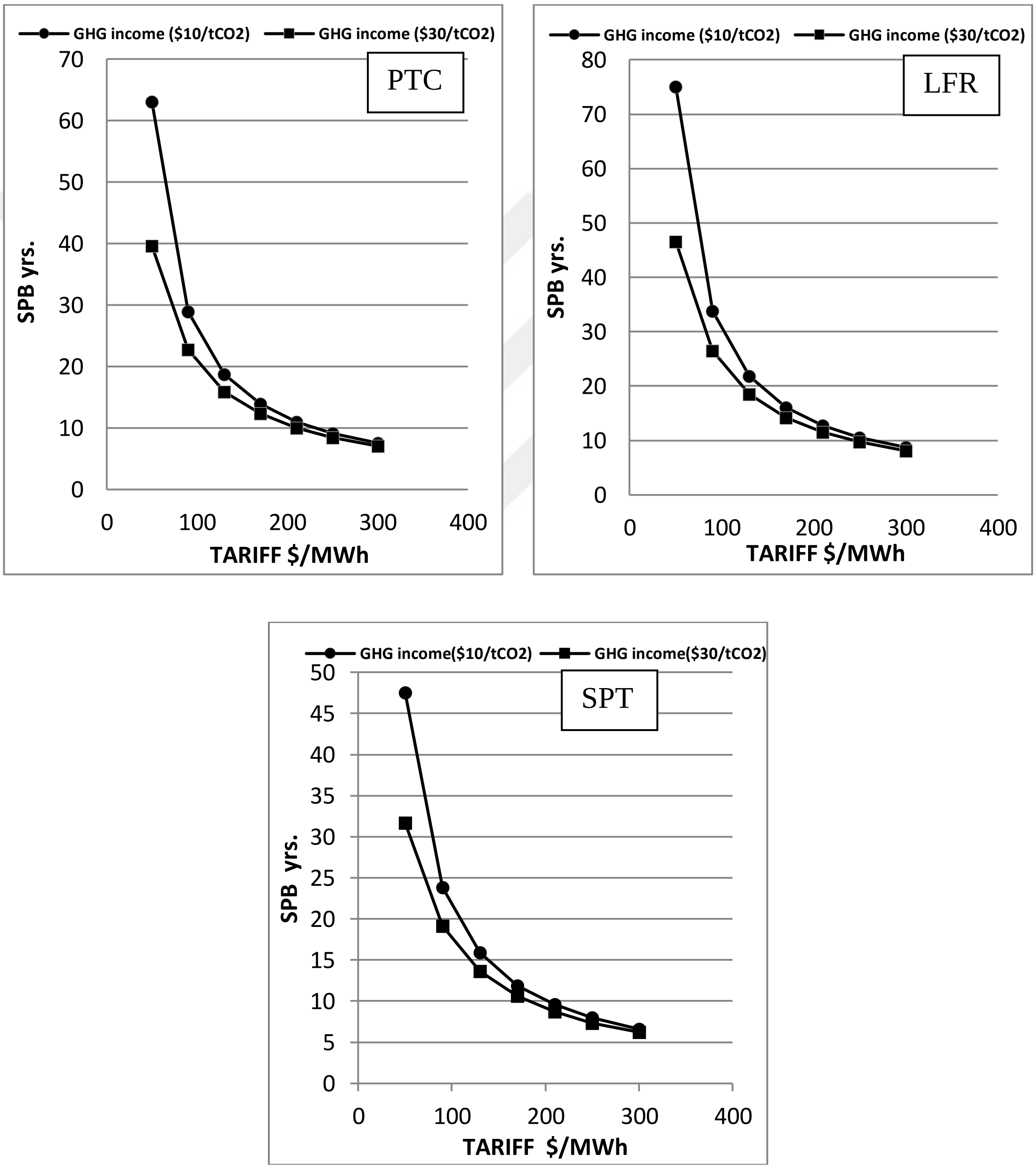


Figure 4.14 : Impact of GHG income on SPB for the different types under storage of 3 h.

Table 4.25: Impact GHG reduction incomeon the SPB under different tariff conditions.

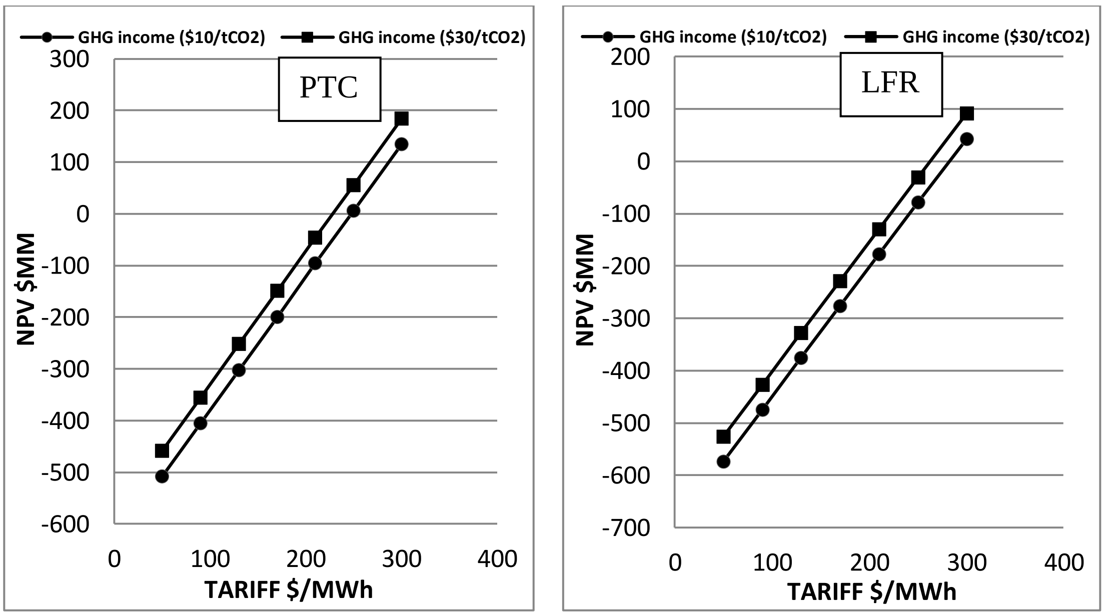
Tariff $/MWh	SPB yrs.					
	PTC with storage 3 h		LFR with storage 3 h		SPT with storage 3 h	
	$10/tCO_2	$30/tCO_2	$10/tCO_2	$30/tCO_2	$10/tCO_2	$30/tCO_2
50	63.1	39.6	75	46.5	47.5	31.7
80	36	26	42	31	29	22
130	18.7	15.9	21.8	18.5	15.9	13.6
170	13.9	12.3	16.1	14.2	11.9	10.6
210	11	10	12.7	11.5	9.6	8.7
250	9.1	8.4	10.5	9.7	8	7.3
300	7.5	7	8.7	8.1	6.6	6.2

- **Impact of GHG income on Net Present Value under different tariff**

By the same way of analysis of TES 0h the following results are obtained:

Table 4.26: Minimum tariffs for positive NPV under the effect of GHG incomes**.**

Types	Minimum Tariff ($/MWh)	
	GHG reduction income ($10/tCO2)	GHG reduction income ($30/tCO2)
PTC	245	230
LFR	280	260
SPT	215	195



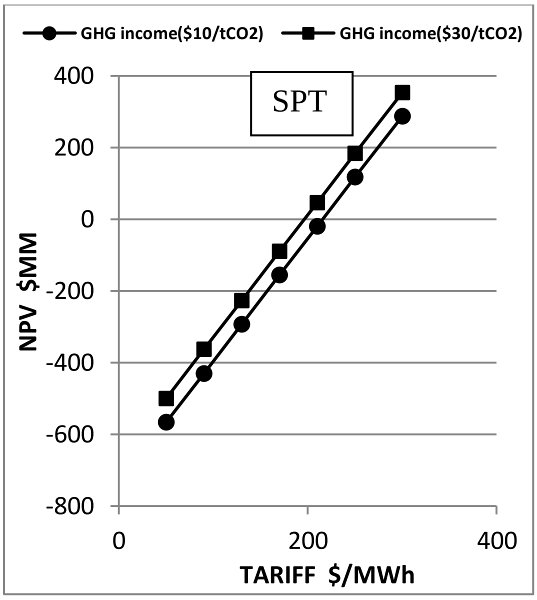


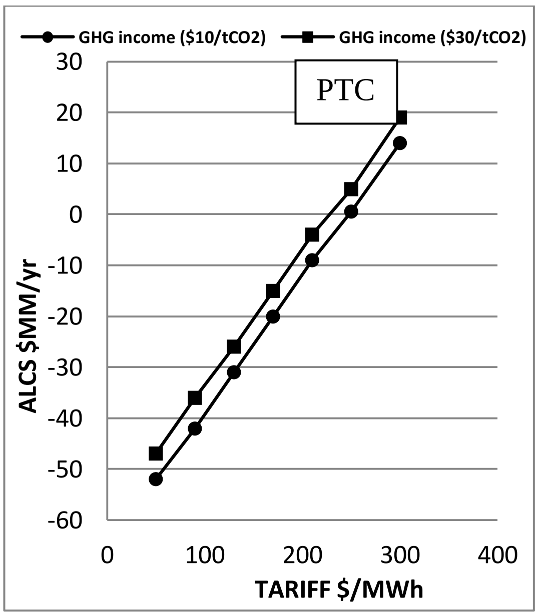
Figure 4.15: Impact of GHG income on NPV for the different types under storage of 3 h.

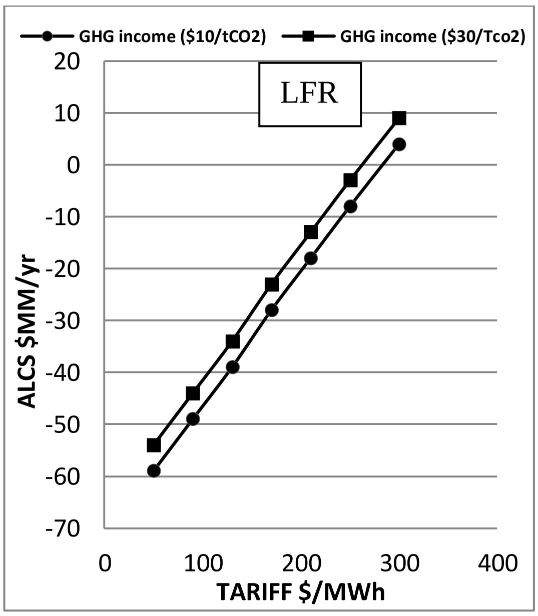
Table 4.27: Impact GHG reduction incomeon the NPV under different tariff conditions.

Tariff $/MWh	**NPV $MM**					
	PTC with storage 3 h		**LFR with storage 3 h**		**SPT with storage 3 h**	
	$10/tCO_2$	**$30/tCO_2$**	**$10/tCO_2$**	**$30/tCO_2$**	**$10/tCO_2$**	**$30/tCO_2$**
50	–508	–458	–574	–526	–566	–500
90	–405	–355	–475	–42	–430	–363
130	–302	–252	–376	–328	–293	–226
170	–199	–149	–277	–229	–156	–89
210	–96	–46	–178	–130	–19	46
250	6	56	–79	–31	117	183
300	135	185	43	91	288	354

- **Impact of GHG income on Annual Life Cycle Saving under different tariffs**

By the same way of analysis of TES 0 h the following results are obtained:





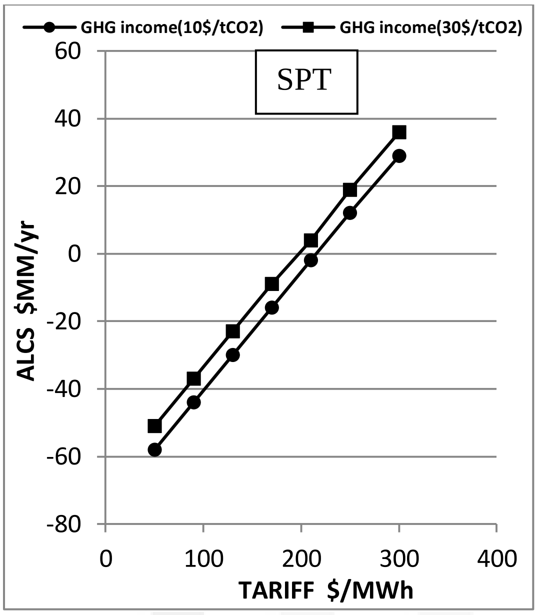


Figure 4.16: Impact of GHG income on ALCS for the different types under storage of 3 h.

Table 4.28: Impact GHG reduction incomeon the ALCS under different tariff conditions.

Tariff $/MWh	ALCS $MM/yr					
	PTC with storage 3 h		LFR with storage 3 h		SPT with storage 3 h	
	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$	$10/tCO_2$	$30/tCO_2$
50	–52	–47	–59	–54	–58	–51
90	–42	–36	–49	–44	–44	–37
130	–31	–26	–39	–34	–30	–23
170	–20	–15	–28	–23	–16	–9
210	–9	–4	–18	–13	–2	4
250	0.6	5	–8	–3	12	19
300	14	19	4	9	29	36

4.8.3 With storage (9 h) for all types

- **Impact of GHG income on Simple Payback under different tariff condition**

By the same way of analysis of TES 0 h the following results are obtained:

Table 4.29: The best tariff give SPB below35 years under the effect of GHG income

Types	Minimum Tariff ($/MWh)	
	GHG reduction income ($10/tCO2)	GHG reduction income ($30/tCO2)
PTC	90	75
LFR	95	85
SPT	65	Below 50

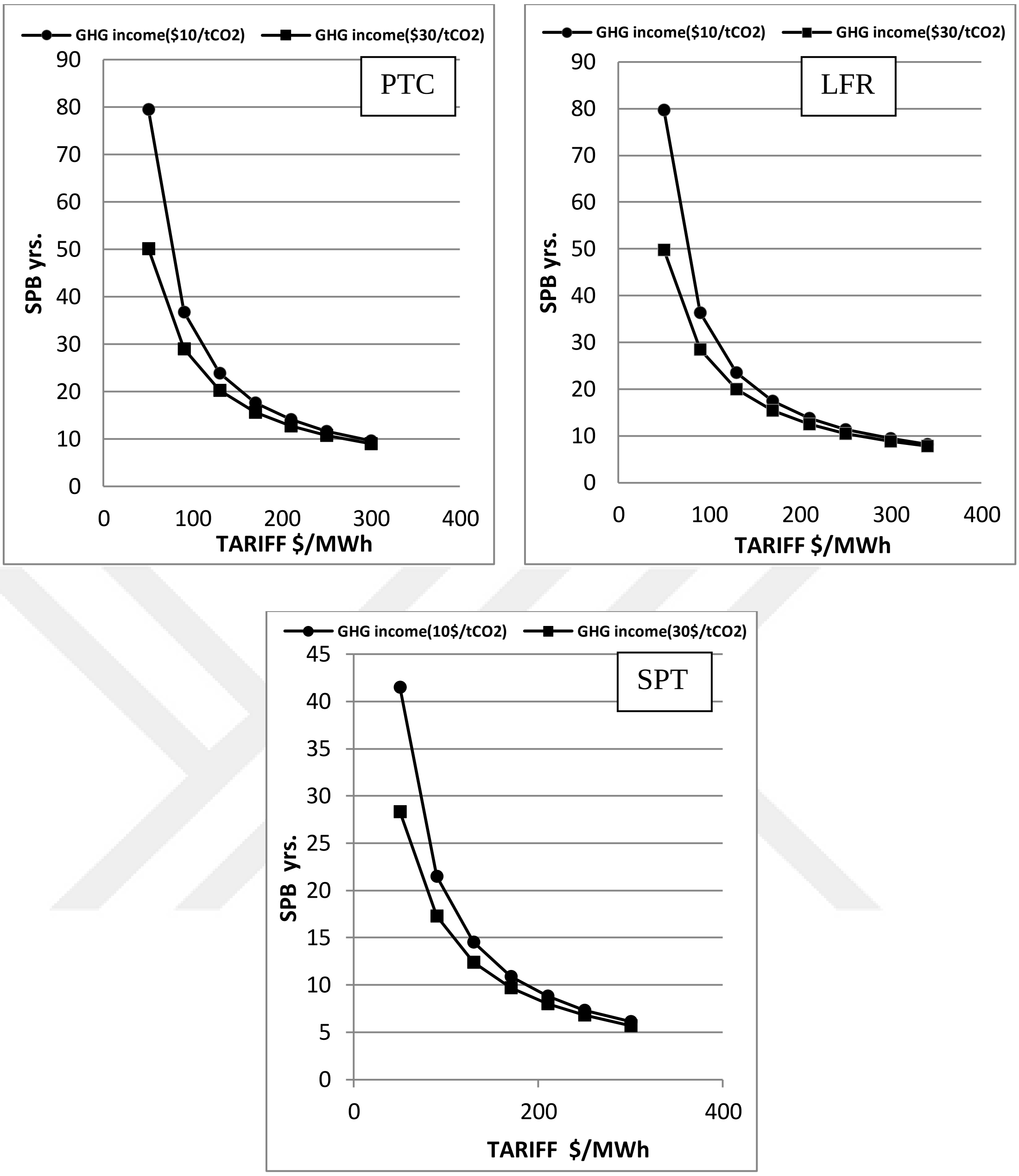


Figure 4.17: Impact of GHG income on SPB for the different types under storage of 9 h.

Table 4.30 : Impact GHG reduction income on the SPB under different tariff conditions.

Tariff $/MWh	SPB yrs.					
	PTC with storage 9 h		LFR with storage 9 h		SPT with storage 9 h	
	$10/tCO$_2$	$30/tCO$_2$	$10/tCO$_2$	$30/tCO$_2$	$10/tCO$_2$	$30/tCO$_2$
50	79.5	50.2	79.7	49.8	41.5	28.3
80	46	32	44	32	25	20
130	23.9	20.3	23.5	20	14.5	12.4
170	17.7	15.7	17.4	15.4	10.9	9.7
210	14.1	12.8	13.8	12.5	8.8	8
250	11.7	10.8	11.4	10.5	7.3	6.8
300	9.6	9	9.4	8.8	6.1	5.7

- **Impact of GHG income on Net Present Value under different tariff condition**

By the same way of analysis of TES 0h the following results are obtained:

Table 4.31: Minimum tariffs for positive NPV under the effect of GHG incomes

Types	Minimum Tariff ($/MWh)	
	GHG reduction income ($10/tCO2)	GHG reduction income ($30/tCO2)
PTC	310	290
LFR	305	285
SPT	200	180

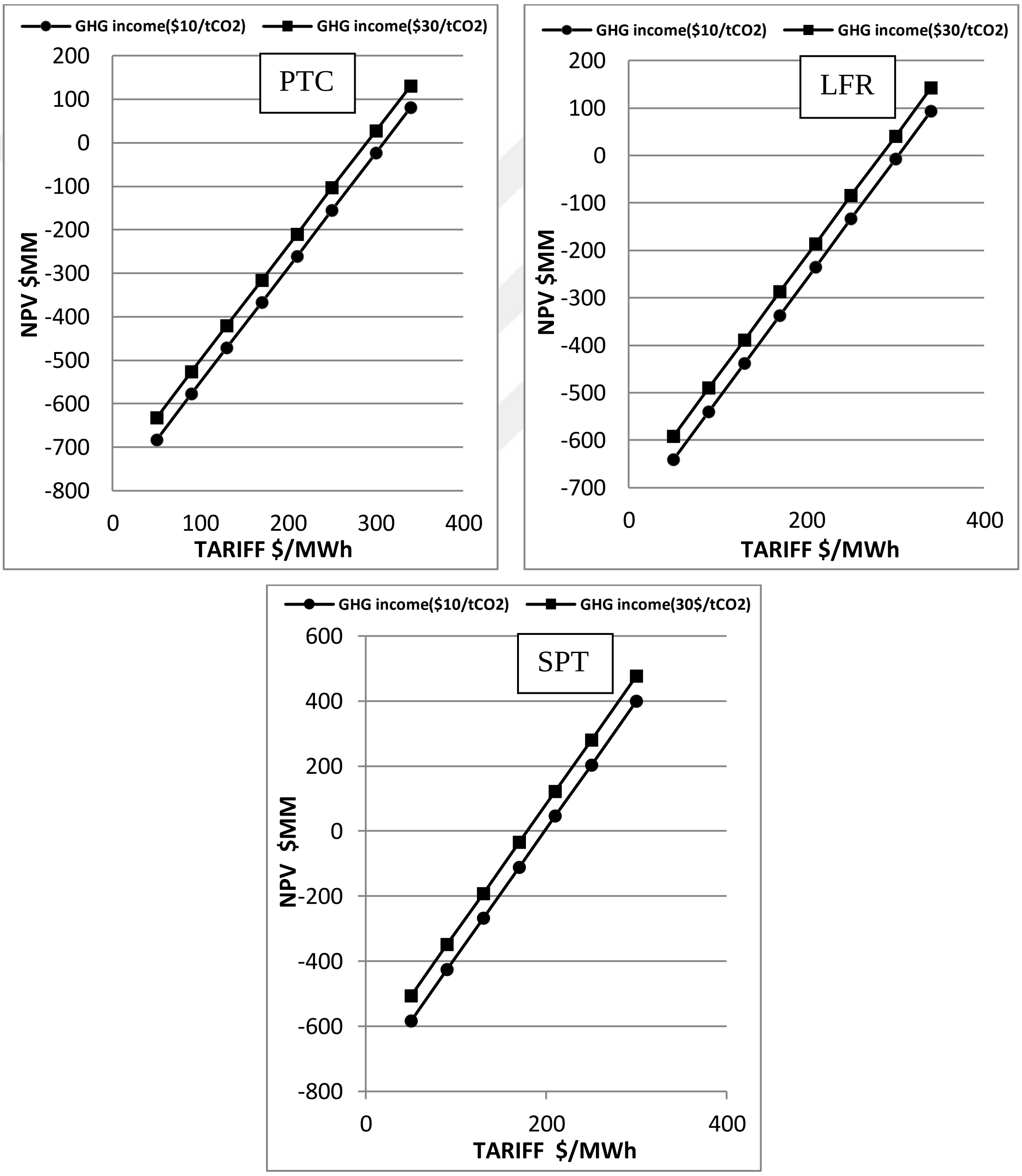


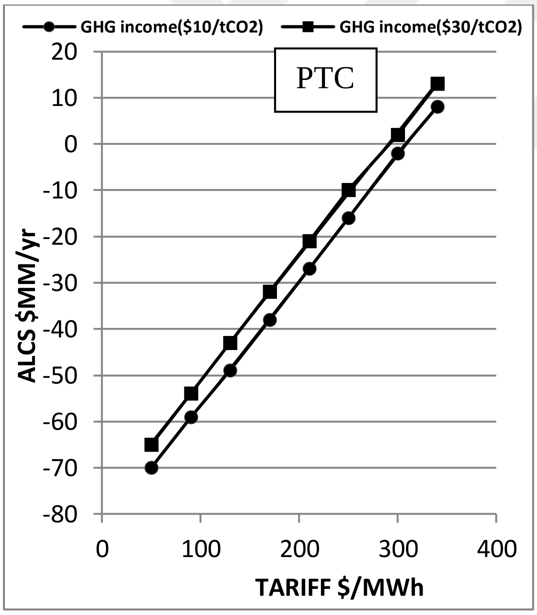
Figure 4.18 : Impact of GHG income on SPB for the different types under storage of 9 h

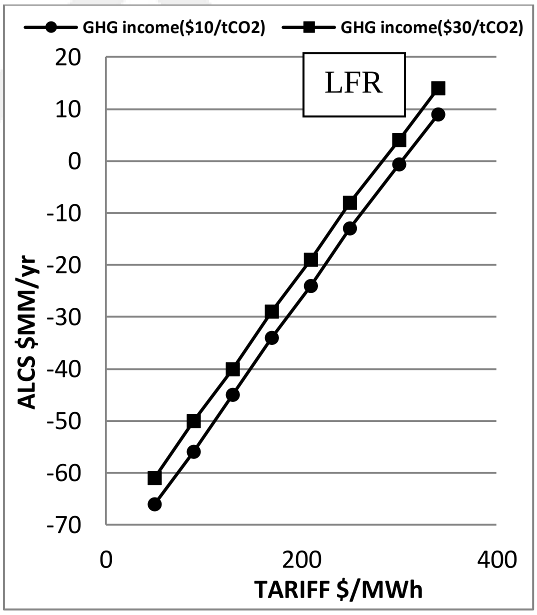
Table 4.32 : Impact GHG reduction incomeon the NPV under different tariff conditions.

Tariff $/MWh	NPV $MM					
	PTC with storage 9 h		LFR with storage 9 h		SPT with storage 9 h	
	$10/tCO_2	$30/tCO_2	$10/tCO_2	$30/tCO_2	$10/tCO_2	$30/tCO_2
50	–684	–632	–641	–592	–584	–505
90	–578	–527	–540	–490	–426	–349
130	–472	–421	–438	–389	–268	–192
170	–367	–316	–337	–287	–111	–34
210	–261	–210	–235	–186	46	122
250	–156	–104	–134	–84	203	280
300	–24	27	–7	41	400	477
340	81	130	93	143		

- **Impact of GHG income on Annual Life Cycle Saving under different tariffs conditions**

By the same way of analysis of TES 0h the following results are obtained:





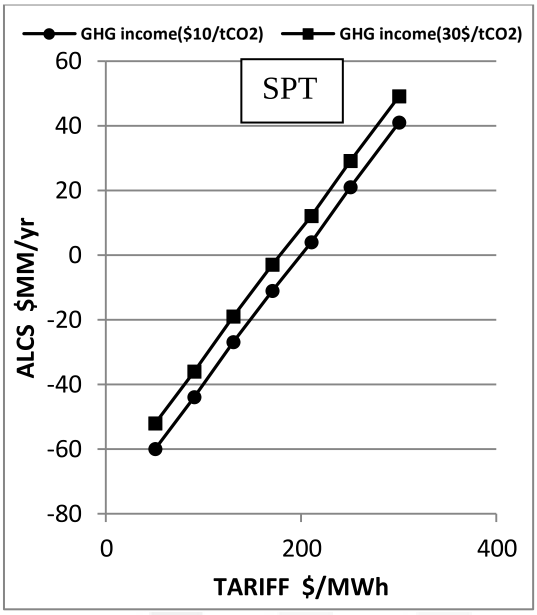


Figure 4.19: Impact of GHG income on ALCS for the different types under storage of 9h.

Table 4.33: Impact GHG reduction income on the ALCS under different tariff conditions.

Tariff $/MWh	**ALCS $MM/yr**					
	PTC with storage 9 h		**LFR with storage 9 h**		**SPT with storage 9 h**	
	$10/tCO_2$	**$30/tCO_2$**	**$10/tCO_2$**	**$30/tCO_2$**	**$10/tCO_2$**	**$30/tCO_2$**
50	–72	–65	–66	–61	–60	–52
90	–59	–54	–56	–50	–44	–36
130	–49	–43	–45	–40	–27	–19
170	–38	–32	–34	–29	–11	–3
210	–27	–21	–24	–19	4	12
250	–16	–10	–13	–8	21	29
300	–2	2	–7	4	41	49
340	8	13	9	14		

Table 4.34 shows the summery of scenario 2 which achieves the best tariff by using NPV indicators.

Table 4.34: Minimum Tariff for positive NPV

Storage	**GHG income**	**PTC**	**LFR**	**SPT**
0 h TES	($10/tCO2)	230	320	280
	($30/tCO2)	215	290	260
3 h TES	($10/tCO2)	245	280	215
	($30/tCO2)	230	260	195
9 h TES	($10/tCO2)	310	305	200
	($30/tCO2)	290	285	180

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

There are many advantages of founding a solar energy project in Baghdad. Those advantages are:

- The presence of water sources which are used in cleaning the solar panels and also in the cooling process to increase the system efficiency.
- The easy access to the electric grid lines and transport routes
- The high solar radiation

Three different thermal power systems are investigated and compared in this study for different thermal storage times. Those are the parabolic trough collector (PTC), the linear Fresnel reflector (LFR) and the solar power tower (SPT). The investigation includes technical estimation for the annual energy production and capacity factor, financial estimation for the project cost, simple pay back, net present value and annual life saving. The effect of grants and GHG emissions are also studied.

The technical estimation has shown that the SPT yields the highest capacity factor and annual energy production followed by PTC. Where, LFR gives the lowest capacity factor and annual energy production. As the thermal storage time increases from 0 to 3 hours, a big jump in the percentage of the annual energy production specially in the case of using SPT (35 % increase in AEP) is noticed followed by LFR (15 % increase in AEP). Where, the increase in AEP by using PTC is only 6.2%. On the other hand, as the thermal storage time increases from 3 hours to 9 hours, the increase in AEP becomes less pronounced with the following parentages; 15% for SPT, 2.65 % for PTC and 2.45% for LFR.

The effect of greenhouse gases (GHG) reduction, which is measured in tones of CO2 (tCO2), of all the different types of concentrated solar power systems is very clear from the results. The results have shown that the SPT yields an annual reduction of about 263 ktCO2 followed by PTC with around 252 ktCO2 and LFR with 222 ktCO2. As the thermal storage time increases, the net annual GHG reduction increases too. The main drawback of using SPT is the large area occupied by the project. 110 MW project using SPT requires a land area of about 7 km2. Using PTC, a land area of around 3.3 km2 is needed. LFR requires the smallest area of about 1.8 km2.

The financial evaluation was conducted under two different scenarios. The first scenario includes the effects of thermal energy storage and three different grants on the simple payback, net present value and annual life cycle savings without analyzing the effects of GHG reduction. In the second scenario, the grants are excluded and the effects of GHG reduction income on the simple payback, net present value and annual life cycle savings are studied for different thermal storage times. The minimum tariff required for each case is also investigated. To do such financial evaluation, a cost analysis of the project using each CSP system must be done. The results of the cost analysis show that the SPT has the highest cost followed by LFR, where, PTC has the lowest cost. The cost increases as the thermal storage time increases.

Scenario 1:

The positive net present value means the project income is more than the project cost and it is a very important measure for the project feasibility. With grant 1, the minimum tariff for positive NPV without storage is lowest in the case of PTC with \$240/MWh followed by SPT with \$295/MWh, where it is the highest in case of LFR with \$330/MWh. This is due to the cost for PTC being the lowest and the annual energy production for SPT being the highest. Where, the AEP is lowest in case of LFR with its cost being in between. As the thermal energy storage increases, the both of the system cost and AEP increase. In case of PTC, as the storage increases, the minimum tariff for positive NPV increases too making the system less efficient at high storage times. The reason is that, for PTC, the increase in storage times causes an increase in the cost more than the increase in AEP income. From the previous analysis, the percentage increase in AEP is only 6.2 % as the storage increase to 3 hours and only 2.65 % as it increase to 9 hours. For the LFR CSP system, as the storage increase to 3 hours, the minimum tariff decrease making the system more efficient. However, as the storage time increases to 9 hours, the minimum tariff increases and the system becomes less efficient. On the other hand, the SPT system becomes more efficient as the storage time increase and the tariff decreases. Looking at the tariff values, without grant, the minimum tariff values are high and higher than the average worldwide tariff (80$/MWh) for all the systems and under the investigated storage times. For acceptable tariffs, at least grant 3 must be supplied. This is the general case for all the concentrated solar power systems in the world. No system can be efficient without grants. The best results were obtained as follow:

- PTC with grant 3 and without storage (tariff is $75/MWh)
- SPT with grant 3 and 3 or 9 hours storage (tariff is $110/MWh)
- LFR with grant 3 and 3 hours storage (tariff is $100/MWh)

Scenario 2:

Here the effects of GHG reduction income on the minimum tariff for positive NPV without grants are studied under different storage times. Two different prices are assigned to each tone of CO2 reduced $10/tCO2 and $30/tCO2. Without grants, the effects of GHG reduction income is seen on the minimum tariff for positive NPV. However, this reduction income is not enough for the project to be feasible. Grant must also be considered for concentrated solar power systems.

5.2 Recommendations

The following recommendations are suggested:

- The ground measurement of the direct normal component of the solar irradiance has to be measured with a Normal Incidence Pyrheliometer for Baghdad and other promising sites across Iraq.
- Further development for financial evaluation could be done on the model to change other factors such as the initial cost of the plant, O&M and project life.
- Merging the plants with conventional power stations (hybrid) to increase annual energy production.
- Further work could be done to contain the compact linear Fresnel Reflector. This kind of LFR achieves the lowest area followed by a reduction in the cost.
- CSP plants can make use of fossil systems to achieve greater operating flexibility and dispatch ability. This provides the ability for the plants to work in any circumstance rather than only when sufficient solar insolation is available to produce electricity.

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