A REAL OPTIONS APPROACH TO VALUATION OF PHOTOVOLTAIC POWER INVESTMENTS ON ROOFTOPS OF RESIDENTIAL AREAS IN TURKEY

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ABSTRACT

A REAL OPTIONS APPROACH TO VALUATION OF PHOTOVOLTAIC POWER INVESTMENTS ON ROOFTOPS OF RESIDENTIAL AREAS IN TURKEY

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Diminishing non-renewable energy resources, increasing energy prices, and the outgrowth of carbon footprints have made investments in renewable energy resources indispensable. Power generation through renewable solar energy can be made through state-of-art photovoltaic (PV) systems. Although PV systems on residential rooftops offer great solar energy potential, initial costs are considerably high, and there exist such uncertainties as fluctuating PV panel prices, changing meteorological conditions affecting power-generation-processes, and governmental demeanors, related to energy market regulations, prices, and fees. The economic feasibility of such investments is generally determined using Net Present Value (NPV). Considering the high initial costs, uncertain, yet increasing annual costs, and high inflation rates, it is apparent that NPV assessment would not favor the investment under the now-or-never enforcement of the method. In this study, the Real Options Valuation (ROV) with Least Square Monte Carlo Simulation (LSMC) method is proposed for evaluating the residential PV investment decisions in Turkey. Respectively, a PV investment on a household roof in Kocaeli, Turkey, is assessed using both methods; "NPV" and "ROV with LSMC having a seven-year deferral option." Consequently, it is demonstrated that while the NPV method results in an infeasible investment, the ROV with LSMC method supports the investment by giving the investor realizable cost-effective options; since it also considers the deferral of the investment in time - by utilizing stochastic simulations, the discounted cash flow method, linear regression, and backward dynamic programming - and thus evaluates the effects of future uncertainties on the potential future opportunities in residential PV investment. Based on the findings, the probable government incentives easing and promoting solar energy generation in Turkey are investigated.

Keywords: Residential Photovoltaic Investments, Turkey, Real Options Valuation (ROV), Least Square Monte Carlo Simulation (LSMC), Government Incentives

ÖZ

TÜRKİYE'DE YERLEŞİM ALANLARININ ÇATILARINA YAPILAN FOTOVOLTAİK ENERJİ YATIRIMLARININ DEĞERLENDİRİLMESİNDE GERÇEK OPSİYONLAR YAKLAŞIMI

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Yenilenemeyen enerji kaynaklarının azalması, artan enerji fiyatları ve karbon ayak izlerinin büyümesi, yenilenebilir enerji kaynaklarına yapılacak yatırımları vazgeçilmez hale getirmiştir. Yenilenebilir güneş enerjisi ile elektrik üretimi, son teknoloji fotovoltaik (PV) sistemler aracılığıyla yapılabilir. Konut çatılarındaki PV sistemleri büyük güneş enerjisi potansiyeli sunsa da, ilk yatırım maliyetleri oldukça yüksektir. Ayrıca bu yatırımlarda istikrarsız PV panel fiyatları, enerji üretim süreçlerini etkileyen değişken meteorolojik koşullar ve devlet tarafından sıklıkla güncellenen enerji piyasası yönetmelikleri nedeniyle değişkenlik gösteren devlet destekleri, harçlar ve ücretler gibi belirsizlikler mevcuttur. Bu tür yatırımların ekonomik fizibilitesi genellikle "Net Güncel Değer (NPV)" kullanılarak belirlenir. Yüksek ilk yatırım maliyetleri, istikrarsız ancak genel olarak artan yıllık maliyetler ve yüksek enflasyon oranları göz önüne alındığında; yatırım için "şimdi" ya da "asla" dayatmasına tabi tutan NPV metodu ile yapılacak bir değerlemenin bu yatırımı yapmamak doğrultusunda bir sonuca varacağı kesindir. Bu çalışmada, Türkiye'de konut çatılarına yapılacak PV yatırım kararlarının değerlendirilmesi için "En Küçük

Kareler Monte Carlo Simülasyonu (LSMC) ile Gerçek Opsiyonlar Değerlemesi (ROV)" yöntemi önerilmiştir. Bu kapsamda Kocaeli, Türkiye'de bulunan bir konutun çatısına yapılması planlanan bir PV yatırımı; "NPV" ve "yatırımı yedi yıl erteleme seçeneğini göz önünde bulunduran LSMC ile ROV" yöntemleriyle değerlendirilmiştir. NPV metodu ile yapılan yatırım değerlemesinden elde edilen sonuç, yatırım karlı olmadığından kesinlikle yapılmaması doğrultusunda çıkmıştır. Ancak LSMC ile ROV metodu kullanılarak yapılan değerlemede yatırımın erteleme opsiyonunun da değeri hesaba katıldığı için yatırımcıya gerçekleşebilecek, elverişli ve karlı bir sonuç ortaya konmuş ve yatırımın önünün kapanmasını engellenmiştir. Bu iki yöntem arasında farklı sonuçlar alınmasının nedeni, LSMC ile ROV metodunun stokastik simulasyonlar, indirgenmiş nakit akışı, doğrusal regresyon ve geriye dönük dinamik programlama gibi yöntemler kullanarak yatırımın barındırdığı belirsizliklerin gelecekte oluşabilecek potansiyel fırsatlar üzerindeki etkilerini göz önünde bulundurmasından kaynaklanmakta olup; bu metodun bu tarz belirsizlik içeren yatırımlara uygulanması olumlu sonuçlar vermektedir. Ayrıca bu çalışmada, Türkiye'de güneş enerjisi yatırımlarını yaygınlaştırmak üzere kullanılan ve kullanılabilecek olası devlet teşvikleri de araştırılmıştır.

Anahtar Kelimeler: Mesken Fotovoltaik Yatırımları, Türkiye, Gerçek Opsiyonlar Değerlemesi (ROV), En Küçük Kareler Monte Carlo Simulasyonu (LSMC), Devlet Teşvikleri

Dedicated to the people who have supported me throughout my education.

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ABBREVIATIONS

AC	Alternating Current
CES	Renewable Energy Certificate
DC	Direct Current
FIT	Feed-in Tariff
GBM	Geometric Brownian Motion
GDP	Gross Domestic Product
GW	Gigawatt
IRR	Internal Rate of Return
ITC	Investment Tax Credit
kW	Kilowatt
kWh	Kilowatt-hour
LCOE	Levelized Cost of Energy
LSMC	Least Squares Monte Carlo Simulation
NEM	Net Metering
NPV	Net Present Value
PTC	Production Tax Credit
PV	Photovoltaic
PwC	Price Waterhouse and Coopers & Lybrand Company
REC	Renewable Energy Certificate

ROR	Rate of Return
ROV	Real Options Valuation
RPS	Renewable Portfolio Standard
SME	Small Medium Enterprises
TEDAŞ	Turkish Electricity Distribution Company
TL	Turkish Lira
TWh	Terawatt-hour
US	United States of America
USD	United States Dollar
Wp	Watt-peak

CHAPTER 1

INTRODUCTION

Energy is an essential part of our daily lives, powering everything from our homes and businesses to our transportation and communication systems. However, the use of nonrenewable energy resources such as fossil fuels has led to significant environmental concerns, including air and water pollution and greenhouse gas emissions that contribute to climate change. The Paris Agreement, a global agreement reached in 2015 to address climate change, aims to limit the global temperature increase to well below 2 degrees Celsius above pre-industrial levels, with a target of limiting the increase to 1.5 degrees. In light of these concerns, there has been an increased interest in renewable energy sources such as solar energy..

Solar energy is a clean, sustainable, and renewable energy source that is generated by harnessing the sun’s power through solar panels. These panels convert the sun's energy into electricity that can be used to power homes, businesses, and communities. One of the key advantages of solar energy is that it is a decentralized form of energy generation, meaning that it can be generated at the point of use rather than transported over long distances. This reduces transmission losses and allows for greater energy independence. Additionally, solar energy is a domestic energy source; it does not require any fuel import and can help reduce the dependency on foreign energy sources.

Despite its many advantages, solar energy has yet to become a mainstream power source due to factors such as the high cost of installation, lack of efficient storage solutions, regulatory and policy challenges, and uncertain market conditions in panel prices, inverter prices, and unit electricity costs. Government incentives and subsidies in many countries provide additional financial support to encourage the adoption of solar energy, making it even more accessible to households, businesses, and communities. Still, according to traditional valuation methods, these investments result in negative cashflows.

Turkey has significant potential for the development of solar energy due to its high levels of solar irradiance and favorable climate conditions. The country receives an average of around 1,800 to 2,200 kilowatt-hours per square meter per year, which is among the highest in Europe. This high level of solar radiation makes Turkey an ideal location for solar power generation, with the potential to generate significant amounts of electricity from solar panels.

The real option valuation method is an advanced financial analysis method that evaluates an investment's potential flexibility and strategic value by treating it as an option. It is used to analyze and make strategic decisions on investment opportunities with high levels of uncertainty. Since solar energy investments involve high levels of uncertainty, the method would be suitable for evaluating these investments. With the addition of the option value, which reflects the value produced with the managerial moves of the decision makers in the procedure such as postponement, abandon etc., the results may end up in favor of solar energy investments that reflects the reality more. Thus, with the use of the real options valuation, the potential loss of investment opportunity in solar energy in Turkey may be prevented, and such investments can be paved.

This thesis has been organized as follows:

In Chapter 2, the literature review made on energy and valuation methods will be summarized. The current status of the energy resources will be investigated. Then, the traditional valuation methods and the real options valuation method will be explained and compared. Also, the ROV applications on energy investments in the literature will be shared. In Chapter 3, the significance of the research will be explained in addition to the research problem, objective, and approach. In Chapter 4, the findings of the interviews made with experts in the solar energy field will be shared on the basis of the questions asked. In Chapter 5, the least square Monte Carlo simulation method which will be used in the case study will be explained under the context of residential solar energy investments. In Chapter 6, a case study that utilizes the method explained in the previous chapter is made and the steps of valuation of a residential PV investment located in Kocaeli, Turkey will be explained. In Chapter 7, a literature review on government incentives for solar PV investments is shared. After the importance of these incentives is discussed, two new incentives are offered for residential PV investments on rooftops of buildings. The two incentives are applied to the case study separately, and the acquired results are also shared in that section. In Chapter 8, the discussion of the findings of both the case study and the impacts of the offered incentives is made from the perspectives of policymakers, investors, and researchers. In Chapter 9, a brief summary of this study is shared. Then the shortcomings of this work are explained and recommendations for future works are shared.

CHAPTER 2

LITERATURE REVIEW ON ENERGY AND VALUATION METHODS

In this chapter, the literature review on energy and valuation methods are shared. Firstly, the energy resources in Turkey are investigated and renewable energy potential of Turkey is identified for various resources. Then, the valuation methods in literature are investigated and the most common ones are explained briefly. The gathered information on real options valuations is explained including the real option types and solution methods. Finally, the literature review on energy investments and real options valuation is shared and the gap in the literature has been identified.

2.1 Energy Sector in Turkey

As defined by the scientist, energy is the capacity to do the work (U.S. Energy Information Administration, 2022b). It is an essential part of our daily lives and is required for many activities, including powering our homes and businesses, fueling our vehicles, and cooking our food. Without a reliable energy source, many aspects of modern society would grind to a halt. Additionally, energy plays a vital role in driving economic growth and development (Kotcioglu, 2011). It is used to power machines and industrial processes, which allows for the production of goods and services. Therefore, access to energy is often seen as a vital indicator of a country's economic strength and stability. Finally, energy is also crucial from an environmental perspective, as the way it is generated and used can significantly impact the planet's health.

Since the late 1800s, many different energy generation ways have been used in countries. Even though there exist many different classifications for energy resources, it is possible to classify energy resources into two groups such as non-renewable and renewable energy resources (Toptaş, 2016) which can be seen in Table 2.1. The most common non-renewable energy resources are coal, oil, natural gas, and nuclear. These resources cannot be replenished or replaced once they are consumed, and eventually, they will run out due to their limited availability. On the contrary, renewable energy resources are considered sustainable since they can be replenished or replaced continuously once the required conditions are met. The most common examples of renewable energy resources are hydroelectric, wind, geothermal, biomass, and solar energy.

Table 2.1 Energy Resources in Turkey

Energy Resource	Non-Renewable Energy Resources	Coal
		Oil
		Natural Gas
		Nuclear Energy
	Renewable Energy Resources	Hydroelectric Energy
		Wind Energy
		Geothermal Energy
		Biomass Energy
		Solar Energy

Turkey has a GDP of 819 billion USD as of 2021, with a population of 85.04 million. Turkey is currently ranked as the 19^{th} highest GDP worldwide and is expected to grow further (The World Bank, 2022). According to a report done by (PwC, 2021) on the Turkish Electricity Market, the electricity demand in 2020 is stated as 305 TWh as seen on Figure 2.1.

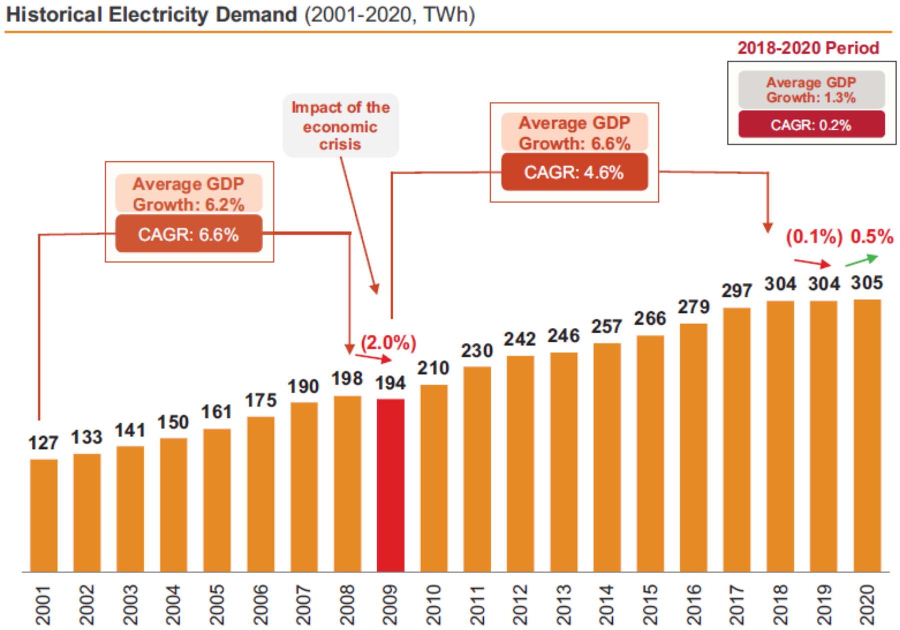

Figure 2.1. Historical Electricity Demand of Turkey (PwC, 2021)

Also, in the same report of PwC (2021), it is stated that due to the dependency of the industrial sector on electricity, energy prices play a vital role in industrial development. Since the main driver of economic growth is industrial development, energy demand and economic growth directly correlate. The correlation can also be seen in Figure 2.2 below.

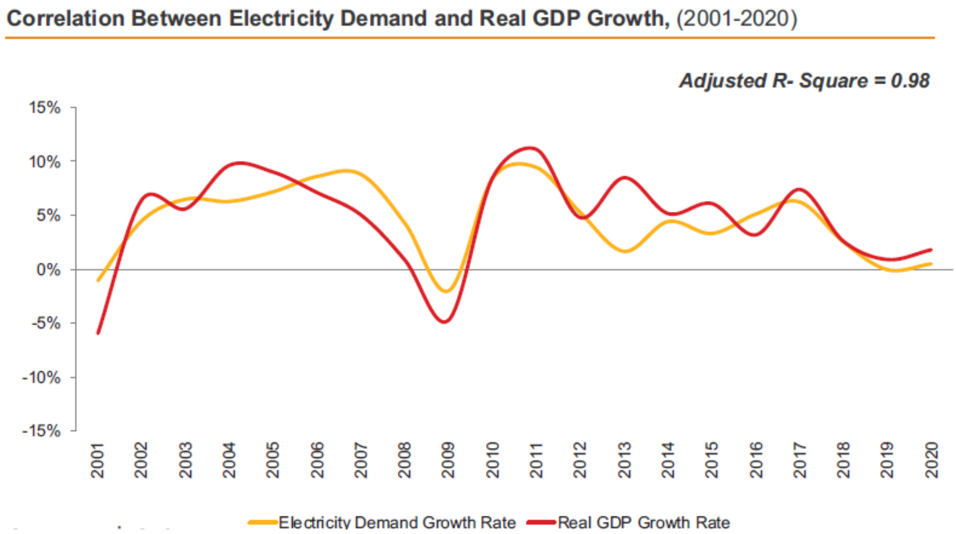

Figure 2.2. Correlation Between Electricity Demand and Real GDP Growth in Turkey (PwC, 2021)

With the ongoing economic growth policies of the Turkish government, it is suitable to state that there will be significant increases in electricity demand. To maintain economic growth, the Turkish government has to meet this demand. As of 2021, Turkey has an installed capacity of 98.5 GW as seen on Figure 2.3. Within this capacity, 20.6% generate electricity using coal, 25.6% generate electricity using natural gas, 0.3% generate electricity using liquid fuels, 31.9% generate electricity using hydropower, and the remaining 21.2% generate electricity using other renewable energy resources as solar and wind. Thus, it can be concluded that over 50% of the installed capacity uses renewable energy resources, and investments in renewable energy resources have increased substantially since 2010.

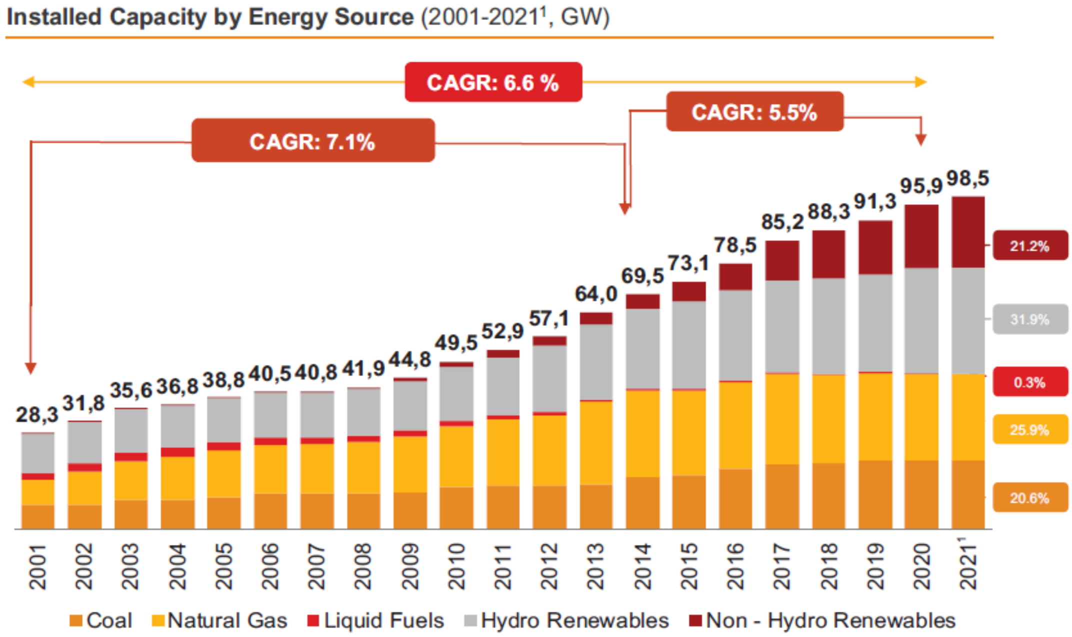

Figure 2.3. Historical Installed Capacity in Turkey by Energy Resource (PwC, 2021)

Even though renewable energy resources drive almost 54% of the domestic energy production in Turkey, Turkey can only cover 31% of its total primary energy supply and is still highly dependent on energy imports from foreign countries (International Energy Agency, 2022a). Since Turkey is not a country rich in natural energy resources such as coal or oil, in order to maintain economic growth, investments in domestic energy production using renewable energy resources should be made, which are highly abundant due to the geographical location of Turkey. However, such investments in renewable energy resources have considerable capital costs, and as a developing country, Turkey does not possess sufficient funds for such investments (Akçay, 2014). Thus, the Turkish government must try to promote such investments to its citizens by demonstrating the potential profitability of such investments and enacting incentive policies for such investments.

The most commonly used renewable energy resources in Turkey, which can be invested in, are hydropower, wind, geothermal, biomass, and solar energy. Each of these energy resources is explained in detail below.

2.1.1 Hydropower

Hydropower is a renewable energy source that involves harnessing the energy of moving water to generate electricity. It is considered a clean and renewable domestic source of energy with low operating costs. It can help to reduce greenhouse gas emissions and mitigate climate change.

In Turkey, due to its geographical location being surrounded by seas on three sides and having many rivers, there is great potential for hydropower investments (Toptaş, 2016). The installed capacity of hydropower in Turkey among years is shown in Figure 2.4. As of June 2022, the installed capacity of hydroelectric energy is 31.558 GW which corresponds to 31.09% of the total installed power.

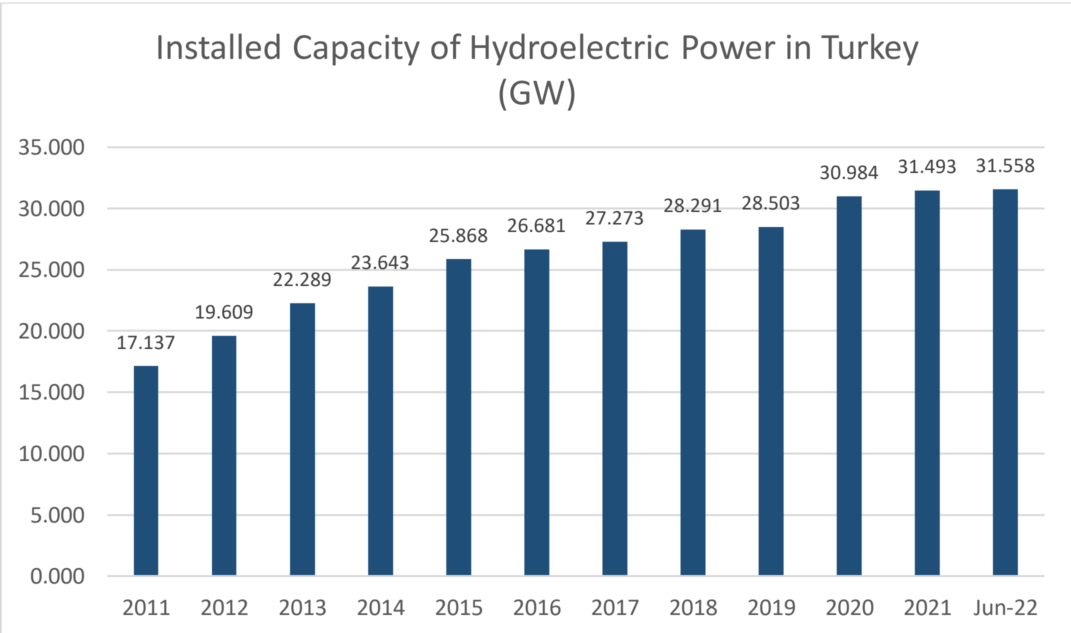

Figure 2.4. Installed Capacity of Hydroelectric Power in Turkey (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022d)

Even though hydropower seems the best viable renewable energy investment in Turkey due to its abundance and low operating cost, the construction cost of a dam is considerably high, reducing the availability of the investment to the majority of the population of Turkey. In addition to that, dams have many negative impacts on their surroundings once they are built. The displacement of local communities and destruction of the surrounding ecosystem due to vast reservoirs of dams are some of the many disadvantages of hydropower investments. Also, hydroelectric energy is highly dependent on weather conditions, and by considering the reduction in the rainfalls due to global warming, the energy production capacity of such investments decreases as the years pass.

2.1.2 Wind

Wind energy is another renewable energy source that uses wind turbines to generate electricity. A wind turbine consists of a rotor with blades, a generator, and a tower. When the wind blows over the blades, it causes the rotor to turn. This movement is converted into mechanical energy, which is then used to turn the generator and produce electricity (Akçay, 2014). The tower supports the weight of the turbine and raises it into the wind, where it can capture more energy.

In Turkey, according to the Ulu & Dombayci (2018), there exist a wind potential of 48GW. However, the current installed capacity as of June 2022 is 10.976 GW which corresponds to 10.81% of the total installed power as shown on Figure 2.5. Wind energy is considered to be a domestic renewable energy source with ease of commissioning and operation of the facility, and low cost of maintenance.

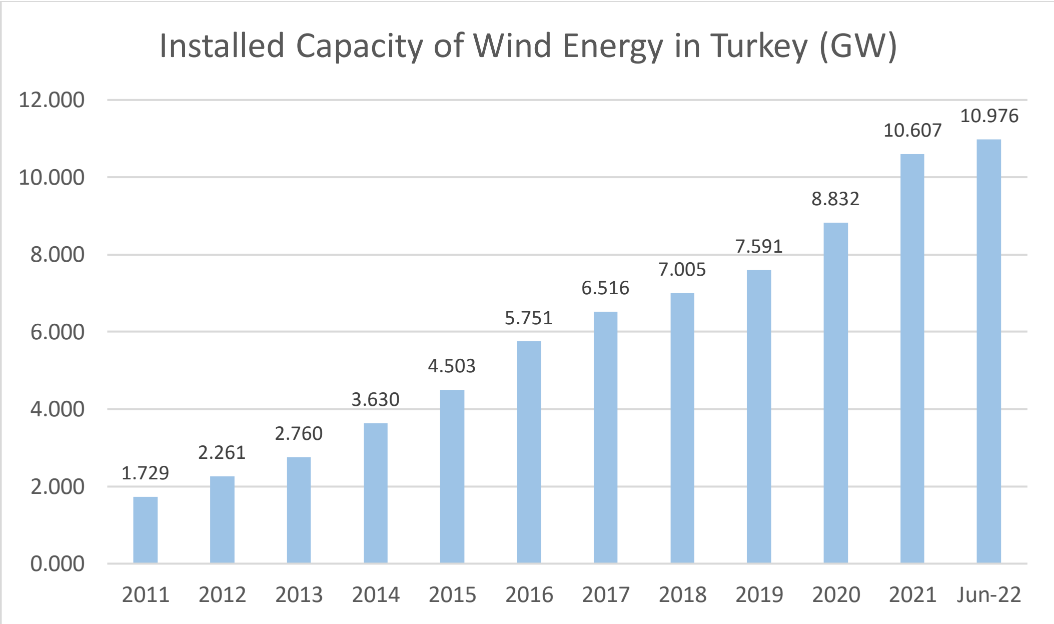

Figure 2.5. Installed Capacity of Wind Energy in Turkey (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022f)

Contrary to the estimated potential of wind energy in Turkey and the advantages, there are many reasons for the lack of such investments. In Turkey, most of the wind potential is in the Aegean region of Turkey as seen in Figure 6. The Aegean region is also one of Turkey's regions with widespread agricultural activities, such as olive and grapes. Also, due to the region's climate, many citizens invest in the lands of that region and live there. Thus, the land acquisition for wind energy investments in that area turns out to be a considerable impediment due to high costs and permit problems. Also, like hydropower investments, wind turbines have high initial costs, making such investments inaccessible to the majority of the public. In addition, since wind is a meteorological event, it is hard to estimate net energy production, and it is highly dependent on weather conditions which makes the investment questionable. Even though wind turbines generate a beautiful view from a distance, they cause too much noise that disturbs the surrounding local communities. Since wind farms composed of wind turbines require vast areas for construction, they damage the surrounding ecosystem by altering the natural habitat and causing the fatality of birds and bats, which affects the agricultural activities of the local communities adversely.

Due to the opposing views of the local communities, making such investments becomes more challenging in Turkey.

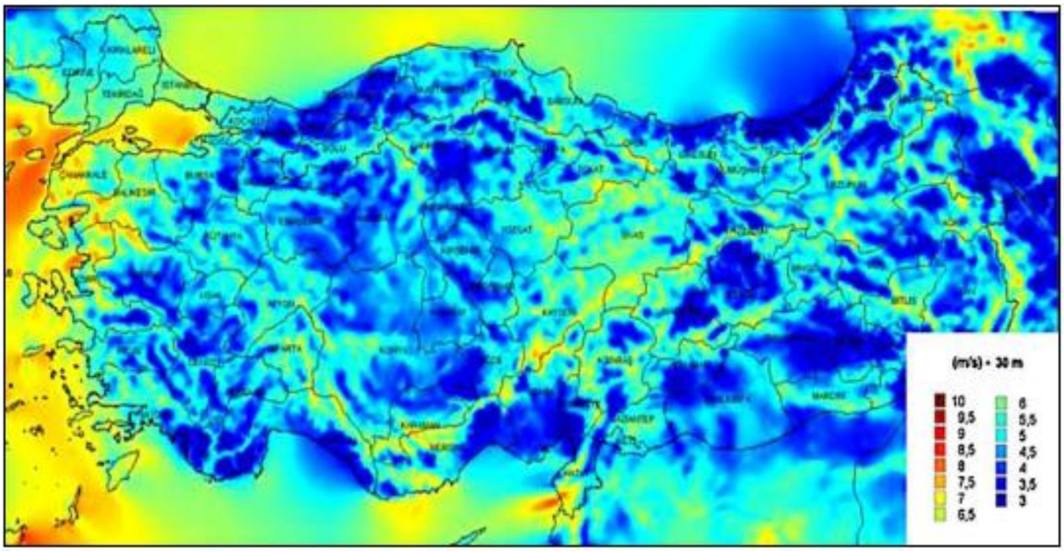

Figure 2.6. Velocity of Wind at 30m High in Turkey (Ulu & Dombayci, 2018)

2.1.3 Geothermal

Geothermal energy is a renewable energy source that involves harnessing the natural heat of the Earth to generate electricity. Geothermal power plants generate electricity by using steam produced by geothermal reservoirs to turn a turbine, which is connected to a generator. The steam is produced when water is injected into the geothermal reservoir and is brought back to the surface as a vapor. The steam is then used to turn the turbine, which generates electricity. It is considered a clean and renewable source of energy, and it has the potential to reduce reliance on fossil fuels. However, the requirement of drilling deep wells to harness geothermal energy can be very expensive and technically challenging. Even though Turkey is ranked 1st for geothermal energy potential in Europe, the cost barrier prevents such investments in Turkey. The installed capacity of geothermal energy in Turkey among years is shown in Figure 2.7. Currently, as of June 2022, the installed capacity of geothermal energy is 1.686GW, which corresponds to 1.66% of the total installed capacity.

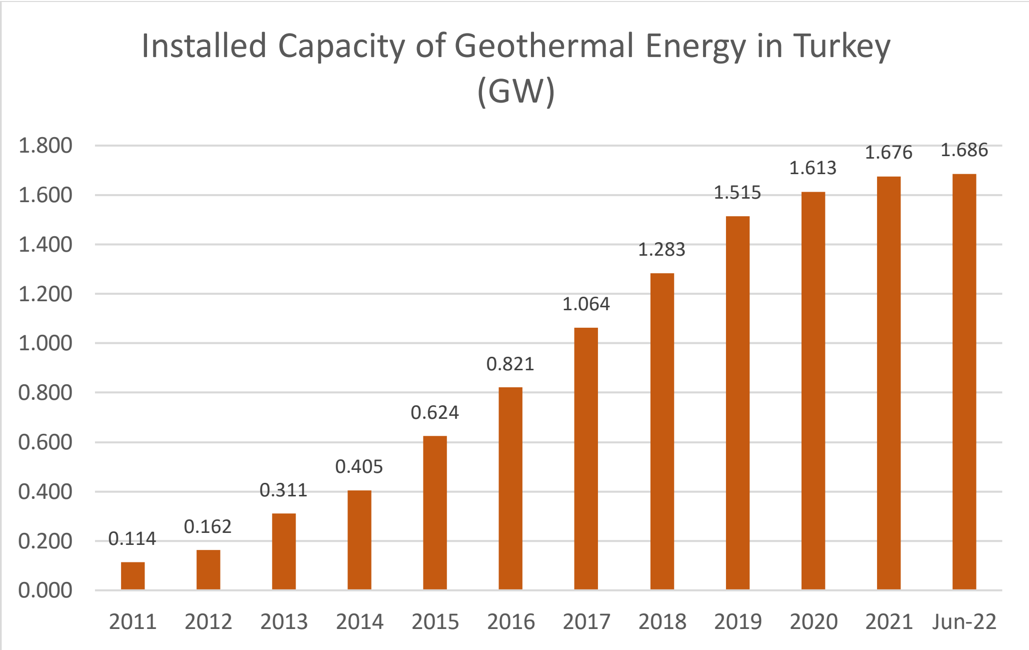

Figure 2.7. Installed Capacity of Geothermal Energy in Turkey (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022e)

2.1.4 Biomass

Biomass is a renewable energy source that involves the use of organic materials, such as wood, crops, and waste, to generate electricity and heat. Biomass power plants generate electricity by burning biomass in a boiler to produce steam, which is used to turn a turbine, which is connected to a generator. The steam is produced when the biomass is burned in the presence of air, and it is used to turn the turbine, which generates electricity.

The installed capacity of biomass energy in Turkey among years is shown in Figure 2.8. In Turkey, the installed capacity of biomass energy as of June 2022 is 2.172GW, which corresponds to 2.14% of the total installed power. Even though the plants burn waste which seems to help the environment, it also releases air pollutants such as carbon monoxide, which have adverse effects on human health and the environment. Also, due to its considerable initial investment cost, such investments are not very popular in Turkey.

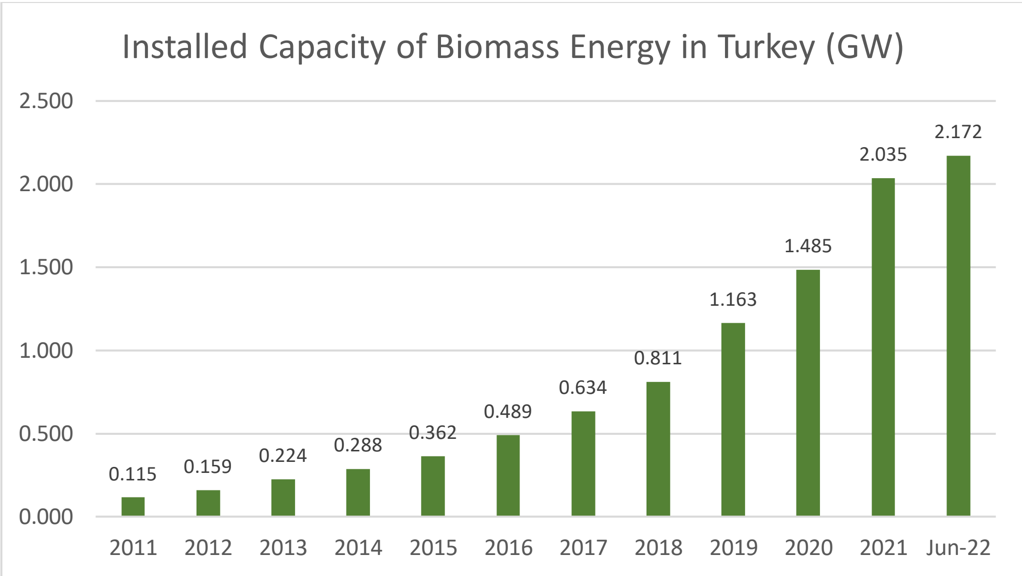

Figure 2.8. Installed Capacity of Biomass Energy in Turkey (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022a)

2.1.5 Solar Energy

Solar energy is a type of renewable energy that is generated by converting sunlight into electricity. Solar panels, also known as photovoltaic cells, are used to convert the sun’s solar energy into electricity. These cells are made of semiconductor materials, such as silicon, which absorbs the energy from the sun and releases electrons, causing a flow of electricity. The electricity generated by solar panels is direct current (DC) electricity, which cannot be used directly by most appliances and devices in our homes. So, it is typically converted to alternating current (AC) electricity by an inverter. AC electricity is the type of electricity that is used in our homes and businesses. The solar panels are typically mounted on the roof of a building or in a solar farm and are pointed towards the sun to maximize the amount of energy they can produce. The solar panels are connected to an inverter and electric grid, allowing the electricity to be used in the home or building or sold back to the grid.

Solar energy is one of the most important renewable energy resources with various advantages and very few disadvantages. Solar energy is one of the cleanest and most sustainable sources of energy which does not generate any pollutants or greenhouse gases during the electricity production processes. It is abundant and can easily be harnessed since sunny days are common in most countries worldwide. In addition to that, to harness solar power, many different applications exist, such as rooftop applications or solar farms, which can be located in remote and off-grid locations to generate electricity. The generated power on these different applications can be used in many ways, such as providing electricity for houses, businesses, factories, plantations, etc. Another benefit of solar energy emerges when applied on rooftops. Once the electricity generated on those rooftops is transmitted to the grid, it will create positive effects on the transmission and distribution networks by regulating the voltage on the grid and stabilizing it, especially at locations with voltage fluctuations (International Energy Agency, 2022b).

When compared with other renewable energy resources, solar energy does not produce any additional pollutants, can be applied in various locations, does not cause any disturbances to the local communities near the area of application, is very easy to install and commission, and causes almost no harm to the environment. Thus, it is suitable to say that solar energy investments are much more favorable than other renewable energy resources. This can also be verified by looking at the following figure about global annual investments in the power sector by technology.

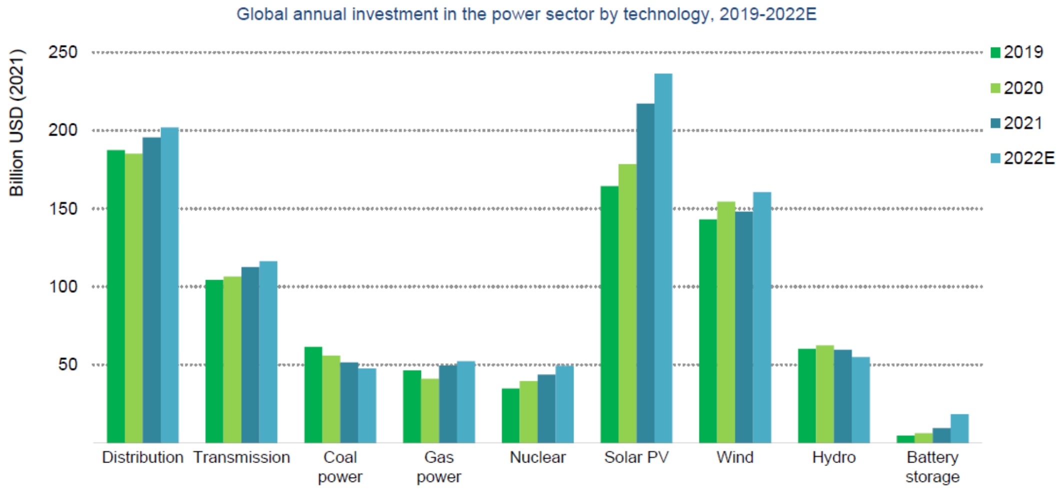

Figure 2.9. Global Annual Investment in the Power Sector by Technology (International Energy Agency, 2022b)

In Turkey, solar energy investments began in 2012. According to the Turkey 2021 – Energy Review by International Energy Agency (2022a), in 2019, the installed capacity reached 5995 MW. One of the reasons for this rapid increase in the installed capacity of solar energy is 1600 MW investments in unlicensed solar production, including installations on rooftops between the years 2017 and 2018. It is estimated that by 2030 Turkey will reach a 38 GW solar potential, and this generates a huge opportunity for upcoming investments in solar energy.

The report of PwC (2021) on the Turkish Electricity Market states that between 2011 and 2020, while the installed capacity of solar energy in the world has increased by 28% and Europe has increased by 13%, Turkey has made investments in the solar energy sector between those years corresponding to a 25% increase in the installed capacity. Thus, it is suitable to state that Turkey is following the trends of the world on solar energy and making progress toward those investments. When the renewable electricity generation amounts of the world and Turkey are compared between 2011 and 2020, the electricity generation using solar power in the world has increased by 33%. In Turkey, the increase is 81%. The installed capacity of Turkey is actively used in electricity generation and has shown a considerable increase between 2011 and 2020.

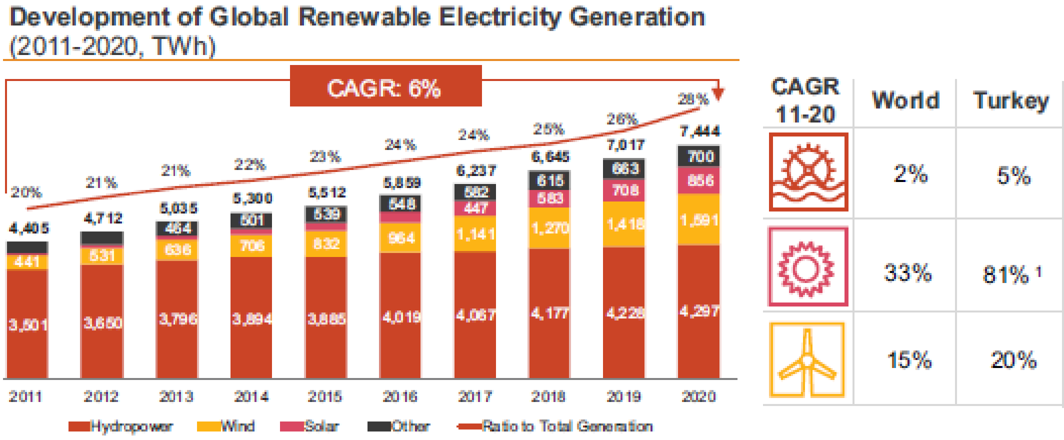

Figure 2.10. Development of Global Renewable Electricity Generation (PwC, 2021)

According to the Turkish Statistical Institute, in Turkey, there exist 11.6 million structures that are suitable for solar energy investments at either their rooftops or facades and 87% of these structures are residential buildings. In addition to that, each year, more than 100000 new buildings are constructed, which are also potential areas of application for solar energy (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b).

Considering all the information, it is suitable to state that solar energy is one of the best renewable energy resources and its investments possess undeniable potential, especially in Turkey. In addition, the fact that solar energy investments can be applied to roofs also presents an opportunity for a country like Turkey, which has many buildings and where more buildings are being built with the leadership of the construction sector. Considering that the majority of these buildings are also residential and the most ideal scenario for a sustainable future is for each individual to produce their own electricity, it is possible to say that solar energy systems built on roofs of residential buildings can be very beneficial and good investments in Turkey.

2.2 Investment Valuation Approaches

Every individual who manages to save some money and company try to make investments in pursuit of growing their wealth, generating income and eventually achieving their financial goals and they have to decide on the best option to invest in. Investment valuation is the process of evaluating and planning these long-term investments. Since the world is a place where there is a scarcity of resources, this process becomes very important and needs to be done with great care. Investment valuation is a critical aspect of financial management that requires analysis of the potential costs and benefits of an investment in addition to the risks and uncertainties associated with it to make solid decisions on the allocation of these resources. The importance of investment valuation lies in its ability to optimize the allocation of capital and to help individuals and organizations achieve their strategic objectives by identifying and prioritizing investment opportunities that are likely to generate positive returns. By providing a systematic and structured approach to decision-making, investment valuation methods help organizations and individuals make informed and effective decisions about how to allocate their capital resources in a way that will maximize the value and profitability of the organization.

There exist many methods of investment valuation, but they are mainly classified into two groups investment valuation methods under certainty conditions and uncertainty conditions. In the group of investment valuation methods under certainty conditions, there exist two subgroups static and dynamic methods. While the static methods do not consider the time value of the money, the dynamic methods consider it (Şenel, 2005).

Even though there exist many different investment valuation methods, among the dynamic methods under certainty conditions, some of them are more commonly used than others. According to a survey done by Graham & Harvey (2001), it is stated that the rate of return, net present value, and payback period methods are the most used ones around the world. Also, in Turkey, according to another survey done by Erkan & Kula (2000), it is found that among 228 SMEs, 32% utilize the net present value method, 29.8% utilize the payback period method, and 26.3% utilize the rate of return method for investment valuation.

The three most common investment valuation methods namely the net present value method, the rate of return method, and the payback period method are explained in detail as follows.

2.2.1 Net Present Value

The net present value method (NPV) is a financial analysis tool that evaluates an investment or asset in terms of profitability by comparing the present value of initial and future cash flows generated. A well-known quote state that the value of a dollar worth less than a dollar yesterday (Messner, 2013). This is known as the time value of money, and present value is the amount of cash in today's value of a future cash flow.

The NPV of an investment is calculated by discounting all the expected cash flows back to the present using a predetermined discount rate which considers the time value of the money and the associated risk of investment. Then, the net equivalent of the discounted cashflows and initial costs are taken. According to the outcome, the investment decision is made such that if the equivalent amount is positive, the investment should be made and if the equivalent amount is negative then the investment should be rejected. The general formula for calculating the NPV of a project is as follows.

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+i)^n} \quad (2.1)$$

where C_t is the emerging cash flows, and i is the discount rate.

The main weakness of the NPV method is that the method relies highly on decisions made by the investor such as the expected cash flows. Under uncertainty, the NPV method falls short and may result in wrong decisions if the investment is evaluated only by NPV.

2.2.2 Internal Rate of Return

The internal rate of return (IRR) is another financial analysis tool that is mainly used to calculate the profitability rate of an investment. The method tries to estimate the discount rate that makes the NPV of the project equal to zero. Then the calculated rate is compared with the opportunity cost of capital, and in order to classify an investment as attractive, the calculated rate is expected to be greater than the opportunity cost of capital (Dai et al., 2022).

Even though the IRR method is easy to use, it has several disadvantages as the method ignores the size of the cash flows and may result in making smaller projects more attractive. Also, similar to NPV, the method highly relies on decisions made by the investor about future cash flows and uncertainty.

2.2.3 Discounted Payback Period

The discounted payback period is a financial analysis tool that evaluates the profitability of an investment by calculating the period required for the recovery of the invested amount of money with the projected cash flows by considering the time value of the money (Bhandari, 1985). The method basically estimates the time the investor has to wait to recover the initial investment cost of an investment.

However, the discounted payback period has a major shortcoming such that the method ignores the future cash flows beyond the discounted payback period. Thus, in case of an investment that generates greater return during the days beyond its discounted payback period, the method falls short and will lead to wrong investment decisions and missed opportunities (Dai et al., 2022).

2.3 Real Options Valuation

Real options valuation is a financial approach that is used specially to evaluate investments that are characterized by uncertainty. It is a very useful valuation method, especially for firms that are trying to make investments in their research and development, which involves great uncertainties and comes with the requirement of managerial flexibility (Mun, 2002). The method estimates the economic value of the decision-making opportunity of the company strategists and enables organizations to make more accurate decisions by including this value. The real option valuation can be classified as an extension of the financial option theory in which, for the case of real options valuation, the options are about the real assets and managerial decisions on those assets. In financial options, the options are clearly explained in contract documentation done by the two parties, but in real options valuation, real options should be identified with in respect of the investment's strategic decisions such as postponement, expansion, etc. (Amram & Kulatilaka, 1998). In this section, the real options valuation will be explained starting from the terminology of uncertainty, risk, and flexibility which are included in the method. Then, the real options, types of real options, and solution methods for valuing real options will be identified.

2.3.1 Uncertainty, Risk, and Flexibility

Although the terms risk and uncertainty are frequently used in the fields of finance and investment, the terminological difference between these two words is not very well known. The most distinguishing part between the terminology of these two words is the existence of knowledge. While under uncertainty, the decision maker lacks information about the possible outcomes and the probabilities of those outcomes; under risk the decision maker has information on the consequences of the decisions and their probabilities (Park & Shapira, 2017).

Uncertainties actually possess opportunities for investors, and real options valuation evaluates these opportunities and concludes them numerically. In every investment, the cause of uncertainties can be classified into several categories, such as market dynamics, political uncertainties, organizational capabilities, know-how, and emerging market competitions which can be related to either external or internal sources (Brach, 2002). With real options valuation, the uncertainties mentioned above are combined with the managerial flexibilities during the valuation processes and better reflect the reality of the decision-making processes (Brach, 2002).

2.3.2 Real Option

According to Mun (2002), real options valuation is a financial solution for organizations that are trying to make strategic investment decisions with flexible managerial decision-making opportunities under uncertain and dynamic markets. To understand real options, financial options which are similar in some ways to real options must be understood and how these financial options are valued must be determined (Smit & Trigeorgis, 2004).

An option is a derivative contract about a real or financial asset. This contract gives the buyer the right to buy (in the case of a call option) or sell (in the case of a put option) an underlying asset at a specified price (known as the strike price) on or before a certain date (known as the expiration date). The most important aspect of financial options is that they do not oblige the option buyer to implement the contract and the buyer does not have any obligations in that contract other than the price of the option that has to be paid when the buyer decides to use the option. The table below compares the financial options with the real options.

Table 2.2 Table of Comparison for Financial Options and Real Options (Mun, 2002)

Financial Options	**Real Options**
Short maturity, usually in months	Longer maturity, usually in years
Underlying variable driving its value is equity price or price of a financial asset	Underlying variables are free cash flows, which in turn are driven by competition, demand, management
Cannot control option value by manipulating stock prices	Can increase strategic option value by management decisions and flexibility
Values are usually small	Major million- and billion-dollar decisions
Competitive or market effects are irrelevant to its value and pricing	Competition and market drive the value of a strategic option
Have been around and traded for more than three decades	A recent development in corporate finance within the last decade
Usually solved using closed-form partial differential equations and simulation/variance reduction techniques for exotic options	Usually solved using closed-form equations and binomial lattices with simulation of the underlying variables, not on the option analysis
Marketable and traded security with comparables and pricing info	Not traded and proprietary in nature, with no market comparables
Management assumptions and actions have no bearing on valuation	Management assumptions and actions drive the value of the real option

The foundations of real options theory were laid when in 1973, Myron Scholes, Robert Merton, and Fischer Black won the Nobel Prize for their work on pricing financial options, leading to the Black-Scholes formula, which revolutionized options trading and the derivatives market. Stewart C. Meyers of MIT coined the term "real options" in 1984 to evaluate non-financial investments using options theory. Scholars have long understood that real options can make financial market strategies applicable to investment decisions. However, only recently has the complex approach become more widely used by decision-makers outside of academia.

Real options valuation is a valuable tool for making strategic investment decisions. It works by enhancing NPV to capture managerial decision flexibilities, as well as taking a complex and uncertain managerial situation and reducing it to a more straightforward analytical structure composed of basic types of real options (Smit & Trigeorgis, 2004). This helps managers to make decisions that are based on what the best outcome may be given the current circumstances, allowing for more strategic, informed decisions. By providing more insight into potential investments, real options valuation can be very favorable when making financial decisions.

2.3.3 Real Option Types

Businesses can take many forms, so there are lots of distinct kinds of real options available. The most common real option types used in the literature are shared below.

2.3.3.1 Option to Abandon

This is the managerial flexibility of abandoning an investment due to disbenefits and losses it generated and trying to earn the salvage value of it. After beginning a project, management has the choice to completely abandon it and gain the sale worth of devoted resources through second-hand trading or other uses within the business. It may be beneficial to give up the project if there are negative market changes or the originally predicted cash flows of the project appear too optimistic (Kaartinen, 2021).

2.3.3.2 Option to Delay

The option to delay is the managerial flexibility of postponing the start date of the investment. This option is mainly used in pursuit of reaching more advantageous prices that are believed to occur in the future for income and expense items in the project.

2.3.3.3 Option to Adjust Operating Scale

This option comes into question when management has the ability to adjust its scale of operations depending on the current market situation, which can be broken down into three separate real options: the option to grow, to reduce in size, or to completely stop and restart operations (Kaartinen, 2021). This option becomes very handy when a company is exploring the potential of expanding into different markets or under economic crisis, making the decision to go downsize.

2.3.3.4 Option to Switch

This option is about the managerial flexibility of altering the inputs, process flexibility, and/or the outputs, product flexibility, of an investment. These changes can be achieved by making decisions related to procurement, sourcing, and product development, which suggests that it would be beneficial for companies to apply real options thinking to other areas, not just capital budgeting (Kaartinen, 2021).

2.3.3.5 Phased and Sequential Investment Option

The option of phased or sequential investment considers the managerial flexibility of making an investment step by step as the boundaries or uncertainties about the investment are resolved. With this option, the organization is not obliged to pay the total capital cost of an investment and will have the opportunity to abandon the investment when anticipated targets are not acquired during the investment period.

2.3.4 Solution Methods for Valuing Real Options

In order to value the real options, many different methods exist in the literature. According to Masunaga (2007) these methods are empowered by either a partial differential equation approach, dynamic programming approach, or simulation approach. The partial differential equation approach is a mathematical way of evaluating the options. It tries to solve the formed equations about the real options and come up with a numerical conclusion. The dynamic programming approach allows for considering a broader range of potential values of the underlying asset over the option's duration. It involves finding the most profitable strategy at the final period, based on the decision made in the preceding period, and discounting the value of this optimal strategy to the present time using a backward recursive process. Finally, the simulation approach tries to evaluate the option price base on a considerable number of simulations from now to the option maturity time. By using these approaches, many different models have been generated. The three most common models are given below and explained.

2.3.4.1 Black&Scholes Model

The model developed by Robert Merton, Myron Scholes, and Fischer Black in 1973 is the most famous European call option valuation model. The generated equations in the model are solved using partial differential equations which are relatively easy to use. However, the model has many limitations and may not end up with the value of the option at all times. Also, the model lacks transparency such that an investor is not able to see the ongoing steps behind the model (Masunaga, 2007).

2.3.4.2 Binomial Lattice Model

In order to compensate for the shortcomings of the Black&Scholes Model, in 1979, the binomial lattice model has been offered by Cox, Ross, and Rubinstein which is empowered by the dynamic programming method and is able to value considerably complex real options. With the help of dynamic programming, the model enables the visualization of intermediate steps until option maturity and creates the possibility of decision-making at those steps (Masunaga, 2007).

2.3.4.3 Monte Carlo Simulation Model

Finally, the Monte Carlo simulation model, which is empowered by the simulation approach, tries to value the option with the help of simulated future scenarios. Under uncertainty, deterministic models fall short. Since Monte Carlo simulation creates scenarios based on the variables of the investments and generates different paths, the model turns out to be very helpful. As an investor, the opportunity to observe the possible scenarios is very beneficial since the investor can prepare for every scenario by following the worst and best-case scenarios. However, the Monte Carlo simulation model is highly dependent on the input parameters, and any influence on these parameters will considerably affect (Kılavuz, 2013).

2.3.5 Benefits of Real Options Valuation over Traditional Valuation Methods

According to Mun (2002) the key difference between the traditional valuation methods and the real options approach is that the latter takes into account the ability of management to adapt to changing circumstances and make multiple strategic decisions over time. Even though the traditional methods recognize the uncertainties within the investments, they do not account for how managerial actions can help mitigate those risks and potentially enhance the value of the project (Brach, 2002). The discounted cash flow approach assumes a fixed set of outcomes and a single decision made at the outset. In contrast, the real options approach allows for the possibility of multiple pathways and midcourse adjustments based on new information as it becomes available. The real options approach recognizes that there is often a high degree of uncertainty in business situations and that management may need to be flexible to make the most optimal decisions. In contrast, the discounted cash flow approach assumes a more static, single-path decision-making process that offers a now-or-never type of conclusion. Thus, real option valuation is a more powerful financial analysis tool for investments that include uncertainty.

2.3.6 Benefits of Least Square Monte Carlo Simulation over other Real Options Application Methods

The least-square Monte Carlo simulation method is another option valuation method offered by Longstaff and Schwartz in 2001. The method combines the least squares method and the Monte Carlo Simulation and uses both simulation and backward dynamic programming approaches to evaluate the price of the option. The method is advantageous when compared with the Black&Scholes and binomial lattice methods since these methods are not able to consider multiple factors and variables in an investment (Longstaff & Schwartz, 2001). The method is structured upon the simulation approach due to its ease, simplicity, and transparency. Even though the method still possesses the weakness of dependency on the input parameters, since it offers a more robust, intuitive, and easy-to-implement way for solving multiple options, the method is said to be powerful. This method will be used in this to evaluate the real options and will be explained in detail in the following sections.

2.4 Valuation of Renewable Energy Investments in Turkey

To seek the potential of renewable energy investments in Turkey, many different studies have been conducted. While some of these studies tried to rank the renewable energy alternatives in Turkey according to different rule sets and investigated their potentials, others have focused on a single renewable energy resource and tried to seize its potential and profitability.

In the study done by Kotcioglu (2011), attention has been drawn to the environmental concerns caused by energy generation processes, and to prevent further pollution Turkey's need to switch to renewable energy resources has been identified. Then, the renewable energy potential of Turkey was investigated, and comments about different renewable energy resources in Turkey were made. It was concluded that Turkey is suitable in terms of transition to renewable energy and if appropriate investments are made, Turkey, which is highly dependent on foreign energy, can produce all its energy needs from renewable energy sources.

In another study done by Şengül et al. (2015), a multi-criteria decision support framework has been used to identify the potential of renewable energy supply systems in Turkey. Hydropower, geothermal energy, wind energy, solar energy, biofuel energy, and hydrogen energy in Turkey has been analyzed using the offered framework that considers various criteria and offerings according to the findings of the analysis made for the Turkish government in order to direct their renewable energy investments to specific resources.

The study done by Erdin & Ozkaya (2019) used a Multi-Criteria Decision-Making method called ELECTRE in pursuit of classifying the regions of Turkey and identifying the most favorable renewable energy resource investments in those regions. With the findings of their study, they aim to notify the people of interest in the renewable energy resources of Turkey and their potential with respect to location.

Another study done by Kumbaroğlu et al. (2008) uses real options valuation in order to identify suitable renewable energy investments for Turkey by considering the decrease in the power generation costs per unit in each available renewable energy resource in Turkey. They have concluded that even though there exist a decreasing trend in costs of renewable energy production, they still cannot compete with the existing energy production methods and in need of additional incentive policies to make them favorable.

There are also other studies that focused on a single renewable energy resource rather than all available renewable energy resources. Ulu & Dombayci (2018) evaluated the potential of wind energy in Turkey and concluded that there exists a hidden potential in wind energy in Turkey. The Aegean and Marmara region of Turkey turned out the have a huge potential in terms of wind energy and it is concluded that additional investments should be made in pursuit of harnessing this potential.

Toptaş (2016) has evaluated the wind energy investments in Turkey using real options valuation. The different application methods of real options have been used in the study and results are compared. It is found that valuation done by real options has given better results that are in favor of wind energy investments while traditional methods fall short. Also, the two different real options application methods have given similar results.

Kılavuz (2013) has also worked on wind energy investments in Turkey. In her study, she used real options valuation to evaluate wind energy investments with and without government incentives in Turkey and compared the findings of real options valuation with the traditional valuation methods. The benefits of government incentives for wind energy investments were proven, and the importance of such incentives on renewable energy investments has been justified.

In the study by Akçay (2014), another renewable energy resource, hydropower energy is investigated, and investments in hydroelectric power plants are evaluated by considering the risks they carry. It is concluded that the traditional NPV method evaluates the hydroelectric power plant investment negatively and another method such as the Monte Carlo simulation results in a much better valuation since the method estimates various scenarios between the worst and best cases.

Topkaya (2012) studied the solar energy potential of Turkey and tried to clear out the ways of investing in solar energy projects in Turkey. It is concluded that at present, Turkey is an alluring untapped market for investors looking to capitalize on solar power, given the country's substantial potential for harnessing solar energy in combination with its expanding economy and increasing energy needs.

Yalili (2021), Öztürk et al. (2012), and Sogukpinar & Bozkurt (2015) have also worked on solar energy investments but rather than exploring Turkey’s potential, they evaluated solar energy investments for either residential or commercial applications in different locations of Turkey using traditional valuation methods. All of the studies have concluded that solar energy investments in Turkey are currently not favorable or at par in terms of profitability and are in need of additional subsidies to make them favorable. While Yalili (2021) has investigated a commercial solar energy investment in Van, both Öztürk et al. (2012) and (Sogukpinar & Bozkurt, 2015) studied residential solar energy investments.

2.5 Valuation of Energy Investments using Real Options Valuation

Real Options Valuation, which is a financial analysis tool mentioned above, offers a better valuation for renewable energy investments due to their uncertainties. Because of its advantages, there exist many different studies in the literature that utilize the real options valuation for investment valuation, especially about renewable energy investments.

Pringles et al (2014) used the least squares Monte Carlo simulation method of real options valuation to evaluate investments in electricity transmission networks in Argentina. Since transmission network investments require high capital costs and are mostly irreversible with highly volatile transmission costs, real options valuation is the tailored fit for such investments. The findings of this study will help investors of electricity transmission networks in Argentina to be informed about the possible outcomes of the investments they are deciding on.

Another application of ROV is done by Öztürk (2010) in the mining industry. In this work, a mining investment located in Russia is evaluated using real options valuation with the uncertain selling price of coal. Since the main source of profit of a coal mine is the unit selling price and due to the volatility in energy prices in the world, the mining investment may end up in a loss. Thus, with a deferral option the value of the investment is calculated, and it results in a suggestion that making the investment 4.5 years later will result in higher profits than now.

As for renewable energy resources, Venetsanos et al. (2002) provided an inclusive, adaptable, and easy-to-apply method for evaluating wind energy investment in Greece by considering the novel deregulated, competitive, and highly unpredictable electricity market conditions. It is concluded that for such investments in Greece, since the deferral option value is greater than the NPV of the investment, it would be more favorable to defer the investment decision until new information that emerges favorable conditions for the investment appear.

There also have been many applications of ROV in solar energy investments around the world. Zhang et al. (2016) utilized ROV for solar energy investments in China. Di Bari (2020) has used ROV for solar energy investments in Italy by considering the unpredictable actions of the government on solar energy investments, varying meteorological factors, and the flexibility of the decision-maker. Pringles et al (2020) have also utilized ROV for solar energy investments in Argentina with a deferral of investment option in addition to a relocation option for the solar farm in case of the emergence of another desirable site that is favorable in terms of cost, accessibility, and regulations. All of these studies have the common conclusion that the current status of solar energy investments is not favorable regardless of the size of the facilities or the locations they are in. However, due to the uncertain electricity market conditions in each country and other factors, the investments possess the potential to become profitable in the near future, suggesting they should not be declined. Also, with additional incentives, the governments have the power to make these investments profitable.

The ROV method is also utilized in the study of Ashuri & Kashani (2011), which has approached the adoption of renewable energy investments in buildings such as photovoltaics in a different way. Since the prices of these investments are high and volatile, the construction of solar-ready buildings has been introduced. These buildings are constructed to be ready for renewable energy investments in terms of infrastructure, and the owners of those buildings can easily execute these investments when the prices are favorable. Then, the construction of solar-ready buildings versus solar buildings is compared using the real options theory. The solar-ready buildings turned out to be more favorable in terms of profitability.

The residential solar energy investments installed on the rooftops of housing buildings have great potential and many benefits as explained in the above sections.

However, due to the extreme initial costs of these investments, the traditional valuation methods end up against these investments. The ROV, which accounts for the value of flexibility of the decision maker and does not result in a static now-or-never conclusion should be used to evaluate such investments and prove their profitability for the future. Penizzotto et al. (2019) and Gahrooei et al. (2016) have tried to use ROV for residential PV investments with a similar goal in Argentina and USA consecutively. While Penizzotto et al. (2019) have applied the LSMC method of ROV for residential solar energy investments considering a deferral option, Gahrooei et al. (2016) utilized a dynamic programming approach for the valuation of real options considering the deferral and staged investment options. In both studies, it is revealed that the current status of residential PV investments in both Argentina and the USA is not favorable for the investors, but with the deferral option, the investments may result in bright conditions in the future. Also, the staged investment option resulted in favor of the investment as well, meaning rather than installing the whole solar energy system, making the installments stepwise when the favorable conditions will result in higher profitability.

ROV can also be used to evaluate governmental policies on renewable energy investments. Due to environmental concerns, governments try to persuade investors to invest in renewable energy facilities. Thus, they offer various incentives to make investments more favorable. ROV can be used to evaluate these incentives' validity and measure their impacts on the overall investment valuation. Zhang et al. (2014) have offered a policy evaluation model for solar energy investments in China which utilizes real options valuation. The offered model evaluates the given incentives from the perspectives of both government and investors and makes conclusions.

Even though there exist various studies on valuation of renewable energy resources in Turkey, contrary to the many studies that utilize real options valuation for different countries, none of these studies utilized the real options valuation method to evaluate the residential solar energy investments in Turkey.

In this thesis, the LSMC method for the valuation of real options will be used to evaluate residential solar energy investments in Turkey. Then, additional government incentives, that are in alignment with the literature, will be offered for the Turkish government to enhance these investments further. The offered incentives will be applied to the given case study, and with the help of the LSMC method they will be re-evaluated, and conclusions will be made.

CHAPTER 3

RESEARCH PROBLEM AND METHODOLOGY

In this section, firstly the significance of this research is explained in detail. Then, the research questions and objectives are presented and explained. Finally, the research approach that was used in pursuit of finding answers to the research questions and reaching the research objectives is explained. In this section, the details of the interviews that were made with two experts on solar energy sector is shared as well.

3.1 Significance of the Research

Due to the geographical location of Turkey, the country has a high solar energy potential such that the yearly average solar radiation is 3.6kWh/m2-day and the total annual radiation period is approximately 2640 hours (Kotcioglu, 2011). This much solar radiation leads to a possible solar energy generation of 380 billion kWh/year (Şengül et al., 2015). Even though Turkey has that great potential, economically it is difficult to fully establish the required facilities to harness its full potential.

The required plant installations to convert solar radiation into consumable energy necessitate great initial capital investments, which make such investments very expensive for both government and private sector (Erdin & Ozkaya, 2019). The high initial costs of solar energy investments hinder the expansion of such investments and the full harnessing of Turkey's solar potential. However, due to the government's climate change agenda, several incentives for the private sector at different periods of time until 2022 have been introduced and promoted solar energy investments.

Solar energy investments in Turkey began in 2014 with 40MW installed power, and each year with new investments, the total installed power has increased, becoming

8.479 MW in June. This corresponds to approximately 8.35% of the total installed power, meaning that 8.35% of Turkey's total energy production comes from solar power (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b).

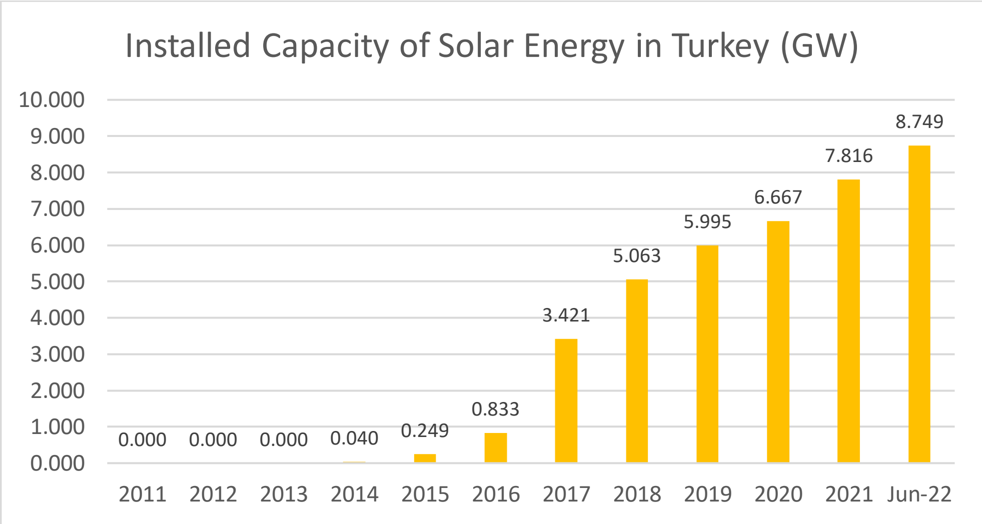

Figure 3.1. Installed Capacity of Solar Power in Turkey over Years (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b)

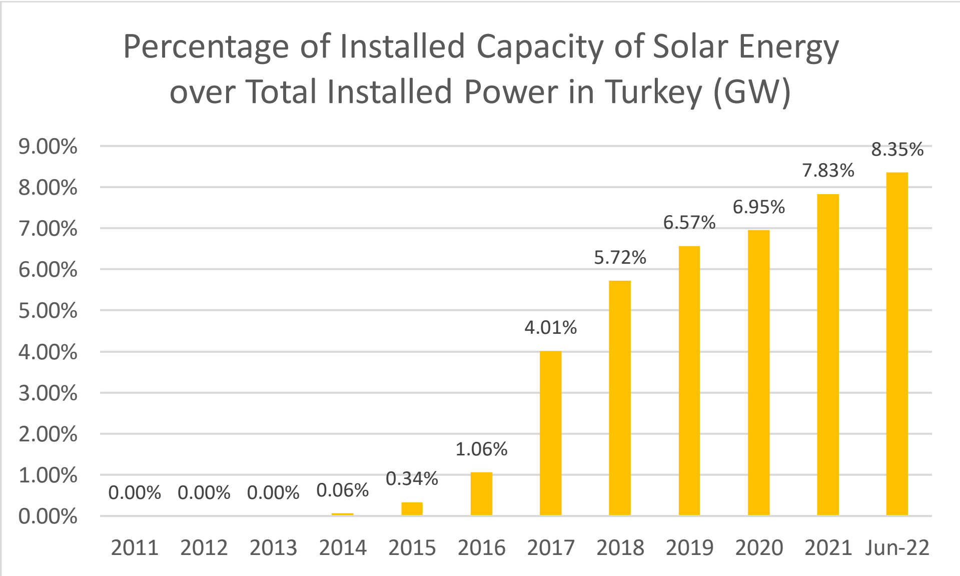

Figure 3.2. Percentage of Installed Capacity of Solar Power over Total Installed Power in Turkey over Years (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b)

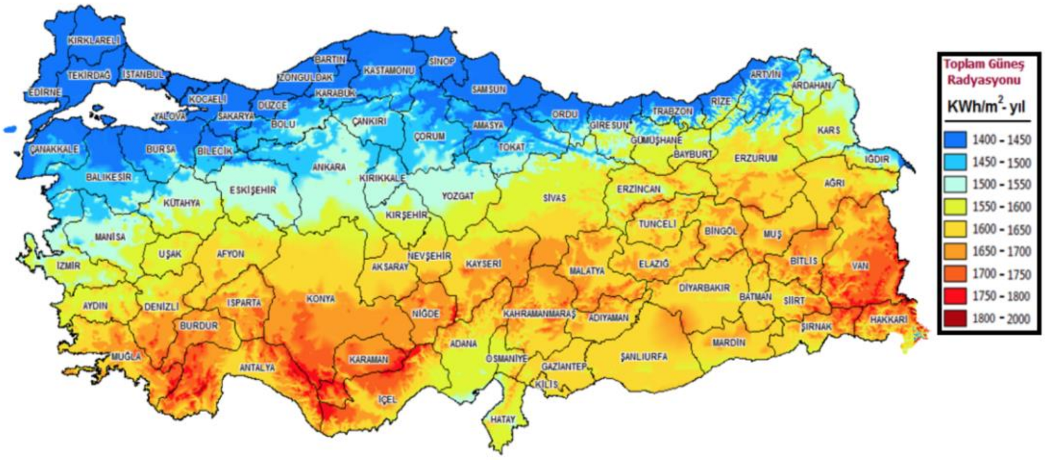

Figure 3.3. Total Solar Radiation of Turkey (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b)

In 2020, Turkey is the 16th country in the global installed solar power capacity ranking (PwC, 2021). But, the necessity to increase the installed solar power capacity still exists because of the environmental pollution caused by fossil fuel usage in energy generation (Erdin & Ozkaya, 2019). Water, air and soil pollution threatens humanity's future. To prevent future catastrophes, governments have decided to take action. The well-known Paris Agreement was established in 2015, which aims to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above the pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (United Nations Climate Change, n.d.). As of 6 October 2021, the Turkish Parliament ratified the Paris Agreement, and under this contract, Turkey has to generate its climate performance program, which will be evaluated every five years. Solar power offers a good replacement for fossil fuels due to its potential in Turkey, as mentioned above.

According to Electricity Distribution Sector Report for 2021 generated by TEDAŞ, the industrial areas consume the highest electricity with 45.7%, followed by commercial and residential areas with 24.8% and 23.1%, respectively (Türkiye Elektrik Dağıtım A.Ş. Genel Müdürlüğü, 2022). Even though the residential areas' energy consumption turns out to be the third among all areas, due to their architectural nature, they offer vast amounts of suitable roof areas for PV panel installations. By using this opportunity of residential areas and their rooftops, the installed solar power can be increased, which will replace fossil fuels to certain extent, prevent pollution and lead to success in Turkey’s climate performance program following the Paris Agreement.

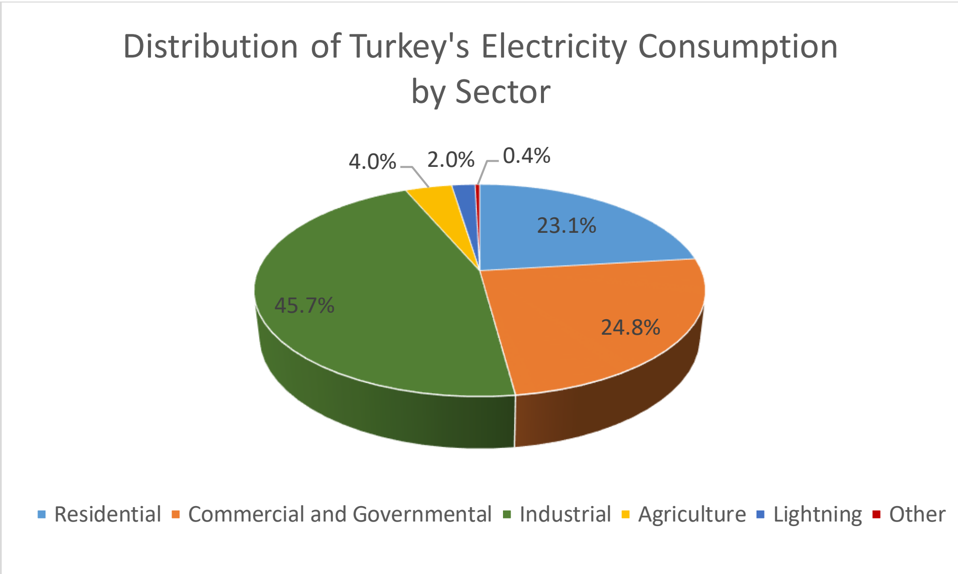

Figure 3.4. Distribution of Turkey's Electricity Consumption by Sector (Türkiye Elektrik Dağıtım A.Ş. Genel Müdürlüğü, 2022)

Regardless of the sectoral areas the PV panels are installed, the investment is still capital-intensive. Also, there are many uncertainties in solar power investment valuations, such as panel prices, inverter prices, and electricity tariff prices. In addition to that, such investments are assumed to be irreversible due to the high costs of disassembling, transportation, and reassembling procedures. Thus, from an investor's point of view, due to the irreversibility of the asset and the uncertainties the investment possesses, it is hard to come up with a clear investment decision. However, if those uncertainties are handled with a probabilistic approach, the investor might well be equipped with some decision-making options that might be reevaluated for go/no-go investment decision at different points in time when the level of uncertainty is decreased or eliminated.

In such cases, the most common valuation method, NPV (Net Present Value) falls short due to its deterministic nature. With the high initial capital costs of this new technology, and uncertain, yet increasing annual costs and high inflation rates, it is almost obvious that NPV assessment would not result in favor of the investment under the now-or-never enforcement of the valuation method. However, ROV possesses a greater advantage and assesses the implied value of flexibility. Using ROV, the investor can defer or modify the investment with the newly acquired information in time and may remove some of the uncertainty from the equation. Even though this will not clear the entry barrier caused by the high initial costs of solar investments, by probabilistically projecting the uncertainty factors and enhancing the decision maker with the flexibility by assessing the value of different options under uncertainty, the real options valuation will bring much better bargains and may make the solar power investments favorable at different points in time.

This research will evaluate residential solar power investments with the real options valuation method. The advantages of the deferral option and the value it generates for such investments will be identified. At the same time, it will set an example for paving the way for such investments, which are not very common for now due to the problems mentioned above. Also, it will be instrumental in reducing the environmental pollution concerns that are increasing day by day by contributing to the spreading of these investments, which will replace fossil fuels.

3.2 Research Problem and Objectives

This study aims to introduce the Real Options Valuation with Least Square Monte Carlo Simulation method for residential PV investments in Turkey and demonstrate whether it can be an alternative to the most common valuation method used in such investments, namely Net Present Value (NPV). The findings of the study consequently lead us to investigate the suggestions that can be made for the government to promote such investments such as the incentives that can be offered by the government in order to solve the problem of high initial investment cost, which is one of the main obstacles to residential PV investments.

To identify the scope of this study, the following two research questions can help:

1. Can the "Real Options Valuation with Least Square Monte Carlo Simulation Method" be used for the evaluation of the attractiveness of the residential PV investments in Turkey as an alternative to the traditional NPV analysis that ignores future uncertainties and bounds the investor to a now-or-never decision?
2. What would be the implications of applying the "Real Options Valuation with Least Square Monte Carlo Simulation Method" for the evaluation of residential PV investments?

Accordingly, the main objectives of this study, considering the above research questions and the knowledge gaps in the literature, are:

1. To systematically identify the valuation methods used for evaluating the attractiveness of PV investments in Turkey and the weaknesses they possess
2. To apply the "Real Options Valuation with Least Square Monte Carlo Simulation Method" for the evaluation of Turkish residential PV investment
3. To demonstrate the benefits of using the "Real Options Valuation with Least Square Monte Carlo Simulation Method" for the evaluation of Turkish residential PV investments
4. To identify the global government incentives offered to enhance the residential PV investments

5. To introduce the government incentives that may enhance Turkish residential PV investments and show the benefits that can be obtained with the offered ROV method

3.3 Research Approach

The research started by realizing the importance of the residential PV investments and the opportunity they offer for the upcoming future. However, the valuation methods that are offered for the residential PV investments in Turkey are not addressing the uncertainties these investments harbor and the potential investment opportunities they possess at the near future. Thus, a literature review is conducted about the residential PV investments in Turkey and the offered methods of valuation for those investments. During this literature review, the importance of PV investments in Turkey and their potential is as well investigated. With the literature review, the weaknesses of the used valuation methods for evaluating the attractiveness of the residential PV investments in Turkey are identified.

In order to investigate the current status of the residential PV investments in Turkey and their valuation procedures in practice, several interviews with experts on the field are made. Through these interviews, the residential PV investment procedures, requirements, factors that affect the investment valuation in practice are identified. Also, the main reason behind the lack of residential PV investments in Turkey, which is the high initial investment costs that are above most of the citizens' pay grade, is identified.

Two consecutive interviews are made with two experts. Expert A is an electrical and electronics engineer who has been in the solar energy sector for 10 years. He is experienced in the implementation of solar PV systems in Turkey. He has his own company in which he gives consultancy to people who are willing to invest in PV systems at any scale. Expert B is a civil engineer who has been in the solar energy sector for 15 years. He is one of the flag bearers of solar PV investments in Turkey.

He has participated in the process of establishing the initial regulations of the solar energy sector in Turkey.

Table 3.1. Summary of Experts Involved in the Interviews

Experts	A	B
Profession	Electrical and Electronics Engineer	Civil Engineer
Years of Experience in the Solar Energy Sector	10 years	15 years
Current Occupation in the Solar Energy Sector	Solar Energy Investment Consultancy and Projecting	Solar Energy Investment Consultancy to both Public and Government

The seven questions that are asked to the experts and the aims and objectives of each question are shown on Table 2. These interviews could not be recorded due to confidentiality reasons. The responses given to these questions and the findings with respect to these responses will be investigated in the following section.

Based on the findings from the interviews and the literature review, a rather new valuation method, called “Real Options Valuation with Least Square Monte Carlo Simulation Method” is applied to residential PV investments in Turkey by using the information and data gathered through literature review and interviews. This method evaluates the potential value that can be obtained with a deferral option for investment in addition to the net present value of the investment by considering the future uncertainties the investment harbors. With the application of this method to an offered real residential PV investment, the advantages that the method possesses are demonstrated in comparison with the traditional NPV method.

Table 3.2. Interview Questions and their Aims and Objectives

#	Question	Aim
1	What is the current status of residential PV investments in Turkey?	The purpose of this question is to investigate the current status of the residential PV investments in Turkey and identify the reasons of the lack of prevalence of such investments. Also, the current incentives are tried to be explored in Turkey.
2	How the initial investment cost and future cashflows are generated in the residential solar PV investments? What the cost and revenue items are? How can I achieve the historic market data for these items?	The purpose of this question is to identify how the investment cost and future cashflows are formed while calculating the costs and revenues for residential PV investments. Also, the key information regarding residential PV systems such as their service life, maintenance requirements etc. are tried to be identified. Finally, in order to be used in the case study to be made, it has been tried to obtain information about how to access the historical data of the income and expense items based on the answer to this question.
3	Which currency do you use while calculating the cashflows and preparing feasibility reports?	The purpose of this question is to identify the currency that is currently in use for the valuation on residential PV investments. According to the responses to this question, the currency that will be used for the case study will be identified.
4	Which methods do you use while making residential solar PV investment valuations? Have you ever heard of the Real Options Valuation method?	The purpose of this question is to explore the current valuation methods in use for residential PV investments in Turkey. Also, the knowledge about the Real Options Valuation method will be questioned and its applicability to residential PV investments will be discussed.

Table 3.3 Interview Questions and their Aims and Objectives (cont'd)

5	What is the best scenario that a house owner can achieve to earn the highest profit from the residential PV investment? Is it wise to spend huge amounts of money to construct the biggest possible PV system on the roof?	The purpose of this question is to identify the best and most profitable case that could be obtained in the residential PV investments. In accordance with the responses given to this question, the case study and the assumptions will be formed. Both Experts A and B denoted that in order to acquire the maximum possible profit, the installed PV systems should generate electricity that is equal to the instant demand. This is due to the fact that the unit price of selling the electricity is lower than the unit price of buying electricity since there are additional costs included in the electricity bills that are not included when selling. Expert B stated that for the case study in this research a hypothetical scenario in which the investor consumes all the electricity generated and does not sell any should be considered to make an accurate estimation of the revenues.
6	What is the efficiency of solar PV systems?	It is known that almost all energy production systems do not work with a 100% efficiency. With this question, the efficiency of the residential PV systems is tried to be identified.
7	Is it possible to sell solar PV systems once they complete their service life and generate income? Do these systems have a scrap value?	The purpose of this question is to explore the scrap value of the residential PV systems in Turkey. Every tangible investment will have a scrap value at the end of its useful life and the scrap value of a residential PV system in Turkey is tried to be identified in order to be used in the case study. Both Experts A and B denoted that since the PV investments in Turkey have not reached the end of their service lives, there is not a certain value for the scrap. However, Expert B stated that the panels, inverters, hardware, and structural elements possess valuable raw materials and they should have a scrap value.

In addition to that, in pursuit of finding a solution to the entry barrier problem of residential PV investments, a literature review is conducted and the international practices on incentives are investigated. By, using these incentives and the information gathered from the interviews, two different government incentives that are possible for Turkey are proposed and the benefits they create are identified using the offered ROV method. Then the results are discussed.

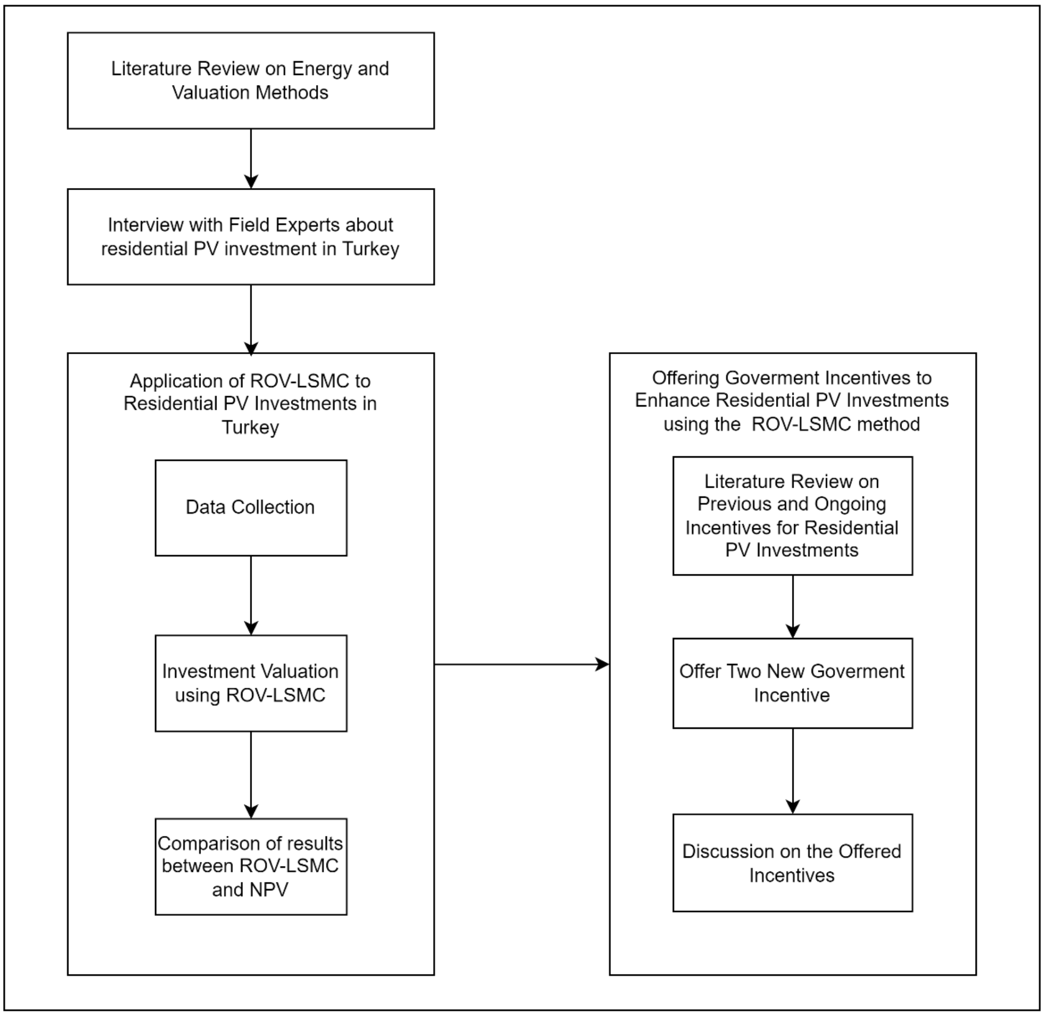

Figure 3.5. Research Approach

CHAPTER 4

INTERVIEW FINDINGS

In this section, the findings from the interview will be explained. In the previous section, it is stated that two interviews were made with two experts on the solar energy sector. These experts were asked the questions stated in the previous section, and several findings were obtained based on the answers they gave to these questions. The answers for each question will be shared separately as follows.

4.1 Question 1

- What is the current status of residential PV investments in Turkey?

Experts A and B both stated that residential PV investments are not very common. However, there is a great need for such systems because of environmental concerns. Expert A denoted that the lack of prevalence is because the public is poorly informed about the existence of such systems. People think that such systems can only be made on huge scales and they are not appropriate for the roofs of their homes. Expert B stated that the lack of prevalence is due to the fact that investments in such systems require high initial investment costs that most of the citizens of Turkey may fail to afford. Also, he stated that under the current conditions it is hard to estimate whether such an investment pays off. Both Experts A and B stated that currently, the Turkish government is offering net metering for those people who are willing to construct PV systems on their rooftops. The system allows the investors to sell the excess power generated by the system. Upon the approval of the application for constructing the system, the electricity meter that the investor owns is changed and a new one that allows the transmission of electricity both ways, from the grid to house and from house to grid is installed. Then, on a monthly basis, the amount of electricity taken from the grid and transferred to the grid is calculated and deducted from each other and the investor either pays for the excess electricity consumed or earns some profit from the excess energy transferred to the grid.

4.2 Question 2

- How the initial investment cost and future cashflows are generated in the residential solar PV investments? What the cost and revenue items are? How can I achieve the historic market data for these items?

Experts A and B both stated that there are mainly six initial investment cost items, namely, the panel prices, the inverter prices, the hardware and load-carrying system costs, labor costs, and finally the project design costs. For the entire service life, which is estimated to be 25 years, the system will need a one-time inverter replacement and several small hardware item replacements. They mentioned, residential roof PV systems do not require additional operation and maintenance costs. Also, since the surface area of the residential PV systems is small, they do not require periodic cleaning. However, Expert A stated that he experimented on this, and cleaning the PV panels led to a slight increase in the energy production from the panels. In addition, Expert A stated that as the size of the system increases, the unit cost decreases. Expert B denoted that the PV panels and inverters generate almost 60% of the initial investment cost and are the main reasons for the massive investment cost. Once the project design is completed and the electricity distribution company is approved, the initial investment cost is paid to the contractor and then system gets installed. Experts A and B said that the revenue generation of the systems would vary from house to house and from time to time. The revenue generation is highly dependent on the system's size, the house's consumption, the amount of generated electricity and the amount of generated electricity transferred to the grid in the relative month. Expert B stated that for this study, it would be wise to create a case study with explicit assumptions in order to estimate the revenues generated. Also, Experts A and B mentioned that the future electricity tariffs and distribution prices should be evaluated to calculate the revenue generated. The most straightforward calculation of income generated in that month can be formed by multiplying the energy generated in that month with the tariff and distribution price of that month. Expert B has also shared several confidential documents to help with the revenue calculations. Experts A and B shared the information regarding several recent investments and their costs for the historical market data. However, they both stated that it is hard to find accurate historical data for the Turkish market since such investments are relatively new in Turkey. They also suggested several websites for data collection.

4.3 Question 3

- Which currency do you use while calculating the cashflows and preparing feasibility reports?

Expert A stated that the prices of panels and inverters are in USD, thus he has been using USD in his calculations. Expert B also denoted that using USD will be much more accurate for the valuation of residential PV investments in Turkey.

4.4 Question 4

- Which methods do you use while making residential solar PV investment valuations? Have you ever heard of the Real Options Valuation method?

Expert A stated that he has never heard of the ROV method but Expert B stated that he came across that valuation method but never used it in the valuation of residential PV investments in Turkey. However, after a brief explanation of the method, Expert B stated that using ROV in residential PV investment valuation would be appropriate. Both Experts A and B concluded that the most common method in investment valuation is the Net Present Value. Expert A has also used the Rate of Return (ROR) method.

4.5 Question 5

- What is the best scenario that a house owner can achieve to earn the highest profit from the residential PV investment? Is it wise to spend huge amounts of money to construct the biggest possible PV system on the roof?

Both Experts A and B denoted that in order to acquire the maximum possible profit, the installed PV systems should generate electricity that is equal to the instant demand. This is due to the fact that the unit price of selling the electricity is lower than the unit price of buying electricity since there are additional costs included in the electricity bills that are not included when selling. Expert B stated that for the case study in this research a hypothetical scenario in which the investor consumes all the electricity generated and does not sell any should be considered to make an accurate estimation of the revenues.

4.6 Question 6

- What is the efficiency of solar PV systems?

Expert A stated that the PV systems have a varying efficiency between 70 to 85 percent. However, many factors affect this efficiency. Thus, he provided the real electricity production data of a 6.6 kWp residential PV system and suggested using this data in this study. Expert B stated that the efficiency of the PV systems is around 80%, but with the technological advancements and production of new technology panels, this value will increase.

4.7 Question 7

- Is it possible to sell solar PV systems once they complete their service life and generate income? Do these systems have a scrap value?

Both Experts A and B denoted that since the PV investments in Turkey have not reached the end of their service lives, there is not a certain value for the scrap. However, Expert B stated that the panels, inverters, hardware, and structural elements possess valuable raw materials and they should have a scrap value.

CHAPTER 5

REAL OPTIONS VALUATION WITH LEAST SQUARE MONTE CARLO SIMULATION METHOD

In this section, the investment model of the residential PV investments in Turkey is explained. The initial investment cost equations, the revenue equations are formed and the variables in these equations are determined. Then, the stochastic models that will be used for estimating the future prices of the variables are explained. Finally, the Real Options Valuation method using Monte Carlo Simulation is explained in detail.

5.1 Investment Model

The Real Options Valuation with Least Square Monte Carlo Simulation Method calculates the option value that an investment harbors and adds this value to the NPV to come up with the total value of the investment. Thus, to calculate the value of the solar power investments, the investment projects should first be assessed using NPV. Then the value of the managerial flexibility calculated using LSMC ROV should be added. The residential solar power investments are composed of different cost and revenue items, which have to be identified to create the cash flow which will be used in NPV calculation. However, several assumptions must be made before model generation, since the power industry is highly dependent on legislation which is susceptible to major changes over the years. To minimize the effects of these changes on the calculation in this research, the following assumptions are made as well.

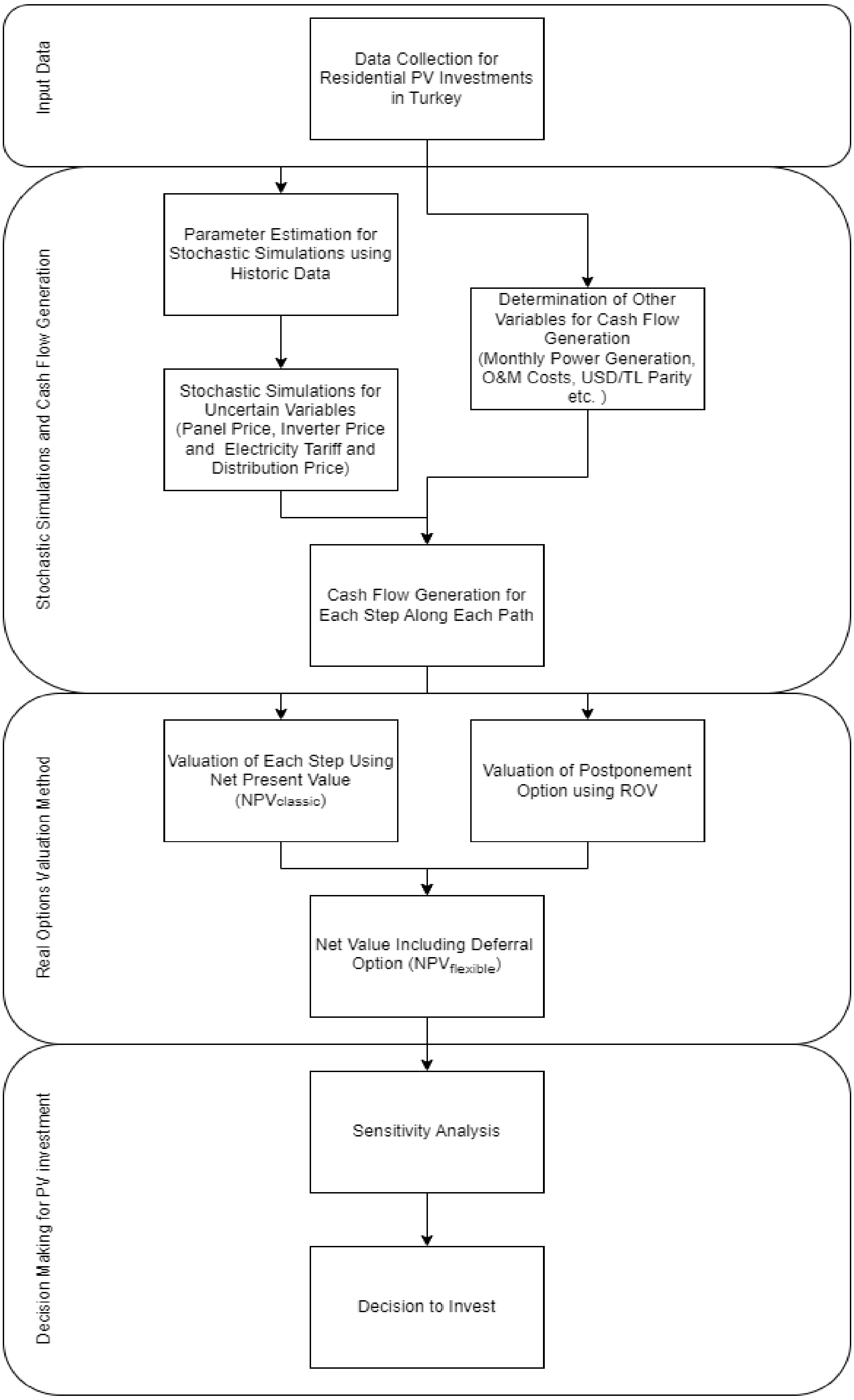

Figure 5.1. Methodology for Real Options Valuation for Residential PV Investments in Turkey

5.2 Investment Revenues

- Assumption 1: The instantaneous energy produced at the on-site PV system is always equal to or less than the instantaneous energy demand, and the generated power is 100% consumed, and none is supplied back to the grid.
- Assumption 2: Overall tax rate is taken as 18%, which includes several taxes for electricity bills.

Following the approval sent by the government for the residential PV system application, a new electricity meter that allows transmission of electricity both ways, from the grid to the house and from the house to the grid, is plugged into the applicant's power line. If the demand in the house instantaneously consumes the power generated, no electricity will be supplied back to the grid. If else, then on a monthly basis, net settlement is calculated in the electricity meter using the amounts of power withdrawn from the grid and supplied to the grid. If the power drawn from the grid is higher, an electricity bill is generated using the net value, which is power withdrawn minus power supplied. If the power withdrawn and supplied is equal, then the user will only pay for the distribution price with a discount. Finally, when the power supplied to the grid is higher, the government will pay for the net, supplied minus withdrawn, kWh supplied to the grid, using a unit price lower than the unit price of buying electricity from the grid. The all-inclusive cost of buying 1 kWh of electricity from the grid is higher than the total earnings generated by selling 1 kWh of electricity.

For this reason, considering the first cost of the PV system, the revenue earned for each kWh supplied to the power line is lower than the revenue to be earned when electricity equal to the amount consumed is produced. Thus, installing a solar PV system with a production capacity of more than the electricity demand of the house increases the investment cost and brings a lower rate of return. Thus, Assumption 1 is made so the maximum benefit can be earned using the PV system.

Secondly, the government's taxation policy has to be considered in the revenue calculations since the generated revenue is actually a benefit by not paying as high electricity bills as the pre-investment conditions. Thus, to neglect the effects of a change in government taxation policy, the current legislation is taken as a ground rule, and assumption two is made.

Then, by considering the two assumptions, the following revenue equation is generated.

<u>In the case of energy produced is equal to, or less than, the energy consumed in the house and power supplied back to the grid is zero:</u>

- The electricity price that a user without a PV system pays at time t

$$Bill(t) = E_c(t)\left(P_{tariff}(t) + P_{distribution\ cost}(t)\right) + tax \quad (5.1)$$

where $E_c(t)$ is the energy consumed by the house between the instant t-1 and t, $P_{tariff}(t)$ is the tariff price of electricity at the instant t, $P_{distribution\ cost}(t)$ is the cost of electricity transmission from the power plant to the house at the instant t. Tax includes all the taxations made by the government in an electricity bill and estimated to be 18%. Thus, the following equation can be formed.

$$P_{bill,w.o\ PV}(t) = [E_c(t) * \left(P_{tariff}(t) + P_{distribution\ cost}(t)\right)](1 + 0.18) \quad (5.2)$$

- The electricity price that a user will pay with a PV system at time t

$$Bill(t) = (E_c(t) - E_g(t))\left(P_{tariff}(t) + P_{distribution\ cost}(t)\right) + tax \quad (5.3)$$

where $E_g(t)$ is the energy generated by the house between the instant t-1 and t and $E_c(t)$ is the energy consumed by the house between the instant t-1 and t. Since there exists a PV system in the house, the user can consume the power generated by the panels instead of taking it from the grid. Considering the assumptions made, the total demand for the house from the grid will decrease with respect to the generated power by the panels, and the user will be charged accordingly.

$$P_{bill,w.PV}(t) = \left[\left(E_c(t) - E_g(t)\right)\left(P_{tariff}(t) + P_{distribution\ cost}(t)\right)\right](1 + 0.18) \quad (5.4)$$

- Revenue (Initial Case – Final Case)

$$R(t) = P_{bill,w.o\ PV}(t) - P_{bill,w.PV}(t) \quad (5.5)$$

$$= \left[E_g(t) * \left(P_{tariff}(t) + \ P_{distribution\ cost}(t)\right)\right](1 + 0.18) \quad (5.6)$$

Then, in order to calculate the benefit that the solar investment generates, the final case is subtracted from the initial case, and the benefit generated is calculated using the equation above.

To calculate the revenue for each month during the investment period, the corresponding values of the variables in the equation above for each month have to be determined, such as the total electricity generated that month, the electricity tariff price at that month, and the electricity distribution price at that month.

There exist many different approaches for modeling the electricity generated each month. The main determinants in the power generation of solar PV systems are solar radiation, temperature, clearness index of the area where the system is located (Sogukpinar & Bozkurt, 2015). Also, the efficiency of the PV panels and inverters is important while modeling the monthly power generation of the installed system. For this model, to overcome the uncertainties generated by the above variables, the monthly power generation rates of a real-life PV System located in Kocaeli, Turkey, are used (Çilli, 2022).

The future electricity tariff and distribution price is another major uncertainty that has to be modeled in order to be used in the revenue equation generated above. Even though the prices are shown as separate items in an electricity bill, their pricing is heavily dependent on each other. Thus, they are treated as a single price which is formed by the summation of the two in this study. They have a major significance since they play a crucial role in investment evaluation, such that if the prices go higher, then the investment becomes more feasible as the profit gets higher and vice versa. Thus, an adequate model that reflects the stochastic behavior of tariff and distribution price should be used. The most commonly used approach to model, the stochastic behavior of the tariff and distribution price, is the Geometric Brownian

Motion (GBM). In 2016, a study by Gahrooei et.al. (2016) justified the applicability of GBM for tariff and distribution price and stated GBM as a "good modeling choice for modeling evolving uncertainty in electricity prices". Also, there are many studies that use the GBM or its approximate discrete form, binomial lattice, to model electricity tariff prices in real options valuation of PV investments (Ashuri & Kashani, 2011; di Bari, 2020; Kumbaroğlu et al., 2008; Penizzotto et al., 2019; M. Zhang et al., 2016; Zhang et al., 2014).

Geometric Brownian Motion has been initially used to model stock price behavior (Hull, 2000). In 1973, Fischer Black and Myron Scholes used it in their famous Black-Scholes option pricing formula. The Black-Scholes formula takes into account the volatility of the asset being priced, the time to maturity, the risk-free interest rate, and the price of the asset at the time of the option. The formula then uses the Geometric Brownian motion to calculate the expected price of the asset at the maturity of the option. This expected price is then used to calculate the option's price. The model is then reapplied to real options analysis as well, in which the value of the underlying asset is assumed to evolve similarly to a stock price (Marathe & Ryan, 2005). In the study by Gahrooei et al., it is stated that:

"A GBM process has a trend growth rate that is geometric, meaning growing at the same rate over time. A GBM process includes a random component as well. One of the most important reasons for the widespread use of GBM models in real options analysis is that calculations with GBM processes are relatively easy and tractable. There are just two parameters that need to be estimated, drift and volatility. Also, developing analytical solutions for real options problem is often possible due to the flexible mathematical structure of GBM process."

Hence, the value of the electricity tariff and distribution price at any time t is given by:

$$P_{et\&d}(t) = P_{et\&d}(t=0) * \exp\left[\left(\alpha - \frac{\sigma^2}{2}\right)t + \sigma W_t\right] \quad (5.7)$$

Where $P_{et\&d}(t = 0)$ is the initial electricity tariff and distribution price at t=0, α is the growth rate of electricity tariff and distribution price, σ is the volatility or the standard deviation of growth rate, W_t is a Wiener process with a mean equal to zero and variance equal to one, $W_t = \sqrt{t}.\varepsilon$ where $\varepsilon \sim N(0,1)$.

Since the electricity tariff and distribution prices in Turkey are in Turkish Liras, and the proposed method aims to make the valuation in USD, the TL/USD parity among the investment's service life has to be determined. To do so, the historic data of TL/USD parity has been collected from the Central Bank of the Repuclic of Turkey, and a linear fit is made to that data. Then, using this line, the future approximations of TL/USD parity have been made deterministically. The process will be explained in detail in the following chapters.

5.3 Investment Costs

The cost items for a residential PV system investment are the system hardware costs, direct labor costs, indirect labor costs, permit-inspection-interconnection costs, overhead costs, and sales and marketing costs as stated in U.S Solar Photovoltaic BESS System Cost Benchmark Report for Q1 2021 (Ramasamy et al., 2021). If the items are investigated in detail, the system hardware costs are panel costs, inverter costs, structural balance of system costs, and electrical balance of system costs. The panel and inverter cost of PV systems is equal to 60% of the whole investment cost (Zhang et al., 2016). Thus, the panel and inverter costs should be investigated in depth since they are the main cost items of PV investments and at the same time the drivers of uncertainty regarding the future investment cost of PV systems. The direct labor costs include electrical, mechanical, and general construction labor costs. The labor costs also vary over time, but since their impact on the total investment cost is low, they are modeled as a deterministic process for this study. The indirect labor costs are engineering design and construction permit administration. For residential PV system investments, there is no requirement for either an engineering or a construction permit. Thus, these items are not taken into consideration. The permit-inspection-interconnection costs are self-explanatory and similar to previous cost items; these costs are not taken into consideration since residential PV investments in Turkey do not have such cost items. Finally, overhead and sales, and marketing costs are not taken into consideration in accordance with Assumption 1 since there will not be a case of selling the excess electricity generated by the PV system.

The panel prices and inverter prices have been decreasing heavily as technology advances. Due to economies of scale, raw material price reductions, R&D processes, and product innovations, the implementation cost of building energy efficiency technologies may decrease over time (Kashani et al., 2015). The cost per watt-peak of a PV panel was 5$ in 1995, and the cost per watt peak of an inverter was 1.78$ in 1990. In 2021, the cost per watt-peak of a PV panel and an inverter has become 0.35$ and 0.27$, consecutively (U.S. Energy Information Administration, 2012). The figures below show the price changes of PV panels and inverters over the years.

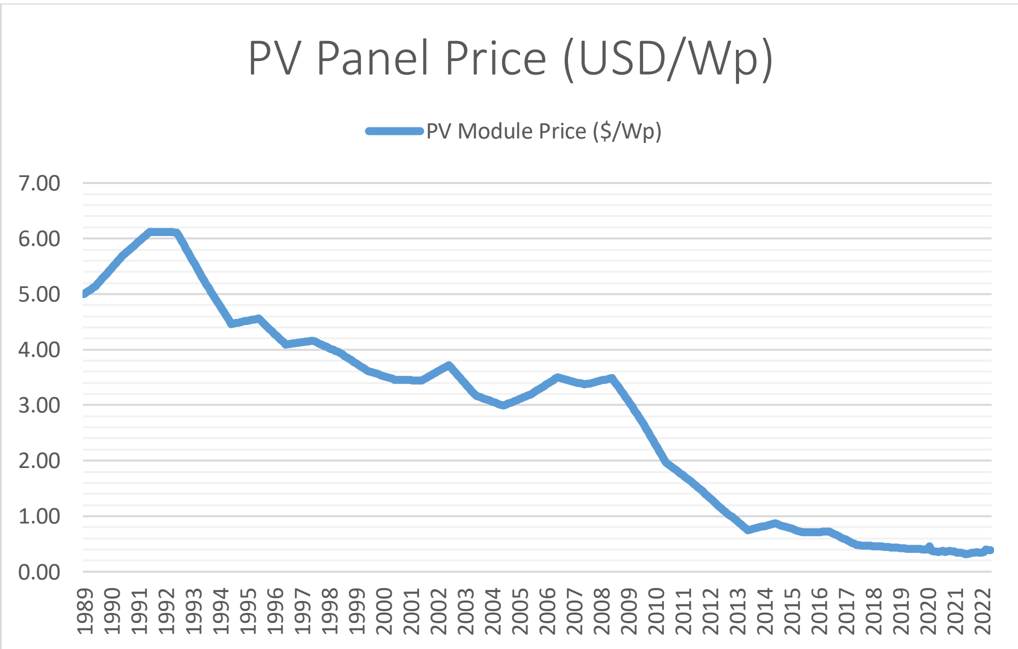

Figure 5.2. Historic PV Panel Prices (U.S. Energy Information Administration, 2012)

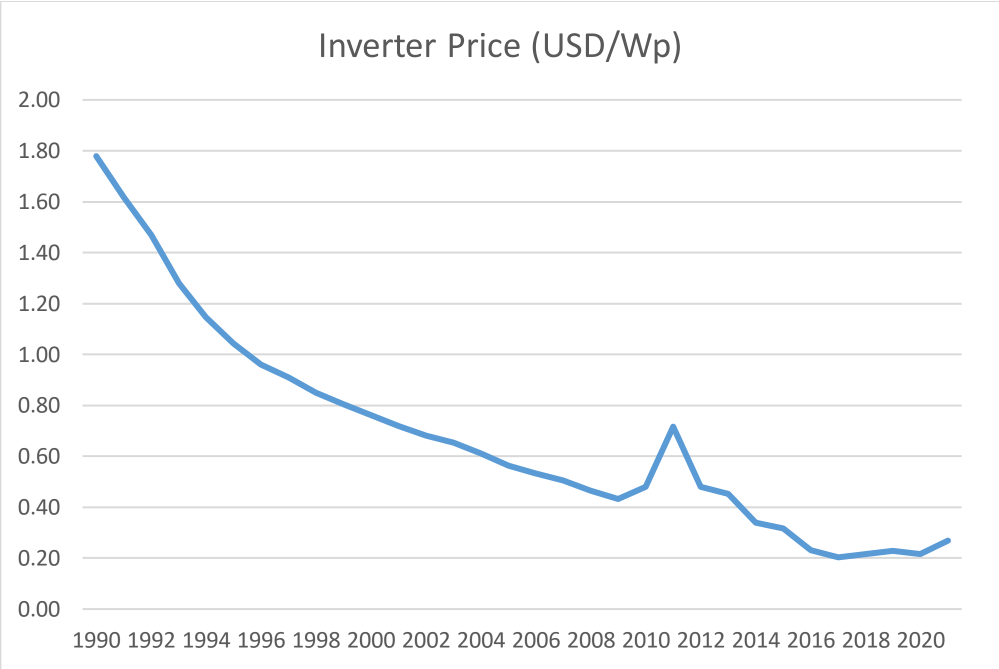

Figure 5.3. Historic Inverter Prices (Energiewende et al., 2015)

As seen from the both figures above, costs of both panels and inverters have a decreasing trend. In order to model this uncertainty for the future costs of both these items, a stochastic model has to be used following the real options approach. However, both for PV panel costs and inverter costs the decreasing trend is not uniform and faces price jumps over time which causes instant price escalations or declinations. Thus, this has to be considered in the model as well.

To model stock prices with a continuous path, GBM has been used. However, for stock prices that face price jumps similar to the PV panel prices above, the GBM has come short. In 1976, Merton offered an option pricing formula for cases where the stock prices show a mixture of both continuous behavior and jumps. The method he offered was also named after him as the `Merton Jump Diffusion Model`. Then, this model was applied to a real options game and gave comprehensive results (Martzoukos & Zacharias, 2001). Thus, the model's applicability for real options valuations has been proven. Finally, the GBM with the Poisson events model was used for the description of the impact of radical technology innovation on the market (Daming et al., 2014). R&D processes and product innovations are the main causes of the decrease in the costs of PV panels and inverters. Thus, PV panel and inverter costs can be treated as a part of radical technology innovation. Finally, the uncertainty in PV panel prices and inverter costs are modeled using the Merton Jump Diffusion Model mentioned above in the research done by Penizzotto et al. (2019) and the results have shown that the model is suitable for modeling PV panel and inverter costs. Thus, this research will use the same model to model PV panels and inverter costs. The value of PV panel cost at any time t is given by:

$$C_{panel}(t) = C_{panel}(t=0)\exp\left[\left(\alpha - \frac{\sigma^2}{2} - \lambda k\right)t + \sigma W_t + \sum_{i=1}^{N_t}(V_i)\right] \quad (5.8)$$

where $C_{panel}(t=0)$ is the initial cost of panel at t=0, α is the growth rate of panel cost and σ is the volatility or the standard deviation of growth rate without considering the Poisson jumps. λ is the mean number of arrivals per unit time, k is equal to $E[V_i - 1]$ where $(V_i - 1)$ is the random variable percentage change in panel cost if the Poisson event occurs. The value of k is calculated by $e^{\mu_j + \frac{1}{2}\delta^2}$ where μ_j is the expected value of the jump size and δ is the standard deviation of the jump size. W_t is a Wiener process with a mean equal to zero and variance equal to one, $W_t = \sqrt{t}.\varepsilon$ where $\varepsilon \sim N(0,1)$. $\sum_{i=1}^{N_t}(V_i)$ is the compound Poisson process which is equal to zero when there is no Poisson event between t=0 and t, V_i resemble the jumps, which are independent of the Wiener process. Overall, the α, σ and W_t variables resemble the continuous Geometric Brownian Motion and λ, k, $\sum_{i=1}^{N_t}(V_i)$ variables resemble the Poisson events that cause the jumps of panel costs.

The value of inverter cost at any time t is given by:

$$C_{inverter}(t) = C_{inverter}(t=0)\exp\left[\left(\alpha - \frac{\sigma^2}{2} - \lambda k\right)t + \sigma W_t + \sum_{i=1}^{N_t}(V_i)\right] \quad (5.9)$$

where $C_{inverter}(t=0)$ is the initial cost of panel at t=0, α is the growth rate of inverter cost and σ is the volatility or the standard deviation of growth rate without considering the Poisson jumps. λ is the mean number of arrivals per unit time, k is equal to $E[V_i - 1]$ where $(V_i - 1)$ is the random variable percentage change in inverter cost if the Poisson event occurs. The value of k is calculated by $e^{\mu_j + \frac{1}{2}\delta^2}$ where μ_j is the expected value of the jump size and δ is the standard deviation of the jump size. W_t is a Wiener process with a mean equal to zero and variance equal to one, $W_t = \sqrt{t}.\varepsilon$ where $\varepsilon \sim N(0,1)$. $\sum_{i=1}^{N_t}(V_i)$ is the compound Poisson process which is equal to zero when there is no Poisson event between t=0 and t, V_i resemble the jumps, which are independent of the Wiener process. Overall, the $\alpha, \sigma\ and\ W_t$ variables resemble the continuous Geometric Brownian Motion and $\lambda, k,\ \sum_{i=1}^{N_t}(V_i)$ variables resemble the Poisson events that cause the jumps of inverter costs.

The parameters for both the PV panel cost and inverter cost are estimated in accordance with the offered method in Özdemir (2019). Firstly, the five parameters, $\alpha, \sigma, \mu_j, \delta, \lambda$ referred to as the growth rate of the cost, the standard deviation of the growth rate, the expected value of jump size, the standard deviation of jump size, and jump intensity, respectively are given arbitrary initial values. Then, the offered simulation is done which utilizes the most likelihood estimation method and the resulting parameters are obtained.

The other initial investment costs, such as labor costs, other hardware costs, and load-carrying structure costs, are modeled using a deterministic process. The previous data collected is investigated and a reduction rate is estimated using the historical data. The equation for other costs is formed as,

$$C_{other}(t) = C_{other}(t = 0)(1 - O_{r.rate})^t \qquad (5.10)$$

where $C_{other}(t = 0)$ is the initial value of other costs at time t=0, and $O_{r.rate}$ is the reduction rate. The overall initial investment cost of the residential PV system including a taxation of 18% can be calculated by,

$$I(t) = [C_{panel}(t) + C_{inverter}(t) + C_{other}(t)] * 1.18 \quad (5.11)$$

5.4 Operation, Maintenance, and Disposal Costs

In practice in Turkey, residential PV systems do not require a periodic maintenance service unless there is a malfunction. Also, the routine cleaning requirement, which is done yearly for commercial PV systems, is not something that is done. Since the surface areas of residential PV investments are small compared to commercial ones, it is assumed that rainfalls will be enough for the removal of dust and dirt over the PV panels. Thus, the yearly operation and maintenance cost includes the inverter, module and component parts replacements costs, system inspection and monitoring costs and insurance (Ramasamy et al., 2021).

Since the total cost of operation and maintenance is relatively low compared with the PV panel and inverter prices, similar to other initial investment costs, they are modeled using a deterministic process. The previous data collected is investigated, and a reduction rate is estimated using the historical data. The equation for yearly operation and maintenance cost is formed as,

$$C_{O\&M}(t) = C_{O\&M}(t = 0)(1 - O_{r.rate})^{t} \quad (5.12)$$

where $C_{O\&M}(t = 0)$ is the initial value of operation and maintenance cost at time t=0, and $O_{r.rate}$ is the reduction rate.

For the disposal costs, since the PV system investments are relatively new, with an expected service life of around 20 to 25 years, there is not any information about the disposal cost of PV systems in Turkey. In a study done by Öztürk et al. in 2012, the problem of the lack of information about the disposal costs of PV systems in Turkey is mentioned, and a salvage value generated by the recycling cost of the aluminum structural elements has been used. However, the residential PV system is assumed to have no disposal costs or salvage values for this study.

5.5 Valuation Method

The classical net present value of the residential PV investment at any time t using the revenues and costs mentioned above is calculated by,

$$NPV_{classic} = -I(t) + \sum_{t=1}^{T_{life}} \frac{R(t) - C_{O\&M}(t)}{(1+i)^t} \qquad (5.13)$$

where I(t) is the initial investment cost at time t, $R(t) - C_{O\&M}(t)$ is the revenue function for any time step between the initial investment time and the service life of the investment, T_{life}, i is the discount rate determined by the opportunity cost of capital.

The values of $I(t)$ and $R(t)$, which are the initial investment cost and revenue function, respectively, are estimated using the values of PV panel and inverter costs and electricity tariff and distribution costs. As mentioned before, the future prices of these items contain too much uncertainty, which can only be modeled using a stochastic model in order to determine the prices during the investment period. The offered methods simulate a number of various paths using the input parameters and the resulting $NPV_{classic}$ values using the equation above is calculated for each path. Then, the average of these $NPV_{classic}$ values is calculated which is called the expected value of the $NPV_{classic}$ values generated from different paths, $E(NPV_{classic})$. Also, the standard deviation of these $NPV_{classic}$ values is calculated, $\sigma(NPV_{classic})$.

Even though this approach handles the uncertainty of items used in the $NPV_{classic}$ calculations, managerial flexibility, such as the deferral of the investment time, is not considered. To reflect such flexibility, the real options approach should be used. The real options approach has been used widely in renewable energy investment valuations and resulted in comprehensive outcomes for such investments. This is mainly due to the similarities between renewable energy investments and options in stock prices. They both have great uncertainty for future prices, the possibility of acquiring better information/estimation about the futures prices as time passes, and the chance of postponing (unnecessity of executing the investment or the option in case of American type). Thus, the real options approach should be used to reflect managerial flexibility.

For the case of renewable energy investments, one of the many options available is the deferral option. In the deferral option, the investor has the flexibility of postponing the decision to invest in the project in pursuit of getting a clear view of the investment and its cost items. However, this means that the capital reserved for that specific investment will be left idle until the investor gets a clear view, meaning the loss of the foreseen cash flows the investment will generate. In time, if the investor acquires much better information and invests in the project, resulting in better cash flows, then the investor will come out ahead. This deferral option is very similar to the American Call Option, in which the option holder has the privilege to acquire the stock at the cost of the strike price at any time during the maturity time, the time frame for which the option is valid. If the stock price rises above the option strike price, then the investor uses the option and acquires the stocks at a lower price than the market and can sell them to earn money. However, if the desired scenario for the investor does not happen at any time during the maturity time, the investor has no obligation to use the call option and only loses the relatively small amount that is paid for acquiring the option. For a residential PV investment, the value of the option to defer the investment at any time t and a specific path w can be calculated using the same formula for calculating the value of an American call option as below (used in Penizzotto et al., 2019),

$$F(t,w) = \max_{\tau \epsilon \Upsilon(t,T)} \{\mathbb{E}_Q[e^{-r(\tau-t)}\Pi(\tau, X_T)]\} \quad (5.14)$$

where $\Upsilon(t,T)$ is the set of optimal times to exercise the option during the defined time frame [t,T]. T Is the option maturity, the latest time the option is valid. $\mathbb{E}_Q[.]$ is the risk-neutral expected value operator which is subject to the information set available in time t and the revenue function, $\Pi(\tau, X_T)$, for the option at time instant τ.

The formula above can be solved using the Least Square Monte Carlo (LSMC), which offers an approximate path for the solution of the stopping problem generated by the American call option. The solution aims to generate an exercise rule that maximizes the option value at each time step along the simulated paths. LSMC is an algorithm that approximates the continuation value in the Bellman equation in the context of dynamic programming. By using a linear least-squares regression, it estimates expected returns based on actual state variables. Using the continuation value, the contingent right can be stopped at the optimal time, and the option's value can be estimated. It is assumed that until the option maturity, the option can be exercised in N discrete times such as $0 \leq t_1 \leq t_1 \leq t_1 \leq \ldots \leq t_N = T$ along the generated paths. For each of these N discrete times, the NPV value is calculated using the I(t) value as the initial investment cost and the expected present value of the cash flows generated as if the investment is made at each of these points in time.

To start the LSMC evaluation, w paths have to be generated, which will be used for the simulation of the stochastic dynamics of the state variables X_T that affect the value of the option. Then, the evaluation begins at the option maturity date and continues recursively until t=0 working towards the generation of an exercise rule that maximizes the option value at each time step t along the generated w paths.

At time T, the option maturity, the value of exercising the option at T, is compared with the value of the underlying asset. For the PV system investment with a postponement option, the value of exercising the option at option maturity means that the deferral option has been used at the last decision-making point available for the fate of the investment, which eventually results in neither expenditure nor income; and the value of the underlying asset means that the decision to make the investment is made and cash flows have been generated due to the investment. When the value of the underlying asset is greater than the option strike price, then the option is said to be executed. If not, then the option is not executed and will run out of time, meaning the option is out of money. For the case of this study, at the option maturity, if the value of the cash flows generated by making the investment is greater than the value of the final deferral decision for investment which results to zero, then the option is exercised. Thus, the optimal option value at option maturity can be calculated as follows,

$$F(T, w) = \max[-I(T, w) + PV(T, w)\,;0] \quad (5.15)$$

where $F(T, w)$ is the value of the call option at time T along path w and $PV(T, w)$ is,

$$PV(T, w) = \sum_{t=T}^{T+T_{life}} \frac{R(t, w) - C_{O\&M}(t, w)}{(1+i)^t} \quad (5.16)$$

For any time, t_i previous to the option maturity date, the optimal strategy to execute results from comparing the value of cash flows generated when the investment is exercised at t_i versus the expected value of the cash flows that might happen by continuing, i.e. keeping the option alive. If the value of immediate exercise is greater than the value of expected cash flows that might arise when continuing, the investment is exercised.

$$F(t_i, w) = \max[-I(t_i, w) + PV(t_i, w)\,;\ \emptyset(t_i, w)] \quad (5.17)$$

The value of continuation, $\emptyset(t_i, w)$, has to be determined to find the value of option. In the theory of arbitrage free valuation, the value of continuing is determined by expectation of the cash flows generated by the option $F(t_{i+1}, w)$ discounted with respect to a risk-free measure Q, where r being the risk-free discount rate.

$$\emptyset(t_i, w) = (1+r)^{-(t_{i+1}-t_i)}.\,\mathbb{E}_Q[F(t_{i+1}, w)] \quad (5.18)$$

Since the goal of LSMC is the maximization of the option value, this can only be achieved once the decision to exercise the investment is made when the immediate value of exercise is greater than the value of continuation, as mentioned above. Thus, the whole offered model leans on the correct estimation of the continuation value. To approximate the conditional expectation function, $\emptyset(t_i, w)$, at each time instant t, the LSMC utilizes the least squares regression technique. The conditional expectation functions at each time instant t are represented as a linear combination of a countable set of orthonormal basis functions $\{L_M\}$. The most common function used are Laguerre, Hermite, Legendre, Chebyshev, Gegenbauer and Jacobi polynomials (Longstaff & Schwartz, 2001).

$$\emptyset(t_i, w) = \sum_{m=1}^{\infty} \varphi_m(t) \, . L_m(t, X_m) \qquad (5.19)$$

For the estimation of the values of φ_m, the least square regression of $\emptyset_M(t_i, w)$ with M elements of the selected base function is used with $M < \infty$ (Pringles, Olsina, and Garcés 2014).

$$\{\hat{\varphi}(t_i)\}_{m=1}^{M} = \arg min_{\{\varphi\}_{m=1}^{M}} \left\| \sum_{m=1}^{M} \varphi_m(t) \, . L_m(t, X) - \sum_{m=1}^{M} (1+r)^{-(t_{i+1}-t_i)} . F(t_{i+1}, \cdot) \right\| \qquad (5.20)$$

where ‖·‖ is the norm of Hilbert vector space from which the estimated value of the continuation function results,

$$\hat{\phi}_M(t_i, w) = \sum_{m=1}^{M} \hat{\varphi}_m(t_i) \, . L_m(t_i, X_m) \qquad (5.21)$$

While determining the estimated value of continuation function, only the cases that are in the money such as the cases that the value of the underlying asset is greater than the strike price is considered. This is because the decision of exercising the investment or the option is available at such conditions. For the case of the value of the underlying asset is lower than the strike price, there is no point for investor to make a decision since there is not case that will generate profit. By eliminating the cases that are out of money, the number of base functions required to obtain a good estimation of continuation function is reduced and the approximation is restricted to a much relevant region (Pringles et al., 2020).

When the estimation of the continuation function is done, the decision of exercising the investment or the option can be made easily. If the condition of the immediate exercise value of investment is greater than the value of expected cash flows that might arise when continuing is satisfied, the investment is exercised.

$$[-I(t_i, w) + PV(t_i, w)] > \widehat{\emptyset}_M(t_i, w) \quad (5.22)$$

Once the decision for time instant t_i is made, one can move on with the instant t_{i-1} since the choices are made for t_i and cash flows are generated for that time instant at all paths. This backward recursive process is done until t=0. By completing this process, the optimal investment timing for each path generated is determined. Finally, the estimated deferral option for the investment is calculated by discounting the option values obtained in each path to t=0 using the risk-free rate, r and taking their average.

$$F(0) = \frac{1}{W}\sum_{w=1}^{W}(1+r)^{-\tau(w)}F(\tau, w) \quad (5.23)$$

The option value obtained for each path is added to $NPV_{classic}$ value of them and the $NPV_{flexible}$ values of each path that includes the value of the deferral option can be estimated.

$$NPV_{flexible}(w) = NPV_{classic}(w) + F(t_0, w) \quad (5.24)$$

When the average value for the paths generated are taken, the expected values for the investment can be estimated.

$$E(NPV_{flexible}) = E(NPV_{classic}) + F(0) \quad (5.25)$$

As mentioned above, to verify the model, the standard deviations of the above variables are computed as well. Also, a sensitivity analysis is made to the offered model for verification.

CHAPTER 6

CASE STUDY

In this section, a case study of a residential PV investment in Kocaeli, Turkey is generated and using the proposed ROV valuation method, this case study is evaluated. The details of the case study are given initially. Then, the process of collection of the data required in the equations formed in previous section is explained. By using the stochastic models explained, the future prices of the variables are modelled and by using these and the valuation model, results are obtained.

6.1 Details of the Residential Solar Power Investment Project

The planned residential PV investment will be constructed in Gebze, Kocaeli, Turkey on the roof of a 3-story building which accommodates 3 families of 4. The investment will be composed of 22 panels which covers a 48m^2 area on the roof of the building. The estimated capacity of the PV system composed of 22 panels is 6.6 kWp. The expected annual energy production from the system is 7600 kWh. According to Chamber of Electrical Engineers in Turkey, the monthly consumption of a 4-person family is 230kWh. Thus, the offered system aims to compensate the 91% of the total power consumed at the 3-story building with an expected 85% efficiency. The service life of the PV investment is 25 years with a deferral option of investment for seven years.

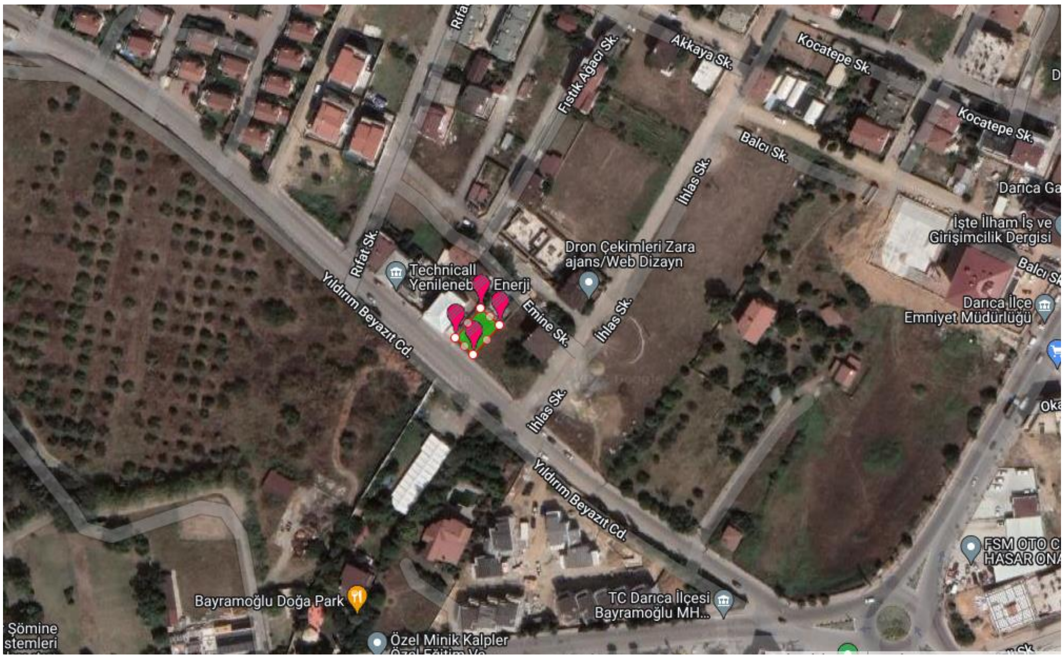

Figure 6.1. Location of the Planned Investment (Taken from Google Maps)

Kocaeli is located at the Marmara region of Turkey and just below Istanbul. It is one of the cities of Turkey that has the lowest solar energy potential as seen from Figure 6.2.

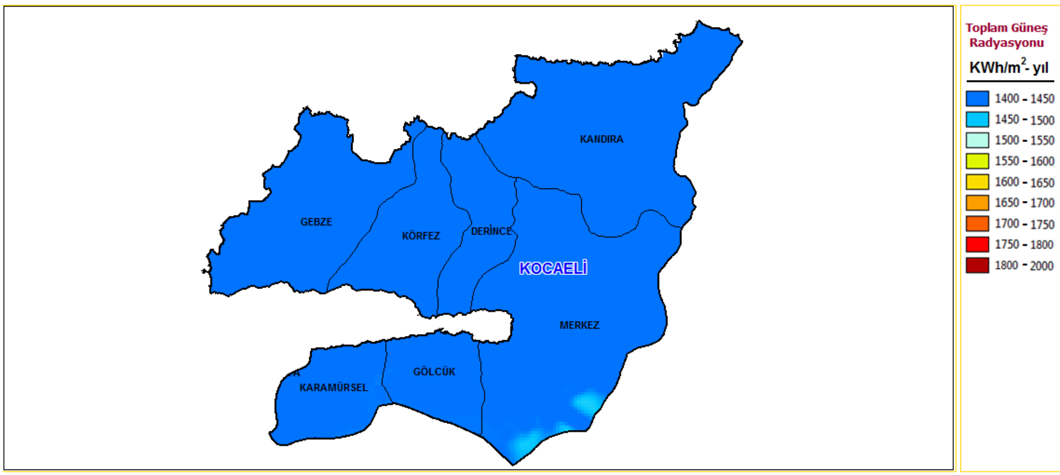

Figure 6.2. Map of Total Solar Radiation of Kocaeli (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b)

Kocaeli is exposed to a total annual solar radiation of 1329 kWh/m^2 which is around 20% lower than the city with the highest solar energy potential, (GNS Solar, 2022.).

It also has one of the lowest annual average daily sunshine durations in Turkey, which is equal to 2373 hours. The monthly histograms of global radiation average sunshine duration are given in Figure 6.3.

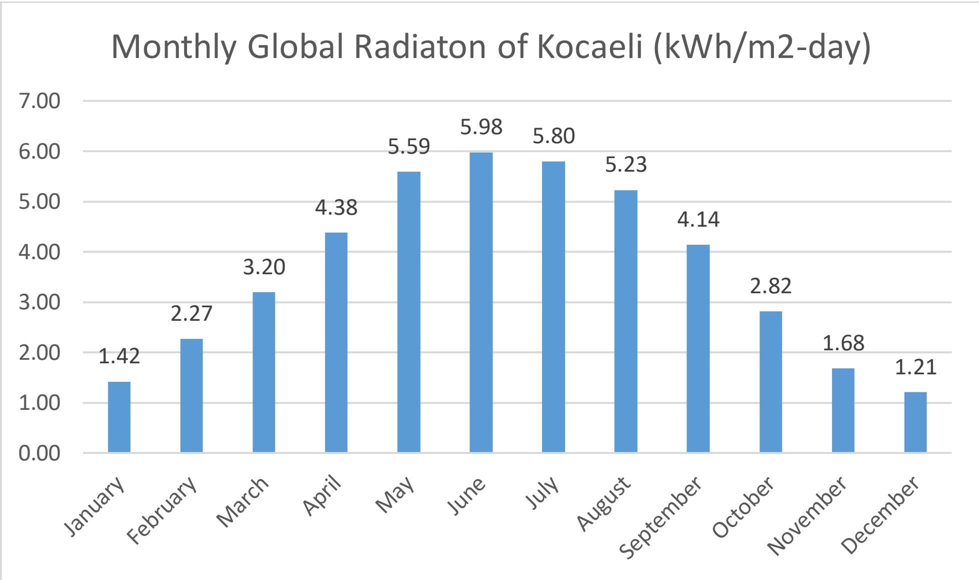

Figure 6.3. Histogram of Monthly Global Radiation of Kocaeli (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b)

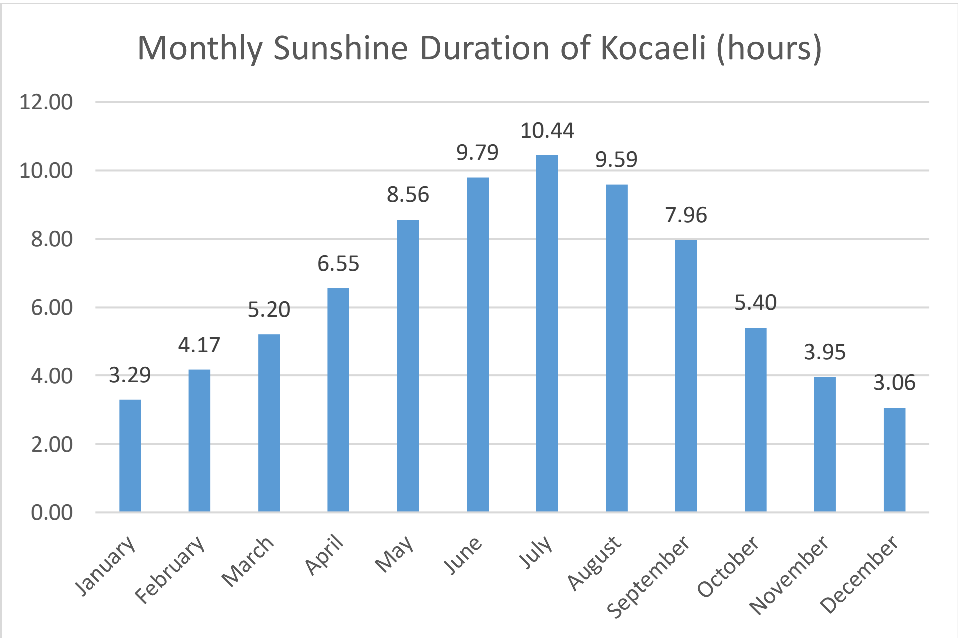

Figure 6.4. Histogram of Sunshine Durations of Kocaeli (T.C. Enerji ve Tabii Kaynaklar Bakanlığı, 2022b)

Even though Kocaeli might not seem an appropriate place to make the investment, due to the increasing global concerns such investments are required to be made at any location possible. Thus, for the case study, this exact location is chosen and the simulations and valuations are made accordingly.

For the simulations and valuations, a self-written program in Python 3 language is used. At first part of the code, the simulations for the variables are completed. The parameters estimated from the historic data is input to the code and the simulation results are obtained. Then, for the valuation, the equations generated in methodology section is input in the code and the NPV values for exercising the investment at each time step available along the paths generated are calculated. Then, the values are input to the LSMC algorithm and the results are obtained.

To prevent additional uncertainty at the model, the monthly energy production of the PV system proposed is not calculated using a software. Rather, the energy production values of a real case study which is located very close to the selected area of investment is used. With a similar setup, a total annual energy production of 7578kWh has been achieved. The monthly histogram of energy production of the real case study is given below. These values will also be used for the calculations for the proposed model.

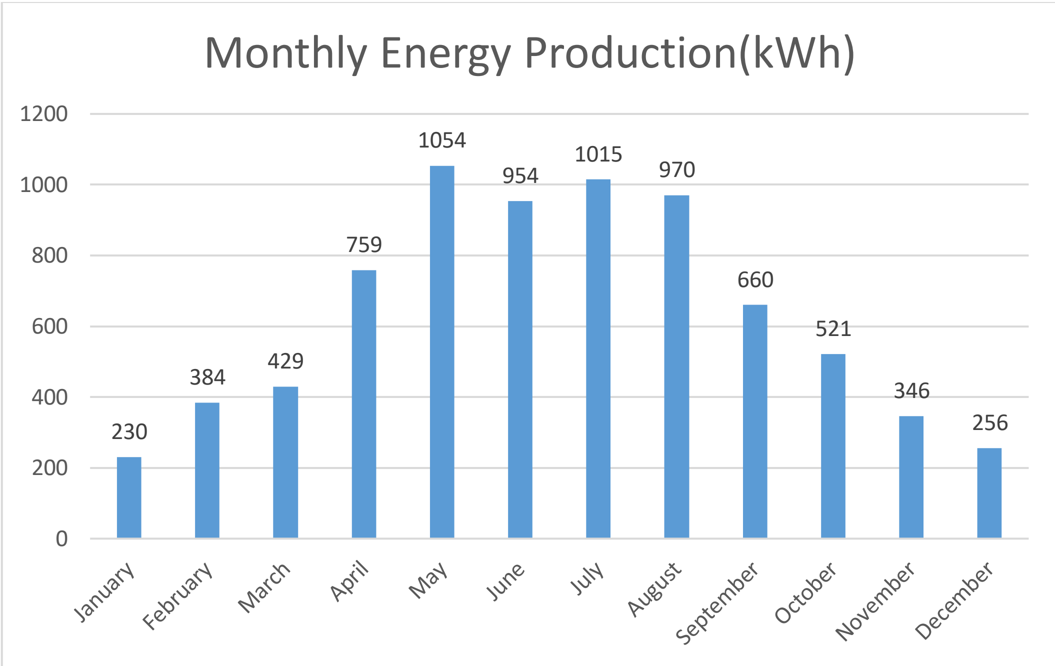

Figure 6.5. Monthly Energy Production of a Near PV System Investment with a Similar Setup

6.2 Data Collection & Simulation Parameters

In order to make a real options valuation with LSMC approach, the variables in the cash flows generated by the investment have to be determined. For the case of this study, the variables in Equations 5.1 to 5.12 such as,

- $E_g(t)$, the energy generated by the PV system between the instant t-1 and t
- $P_{et\&d}(t)$, the price of electricy tariff and distribution at time t
- $C_{panel}(t)$, the cost of PV panel at time t
- $C_{inverter}(t)$, the cost of inverter at time t
- $C_{other}(t)$, total of other costs in investment at time t
- $C_{O\&M}(t)$, the operation and maintenance cost the investment will require at time t

- w, number of simulation paths generated for the LSMC simulation
- i, the discount rate determined by the opportunity cost of capital
- T_{life}, the service life of the investment
- T, the option maturity, the time period that the deferral option is valid for
- r, the risk-free discount rate used in LSMC
- $O_{r.rate}$, the reduction rate for labor and operation and maintenance costs

will be determined. The t values at the variables above represents the instants of investment decision points. Since the model involves a stochastic simulation, the corresponding values of variables that are dependent on time have to be determined considering the frequency of this investment decision points. For this study, it is assumed that at the first day of every month the decision to exercise the investment will be made. Thus, the time step is monthly and the values of time-dependent variables are estimated for each month. In order to do that estimation, stochastic simulations are used as mentioned before.

To generate stochastic simulations like GBM, the parameters have to be estimated as well as the number of simulation paths. In Figure 6.6, the option value versus the number of simulations can be seen. According to the Figure 6.6, as the number of simulations increase the resulting option value converges and becomes stable. Thus, as can be seen from graph, using 10000 is adequate to have a comprehensive estimation for option value. Thus, the number of simulations is estimated to be 10000 for this study.

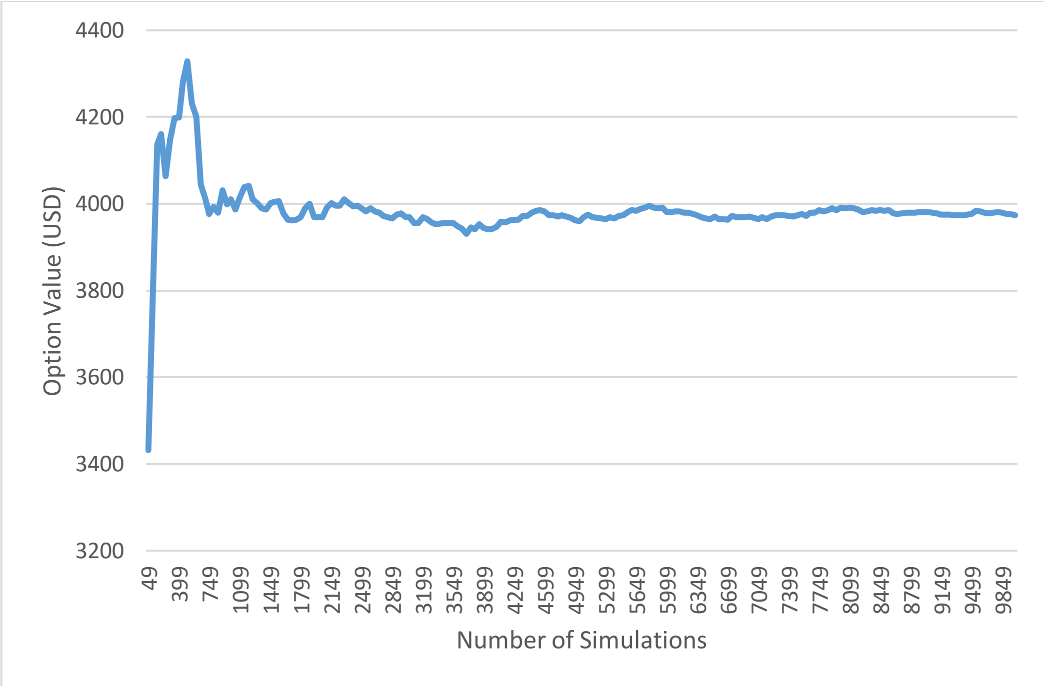

Figure 6.6. Graph of Number of Simulation versus Option Value

As for the determination of simulation parameters for stochastic simulations, the historic data has to be acquired. Thus, the historic data for electricity tariff and distribution costs, PV panel costs, inverter costs, total of other PV investment costs and operation and maintenance costs are found. Even though the monthly generated energy from the offered residential PV system is a time dependent variable, since the production values from the nearby real PV system with identical attributes will be used, there is no need for historic data.

The historic electricity tariff and distribution costs are collected from monthly real-time electricity bills, that lasts to December, 2011, of a house in Turkey. The total electricity bill is divided to 1.18 to remove the presumed value-added tax from the total price. Then, the result is divided to the total electricity consumption in kWh and the equivalent value is noted in TL/kWh unit. Even though the tax items in the total electricity bill calculations have changed a lot since 2012, the offered method compensates these changes by projection the taxes above 18% to the electricity tariff and distribution costs.

The historic data of PV panel costs are taken from the reports released by the U.S Energy Information Administration (U.S. Energy Information Administration, 2012, 2022a). The available historic data is between 1988 and 2021. Since, the PV investments are relatively new in Turkey compared to U.S, there is not a historic data source that can be used. Thus, it is assumed that the price of PV panels in the Turkish market excluding the value-added tax is equal to the price of PV panels in the U.S. market. The price of PV panels is in USD/Wp unit, where Wp is the watt-peak.

The historic data of inverter costs are taken from a study about the "Current and Future Costs of Photovoltaics" and the report released by U.S Energy Information Administration (Energiewende et al., 2015; Ramasamy et al., 2022). The historic data available is between 1990 and 2021. Similar to PV panels, there is not a historic data source in Turkey for inverters that can be used. Thus, the prices found on the global market are assumed to be equal to prices in Turkey excluding the value-added tax. The historic data of inverter costs in "Current and Future Costs of Photovoltaics" study is in Euros/Wp, thus they are converted to their USD/Wp equivalent using the financial parity data of USD/Euro. Then, all the historic inverter prices have become USD/Wp in units.

For the total of other PV investment costs and operation and maintenance costs, the historic data is taken from the U.S Energy Information Administration report (Ramasamy et al., 2022) because of the reason above. The units of these two cost items are again USD/Wp. As mentioned before since these two cost items are relatively smaller than the ones above, these future values of these cost items are determined using a deterministic process for the sake of simplicity. The reduction rate for these costs is determined to be 1% each year, estimated from the historic data.

As for the rest of the variables that are not dependent on t, they are determined using previous studies. The value of i the discount rate determined by the opportunity cost of capital value is taken between 10-13% in previous studies on renewable energy investments in Turkey (Kılavuz, 2013; Öztürk et al., 2012; Toptaş, 2016). However, among these studies, the one related with the valuation of commercial PV investments in Turkey has taken the opportunity cost of capital as 10%. In this study 11% will be used for the discount rate by considering the time passed over that previous study. The service life of PV investments is taken as 25 years in previous studies (Penizzotto et al., 2019; Pringles et al., 2020), thus the same value will be used for this study as well. The option maturity is taken as 7 years. Finally, the risk-free discount rate is taken as 8%.

In order to convert the electricity tariff and distribution price to USD/kWh unit, an estimation for the future prices of USD/TL has to be made. To do so, the parity values between 2012-2021 are taken from the Central Bank of the Republic of Turkey (2022) database. Since the USD/TL parity has shown a jump between September, 2021 and December 2021 which disrupted the general linear increase trend, by removing the data points between and at those dates, a linear fit is made and the slope is determined as 0.06. Then the new trend line is put on top of the value of December, 2021 and the future values of the USD/TL are obtained.

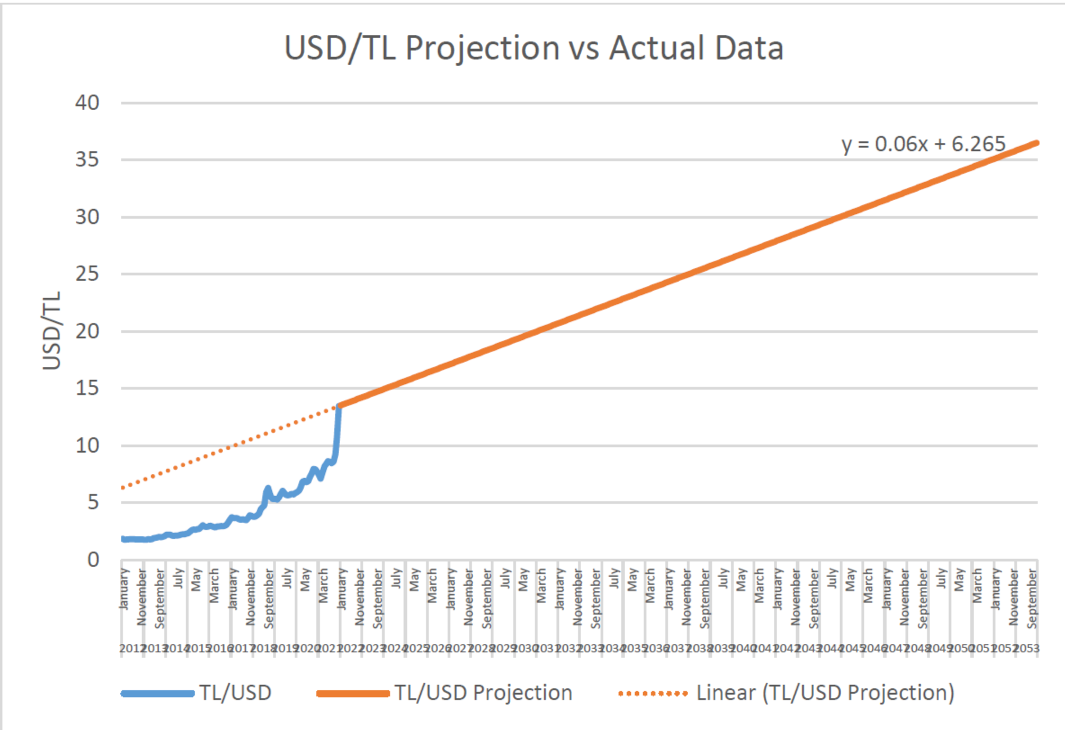

Figure 6.7. USD/TL Projection vs Actual Data between 2012-2053

Table 6.1 Simulation Parameters of the Case Study

Parameters		Unit
Capacity of the PV system	6.6	kWp
Annual energy generation of the PV system	7578	kWh
Service life of the PV system	25	years
Deferral option length	7	years
Number of simulation paths	10000	
Discount rate determined by opportunity cost of capital	11	%
Risk-free discount rate	8	%
Electricity tariff and distribution price at t=0	0.7759	TL/kWh
PV panel cost at t=0	0.3476	USD/Wp
Inverter cost at t=0	0.27	USD/Wp
Total of other initial investment costs at t=0	0.5	USD/Wp
Yearly reduction rate of other initial investment costs	1	%
Operation and maintenance cost at t=0	28.97	USD/Wp
Yearly reduction rate of operation and maintenance cost	1	%
Investment cost at t=0	8703.9	USD

6.3 Parameter Estimation

In order to make stochastic simulations of electricity tariff and distribution price, PV panel cost and inverter cost; the parameters of stochastic simulation should be determined. For electricity tariff and distribution price simulation, GBM will be used. Thus, according to Equation 5.7 the values of growth rate and volatility has to calculated using the historic data. This is done on Microsoft Excel and the resulting values are:

Table 6.2 Parameters for Electricity Tariff and Distribution Price

Parameters for Electricity Tariff and Distribution Price	
Growth Rate (α)	Volatility (σ)
0.1132	0.1024

Since the PV panel cost is highly driven by technology advancements, the Merton Jump Diffusion model for the simulation of future prices is used. In order to find the parameters required for this method, the algorithm proposed at the thesis of Özdemir (2019) is used. Initially, arbitrary variables are given to the algorithm. Then, the resulting parameters for the Merton Jump Diffusion model are:

Table 6.3 Parameters for PV Panel Cost

Parameters for PV Panel Cost				
Growth Rate (α)	Volatility (σ)	Expected Jump Size (μ_j)	Standard Deviation of Jump Size (δ)	Jump Intensity (λ)
-0.0743	0.1243	-0.0029	0.1243	0.2000

Invert costs are simulated using the same model, the Merton Jump Diffusion, as the PV panel costs. Thus, the same procedure explained above is done and the resulting parameters are:

Table 6.4 Parameters for Inverter Cost

Parameters for Inverter Cost				
Growth Rate (α)	Volatility (σ)	Expected Jump Size (μ_j)	Standard Deviation of Jump Size (δ)	Jump Intensity (λ)
-0.0563	0.0548	-0.0765	0.1289	0.1330

6.4 Variable Simulations

By using the above parameters, the future monthly prices of electricity tariff and distribution price, PV panel cost and inverter cost are estimated using 10000 paths. In order to verify the parameters, simulations with 10 paths are done for the timeframe that the historic data exists and the resulting graphs and expected values at the end of simulations are compared with the real data.

The electricity tariff and distribution price in December, 2011 was 0.2525 TL/kWh. By using the parameters for electricity tariff and distribution price, a simulation is made between 2011 and 2021 and the 10 synthetic paths generated from the simulation are shown in Figure 6.8.

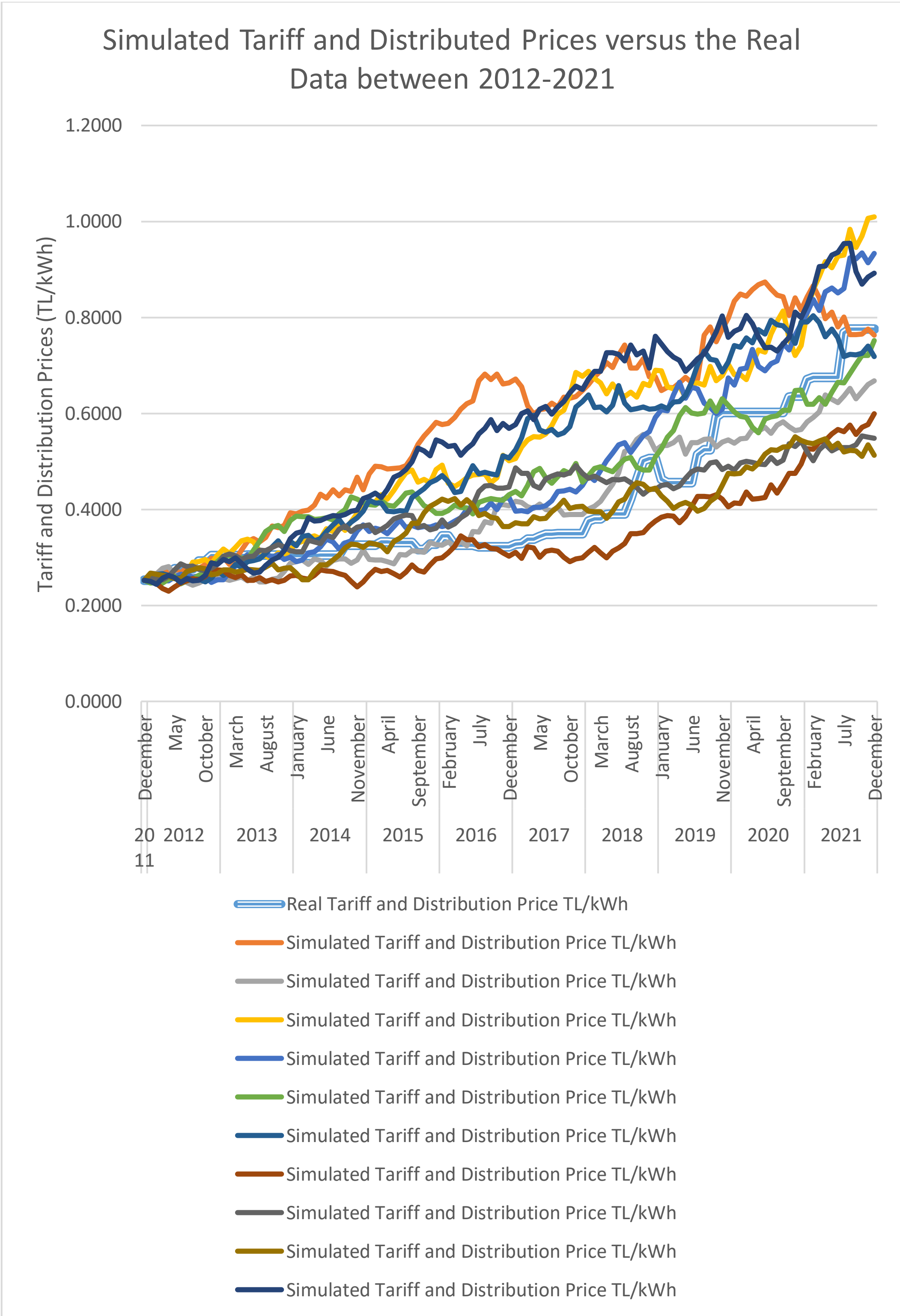

Figure 6.8. Simulated Tariff and Distributed Prices versus the Real Data between 2012-2021

As seen from the Figure 6.8, the simulated paths and the real path are very similar to each other and the expected value of the simulation in December 2021 is equal to 0.7397 TL/kWh. The corresponding value in the historic data is 0.7759 TL/kWh. There is only a 5 percent difference between the simulation results and the historic data. As the number of simulation paths increase, this difference will become much less. Thus, it can be said that the estimated parameters are fit. A sample from the simulated monthly electricity tariff and distribution prices with 20 synthetic paths can be seen in Figure 6.9.

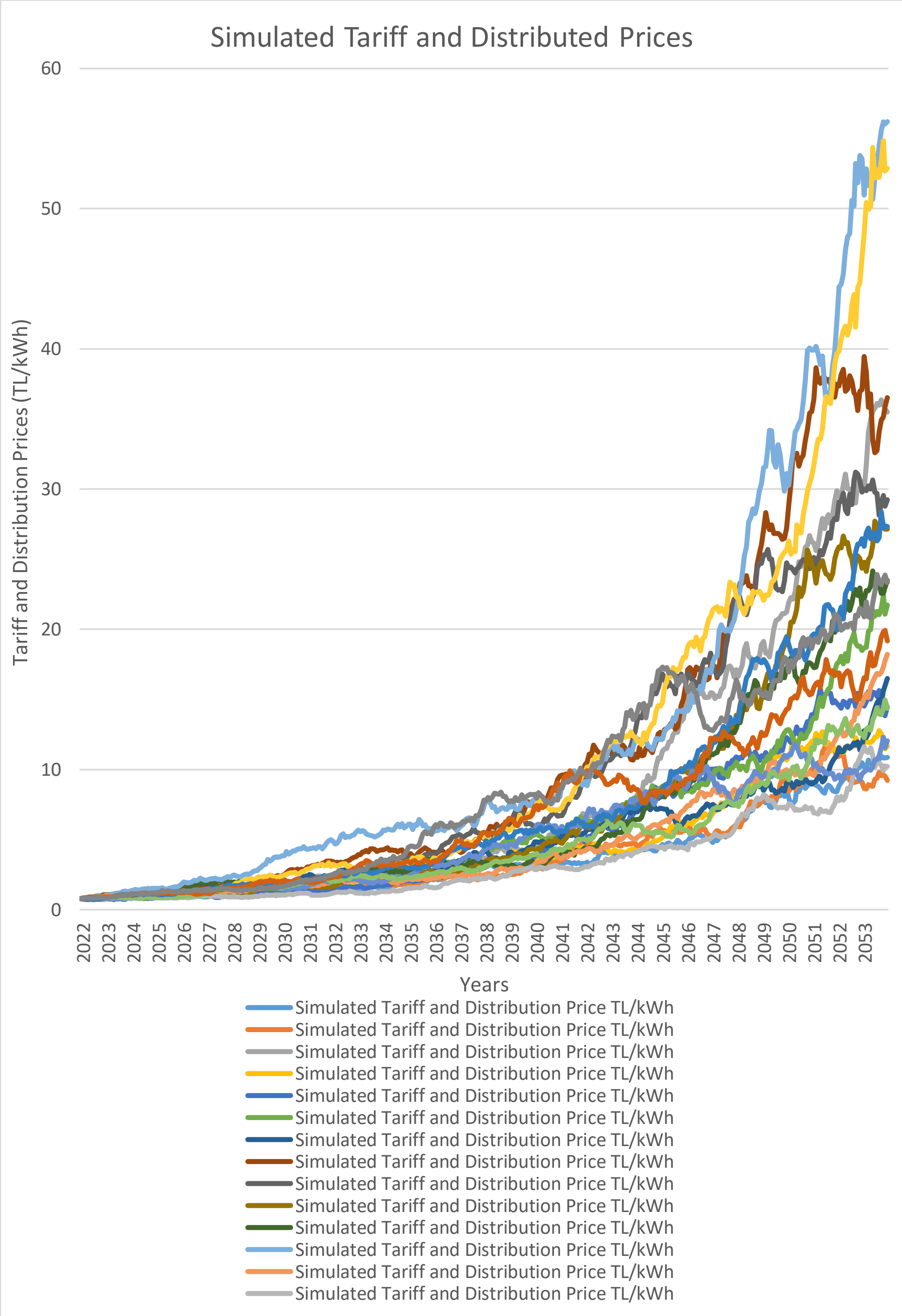

Figure 6.9. Simulated Future Tariff and Distributed Prices

The PV panel cost in December, 1988 was 5 USD/Wp. By using the parameters for PV panel cost, a simulation is made between 1988 and 2021 and the 10 synthetic paths generated from the simulation are shown in Figure 6.10.

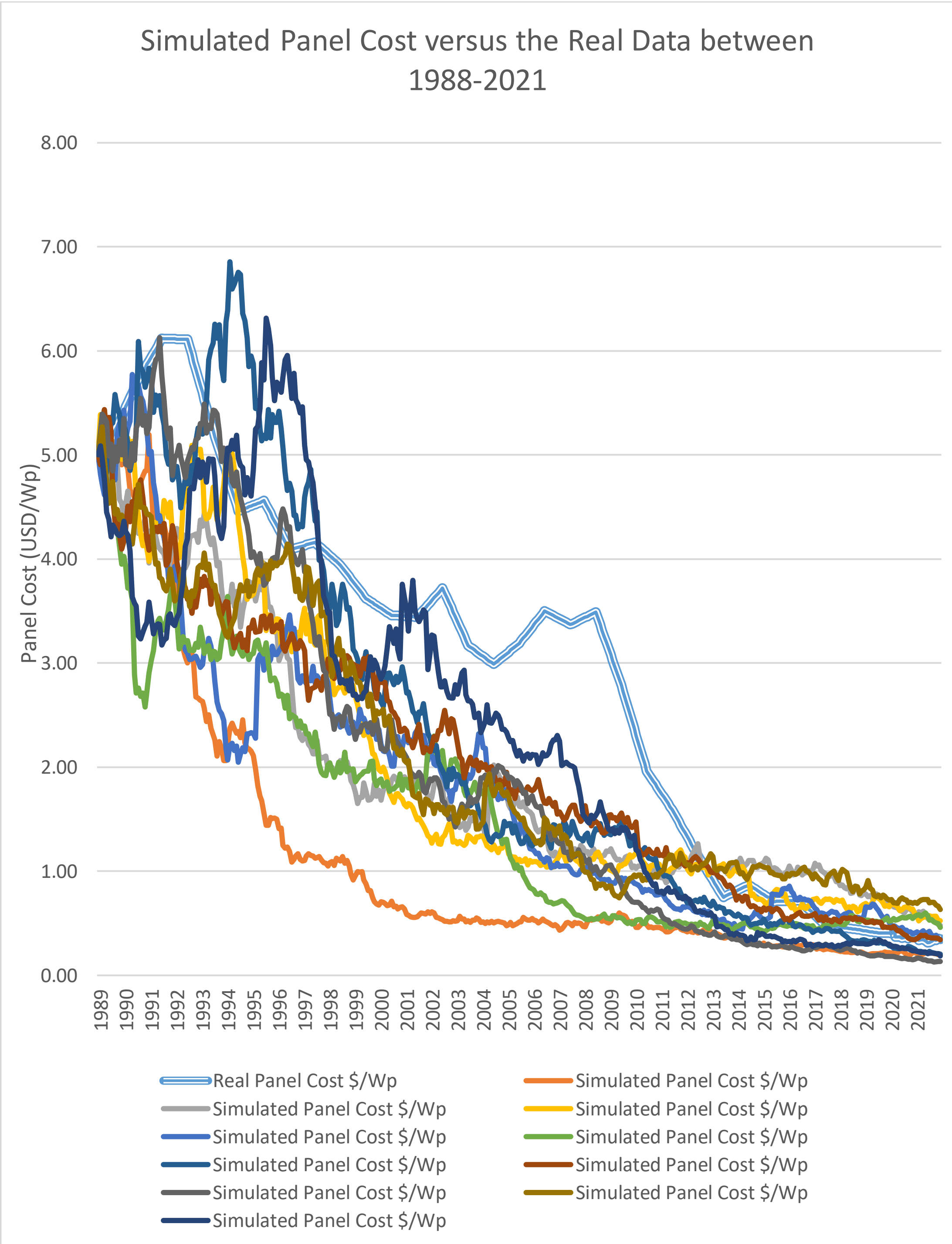

Figure 6.10. Simulated PV Panel Cost versus the Real Data between 1988-2021

As seen from the Figure 6.10, the simulated paths and the real path behaves very identical to each other except the location of the jumps. This is mainly due to the fact that the Merton Jump Diffusion Model assigns only the behavior of the PV Panel Cost but does not specify the jump location. Rather the model mimics the jump frequency among the years. The expected value of the simulation in December 2021 is equal to 0.351293 USD/Wp. The corresponding value in the historic data is 0.34760 USD/Wp. There is only a 1 percent difference between the simulation results and the historic data. Thus, the parameters estimated for the model using the algorithm offered is valid. A sample with 20 synthetic paths from the simulation of PV panel cost can be seen in Figure 6.11.

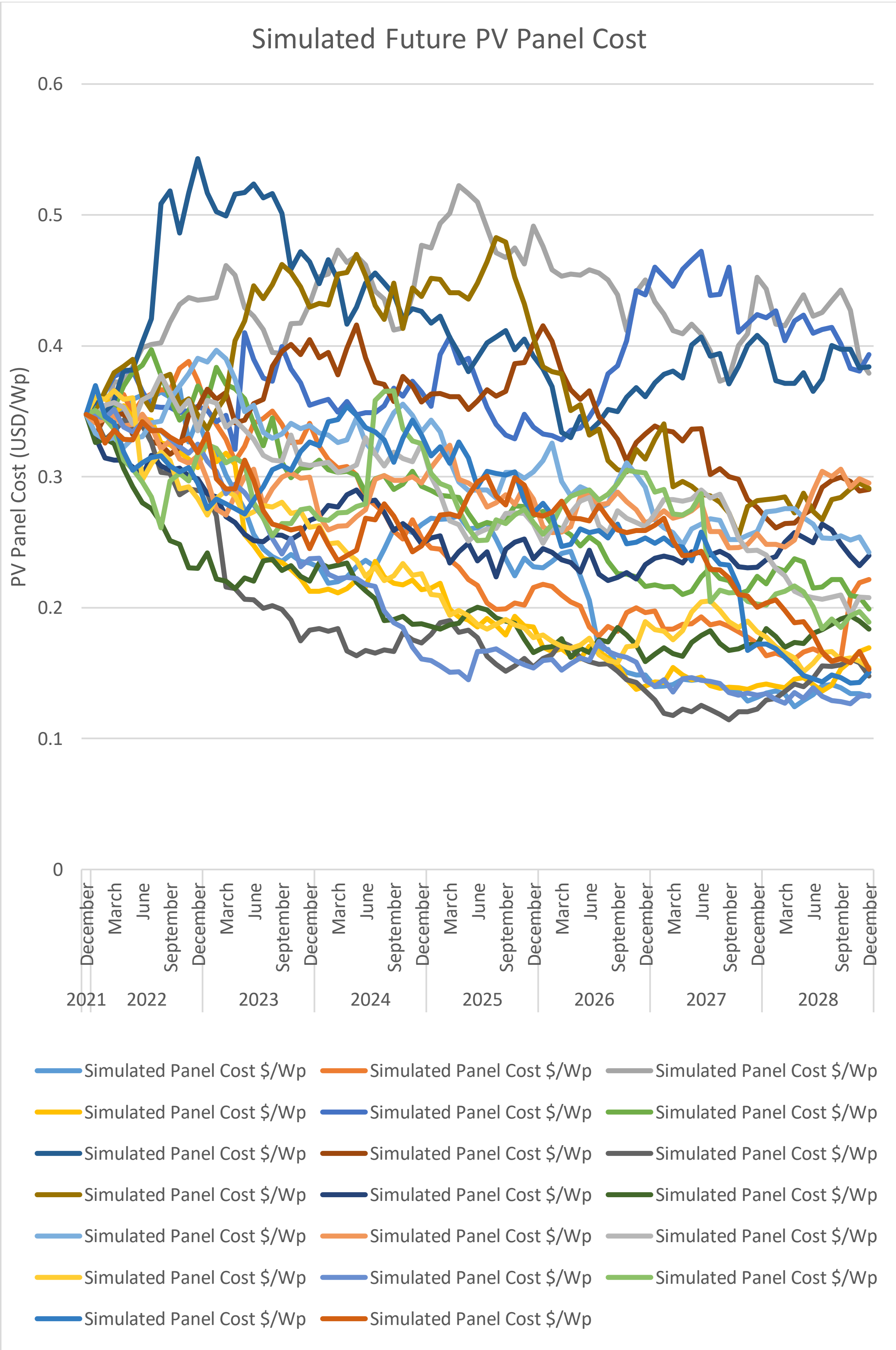

Figure 6.11. Simulated Future PV Panel Cost

As for the inverter cost, the cost in 1990 was 1.78 USD/Wp. Using the parameters estimated, a simulation is made between 1990 and 2021 and the 10 synthetic paths generated from the simulation are shown in Figure 6.12.

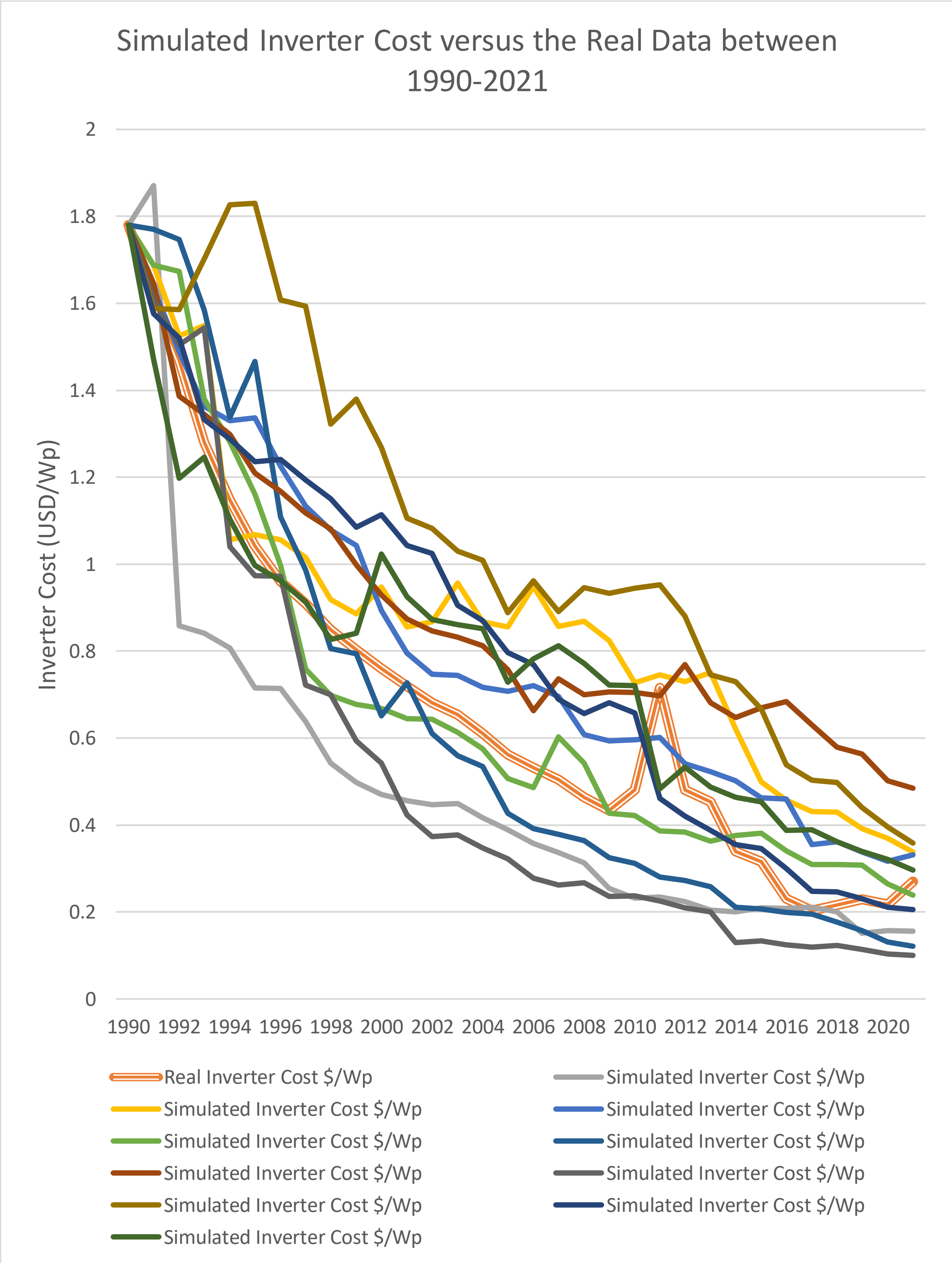

Figure 6.12. Simulated Inverter Cost versus the Real Data between 1990-2021

In Figure 6.12, it can be seen that the simulated paths and the historic data path behaves very similar to each other. The simulation for inverter cost is made monthly and the Wiener Process generates a random variable of increment each month. This is the cause of the small vibrations in the simulated paths. Since the historic data available for inverter costs are annual, the historic data path is smoother. The expected value of the simulation of inverter costs in December 2021 is equal to 0.263016 USD/Wp. The corresponding value in the historic data is 0. 0.27 USD/Wp. The difference between the two value is 2.5%, which is acceptable. Thus, the parameters estimated for the model using the algorithm offered is valid. A sample from the simulated inverter cost with 20 synthetic paths is shown in Figure 6.13.

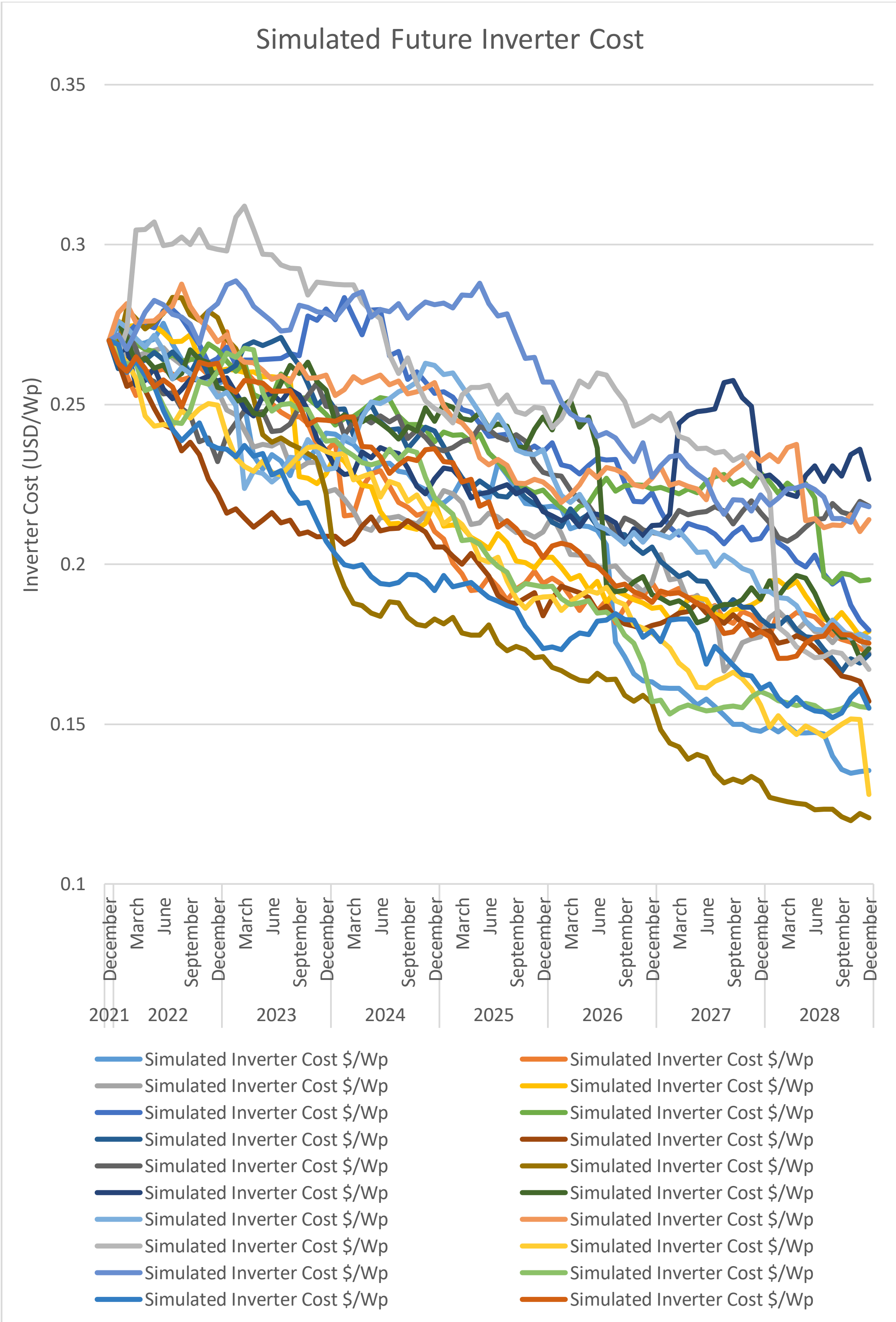

Figure 6.13. Simulated Future Inverter Cost

6.5 Valuation Results

The real option valuation is conducted using the variables and the simulations mentioned above. Since there are stochastic simulations, in order to comment about the results, the expected values of each of the valuation method is calculated.

$$E(NPV_{classic}) = -1730.04\ USD$$

$$E\left(NPV_{flexible}\right) = \ 2242.87\ USD$$

$$E(F(0)) = \ 3972.92\ USD$$

As seen from the expected values, the $NPV_{classic}$ results in a negative value, meaning that the investment is currently not desirable. However, when the investor owns a deferral option for the time of investment, an additional value is generated which is denoted as F(0), the option value. By using the proposed method which accounts for this option value at the NPV calculations, the resulting $NPV_{flexible}$ results in favor of the investment which means that instead of rejecting the investment today, if the investor postpones the decision making to a future point in time, there is a possible favorable outcome for the investor. Thus, for residential PV investments in Turkey, even though it is not advantageous to make such an investment now, making the investment at some time in the subsequent seven years will result in a positive cash flow. By using the proposed method for valuation of PV investments in Turkey, the potential of the investment is not overlooked and it is suggested that the investment may result in positive cashflows in favor of the investor in the following years.

In order not to comment only on the expected values of $NPV_{classic}$ and $NPV_{flexible}$, the valuation results are shown on the histogram below with their probability density functions. While $NPV_{classic}$ is shown as blue, the $NPV_{flexible}$ is shown as orange.

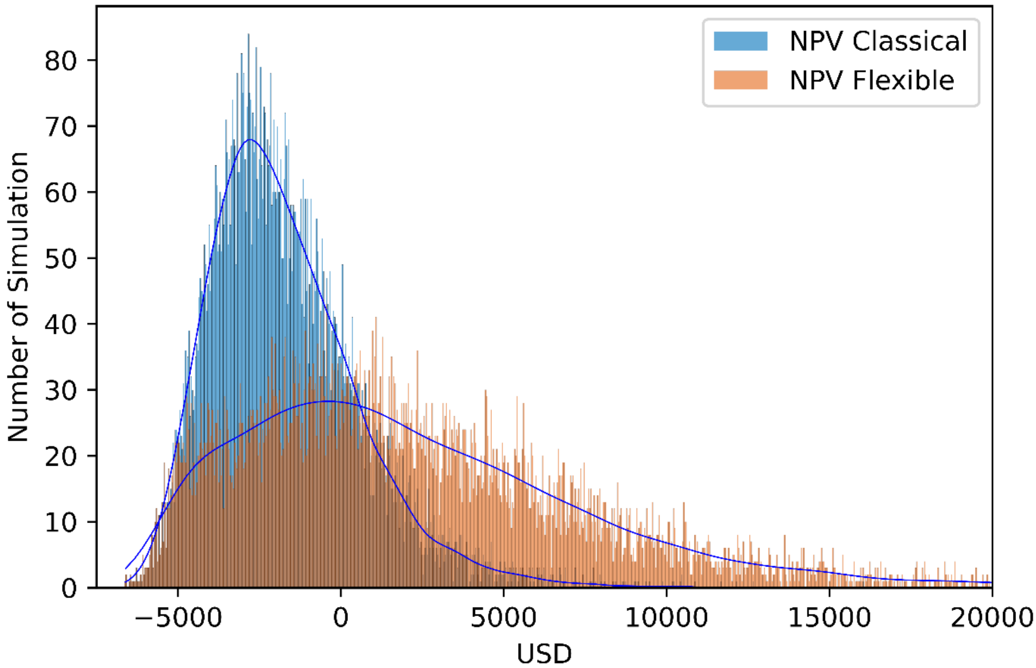

Figure 6.14. NPV (classical and flexible) Histogram Bars

According the Figure 6.14, most of the blue bars, paths of $NPV_{classic}$, are at located at the negative region. This means that most of the paths of $NPV_{classic}$ calculation will result in negative cashflows. Also, they are almost stacked up between -5000 USD and 2500 USD values, forming a bell-shaped histogram, meaning the probable outcomes from $NPV_{classic}$ calculations are limited in between those values. However, the histogram of $NPV_{flexible}$ is right skewed. This means that the $NPV_{flexible}$ are dispersed towards the right of the x-axis meaning there are more possible scenarios for the outcomes of $NPV_{flexible}$ values. Even though there are negative $NPV_{flexible}$ values, the expected value becomes positive due to the skew. The results of the valuation will be further investigated in the discussion of findings section.

6.6 Sensitivity Analysis

In order to identify the impacts of different variables in the cash flows equations generated above, sensitivity analysis was made. There were 13 different variables in the generated cash flow equations such as,

- $E_g(t)$, the energy generated by the PV system between the instant t-1 and t
- $P_{et\&d}(t)$, the price of electricy tariff and distribution at time t
- $C_{panel}(t)$, the cost of PV panel at time t
- $C_{inverter}(t)$, the cost of inverter at time t
- $C_{other}(t)$, total of other costs in investment at time t
- $C_{O\&M}(t)$, the operation and maintenance cost the investment will require at time t
- w, number of simulation paths generated for the LSMC simulation
- i, the discount rate determined by the opportunity cost of capital
- T_{life}, the service life of the investment
- T, the option maturity, the time period that the deferral option is valid for
- r, the risk-free discount rate used in LSMC
- $O_{r.rate}$, the reduction rate for labor and operation and maintenance costs

The variables that are time-dependent, which has (t) next to their symbol, are simulated using either stochastic or deterministic methods. Thus, they are excluded from the sensitivity analysis. Also, from the literature review and interviews, it is known that the major cost items are the cost of PV panel, inverters, electricity distribution and tariff prices. The other costs that are included in the cash flows have minimal effect on the outcome. The impact of the number of paths generated in the stochastic simulations is explained in previous sections and it is proven that increasing the value more than 10000 does not have any impact. The T_{life}, the service life of the investment, is chosen with respect to the interview findings and is actually not a variable. Thus, the variables i, T, and r were used in the sensitivity analysis made.

6.6.1 Case 1

- Constant T=7 years & r=8% and Varying i=9%-13%

In this analysis, the value of option maturity and risk-free discount rate used in LSMC is taken as constant with the values of 7 years and 8% consecutively. Then, the value of the discount rate determined by the opportunity cost of capital is changed between 9% to 13%. The following graph is obtained.

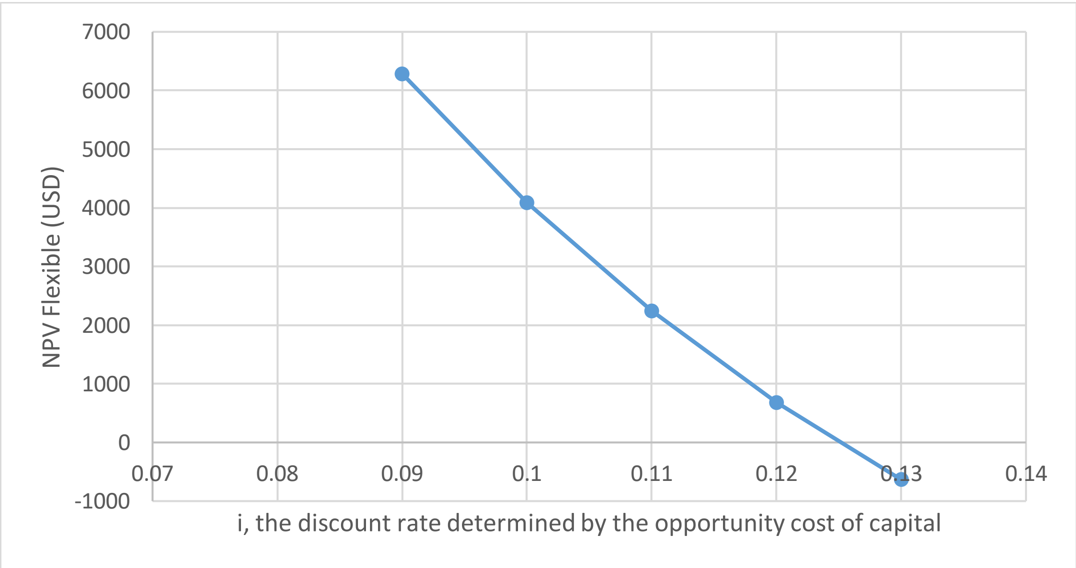

Figure 6.15. Sensitivity Analysis for T=7 years, r=17.7% and Changing i between 8%-12%

By looking at the figure it can be stated that as the discount rate increases, the $NPV_{flexible}$ value decreases. Thus, one can comment that they are inversely proportional. For the case study, it can also be commented that discount rates above 12.5% will result in negative $NPV_{flexible}$ values meaning that the investment will result in a loss even with the value of deferral is included.

6.6.2 Case 2

- Constant T=7 years & i=11% and Varying r=6%-10%

In this analysis, the value of option maturity and discount rate determined by the opportunity cost of capital is taken as constant with the values of 7 years and 11% consecutively. Then, the value of risk-free discount rate used in LSMC is changed between 6% to 10% and following graph is obtained.

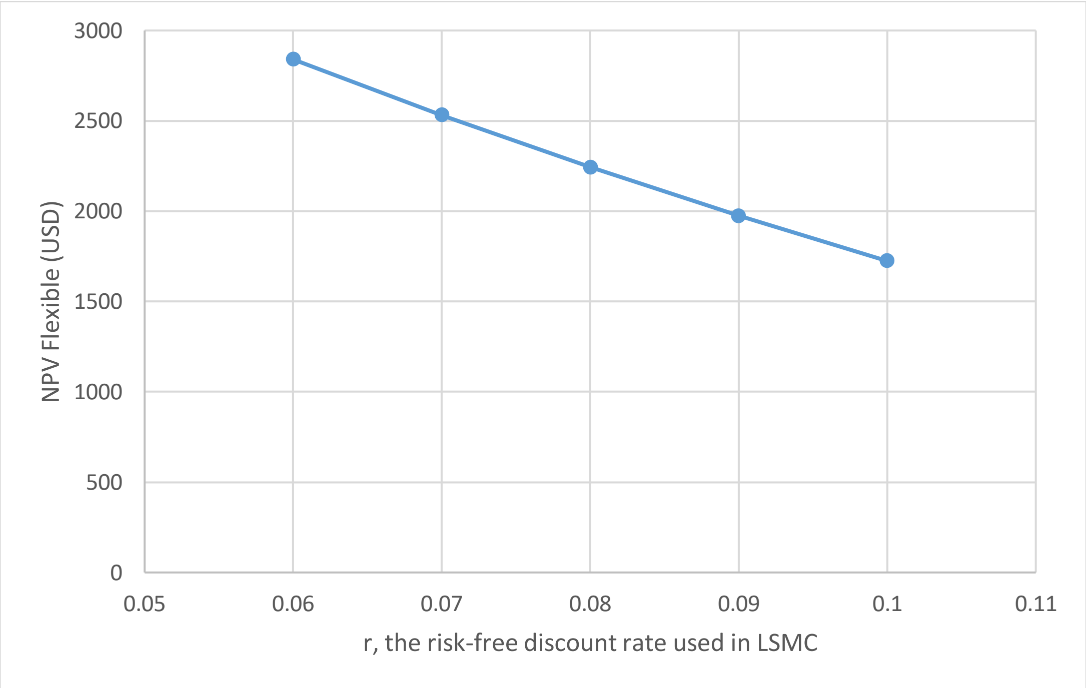

Figure 6.16. Sensitivity Analysis for T=7 years, i=11% and Changing r between 6%-10%

By looking at the graph, it can be commented that the $NPV_{flexible}$ value decreases as the risk-free discount rate decreases. Thus, it is appropriate to state that the risk-free discount rate and the $NPV_{flexible}$ value are inversely proportional.

6.6.3 Case 3

- Constant i=11% & r=8% and Varying T=2-7 years

In this analysis, the value of discount rate determined by the opportunity cost of capital and risk-free discount rate used in LSMC discount rate determined by the opportunity cost of capital is taken as constant with the values of 11% and 8% consecutively. Then, the value of option maturity is changed between 2 years to 7 years and following graph is obtained.

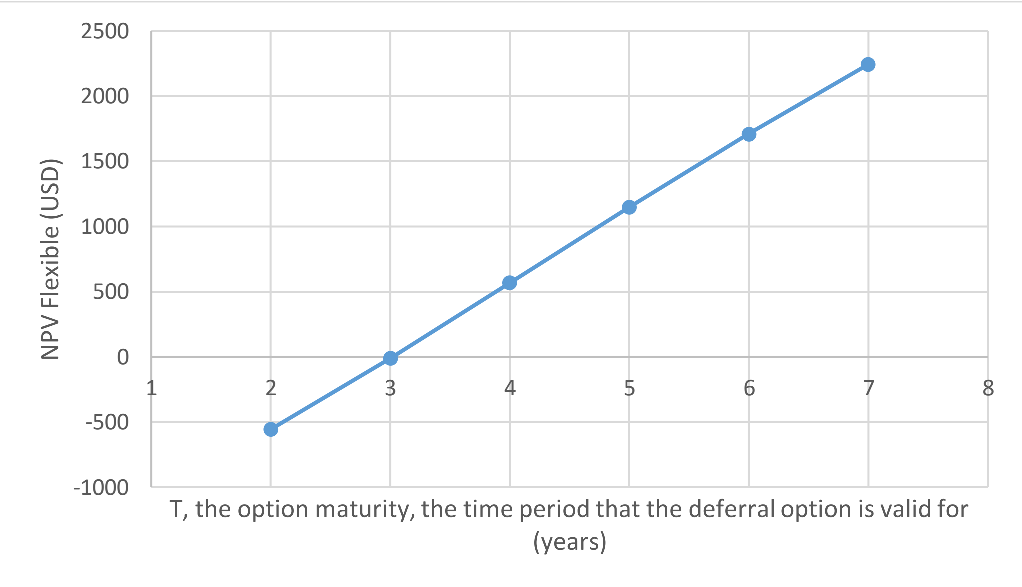

Figure 6.17. Sensitivity Analysis for r=8%, i=11% and Changing T between 2 years to 7 years

In order to determine the impact of the option maturity, Figure 6.17 is investigated and it can be commented that as the time of option maturity increases the $NPV_{flexible}$ value increases. Thus, it can be stated that the option maturity and $NPV_{flexible}$ values are directly proportional.

6.6.4 Case 4

- Constant T=7 years and and Varying i=9%-13% & r=6%-10%

In order to further investigate the impact of the discount rate determined by the opportunity cost of capital and the risk-free discount rate, a bivariate sensitivity analysis is made. In this analysis, only the time of option maturity is held constant as 7 years. Then, for different variables i and r, the $NPV_{flexible}$ values are calculated. The results are shown in two different figures. The first figure will have the axis of $NPV_{flexible}$ and i, the discount rate determined by the opportunity cost of capital. There will be different lines for the values of r. The second figure will have the axis of $NPV_{flexible}$ and r, the risk-free discount rate. There will be different lines for the values of i. The purpose of this bivariate sensitivity analysis is to observe the impact of the both discount rates and determine their cruciality by comparing them with each other.

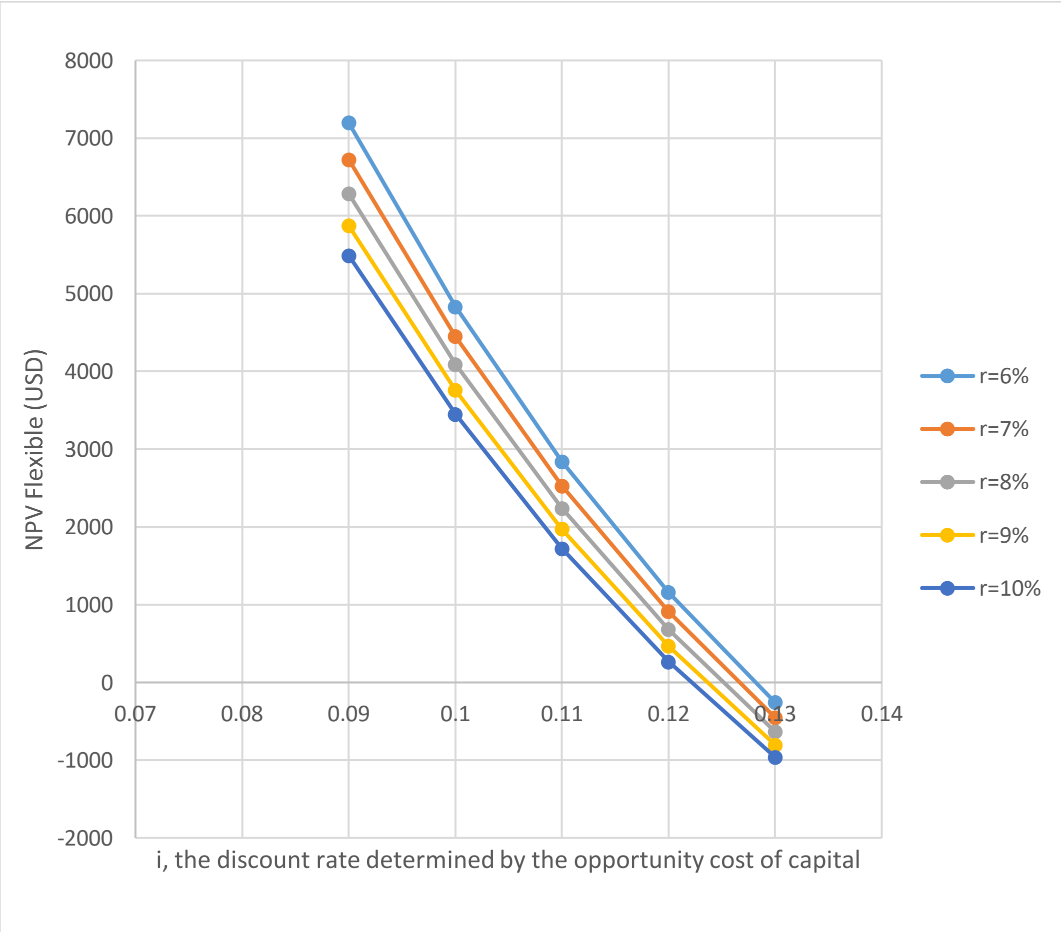

Figure 6.18. Sensitivity Analysis for T=7 years and changing i between 9%-13% for r between 6%-10%

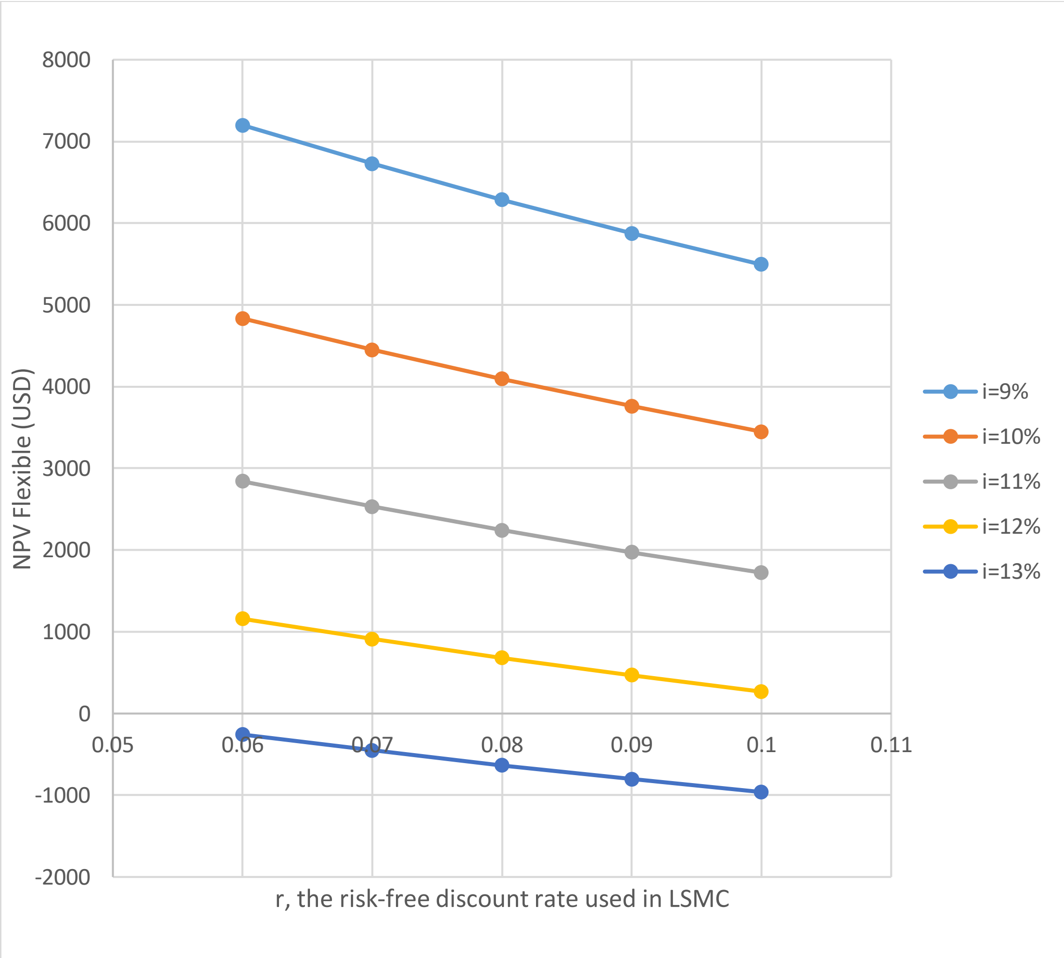

Figure 6.19. Sensitivity Analysis for T=7 years and changing r between 6%-10% for i between 9%-13%

By looking at the figures generated above, the slopes of the lines in Figure 24 are much greater than the slopes of lines in Figure 25. Thus, it can be stated that the impact of the change in the values of i, the discount rate determined by the opportunity cost of capital on the $NPV_{flexible}$ is much crucial than the impact of the r, the risk-free discount rate. The results of the sensitivity analysis will further be investigated in the discussion of findings section.

CHAPTER 7

GOVERNMENT INCENTIVE OFFERINGS FOR RESIDENTIAL PV SYSTEMS IN TURKEY

In this section, two government incentives are generated and evaluated using the proposed ROV method in order to tackle the entry barrier which is the high initial investment costs. Initially, a literature review on previous and ongoing government incentives on solar PV investments is made. Then, with respect to this review and the needs of the Turkish market, two new incentives are offered. In order to measure the benefits of the offered incentives, the proposed ROV method is used on the previous case study including the offered incentives and results are obtained.

7.1 Government Incentives on Solar PV Investments

Incentives can be classified as the supports or aids that are provided by the government in pursuit of enhancing the development and establishment of economic activities at a faster pace. They can also be referred as support, subsidy or governmental aid. The first application of government incentive for an economic activity in the world was in the 19^{th} century. The incentive was given in the form of cash payments for the construction of railway network in United States (Sevinç, 2016). Then, such applications have become widespread and nearly all of the countries have used incentives to promote different investments or economic activities.

As the demand for energy increases and the depletion of non-renewable energy resources accelerates, the need for renewable energy resources which are sustainable and cleaner is increasing day by day. Solar energy is a clean, renewable source of energy that has the potential to help reduce our reliance on fossil fuels and decrease the amount of pollution in the environment. In addition to being environmentally friendly, solar energy is also cost-effective and can provide a reliable source of electricity, particularly in remote or off-grid areas. It is also a limitless resource, as the sun is expected to continue to produce energy for billions of years. Overall, the use of solar energy can help to create a more sustainable future for humanity. Thus, in order to increase the attractiveness of the solar energy investments, the governments have been offering different incentives.

The government incentives that are in use nowadays for solar energy investments can be classified into two groups such as the regulatory policies and financial aids and public finance (REN21, 2022). The regulatory policies are the incentives that aims to encourage the production and investments with policies. Feed in tariff (FIT), Net Metering, Renewable Portfolio Standard (RPS), Renewable Energy Certificate (CES) can be given as examples to such policies. The financial aids and public finance are the incentives that aims to enhance the solar energy investments through finance. These can be classified as the financial supports given by the government in pursuit of lowering the considerably high initial investments costs. Tax subsidies such as Investment Tax Credit (ITC) and Production Tax Credit (PTC), Cash Rebates, Long Term Low Interest Loans can be given as examples to financial supports for solar energy investments (Aydınlı, 2013; International Energy Agency, 2011; Kılıç & Kekezoğlu, 2022; Ulgen, 2018; Ulusoy & Bayraktar Daştan, 2018). Each of these incentives are briefly explained as:

- Feed In Tariff

  A feed-in tariff (FIT) is a policy mechanism designed to encourage the adoption of renewable energy sources. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generating the energy. These contracts are typically designed to make renewable energy production more financially attractive to investors, allowing for the cost of the energy produced to be recovered over time.

- <u>Net Metering</u>

  Net metering is a billing mechanism that credits solar energy system owners for the electricity they add to the grid. For example, in a net metering arrangement, a homeowner with a solar energy system on their roof is credited for the electricity they generate, offsetting what they would otherwise purchase from the utility.

- <u>Renewable Portfolio Standard (RPS)</u>

  Renewable Portfolio Standard (RPS) is a regulation that requires electricity suppliers to produce or purchase a minimum percentage of their electricity from renewable energy sources, such as solar, wind, geothermal, biomass, and hydro power. It is a policy that encourages the increased use of renewable energy sources for electricity generation.

- <u>Renewable Energy Certificate (CES)</u>

  A Renewable Energy Certificate (REC) is a market-based instrument that represents the environmental, social, and other non-power attributes of renewable electricity generation. RECs provide an incentive for the development of new renewable energy capacity by allowing project owners to sell the environmental attributes of their projects to entities that wish to support renewable energy but are unable to install their own renewable energy generating facility. RECs can be bought and sold separately from the energy generated by a renewable energy facility, thus allowing renewable energy generators to earn additional revenue. Additionally, the sale of RECs can help reduce the cost of renewable energy by providing an additional revenue stream to project owners.

- <u>Investment Tax Credit (ITC)</u>

  Investment Tax Credit (ITC) is a tax incentive to encourage businesses to invest in new equipment, technology, and other business-related activities. The ITC reduces the amount of taxes a business owes based on a percentage of the cost of the investment. The credit can be used to offset both income and payroll taxes, and can be carried forward to offset taxes in future years.

- Production Tax Credit (PTC)

  Production Tax Credit (PTC) is a tax incentive designed to encourage the development of renewable energy sources. It is a federal tax credit that is given to businesses that produce electricity from renewable sources such as wind, solar, geothermal, hydropower, and biomass. The tax credit is based on the amount of electricity produced and can be taken for up to 10 years. The credits can be used to offset the cost of purchasing and installing renewable energy equipment.

- Cash Rebates

  Cash rebates for solar investments are incentives provided by state and local governments to encourage renewable energy investments. These rebates provide a financial incentive to homeowners and businesses that install solar panels, typically in the form of a one-time payment for a portion of the total cost of the installation. These rebates are designed to help reduce upfront costs and make solar investments more affordable.

- Long Term Low Interest Loans

  Long Term Low Interest Loans for Solar Investments are loans offered by the government or private lenders to help people and businesses invest in solar energy systems. These loans usually have lower interest rates than other forms of financing and longer repayment terms, allowing borrowers to spread the cost of their solar energy investment over a number of years. These loans can be used to finance the purchase of solar panels, solar inverters, and other necessary equipment, as well as the installation costs for a solar energy system.

7.2 Why are Incentives Required in Residential Solar Energy Investments?

Following the United Nations Conference on Climatic Change in 1992 and the Kyoto Protocol in 1997, every country including Turkey has expressed their commitments on taking necessary actions to reduce the CO2 emissions (Tryndina et al., 2022). To meet its energy needs, Turkey relies heavily on fossil fuels. As far as fossil fuels are concerned, natural gas dominates the country's energy generation and the economic impact of this dependence is severe such that the energy independence of Turkey is getting jeopardized and the current account deficit is considerably increasing in time (Çeçen et al, 2022). In order to fulfill the responsibility in terms of environmental concerns and mitigate the possible threads due to the dependence on energy imports, Turkey has to diversify in terms of energy production and should direct their investments on to renewable energy (Kılıç & Kekezoğlu, 2022).

According to the Deploying Renewables Report done by International Energy Agency, there are three factors to consider in order to provide an economic support to a new technology in energy production (International Energy Agency, 2011). The first factor is the estimation of the levelized cost of energy (LCOE) and comparison with other existing alternatives. For the case of solar PV investments, the values that can be generated from the environmental benefits of solar PV systems cannot be taken into account during the estimation of LCOE process since there is not a quantifiable financial benefit that can be estimated. Thus, the LCOE estimation will fall short and result against giving economic supports to solar PV investments. But this will be misleading and ignores the big picture about the environmental problems. The second factor is the comparison of total expenditures during the service lives of the new investments with the existing ones using fossil fuels. Energy generation using fossil fuel has been used almost over a century and due to this fact, their initial investment costs are relatively low when compared to the solar PV investments. However, the changes in fossil fuel prices and stock availabilities directly affect the operational costs due to their inevitable dependance on fossil fuels. As for the solar PV investments, even though their capital costs are high, since they do not have any dependency to any goods, their operational costs are fairly low. Thus, the energy development using solar PV investments results in stable recurring costs which will provide price safety for the end users. The third and the last factor is the state of maturity of the offered new technology. Solar PV systems have been used for almost 30 years and when the capital costs are investigated during this period, it can be seen that as the technology advances there is considerable decline. When compared to the traditional energy production methods utilizing fossil fuels, since they exist for a longer time, they have experienced a great cost reduction with the researches and developments on them. However, with the price changes due to initial and small scaled research and development efforts, the capital costs of solar PV systems have reduced a lot. Once the investments on solar PV systems are expanded, they possess a huge potential for further capital cost reduction which will lead to higher attractiveness for such investments. Thus, it is appropriate to say that solar PV investments deserves economic support when it is investigated under the three factors mentioned above.

7.3 Previous and On-going Government Incentives on Solar PV Systems

In order to investigate the previous and ongoing government incentives on solar PV investments, a literature review has been conducted. There are countries that have adopted such investments long ago and there also countries that are recently involved in such investments. Thus, both of these countries' policies should be investigated in order to understand how to achieve success while converting to energy production using solar PV systems. There are various studies about different countries' incentive policies in the literature (Castaneda et al., 2018; Congressional Research Service, 2019; Goel, 2016; Griffiths & Mills, 2016; International Energy Agency, 2011; Kılıç & Kekezoğlu, 2022; Kumar Sahu, 2015; Kural & Ara Aksoy, 2020; Rathoreet al., 2019; Shuai et al., 2019; Solangi et al., 2011). After all these studies are investigated, the following summary about the previous and on-going incentives on different countries is made.

Table 7.1 Offered Solar PV System Incentives by Country (Kılıç & Kekezoğlu, 2022)

Countries	FIT (Feed-in Tariff)	NEM (Net Metering)	Categorized Incentives Policy	Additional Subsidy	Tax Exemption	Funding and Interest Discount	Public Establishment Incentives	Standards	Tendering and Project Incentives
Germany	✓	✓	✓	✓	✓	✓			
Spain	✓		✓			✓			
France	✓		✓			✓			
USA	✓			✓	✓	✓		✓	
China	✓	✓	✓	✓	✓			✓	✓
India	✓	✓			✓				✓
Malaysia	✓	✓							
Canada	✓	✓	✓						
Mexico									✓
Brasil		✓		✓			✓	✓	
UAE	✓	✓							✓
Turkey	✓	✓		✓	✓	✓			✓

As seen from the above table, there are various incentives in practice. However, the incentives given above are generalized such that the incentives given above are for all sort of PV investments including both commercial ones and residential ones. However, when these countries are investigated it can be commented that there are also specialized programs for residential roof PV investments due to the higher desirability of such investments for governments.

Table 7.2 Special Incentive Programs Given to Micro PV Systems by Country (Kılıç & Kekezoğlu, 2022)

Countries	Special Incentives Applied to Micro PV Systems and Rooftop Systems
Germany	* 1000 ve 100 000 Roofs Programs * Additional incentives for generation facilities below 100 kW * Additional subsidy for power plants installed on an area of 20–100 square meters
Spain	* Low incentive application for power plants with an installed power of more than 100 kW * 100 kW capacity allocations * Additional subsidy to micro-generation facilities
France	* Incentive system categorized with 3 kW, 9 kW, 36 kW, 100 kW values. * Incentive reduction or even reset model over 100 kW.
China	* Solar Roofs Programı ile çatı üzeri sistem teşvikleri
India	* Solar Home Programs * Promoting small scale facilities with the Rooftop Pv and Small Scale Generation Program
Malaysia	* With the Small Renewable Energy Program promoting small scale production facilities
Canada	* High incentive implementation for small-scale Power Plant
Turkey	* Facilitation of paperwork processes for facilities below 10 kW

As seen from the above Table, there are many different incentive programs specialized in residential PV investments. This is because residential PV investments have many advantages over the production plants. One of the advantages of residential PV systems is that such systems are directly connected to grid contrary to the commercial solar production plants. With this advantage, not only the need for additional electricity transmission networks is overcome, also the grid voltages at that location is improved as well. In addition to that, one of the main targets in transitions to power production using renewable energy resources is enabling consumers to meet for their own energy demands and residential PV investments achieves this target (Çeçen et al., 2022).

In Turkey, even though many incentives are given for the overall PV investments, the incentives for residential PV systems are very few such as the above mentioned "Facilitation of paperwork processes for facilities below 10kW" and the net-metering. In the review done by Kılıç & Kekezoğlu (2022), it is concluded that new incentive methods can be developed for the rooftop PV systems in the future with the aim of making it accessible to all consumer including the ones that are in a lower pay grade.

7.4 Incentive Offers for Resident PV Investments in Turkey

In accordance with the conclusion of the review done by Kılıç & Kekezoğlu (2022), two new government incentives have been offered using the literature review on government incentives for residential PV investments and the effects of the two offered government incentive has been evaluated using the offered valuation method, ROV.

7.4.1 Offer 1: Long Term Low Interest Loan Specialized for Residential PV Investments

The main purpose of this incentive is to eliminate the high initial cost, which is one of the biggest obstacles to residential PV investments. Most citizens in Turkey avoid making such investments because the initial investment costs are high. In addition, most citizens do not have the savings to cover the initial cost of this investment. For these reasons, such investments are not preferred in Turkey. However, with this incentive, the entire initial investment cost of the system will be covered by bank loans provided by the state. Citizens who want to invest will first receive project service from the authorized institutions related to this investment and apply with the feasibility reports, which includes the total cost of the investment and the construction documents. If the project is accepted by the government, a bank loan that equals to the total initial cost is prepared with a low interest and a credit period equal to the service life of the investment. Then, once the residential PV system is constructed, the contractor company will send the receipt to the bank and get their payment. The loan is repaid monthly by the applicant during the service life of the investment. Once the PV system is installed, it is assumed that instead of the electricity bills the applicant will pay the loan and owns a residential PV system.

For the offered loan, the interest rate is chosen to be 1.12%. It is assumed that the loan given mimics the housing loan due to their similarities in terms of credit period which are considerably long. The credit period of the aforementioned loan is assumed to be equal to the service life the investment, which is taken as 25 years due to the case study.

By using the loan, the equation of the classical net present value of the residential PV investment at any time t using the revenues and costs mentioned above is,

$$NPV_{classic} = \sum_{t=1}^{T_{life}} \frac{R(t) - C_{O\&M}(t) - C_{loan}}{(1+i)^t} \qquad (7.1)$$

where C_{loan} is the loan repayment at time t, $R(t) - C_{O\&M}(t) - C_{loan}$ is the revenue function for any time step between the initial investment time and the service life of the investment, T_{life}, i is the discount rate determined by the opportunity cost of capital.

As seen from the above equation, the initial investment cost is avoided. The investor paid this cost using the loan and instead of the requirement of having that whole amount of money at t=0, the loan repayments are distributed monthly during the service life of the investment.

The offered ROV method is then used to interpret the outcomes of having such loan and the results turn out to be as follows,

$$E(NPV_{classic}) = -3337.22\ USD$$

$$E\left(NPV_{flexible}\right) = 14.17\ USD$$

$$E(F(0)) = 3351.39\ USD$$

In order not to comment only on the expected values of $NPV_{classic}$ and $NPV_{flexible}$, the valuation results are shown on the histogram below with their probability density functions. While $NPV_{classic}$ is shown as blue, the $NPV_{flexible}$ is shown as orange.

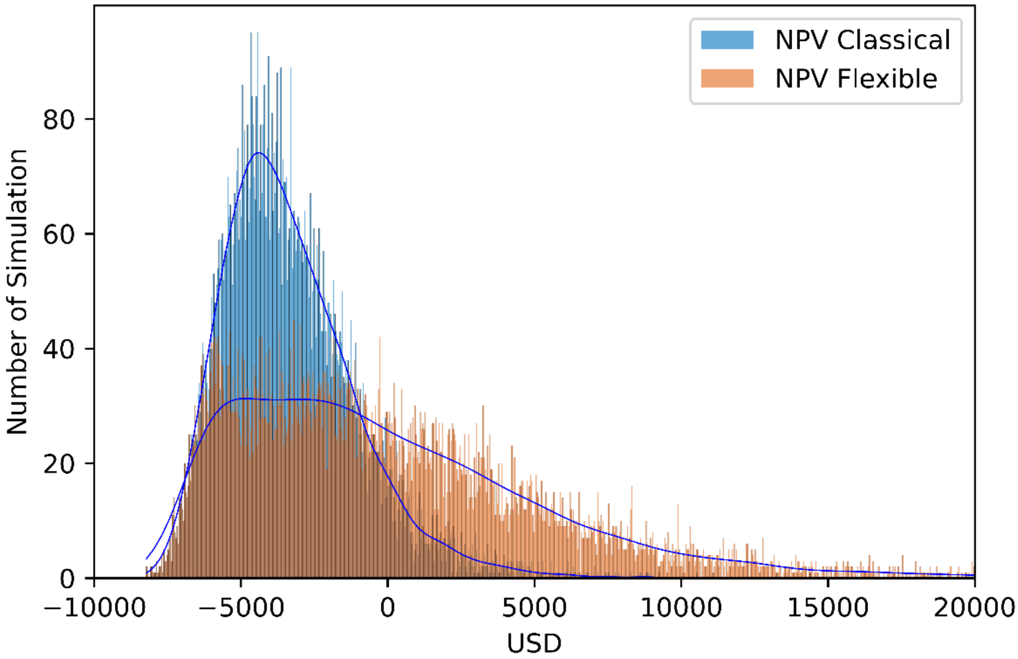

Figure 7.1. NPV (Classical and Flexible Using the Offered Loan) Histogram Bars

As seen from the expected values and the histograms, it can be commented that the investment decision without having the deferral option results in a negative cashflow. When compared with the expected value of $NPV_{classic}$ at the case study, the attractiveness of such investments using a bank loan without having a deferral option considerably decreases. This is due to the interest rate applied to the bank loan, which is actually the common case when using a bank loan. Since the investor has to pay a higher amount in return for the loan taken, this eventually affects the $NPV_{classic}$ calculation. However, the expected value of $NPV_{flexible}$ is not negative but very close to 0. This means that the decision making for this investment with using a bank loan and having a deferral option of 7 years to make the investment results in a neutral cashflow, which means there is a possibility of making this investment without any loss or income. When the histogram bars are investigated, similar comments can be made. Most of the paths using $NPV_{classic}$ are resulting in negative values with having a bell shape. However, when there is flexibility for the time of investment, the resulting values of the $NPV_{flexible}$ paths are more dispersed between -7500 USD and

20000 USD. Also, the generated histogram is right skewed. The results of having such a loan incentive are further investigated in the discussion of the results section.

7.4.2 Offer 2: Cash Rebate Equal to the Tax of the Initial Investment Cost

The second offer aims to decrease at least some part of the initial investment cost. In Turkey, citizens have to pay value-added tax while buying anything. Thus, while making a solar PV investment in Turkey, the investor will eventually pay the designated amount of tax for the initial investment cost. Such taxes create an extra cost burden for investments that are not very attractive for investors. As mentioned above, one of the main obstacles of residential PV investments is its high capital cost. With the inclusion of the VAT, this cost increases much more and decreases the attractiveness of the investment even more.

By offering a cash rebate which is equal to the tax of initial investment cost, some part of this heavy initial investment cost is diminished. With the information gathered from the aforementioned interviews, solar PV investors pay 18% VAT and with the offered cash rebate the investors will retrieve equal amount of money once they make the investment.

Citizens willing to invest in residential PV systems will initially apply to an authorized project firm to acquire construction documents and feasibility reports for this project. Then, they will apply to the related government institution with these documents. If the application results in a positive way, then they will get in contact with the contractor and construct the PV system at their rooftops and pay for the system. Then with the receipt they got from the contractor and proof of investment, they will again apply to the aforementioned institution and request their cash rebate. After the required examinations are completed by the institution, the investor will retrieve the tax amount to their bank accounts. It is assumed that this retrieval of tax amount is done within the same month of investment. Thus, within the generated cashflows, the initial investment cost and this retrieval will be on the same month.

The following new initial investment cost equation is formed with the help of this offered incentive, where the 1.18 multiplier is removed from the equation. This new $I(t)$ term is used in the NPV equations.

$$I(t) = [C_{panel}(t) + C_{inverter}(t) + C_{other}(t)] \quad (7.2)$$

Then, the offered ROV method is used to interpret the outcomes of having a cash rebate equal to the tax amount of the initial investment cost and the following results are obtained,

$$E(NPV_{classic}) = -402.33\ USD$$

$$E\left(NPV_{flexible}\right) = 4116.27\ USD$$

$$E(F(0)) = 4518.60\ USD$$

In order not to comment only on the expected values of $NPV_{classic}$ and $NPV_{flexible}$, the valuation results are shown on the histogram below with their probability density functions. While $NPV_{classic}$ is shown as blue, the $NPV_{flexible}$ is shown as orange.

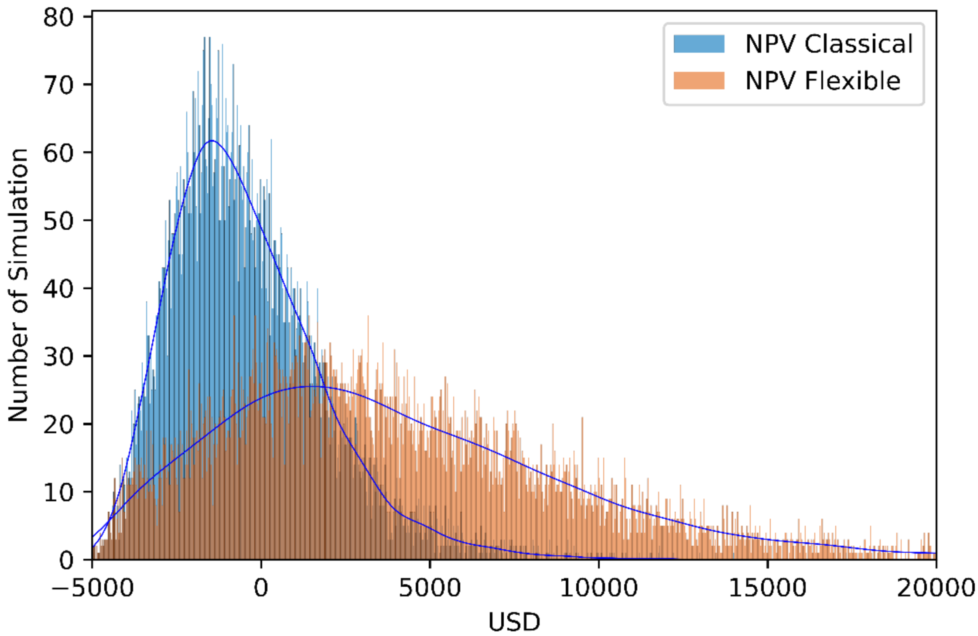

Figure 7.2. NPV (Classical and Flexible Using the Offered Cash Rebate) Histogram Bars

When the obtained expected values are investigated, it is seen that with the offered cash rebate incentive, both the $NPV_{classic}$ and $NPV_{flexible}$ has considerably increased when compared with the valuation results of the case study. The $NPV_{classic}$ got very close to zero and with an additional tiny rebate, it can even become positive. This shows us that a cash rebate which will led to a decrease in the initial investment cost can cause the investment to become attractive even today. Without a deferral option, the most probable scenario will lead to a -402.33 USD loss in today's money. When the option value generated from the deferral option is added, the most probable scenario will generate a 4116.27 USD income.

As seen from the histograms, when compared with the case study, both the $NPV_{classic}$ and $NPV_{flexible}$ paths are shifted towards right, the positive values. This is because of the decrease in the initial investment cost since some part of it is compensated by the government with this incentive, and the majority of both the paths of the $NPV_{classic}$ and $NPV_{flexible}$ are at the positive side, thus resulting in positive expected values. The results obtained using the offered cash rebate incentive are discussed in detail in the following discussion of results section.

CHAPTER 8

DISCUSSION OF FINDINGS

In this section the implications of the findings from the case study results and the offered incentives valuation results will be discussed in depth. Firstly, the results obtained will be discussed and compared. Then, the implication of these results for both the policy makers and potential investors will be investigated. Finally, the results will be investigated from the researchers' point of view and comments about it will be made.

Due to environmental concerns and efforts to reduce carbon emissions, renewable energy investments play a vital role. Thus, recently there has been many different researches and attempts on such investments. Although it is known that such investments have positive effects on environmental problems, financial return is still the most important factor when making investment decisions for such investments. However, when calculating the financial returns to make decision, the main generated value which is the environmental benefits cannot be accounted due their lack of tangible incomes. Due to the nature of the renewable energy investments, their initial investment costs are considerably high and once the investment decision is made such systems do not provide for reversibility. In addition to that, due to the uncertainties at the energy sector, the potential revenues cannot be clearly estimated. As an investor, irreversibility, high capital costs and uncertain future revenues create a challenge and it is hard to make a decision under these circumstances. Thus, making a clear decision about solar PV investments is not an easy task.

Currently in Turkey, the investment valuations are usually done by methods that consider the Discounted Cash Flow (DCF) generated by that investment. The Net Present Value method which uses DCF and represents the net return generated on the investment is a static method and the possible results that can be obtained from the NPV method is either to accept or reject the investment. In accordance with the outcome of this method, the investor will either make the investment or reject it for the rest of the time and canalize their focus on other projects to gain profit. Due to the nature of the residential PV investments in Turkey, it can be commented that NPV method is not suitable. As mentioned above the future cash flows generated by the investment is highly uncertain. Also, since such investments are irreversible and in need of a considerable capital costs, they require flexibility for the time of the investment. The aforementioned NPV method does not account for neither of these. Once they are used for residential PV investments in Turkey, they will result in negative values which leads to early rejection of such projects.

In order to prevent such early rejections to highly valuable investments for the future of the Earth's ecosystem, in this study a rather new investment valuation method called the Real Option Valuation is offered and applied in a residential solar PV investment valuation. The ROV method accounts for the uncertainties of the initial investment cost mainly caused by the PV panel and inverter prices and the future cashflows due to the electricity tariff prices. The suggested method models the future prices of these uncertain items using stochastic simulation methods, i.e., Geometric Brownian Motion. Also, the method provides time flexibility such as the investment decision is not just made for the present but considers a predefined prospective time period. Thus, the suggested method satisfies the requirements of the residential PV investments in Turkey.

The residential solar PV project which is located in Kocaeli is valuated using both the traditional NPV method and the proposed ROV method. With the traditional NPV valuation, the result of the investment in today's money turned out to be -1730.04 USD. By looking at this value, it can be stated that making the residential PV investment is not profitable under current conditions, thus the investment should be rejected. The result of the valuation using the proposed ROV method turned out to be 2242.87 USD in today's money and it can be commented that when the investment decision is made using this method there is a potential profit and the investment should not be rejected. The difference between the results of the methods in consideration occurs due to the option value that is accounted for in the ROV method which is equal to 3972.92 USD. This option value actually represents the potential profit that the investor can obtain in different scenarios that may arise once the future uncertainties unfold. Since the ROV method uses stochastic simulations to model the future values of the uncertain variables and reflects the investors opportunity to decide on making the investment in the future when a profitable scenario arises, the results of this method actually bring much more comprehensive results.

Also, a sensitivity analysis using the variables i, the discount rate determined by the opportunity cost of capital, r, the risk-free discount rate used in LSMC and T, the value of option maturity is made. The purpose of this analysis is to evaluate the integrity of the model generated and to identify the impacts of the variables to the output of the Real Option Valuation. The option maturity is one of the key values in the generated ROV model. The value of the option maturity reflects the investor's allowed deferral time to make the investment and it turned out to be directly proportional with the results of the ROV method, meaning that as allowed deferral time of investment increase, the results generated from the ROV method will increase. When the current trends of the residential PV investments in Turkey is investigated, it is suitable to state that the initial investments costs are decreasing day-by-day and due to the increase in the electricity tariff and distribution prices, there exists a higher revenue potential in the future for such investments. Thus, having a longer deferral time for the investment should result in better results, which the sensitivity analysis made resulted in the same way. As for the discount rates, since the discount rates are both used in the discount cash flow calculations, as their rates increase, due to a greater loss due the time value of the money, the results of the ROV method should decrease. When the results obtained from the sensitivity analysis is explored, as both the discount rates i and r increase, the results of the ROV method decreases. Thus, it is suitable the say that the generated model is verified.

When commented about the case study and sensitivity analysis results obtained from an investors point of view, it can be stated that with the usage of the suggested ROV method, the potential of the residential PV investments in Turkey is not overlooked and the results have proven that early rejections due to the NPV method will lead to loss of opportunities. Even though the current status of the residential PV investments in Turkey is not favorable, causing a 1730.04 USD loss, there is possibility of making a profit of 2242.87 USD with these investments. Thus, the projects should not be rejected at once and the rooftops should not be used for other investments that may prevent the application of the PV systems in the future. Also, the suitability of the suggested ROV method for investment valuations that contain uncertainties can be stated. For similar cases, the investor can take advantage of the ROV method and evade any misleading results or falsified early decisions. Also, investors who are willing to invest in residential PV systems in Turkey should allow a longer deferral option in order to achieve higher incomes. Due to the current trends in PV systems, with respect to the sensitivity analysis results, it is suitable to say that the residential PV investments will generate better income as an investment in the near future, thus an investor should not restrict himself in strict time frame to make the investment and allow for a longer decision-making time to invest in the project. Also, from an investor's point of view, the discount rates chosen has an impact on the cash flows generated, especially the discount rate determined by the opportunity cost of capital. Thus, while using the ROV method for residential PV investments in Turkey, investors should be sensitive for the choice of the discount rate in order to achieve accurate results.

The results of the case study might well be beneficial for the Turkish government. Since the government aims to decrease the carbon emissions, they are in need of expanding such investments. However, without having the ROV method for the valuation of such investments, residential PV systems turn out to be infeasible to invest for the public and the future economic advantages, will there be any, cannot be foreseen. But once the ROV method is introduced and the results of the method are presented, the hidden potential of such investments will be unveiled. Thus, the residential PV investments in Turkey is proven to have a good potential and their implementation will help the government's goal of decreased carbon emission. The government can also plan their future budgets to provide additional incentives to enhance such investments since the NPV values of these investments are still negative. Also, they can reduce the future uncertainties in favor of the public with the policy decisions they make and with those decisions the ROV method will lead to better results that will increase the appetite of the investors.

In order to help the Turkish government in promoting the expansion of residential PV investments, the government incentives on several countries have been investigated and two incentive offers that are suitable for Turkey are made. The suggested ROV method is used to evaluate the offered incentives. Due to the current economic conditions of Turkey, the high initial investment costs of such systems are identified as the main entry barrier for such investments. Thus, the offers made mainly aim to reduce this cost or distribute this cost over the service life of the investment.

The first offer is a bank loan with a 1.12% interest rate and 300-month credit period. With this incentive, the cost burden is distributed along the investment period and the investors will repay the credit with the revenues they earn. The case study example is reevaluated using the offered incentive and the result of the ROV, came out as 14.17 USD, which is almost zero. It can be stated that the utmost probable scenario for the investment with the deferral option will not generate any income. Thus, from the perspective of an investor, such loan will not enhance these investments. Thus, by just looking at the resulting expected values from the NPV calculations and commenting on the offered loan will fall short. But as mentioned above, investments on renewable energy production have a hidden value which is generated from the positive impacts on environmental concerns by clean energy production. The results can also be interpreted from a different perspective. Since the resulting $NPV_{flexible}$ values are almost zero, which means the investment will not result in any profit or loss, investors from non-profit organizations or the public institutions might consider to benefit from such a loan. Such organizations and institutions usually have their own offices and some of them have many workers consuming greater energy during working hours. Thus, by using this loan, they can invest in such a project in the next seven years and without making any profits or facing losses, they can serve the environment and the aforementioned climate concerns. So, for the Turkish government it can be stated that even though giving a loan incentive for solar PV investments will not lead to higher profits, it will lead to the removal of the initial investment cost burden and parties that are not seeking profit can use this incentive in order to construct their PV systems.

The second offer is giving a cash rebate that is equal to the tax of the initial investment cost. In the case study, the tax percentage is taken as 18% and with the help of this incentive the tax is removed from the equation. Then, the case study is reevaluated with eliminating the tax of the initial investment cost. The results of both the ROV method and the NPV method has considerably increased when compared with the results of the case study without having this cash rebate. By just eliminating a small share of the initial investment cost, residential PV investments in Turkey ended up as advantageous investments that generate considerable income and value almost now and in the future. Thus, from the governments point of view the severity of the capital cost burden and the requirement of such incentives that decrease the initial investment cost are justified. The same effect can be obtained with an increase in the revenues as well and governments can also try to increase the revenue generations of such PV systems. However, from an investors point of view, the initial investment cost still stands as a huge obstacle for the future of these investments. Even with a cash rebate, only the 18% of the initial investment cost is compensated and the investors are still in need of a considerable amount of saving to make the investment. When the current economic status in Turkey is considered, most of the citizens may not be able to make the investment due to that cost burden even with the cash rebate. Thus, in order to extend residential PV investments in Turkey to most of the residential roofs, more incentives should be provided.

As for the researchers, this study provided several outputs as well. The applicability of the ROV method for residential PV investments in Turkey has been justified and the same method has proven to be useful when evaluating new government incentives that aim to enhance such investments. Also, the method can be applied to any sort of investment which mimics the characteristics of residential PV investments such as the future uncertainties and the requirement of time flexibility for the investment. Also, the current, as of end of 2021, status of the residential PV investments and the potential they possess has been justified and this study can be used to reflect them in further studies.

CHAPTER 9

CONCLUSION

In this study, a new valuation method called Real Options Valuation has been used to evaluate the residential PV investments in Turkey. The newly suggested method has many advantages compared to the traditional valuation methods which utilize the Discounted Cash Flows. The suggested method handles the uncertainties related to the cost and revenue items of the investments by modelling their future values using stochastic simulations. Also, the strategic value of flexibility for the investment time is included during the valuation and the method does not restrict the investor to a “now-or-never” decision. The residential PV investments require considerable initial investment costs and possess uncertain future cashflows due to the inconsistent market conditions. In addition to that, due to their nature, they are considered as irreversible investments. Thus, the decision-making process is a huge challenge for the investors and great care should be taken. The suggested ROV method provides for all these challenges the residential PV investments in Turkey possesses. After detailed explanation of the valuation method, a case study has been made and a real investment decision in Kocaeli, Turkey is evaluated using this method. The results have proven that while the traditional valuation method, NPV will lead to the rejection of the investment, the proposed ROV method suggests that the investment in consideration has a potential in the future and should be put on hold rather than rejection. Thus, with the help of this method, the actual potential that the residential PV investments in Turkey owns has not been overlooked and upon the unfolding of the uncertainties in favor of the investor in the future, the investment will provide profit. Since the residential PV investments also have other benefits for the environment such as decreasing the carbon emissions and providing clean energy, it is of great importance to prevent the early rejection of such investments with this method. In addition to that, one of the main obstacles for this investment is identified as the high initial investment cost and in alignment with the past and ongoing government incentives around the world, two new incentives are offered for the Turkish government. The main aim of these incentives is to make those investments attractive by either removal of the initial investment cost with loan supports or reduction of it. In accordance with this aim a low interest long term loan is offered and the initial investment cost is removed. The second incentive is a cash rebate that aims to provide for the tax of the initial investment cost. Both of the incentives are then evaluated using the ROV method and it can be concluded that any sort of decrease in the initial investment cost makes residential PV investments in Turkey favorable for the investors. However, rather than decreasing the initial investment cost, the bank loan distributes the initial investment cost among the service life of the investment and takes interest, the offered incentive won't result in a profit. But the incentive can still be regarded as advantageous because the government institutions, municipalities or the non-profit organizations get the chance to invest in such environmentally friendly system without the need to pay considerable initial investment costs and facing any losses.

Even though in this study the ROV method is applied to the residential PV investment decisions in Turkey there are several shortcomings. Firstly, since the renewable energy investment regulations are very dynamic and differ from size to size of the PV system, many assumptions have to be made to come up with a case study that reflects the outcomes of the ROV method. Thus, the case study is not generalized and several changes have to be made in order to use this method for other sort of renewable energy investments. Secondly, due to the economic conditions Turkey currently faces, the USD/TL parity, the risk-free interest rate etc. assumed in this study may face huge changes and the results will be influenced by them. Thus, the estimations should be remade in the future with refined data sets. Finally, while generating the government incentives, the impact of those incentives for the government should be identified as well, since if they create a huge burden which is greater than the earned value with the enhancement of residential PV systems, then the incentives will be out of discussion. Thus, they should also be evaluated from the government's point of view before being implemented.

For future studies, the aforementioned shortcomings can be tried to be overcome. Also, the suggested valuation method can be applied to a larger solar system investment and the results can be compared to enhance such investments. For the incentives, since there are many different approaches and ongoing projects to enhance residential roof PV investments, more incentives can be generated which will extend the residential PV investments and remove the entry barriers. By this way, not only the investors earn profit, also the environmental pollution caused by the usage of fossil fuels in energy production can be decreased.

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