NATURAL GAS INFRASTRUCTURE EXPANSIONS IN TURKEY: ECONOMIC FEASIBILITY AND A COST COMPARISON WITH PV INVESTMENTS

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submitted by **BİLGE MANSIZ** in partial fulfillment of the requirements for the degree of **Master of Science in Earth System Science, Middle East Technical University** by,

Prof. Dr. Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences** ________________

Prof. Dr. Bülent Gültekin Akınoğlu
Head of the Department, **Earth System Science** ________________

Prof. Dr. Bülent Gültekin Akınoğlu
Supervisor, **Earth System Science, METU** ________________

Dr. Bora Kat
Co-Supervisor, **TÜBİTAK** ________________

Examining Committee Members:

Assoc. Prof. Dr. İzzet Arı
Energy Economics and Management, Social Sciences University of Ankara ________________

Prof. Dr. Bülent Gültekin Akınoğlu
Earth System Science, METU ________________

Assoc. Prof. Dr. Onur Taylan
Mechanical Engineering, METU ________________

Date: 03.08.2021

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name / Last Name : Bilge MANSIZ

Signature :

ABSTRACT

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Mansız, Bilge
Master of Science, Earth System Science
Supervisor: Prof. Dr. Bülent Gültekin Akınoğlu
Co-Supervisor: Dr. Bora Kat

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Turkey, from 1980s on, has greatly invested in urban usage of natural gas, which is mostly imported. Alongside urban usage, natural gas is now widely consumed for electricity generation and industry. Beginning with 2014, even remote towns are also started to be supplied with natural gas. While there are many environmental and societal advantages of natural gas consumption over coal and fuel-oil, it can be argued that natural gas supply of remote areas is mostly due to social or political concerns. Natural gas, however, is not pollution free and emits greenhouse gases, nonetheless. Therefore, a holistic and proper analysis of costs and benefits of these investments should include environmental and social concerns and should weigh in the opportunities of renewable alternatives compared to use of natural gas.

In this study, 22 towns are selected from different locations, 6 from northern, 13 from centre, and 3 from southern regions of Turkey where natural gas investments are being planned. These 3 regions have differing solar power generation potentials received due to solar irradiation difference. In general, two towns from each city are chosen to be investigated to analyse the impact of investment difference knowing that their solar potentials are similar. To this end, the question of "Could PV investments be more feasible rather than natural gas investments in remote regions?" will be investigated.

Keywords: Turkish Remote Natural Gas Investments, Renewable Alternative to Natural Gas, Solar PV, Cost-Benefit Analysis

ÖZ

TÜRKİYEDE DOĞAL GAZ ALTYAPI GENİŞLEMELERİ: EKONOMİK FİZİBİLİTE VE PV YATIRIMLARI İLE MALİYET KARŞILAŞTIRMASI

Mansız, Bilge
Yüksek Lisans, Yer Sistem Bilimleri
Tez Yöneticisi: Prof. Dr. Bülent Gültekin Akınoğlu
Ortak Tez Yöneticisi: Dr. Bora Kat

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Türkiye, 1980'lerden itibaren, çoğunlukla ithal edilen doğal gazın kentsel kullanımına büyük yatırımlar yapmıştır. Bunun yanı sıra, artık doğal gaz elektrik üretimi ve endüstride de yaygın olarak tüketilmektedir. 2014 yılından itibaren uzak ilçeler de doğal gazla buluşmaya başlamıştır. Doğal gaz tüketiminin kömür ve fuel-oile göre birçok çevresel ve toplumsal avantajı olsa da, uzak bölgelere doğal gaz arzının büyük ölçüde sosyal ve politik kaygılardan kaynaklandığı söylenebilir. Çevresel avantajları olsa da doğal gaz kirlilikten ari değildir ve sera gazı salımı yapar. Bu kaygılar, yenilenebilir enerji alternatiflerine yönelebilecek bu yatırımların maliyet ve faydalarının doğru analizini engellemektedir.

Bu tezde, doğal gaz yatırımlarının planlandığı 6 kuzey, 13 merkez ve 3 güney olmak üzere Türkiye'nin farklı bölgelerinden 22 ilçe seçilmiştir. Bu 3 bölge, güneş ışınımından kaynaklı olarak farklı güneş enerjisi potansiyeline sahiptir. Genel olarak, her bir şehirden ikişer ilçe seçilerek güneş enerjisi potansiyeli benzer yerlerde yatırımların etkisi de incelenmiştir. Bu çerçevede, "Kırsal bölgelerde doğal gaz yatırımlarından çok fotovoltaik yatırımları daha uygun olabilir mi?" sorusuna cevap aranacaktır.

Anahtar Kelimeler: Türkiye Kırsal Doğal Gaz Yatırımları, Doğal Gaza Karşı Yenilenebilir Enerji Alternatifi, Fotovoltaik, Maliyet-Fayda Analizi

to my son and to all who cares for nature

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LIST OF ABBREVIATIONS

ABPRS	Address Based Population Registration System
APC	Announced Pledges Case
BECCS	Bioenergy with Carbon Capture and Storage
BOTAŞ	Petroleum Pipeline Company
CAPEX	Capital Expenditures
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
DSO	Distribution System Operator
EMRA	Energy Market Regulatory Authority
ENPV	Economic Net Present Value
EU	European Union
FNPV	Financial Net Present Value
GHG	Greenhouse Gas
GIS	Geographical Information System
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
JRC	The Joint Research Centre
MENR	Ministry of Energy and Natural Resources
NEMP	National Energy and Mining Policy
NREL	National Renewable Energy Laboratory
OPEX	Operational Expenditures
PV	Photovoltaic
RES	Renewable Energy Sources
RMS	Regulating and Measuring Stations
SCADA	Supervisory Control and Data Acquisition
STEPS	Stated Policies Scenario
TPAO	The Turkish Petroleum Corporation
USSR	Union of Soviet Socialist Republics

CHAPTER 1

INTRODUCTION

Energy, especially electricity, landscape is constantly changing and revolutionizing fast in recent years. Natural gas has asserted itself to take over the coal and oil dominance by the help of advents in (1) excessive use of natural gas's liquefied form, (2) increased application of hydraulic fracturing, most notably in USA, (3) escalated efforts in construction of interconnections, (4) foundation of hubs and price maker markets, thus, moving away from oil indexed prices, and (5) escalated tendency and sentimentality towards climate change problems. On the other hand, renewable alternatives are increasing in numbers and enhancing to be more feasible and price competitive destined to end the reign fossil fuels. While ever-increasing gloomy concerns over all-pervasive effects of climate change are seen as the main driver of the drift towards renewables, the rigorous and ambitious research that has been put in by many researchers, most of whom are unbeknownst to the most of us and who mostly pride in the good they are bringing into this World, is the foundation that all has been built upon.

In these revolutionary times, it is our duty as researchers, policy setters, and regulators in the field of energy to assess the full costs and benefits of all reasonable alternatives in order to protect, preserve, benefit, and serve the society, environment, businesses, and more importantly next generations. Even the simple steps we take and the trivial works we do, resonate on the collective level and make a big difference for all. In this sense, the energy policies should regard the pros and cons of all alternatives.

As a result of this understanding, this study ventured to find out an overall answer to the question whether renewables could be a more price competitive solution in terms of energy in remote regions of Turkey where the use of natural gas is incentivized and have been tried to be promoted. The decision to natural gas supply to remote regions has been made by the Turkish government as an inference from the experience in having big cities supplied with natural gas. The big cities were lacking greatly in air quality as of 1980s, and supply of natural gas was the only possible and feasible solution of that time. Afterwards came the 2000s where we have seen a surge in construction of natural gas grids all over Turkish cities, with an initiative which gave away distribution rights to the cities in question for 30 years at least. This surge in construction was possible due to 2 main reasons, Turkish economy was flourishing, and it was the high time to invest in Turkey, and the social benefits of having public to meet with clean, easy to use, high quality, and price competitive natural gas.

Whereas, what has been forgotten is that the energy landscape is constantly changing, and every policy decision should be based on its economic, environmental, and societal feasibility. While one rule of thumb, in our case introducing natural gas to any city, could be economically and socially beneficial in 1980s, 1990s, and 2000s with no doubt, this would not mean that the same rule could apply to invest in smaller cities in 2010s and 2020s while renewable alternatives are becoming increasingly competitive and on top of this an economic recession is looming.

Whether PV installations are economically feasible compared to its conventional substitutes or not is a critical research and investment question. The answer to this question is straightforward for individual households who can compare the cost of both alternatives based on their current energy demand as well as the cost and efficiency figures of the alternative options. The general attitude in making such kind of feasibility analysis is to focus on the solar potential of the region while the cost of conventional alternatives generally relies on the simple aggregation of cost items. However, this study puts forward the complex nature of the cost calculations of natural gas investments using the reference company model for 22 towns which are under expansion plan of Turkey. It is explicitly shown that natural gas investments consist of a large number of components (steel pipes, polyethylene pipes, service lines, personnel, maintenance, office expenses, renting costs, fees, insurance, etc.) some of which are fixed, and the rest is variable. Moreover, the average cost depends on the average consumption in the region, the number of current subscribers, and the number of new subscribers. Then, the usual expectation that the higher the solar radiation potential, the higher the feasibility of PV modules would not be satisfied depending on the levels of aforementioned indicators.

Moreover, it should be emphasized that instead of rooftop PV other technologies such as heat pump, chiller etc. can be selected as another alternatives for cost comparison. However, in this thesis, for heating and kitchen use, we envisaged electricity as a substitute for natural gas since PV is evaluated as a more up-to-date and widespread technology for Turkey. On the other hand, the effect of cooling and other use of electricity generated from PV was not considered in this study. Since these other advantages provided by PV are not taken into account, the competitiveness of PV which is found in this study should be considered as a lower limit. Furthermore, the decision to choose rooftop PV but not solar power plant as an alternative to natural gas investments are due to the thinking that rooftop PVs can be realised and rolled over very quickly and without much ado by making use the already in place investments such as electricity distribution lines, in-house instalments, and the very roofs that PVs are going to be laid down.

In the study, first, the total costs of rooftop PVs are calculated for an average household based on the average energy demand and solar potential in the region. Next, the total costs of being a natural gas subscriber are determined using the detailed cost components particular to the region under a subscription level of 60%. Moreover, a sensitivity analysis is conducted over different subscription levels. On top of these, two types of break-even analyses have been made for each region, i.e., 1) required decrease in PV cost figures for break-even, 2) required subscription rate for break-even.

To conclude, it must be admitted that very important steps have been taken and continue to be taken towards the promotion of renewable energy. However, there is also a need to question whether it is possible to make bolder decisions in the use of renewable energy instead of natural gas networks in remote regions without basing policy makers' decisions on past convictions, rule of thumbs and beliefs. With this study, we have tried to find an answer to "What would happen if solar roof-top applications are implemented instead of natural gas investments in the remote regions of Turkey?" To accomplish this, the study will try to put forward a cost benefit analysis of natural gas grids in selected provinces and by incorporating electricity generation equivalent would-be-attained by photovoltaics from those regions’ solar irradiation, we have tried to show a glimpse of how much would a policy decision could be swayed towards renewables. In hopes of societal and environmental responsibility, we believe that our study will question the necessity of expanding natural gas networks and reveal the possibility of better, renewable, sustainable alternatives.

CHAPTER 2

BACKGROUND AND LITERATURE REVIEW

Before delving into our core analysis, it would be appropriate to understand the natural gas market structure of the country and then its solar energy potential. Therefore, in this chapter, first the overview of natural gas market will be given including the market structure, especially in natural gas distribution sector, the legislation and liberalization process, production, import and consumption figures and the tariff setting procedure. After reviewing the natural gas market of Turkey, solar energy will be investigated, including the solar potential, legislation, and subsidies, and in particular the roof-top applications.

2.1 An Overview of Turkish Natural Gas Market

In this part of this chapter, a brief history of natural gas market of Turkey, encompassing production, import and consumption data will be given. Then, natural gas market structure will be discussed.

2.1.1 Brief History of Natural Gas in Turkey

When we look at the milestones in development of Turkish natural gas market, it seems that the first thing to notice is the exploration of the first domestic gas field in 1970 in Kırklareli which is started to be consumed in Pınarhisar Cement Factory by 1976. Then, The Turkish Petroleum Corporation (TPAO) has established Petroleum Pipeline Company (BOTAŞ) in 1974 by Decree No 7/7871. In parallel with population growth and industrialization, there has been an increase in energy need. Increasing the share of natural gas has come to the fore in order to be an alternative energy source and to find a solution to the increasing air pollution in big cities. In this context, on 18.09.1984 Turkey and the Union of Soviet Socialist Republics (USSR) have signed the first agreement for the delivery of natural gas. The first purchase agreement with the USSR was followed by other purchase agreements which are destined to meet the increasing natural gas demand.

Big metropolises that are on the route of Russian Federation-Turkey Natural Gas Pipeline were supplied with natural gas. Firstly, natural gas was put into use in the commercial sector and households in Ankara by 1988, in Istanbul and Bursa by 1992, in Izmit and Eskişehir by 1996.

Natural Gas Market Law, No.4646 / dated 02.05.2001, entered into force as a requirement of the process of harmonization with the global economy and integration with European Union (EU) criteria. Thus, the struggle to extend the use of natural gas to all Turkish cities and to regulate the natural gas market and restructuring it in order to incentivize competition has begun. With this law, it is aimed to have natural gas available to all consumers in a high quality, continuous and economic manner. In this framework, the Law set out to transition the gas market from a monopolistic structure where BOTAŞ, a public-owned company dominated, to a competitive market structure where activities that are eligible for competition and started the liberalization process. On the other hand, in sectors where competitive elements were yet to be found, regulation and supervision are carried out by the regulatory body which is called Energy Market Regulatory Authority (EMRA). With this Law, all duties of regulation and supervision of the natural gas market were given to the EMRA which have also been attained as the regulatory authority for electricity sector by the Electricity Market Law, numbered 4628 [1].

2.1.2 Production, Import and Consumption

In this part, the amount of production, import and consumption of natural gas values will be given and discussed, in order to understand Turkey's dependence on imports in natural gas. Turkey has almost no proven reserves of natural gas[1], and this seems rather a continuing stage for a very long period. Figure- 1 is compiled from the annual natural gas sector reports published by EMRA in 2011 [1], 2015 [2] and 2020 [3] and shows domestic production values between the years 2006 and 2020. It indicates a declining trend. Herein, it should be said that a declining trend alone cannot express the situation well enough, also the share of domestic production in meeting total demand should be examined.

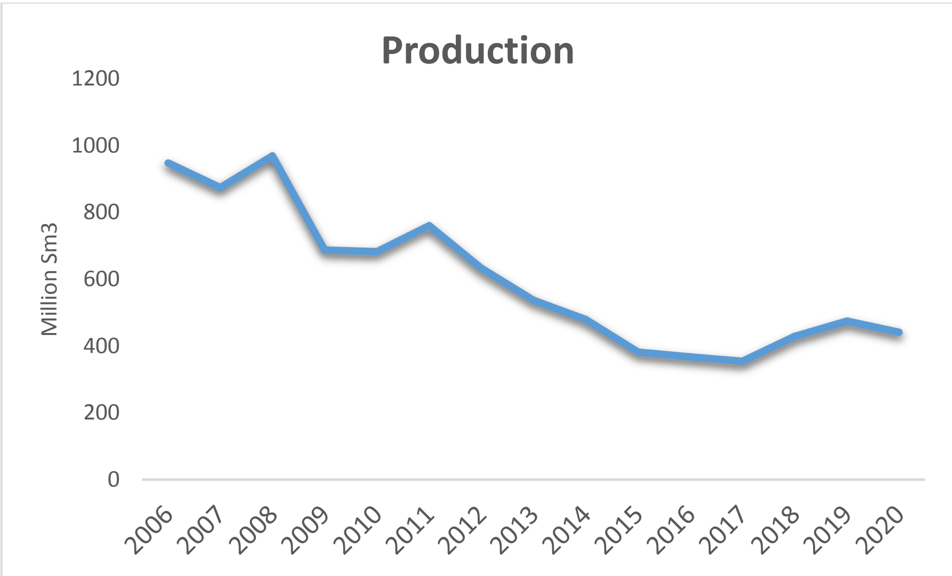

Figure 1: Domestic Natural Gas Production in Turkey

Figure-2 shows the import, export, production, consumption, total demand (consumption + export) and total supply (production + import) values in the years between 2013 and 2020. These data are again compiled from the annual natural gas sector reports published by EMRA.

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[1] Although it has announced that 320 billion m^3 natural gas reserve has been found in 2020 in Black Sea region, all drilling must be completed in order for this value to be defined as a proven reserve.

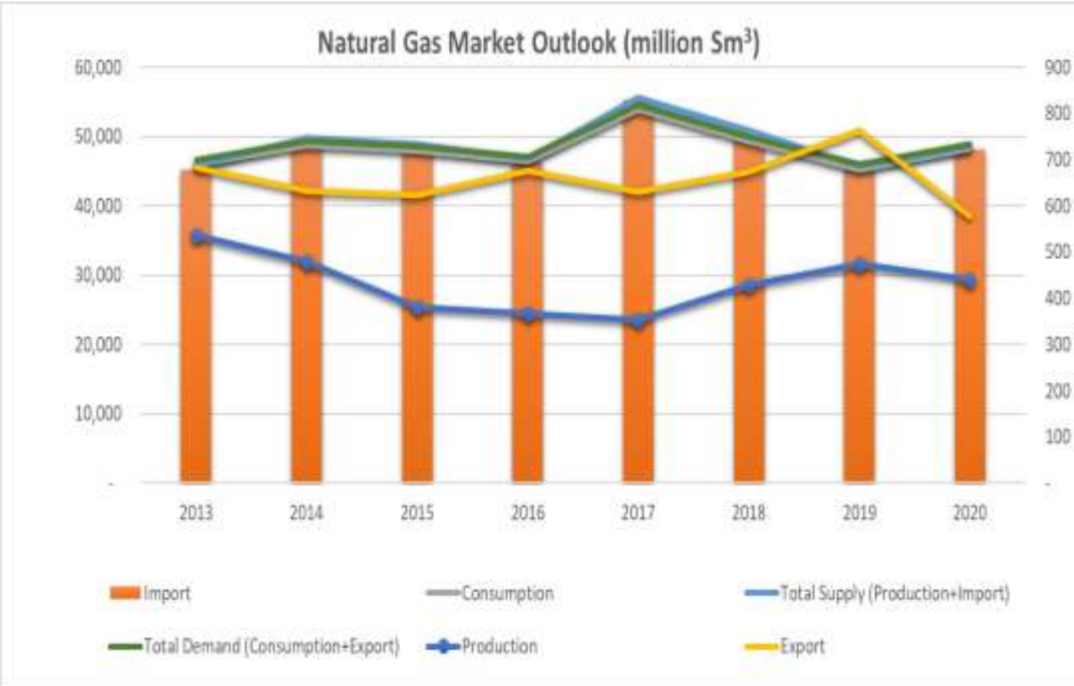


Figure 2: Natural Gas Market Outlook between 2013 and 2020

As seen from the graph above, the domestic reserves and production amounts (reflected on the right axis, always under 600 million cubic meters) are almost negligible compared to total demand (reflected on the left axis, always above 40 billion cubic meters). Therefore, it is obvious that natural gas imports were always mandatory for the Turkish natural gas market.

In 2020, 441 million Sm^3 natural gas was extracted domestically and offered for sale by nine companies. Whereas in the same year, 48 billion Sm^3 natural gas was imported by Turkey. Due to the increase in consumption, natural gas imports increased by 6.45% compared to 2019. Although both import and consumption values are on an increasing trend with a rate of more than 6%, when the domestic production of Turkey as the end of 2020 is examined, given in Table-1, the amount of natural gas produced domestically decreased by 6.88% compared to 2019. Also, it should be added that, it has only a share of 0.91% of total gas supply [3]. This percentage is the most prominent indicator of natural gas dependency of Turkey to the foreign countries which should be deserving detailed consideration and analysis.

Table 1: Natural Gas Market Outlook as End of 2020 (million Sm^3)

Production	441
Import	48,126
Consumption	48,261
Export	578
Total Supply (Production+Import)	48,567
Total Demand (Consumption+Export)	48,839

Turkey's natural gas imports, for many long years, have been mainly from five countries which are Russia, Iran, Azerbaijan, Algeria, and Nigeria. Figure-3 depicts the imported natural gas data spanning the years from 2005 up to 2020, based on the annual natural gas sector reports of EMRA. When the figure is examined, it can be easily seen that Russia maintains its position as the country with the largest share in terms of imports. The import amount form Russia has increased by 6% in 2020 when compared to 2019, while it has the same share of 34% of total gas import.

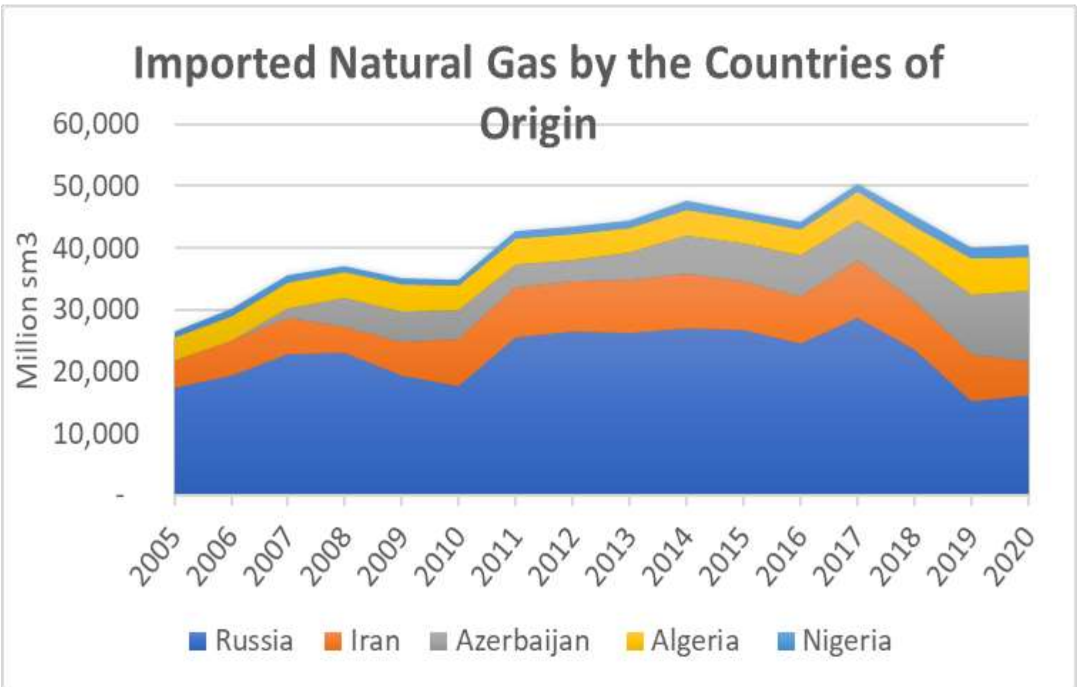


Figure 3: Imported natural gas share by the countries of origin

Moreover, Iran should be studied with a special attention because it has a very close political relationship with Russia. Iran maintains its share almost steady at the end of to 2019, but in 2020, it has decreased its share in gas exports to Turkey compared to previous years. The total share of Russia and Iran was 51% in 2019, 45% in 2020 and it would not be wrong to say that this share is a sufficiently thought-provoking ratio in terms of import dependency. In Table- 2, Turkey's gas import agreements are given which shows the importance of Russia in terms of import dependency [4].

Table 2: Turkey's Gas Import Agreements

Aggrement	Signature Date	Operating Date	Duration (year)	Amount (billion m^3/year)	End Date
Nigeria (LNG)	1995	1999	22	1,2	2021
Iran	1996	2001	25	10	2026
Algeria (LNG)	1988	1994	27	4	2021
Russia (Blue Stream)	1997	2003	25	16	2028
Russia (Balkan Route)	1998	1998	23	8	2021
Russia (Balkan Route)	1998	1998	23	4	2021
Russia (Balkan Route)	2013	2013	23	1	2036
Russia (Balkan Route)	2013	2013	30	5	2043
Azerbaijan	2001	2007	15	6,6	2022

From all these information and data, the main point that should be investigated for Turkey is that "Do Turkey really have to spread the use of natural gas by extending its distribution lines even to small towns while it suffers from recurring dependency to foreign gas producers?"

2.1.3 Distribution Sector

In accordance with the Law no 4646, the companies that won the tenders for the distribution regions determined by EMRA are authorized to distribute natural gas by receiving their distribution licenses. In other words, only one distribution system operator (DSO) has the right to invest in natural gas distribution facilities in one region, which required government to set tariffs. The tariff making process is described in detail in the following chapter.

The number of companies that have natural gas distribution license in 2019 and thus the number of distribution regions is 72 as in the previous year. Natural gas was supplied to all 81 provinces in 2019. As of the end of 2020, the total length of the high-pressure resistant steel pipeline constructed increased by 5.48% compared to the previous year, reaching to approximately 14,924 km in total. The length of the polyethylene pipelines (excluding the length of the service/connection lines) which are resistant to lower pressure compared to steel pipelines, increased by 6.64% compared to the previous year, reaching to approximately 101,496 km in total [5]. The total number of consumers that natural gas distribution license holders provided natural gas services to, increased by 6.18% compared to the previous year, reaching to 16,848,604 customers in total. The number of eligible consumers who have a right to change their natural gas supplier/wholesaler, has increased by 5.05% and reached 655,464 in total. The natural gas consumption of customers in 2020 increased by 8.49% compared to the previous year, reaching to 15,135 million Sm^3. Consumption of eligible users has decreased by 3.24% compared to the previous year, reaching 9,770 million Sm^3 [6]. This shows that the share of competitive market of wholesale has reached nearly to 40% of the natural gas market in terms of consumption. This is somewhat promising news that nearly 40% of the natural gas market is now open to competition.

The downside of setting tariffs for natural gas distribution companies is that their investments and expenditures are guaranteed with a high and almost risk-free return rate. Therefore, distribution companies always tend to do more investments, which is named as gold plating in literature. But this is not the only reason. By the decision of the Council of Ministers, the towns that have the population of 20,000 or more should be supplied with gas. After this decision, EMRA Board also took a decision to implement the decision of Council of Ministry. With this decision, EMRA started to re-open the tariff setting processes and revised the tariffs of those who will invest in natural gas distribution lines for these small towns.

Furthermore, in districts with a distance of less than 30 km to the BOTAŞ transmission line, it is essential that the city supply line investments made by related distribution company. This also meant that more investments will be burdened on the distribution company and as a result, on the consumer tariffs.

In districts with a distance of 30 km or more to the transmission line, city feed line investments are carried out exclusively by BOTAŞ. Therefore, transmission line operator carried these costs over.

Another important point is that in case the distribution company requests, and it is approved by EMRA, the city supply line investment for supply of natural gas to these towns can be made exclusively by the distribution company. This supply line either can reach to a BOTAŞ transmission line or directly to the distribution network of a nearby city. This also meant that if the distribution company requests it can take on all those investments upon itself and increase the asset base of its company and therefore causing a hike in consumer tariffs.

In case of expansion of distribution regions, the EMRA Board may re-establish tariffs by taking into account the amount of grid investment for the region subject to expansion and the investments to be made in the area of expansion.

2.1.4 Tariff Setting

As mentioned earlier, only one DSO is authorized to do distribution task in one region. This makes the DSO a monopoly in that region which could lead DSOs to a tendency to increase their prices in defiance of the natural gas users. In order to reach to the competitive market conditions, and therefore, protect both consumers and investors, EMRA sets tariffs for the distribution companies. The overall objective is to promote economic efficiency which means that prices should be at the level of a perfect competition market. This tariff setting procedure supplies network owners to earn a reasonable return on capital employed, under the condition of efficient grid development and its operation. This reasonable return on capital should satisfy investors' expectation for profits so that they choose to invest in grids among many other possibilities, such as depositing their capital to banks.

In order to find distribution charge of a company, first the revenue requirement should be determined. The revenue requirement is based on operational expenditures (OPEX) and capital expenditures (CAPEX). By examining these expenditures, company's revenue requirement is calculated. When this requirement is divided into forecasted consumption, distribution company's charge to be collected from consumers can be calculated (Figure- 4). From this figure, it is easy to understand that each investment should bring enough consumption to be feasible, and it is the regulator's job to ensure that the distribution companies do investments in regions where consumption gains are enough to account for the increase in revenue requirement base.

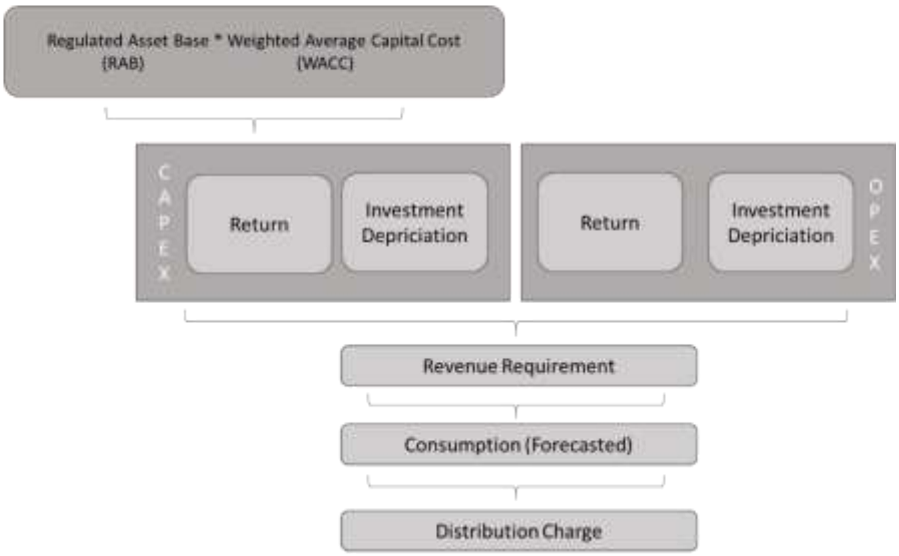


Figure 4: Distribution Charge Setting

2.2 Comparison of Photovoltaic and Natural Gas

When solar photovoltaic (PV) generation is considered, solar potential of Turkey is relatively high. On the other hand, renewables such as solar and wind have intermittent nature; they produce electricity when wind blows and sun shines. Therefore, this poses another security question. On the upside, renewables have lower vulnerability towards shocks in energy prices especially when compared to fossil fuels and natural gas. As everyone is well aware, environmental cost of energy consumption is another important issue that should be addressed. Although natural gas is considered to be more environmentally friendly opposed to oil and coal, it causes a certain level of pollution, too. Renewable applications are much preferred in that aspect. Also, the distributed generation from renewable sources reduce transmission and distribution costs and their respective losses. Another important advantage of them is that they have very low maintenance cost over long periods of time. But the most important disadvantage of solar PV's are their high initial costs. Due to the high initial investment need for rooftop PV systems, the installation of these systems in Turkey seems economically not feasible without incentive mechanisms in place. As a result, incentive mechanisms such as purchase guarantee, tax and investment incentives can be considered in order to ensure expansion of installation of rooftop PV systems.

It is straightforward to deduct from the facts which is discussed in tariff setttings that new investments increase CAPEX and as a result, the tariffs of the existing consumers; only if not enough consumption is acquired from these extra investments. In other words, existing consumers subsidize new or future comers. For that reason, it is very important to decide whether the investments in remote towns are necessary or not? Therefore, in this thesis we seek the answer to the question of: "Can the solar PV be applicable instead of natural gas?" Before going into detail in economic analysis, it is better to look over the cons and pros of both, which is supplied in bullets in Table-3.

The most important disadvantage of natural gas is its effect on increasing the current account deficit, since Turkey lacks the necessary natural gas resources which causes a great amount of import. On the other hand, it is more reliable because its flow is continuous unlike the intermittent nature of solar power. However, when the natural gas investments are brought to remote regions, there is no doubt that the tariffs for existing users will increase. This means a cross-subsidy, because the investments to the new potential users will be paid by the existing ones. Another important point to be analysed is that natural gas users are greatly open to shocks in energy prices, though solar energy alternatives do not have price shocks.

Table 3: Comparison of Natural Gas and Solar PV

	Advantages	Disadvantages
Natural Gas	• Relatively lower health costs compared to coal, • More reliable • Social acceptance	• Increase in dependency • Serious increase in current account deficit • Cross-subsidy • Increased tariffs • Energy price shocks • Still produces greenhouse gas (GHG) emissions
PV	• Energy Security •Reduced transmission and distribution costs and losses • Peak shaving • High solar potential • No GHG emissions • Local business and job opportunities • More health costs reduction • Low maintenance over long period • Net-metering • Government Incentives	• High initial cost • Intermittent nature • Willingness to pay / Willingness to adopt

2.3 Energy Transition

Due to the advantages of renewables that can be seen from the Table-3, lots of countries have started to shift their energy consumption to green sources by realizing their renewable potentials. The most important milestone in climate change issue is the Paris Agreement since it is the first universal and legally binding global climate change contract held in December 2015. This agreement sets a global framework for preventing climate change. 197 countries' governments agreed a long-term goal of keeping the increase in global average temperature to well below 2°C above pre-industrial levels and to aim to limit the increase to 1.5°C. The 2018 Special Report on Global Warming of 1.5°C of the Intergovernmental Panel on Climate Change (IPCC) reveals both the urgency of limiting global warming to 1.5°C and a 45% reduction in global greenhouse gas emissions by 2030 from 2010 levels. Moreover, IPCC (2018) suggests that to meet the Paris Agreement's temperature goals, the World will need to reach net-zero GHG emissions early in the second half of the century [7]. By July of 2020, 19 countries and the EU have adopted net-zero targets, and more than 100 others are considering doing so [8]. In order to put forth the struggle towards those targets, energy transition in the World and Turkey's relevant strategy will be mentioned.

Energy transition is defined as transferring energy production and consumption patterns from fossil fuels to renewable energy sources, to combat with and mitigate the global climate change and prevent the depletion of fossil fuel reserves. Besides these drivers, there are many pillars for this transition but the key ones for the 21st century energy transition are; (1) accelerating implementation of the Paris Agreement, (2) the escalating frequency and severity of catastrophic climatic events and (3) technological innovations, including energy efficiency, renewable energy, and energy storage [9]. The World Energy Transitions Outlook identifies six main components of CO_2 emission abatement: (1) renewable energy solutions, (2) energy conservation and efficiency in all parts of the value chain, (3) excess electrification in end-use sectors, (4) extension and dissemination of hydrogen and its derivatives to all sectors, (5) carbon capture & storage (CCS) and carbon capture & utilisation (CCU), (6) bioenergy with CCS (BECCS), and other carbon removal measures. According to International Renewable Energy Agency (IRENA), by 2050, electricity would be the main energy carrier with over 50% (direct) share of total final energy use, up from 21% today. Another outcome will be that 90% of total electricity needs would be supplied by renewables followed by 6% from natural gas and the remaining from nuclear [10]. Renewable energy is growing rapidly in all scenarios implemented by the International Energy Agency (IEA) and solar energy is the focus of these new electricity generation technologies. As a result of the considerable cost reductions over the past decade, solar projects have begun to offer the lowest-cost electricity ever seen. According to Stated Policies Scenario (STEPS), renewables will meet 80% of the growth in global electricity demand by 2030. Although, hydroelectric power generation will remain the largest source of renewable electricity, the solar energy will be the main driver of growth, breaking new records every year after 2022. The development of renewable generation sources, especially solar energy, and the contribution of nuclear energy are much obvious and much stronger in Sustainable Development Scenario which projected to have net zero emissions by 2050. As India becomes the largest market for utility-scale battery storage, storage plays an increasingly vital role in keeping power systems running flexible. In that report, IEA also considers natural gas. In the STEPS, a 30% rise in global natural gas demand by 2040 is concentrated in South and East Asia. In these regions, a tendency to improve air quality and to support growth in manufacturing, combined with lower prices will promote the gas infrastructure. On the contrary, this report is the first in which the STEPS projections show gas demand in advanced economies going into slight decline by 2040 [11]. Moreover, IEA published Net Zero by 2050 Report which maps out how the global energy sector can reach net zero by 2050. In that report two scenarios, the Stated Policies Scenario and the Announced Pledges Case (APC) are compared. Although STEPS takes account only of specific policies that are in place or have been announced by governments, APC assumes that all announced national net zero pledges are achieved in full and on time, whether or not they are currently underpinned by specific policies. According to STEPS, renewables provide almost 55% of global electricity generation in 2050 (up from 29% in 2020), but clean energy transitions lag in other sectors and natural gas use is almost 50% higher. On the other hand, APC's projection for the share of renewables in electricity generation is nearly 70% in 2050 and natural gas use expands by 10% to 4,350 bcm in 2025 and remains about that level to 2050. Moreover, in APC, the global rise in energy supply is steered by renewables that raise their share in the energy mix from 12% in 2020 to 35% by 2050 (compared with 25% in 2050 in the STEPS). Wind and PV in the electricity sector together conduce 50% of the growth in renewables supply. To this end, with a 50% probability STEPS results in a temperature rise of around 2.7 °C, while APC assumes a temperature rise of around 2.1 °C by 2100 [12].

2.3.1 Energy Transition in Turkey

When Turkey's position in energy transition is discussed, the most important drivers are dependency on imports and growing energy demand. Besides these factors, climate change issues also influence Turkish energy policy. In line with its national energy strategy, Turkey is taking important steps to reduce dependency on energy and improve its efforts to increase the share of renewable energy sources to maximize the use of domestic resources and combat climate change [13]. Because of these concerns, Turkey has undergone an important energy transition between the years 2002 and 2017. The government presented the National Energy and Mining Policy (NEMP) in 2017 which is a set of objectives and goals based on three main axes: (1) localization, (2) security of supply and (3) predictability in the markets. By means of NEMP and applications in line with it, Turkey aims to achieve regional supply security, energy self-sufficiency, and facilitate robust international cooperation [14]. Figure 5 shows a regular increase in Turkey's renewable energy market both for capacity and production which is compiled from IRENA's Renewable Energy Statistics Report.

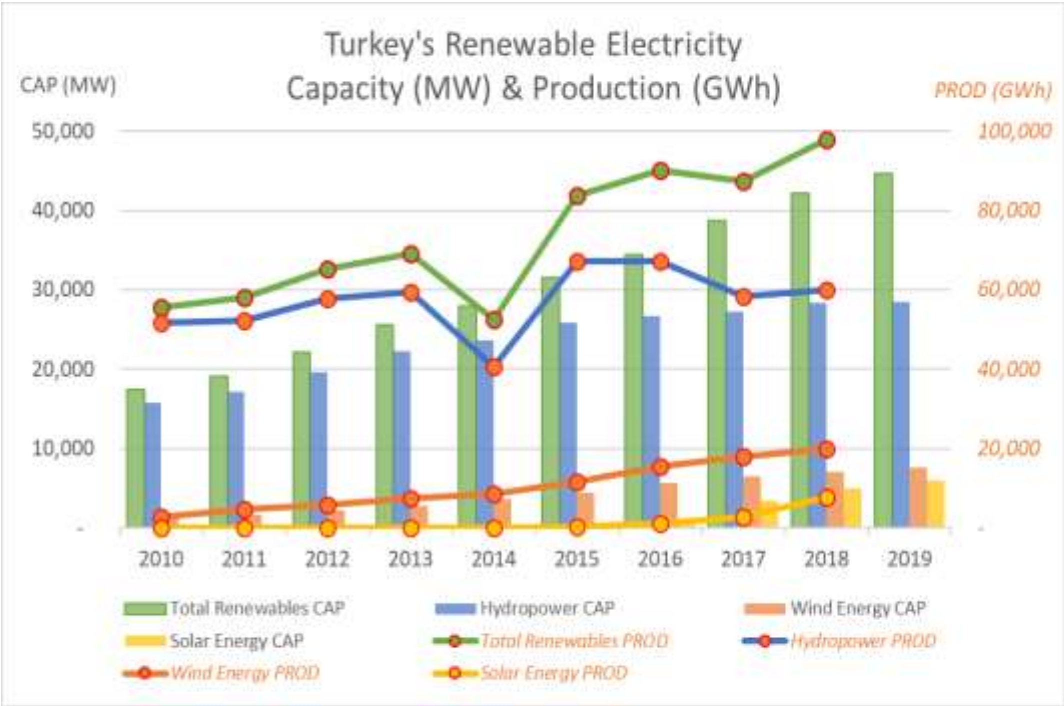


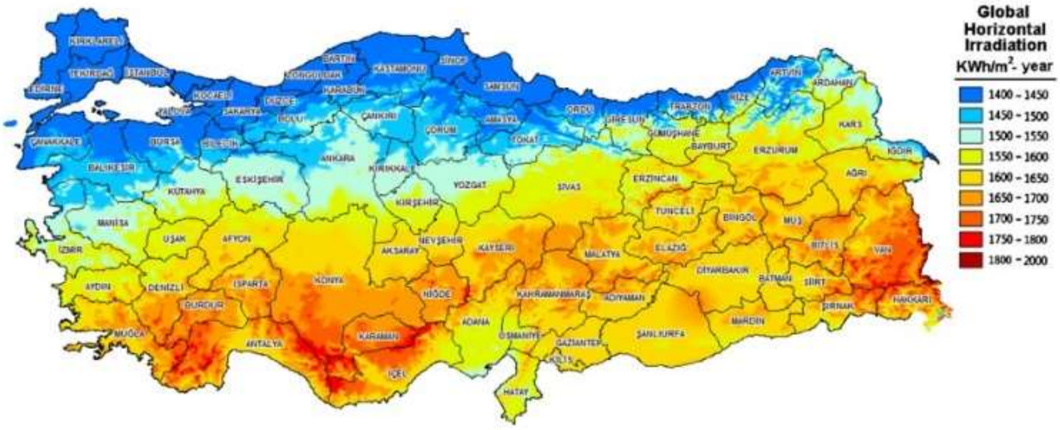
Figure 5: Turkey's Renewable Energy Statistics

Moreover, the 2020 report of the Ministry of Energy and Natural Resources (MENR) shows that this increasing trend also continues in harmony with NEMP. According to that report, the installed power based on solar energy is 6,667 MW, installed hydroelectric capacity is 30,984 MW, geothermal energy and biomass energy is 3,098 MW and the capacity installed using wind energy is 8,832 MW. The share of renewable resources in electricity generation has reached to 42.39% [15].

2.4 Solar Power in Turkey

Solar potential in Turkey is relatively high due to its geographic location and it has the second largest potential in Europe after Spain. The solar radiation level decreases moving from south to north as expected in the northern hemisphere

(Figure 6) [16]. In the northern part of the country, solar irradiation notably decreases related to specific climatic (cloudy) and geographic (incoming angle of



sun rays and mountainous) conditions of the region. In this thesis, that's why districts from northern, centre, and southern part of the country have been chosen in order to allow for an unbiased comparison of the costs of natural gas investments and PV.

Figure 6: The Global Irradiation and Solar Electricity Potential of Turkey

Considering the PV systems that are the subject of this thesis, there are studies in the literature about the feasibility of rooftop PV systems in Turkey, whereas changing cost levels of PV investments always render these studies outdated. But regarding annual solar radiation of 1,527 kWh/m^2-year and sunshine duration of 2,767 hours (which means more than 7.6 h per day) [17]. The research shows that Turkey has the potential of 189 GWh/year in electricity production obtained from solar energy [18].

In this regard, some research is worth noting in terms of shedding light on our work. One of them is Tetra Tech's research on Turkey's rooftop PV market. Turkey's great solar potential and, on the contrary, the lack of rooftop PV and other similar small size project penetration has been greatly emphasized by this project. This study too has pointed out the inefficiency caused due to unlicensed feed-in tariff policy that is granted for the projects under 1 MW generation capacity.

Whereas in the developed countries with increased solar penetration, an important solar generation share is achieved from rooftop PVs. This study has valuable policy recommendations derived from best practices in accomplished solar electricity generation markets. It is advised that licenses and permits should follow a simpler, online solution and be subjected to a strict time frame for completion. A move towards self-consumption and net-metering of generation over consumption is also advised, whereas this policy advice on these issues is not fully assessing its reflection on the Turkish electricity market and the propositions are somewhat uncertain. There is a trade-off between self-consumption level and feed-in tariff incentive amount. Increased self-consumption of the solar electricity generator would cause a decrease in feed-in income and vice versa. Therefore, any policy that tries to increase the consumption volume of solar PV investors should choose different schemes than applying feed-in tariffs.

Other policy recommendations are stated as: (a) increasing financial incentives, diversifying financial channels, and easing access to financial options for these investments; (b) varying incentive opportunities; (c) education for capacity building and instating related outreach programs. While all these are important policies, it is well-known that they should be adapted to Turkish market after rigorous analysis and assessments. Another advice from this study is the integration of battery storage into rooftop and solar electricity generation. In case of Turkey, it would be better to fully recognize and implement those solutions before incentivizing battery storage options for every small rooftop solar PV. Battery solution should be regarded inherent part for PV instalments in remote regions [19].

Another study done by SHURA (2020) has shown that rooftop photovoltaics could account for 17% of electricity need of households, if fully realized by use of various financing and policy means. It also shows that 70% of all rooftop PV potential is from households. This study's findings differ from our study's perspective. SHURA ventures to find out the feasibility of rooftop PV instalments with respect to Turkish consumer electricity prices, as a result it finds out that PV costs for households are 30 to 50 percent more expensive. For commercial, public, and industrial rooftops PV costs are shown to be much lower than related consumer electricity tariffs. The margin between PV costs and electricity tariff can be mainly attested to subsidized household electricity prices [20]. Under subsidized and therefore perplexed energy market conditions, many analyses would fail to acknowledge the true importance and feasibility of renewable energy solutions. In Turkish electricity market even coal-fired power plants and nuclear power generation (yet to be built) is subsidized. In Turkish natural gas market, household and industrial consumers are subsidized in expense of natural gas power plants. Under this much noise, any electricity price or even gas price would be a terrible benchmark for an accurate feasibility study. Therefore, in our study, we have used the total natural gas investment and operational expenditure to be a starting point in assessing the feasibility of PV instalments instead of natural gas usage. Our study mainly tries to show that due to stagnant policies, lack of necessary incentives and encouragement, better opportunities for environment, energy, innovation, economic development, and society are missed out.

In a study that ventures in efficient cogeneration possibilities in Cyprus, economic and technical potential of several heating and cooling systems are accessed [21]. The most important outcome of the study that would shed great light to our research is that solar gives top primary energy saving possibility (reduction in the consumption of climate damaging fossil fuels). We must remind that this economic potential study was done before the great solar cost efficiency that occurred since then. Therefore, we could only argue that solar power generation and heating and cooling possibilities from solar power has greatly surpassed other candidates in consideration.

Another aspect of this JRC research shows that even before realizing the cost deductions in solar power, countries could have moved onto use of solar power more excessively, if they have been constantly checking for alternatives and doing proper assessments accordingly. State policies greatly defines the direction for public and private sectors and for the society as a whole. On the other hand, government employees and policy setters generally work in a stable environment. As a result, it becomes really hard to change that direction in order to follow on the fast paced, ever-changing path of energy sector. While there would be many experts, policy setters, and advisors in public sector that constantly involve themselves in search for best energy options, these efforts seldom result in policy changes.

The extensive study of JCR (2016), both economic net present value (ENPV) and financial net present value (FNPV) of several heating and cooling system options have been assessed. While ENPV shows the value of that option in respect to a total societal outcome, FNPV only shows the value of the option in monetary cash flows term. This differing present valuation studies pinpoints where a policy determination is required by the government in forms of subsidies or other tools. Furthermore, this research takes into consideration the primary energy offsetting benefits of each option. While solar and other renewable options offset a great deal of fossil fuel consumption, the combined heat and power solutions add to the consumption of fossil fuel use. In conclusion, this research shows that in high energy demand density areas (big cities) would require district heating and cooling, whereas in low density areas, decentralized, in situ, solutions are found to be reasonable. When combination of solutions is applied, solar and heat pump when combined together, are found to be the most affordable solutions even in big cities. Overall solar is the most reliable option considering that it furthermore offsets fossil fuel use in the economy [21].

Moreover, Clark et. al. (2007) has shown the economic advantages of green roofs over conventional rooftops by assessing their advantages for roof longevity, decrease in stormwater infrastructure investments, the downward move on water runoff in green rooftops. While in the short-run green roofs may require higher capital investment, their net present value analysis of a 40-years long analysis showed that green roof systems twenty to twenty five percent more beneficial in terms of their respective present valuations. By this paper, we observe that greener rooftops have various advantages over conventional ones. As a result, the positive effects of revolutionizing rooftop investments by integrating solar photovoltaics would give us spill-over benefits that we may not even think of at this stage of this study.

Any NPV assessment should fully account for costs and benefits and monetize those so that a trustable analysis could be made. Another outcome of this study and many others is coupling innovative solutions together while integrating a new and clean system to a conventional system, or even better, replacing the conventional with the more innovative one would require a whole systematic thinking. With this whole systematic thinking innovative solutions stand a better chance to success and achieve a wider acceptance.

In this study, we are aching to show even without consideration of side benefits and spill-over benefits of Solar PVs over natural gas consumption, strategizing and incorporating Solar PVs in Turkish small towns would be more valuable and desirable in terms of costs. Moreover, in this study we analysed that whether the realized costs of investments in selected provinces would be accounted by only using Solar PVs may they be on rooftops or on a land. The land to be used could differ from region to region and it does not have to be an arable parcel. Municipal wastelands, parking lots, shading areas for parks, or over a body of water. Using Solar PVs in these land areas has many side benefits that could even surpass the overall electricity generation benefit that is derived from these Solar PVs. These benefits could be prevention of loss of water in a body of water that is susceptible to intense evaporation. Using PV panels as shaders over parking lots, in parks or for livestock has cooling effect for people and the animals which in turn has added benefits of lower cooling need and increased relaxation [22].

Zhu et. Al. (2013) has analysed the barriers and opportunities for natural gas and PV use for water heating in Nanjing region of China. While both sources are seen as clean energy compared to prevalent sources in the region, they have foreseen that Solar PV would prevail with a great price deduction by the help of technology improvements and widespread investments [23].

Many studies on PV solar and natural gas comparison for household use were carried out for European countries in which natural gas has already widespread nationwide use in buildings. Therefore, these studies mainly tried to deal with energy transition and household energy renovation from natural gas to solar, hybrid, and renewable alternatives. The case of providences of Turkey is somewhat differing from this perspective. While some European studies has been included in our literature review, one important and close example study for us had been Noorollahi et. al.'s (2021) simulation of solar or wind energy replacement in the expense of natural gas use for heating demand in households sector. Natural gas use in buildings sector in Iran is by far the largest (89%). This is due to the excessive natural gas presence in the region. As a result of this, the economic analysis would greatly differ from Turkey. Therefore, the study has found out that solar energy use costs 27% more and wind energy use costs 226% more on average in buildings sector of the country. Only beneficial cost reduction was found to be from solar thermal collectors with 13% reduction in costs. Considering the excessive network and investment for natural gas use in Iran, the energy transition can be redeemed problematic [24].

For example, Broers et. Al. (2019) states that this transition starts with first introduction of renovation idea to the minds of house owners and tenants. This introduction can stem from physical, societal, environmental, and technological concerns or factors. After this stage comes the knowledge and background gains from professional and social networks. Last stage is both implementation of these renovations and influence of these on other households [25]. In another study, Bjørnstad (2012) has analysed the Norwegian subsidy for other heating technologies such as heat pumps and pellet stoves. The study found out that while these alternatives have shown big economic returns, these returns are not the superior reasons for people to move onto the alternatives, but quality received by the technology, indoor air quality increases, and comfort gains in heating the household are much bigger incentives [26]. Weiss et. al. (2012) has developed a study for German household's refurbishments for increasing energy efficiency which aimed to put forward policy advice on the issue. In the study, two significant energy reduction potential has determined as insulation of exteriors (the walls and the rooftops) and use of renewable energy alternatives. One important point in this research is the finding that while the regulations and policies are, without any concern, economically benefiting the households, the enforcing the laws and the regulations are greatly lacking and this deficiency has been the pillar for slow refurbishments that had been seen in the German household energy efficiency market [27].

For Turkey, energy transition from natural gas to renewable sources are not limited to solar PV. Turkey has a lot of geothermal potential which waits to be tapped into. Keçebaş et. al. (2010) has pointed out that geothermal energy and natural gas greatly decreases local SO_2 and Particulate Matter emissions. While the two are proposed for air quality increase, one can realize that geothermal energy use has much wider benefit than natural gas consumption for heating. Since the results of this research show that the local emissions of SO_2 and PM associated with fuel combustion have been reduced annually by 1.7 thousand tons/year and 421 tons/year for geothermal energy and 0.2 tons/year and 3.8 tons/year for natural gas, respectively [28].

Boyraz and Çetin (2019) has revealed in their study of hotels in Denizli city that even without centralized and planned approach to geothermal energy use (pumping, distributing, and re-injection of geothermal waters), energy bill is greatly reduced, pollution from fossil fuel use (including natural gas) is mitigated, and income of the hotels increased indirectly [29].

After covering solar potential of Turkey and some research that may shed light into this study, it is better to mention about legislations held by Turkish government in line with the energy transition policies. Due to the import dependency on natural gas, critical legislations have been put into effect in order to decrease import dependency and climate change issues. Since Turkey has to use the full potential of renewable energy resources, in the most efficient manner, The Electricity Market

Law No. 6446, the Law No. 5346 on the Use of Renewable Energy Resources for the Purpose of Generating Electricity (RES Law) and the Electricity Market Licensing Regulation, the Regulation on Unlicensed Electricity Generation in the Electricity Market, the Communiqué on the Implementation of the Regulation on Unlicensed Electricity Generation in the Electricity Market are in force.

The purchase guarantee for all renewable resources was first applied with the upper limit of 5.5 Euro cent/kWh with the RES Law No.5346. However, when sufficient progress could not be made due to the insufficiency of this incentive, a source-based incentive mechanism and additional incentives for the use of domestic products were introduced with the Law No. 6094 of 29/12/2010. For the generation license holders subject to the RES Support Mechanism, it has been regulated that 13.3 USD cents/kWh has been applied for a period of ten years for the plants generating electricity from the solar energy that are in operation until 30/06/2021. According to the RES Law, if local parts are used in the production facilities that were put into operation before 30/06/2021; additional incentives are applied to the specified prices for a period of five years from the date of operation of the production facility.

Photovoltaic systems to be installed on building roofs are exempt from the obligation to obtain a license since they are from generation facilities below 1 MW within the scope of the Law "*Activities that can be carried out without license*". In this context, the main legislative infrastructure for roof photovoltaic systems is the Electricity Market Law No. 6446, the RES Law, the Regulation on Unlicensed Electricity Generation in the Electricity Market (Unlicensed Generation Regulation).

CHAPTER 3

DATA AND METHODOLOGY

In this chapter, it is communicated the data and methodology with which have been tried to come up with solar energy alternative to the natural gas investments in remote regions of Turkey. To do so, methodologies for natural gas investment calculations and PV investment calculations will be explained. To choose a relevant, encompassing providence basis for the study, we had looked into recent investment plans for remote regions by 2017, and we had chosen providences from the exact corresponding cities in Duman et. al. (2020) [30] and Ozcan et. al. (2019) [18] study or the provinces that are in the same solar irradiation region in Turkey solar map given in Figure 6. Since solar irradition levels differ from north to south, we tried to include as much providences as we can to reflect on this aspect. In the northern part of the country, solar irradiation notably decreases related to specific climatic (cloudy) and geographic (incoming angle of sun rays and mountainous) conditions of the region. In this thesis, that's why providences from northern, centre, and southern part of the country have been chosen in order to allow for an unbiased comparison of the costs of natural gas investments and solar PV.

3.1 Natural Gas Investment Calculations

In this calculation the answer of how much should a company invest to supply a certain district with natural gas is sought after. Investments were analyzed under two main headings; capital expenditures (CAPEX) and operational expenditures (OPEX). While performing these calculations some parameters such as the number of potential consumers, average consumption etc., have been estimated (Figure 7) which will be explained in the following part. Since those assumptions directly influence CAPEX and OPEX calculations, it is better to start with those parameters.

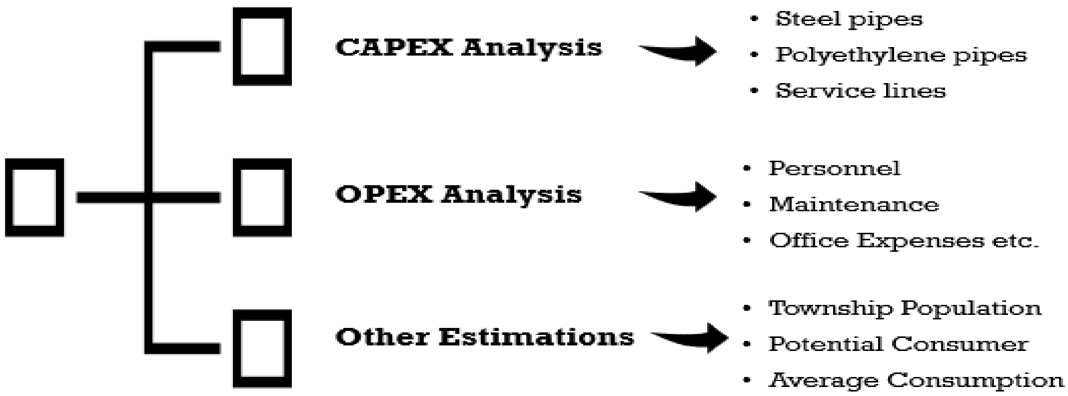


Figure 7: The Components of Natural Gas Investments

3.1.1 Number of Subscribers

Since both OPEX and CAPEX have been calculated per consumer and so affect all the calculations, first, potential number of subscribers has to be found. To accomplish this, population estimates should be done for each town subjected to analysis. The past population data of the year 2012 is taken as the base year and magnified by 0.5% which is Turkey's population growth rate in 2020. This percentage is taken as the population growth rate due to the following legislative changes. In the Metropolitan Municipality Law No. 5216, significant changes were made with the Law No. 6360 dated 12.11.2012. With this law, the definition of metropolitan municipalities was changed and the distinction between center and village was removed. When villages are accepted as neighborhoods, remote and central populations are given collectively in the Address Based Population Registration System after 2012. For this reason, the 2012 data, which was kept by the Turkish Statistical Institute when there was a center-village distinction, was enlarged and other years were calculated shown in Appendix-A [31].

The population figures of the following years have been estimated by using this average population growth ratio.

To have the yearly estimates on the population growth of each remote region, the populace is increased by the growth rate assigned to the region up to the year 2022. We have seen that initial natural gas investments are being realized regarding the population level in upcoming 6 years for the remote regions. That is because further population growth is uncertain for remote regions due to continuous migration to bigger cities. These investments will need to be matched with increase in solar investments, but since solar energy investment costs are plummeting each year, any further investment comparison after 6 years of time will be greatly benefiting the solar power. Therefore, uncertainty in population growth and decreasing unit solar investment costs refrain us from considering investment and consumption for long-term population figures.

Table 4: Population Forecast on the Expanding City

Towns	2017	2018	2019	2020	2021	2022
Aydın- I	20,761	20,865	20,969	21,074	21,180	21,286
Aydın- II	21,117	21,223	21,329	21,435	21,543	21,650
Adana - I	80,571	80,974	81,379	81,786	82,195	82,606
Adana- II	7,693	7,732	7,771	7,809	7,849	7,888
İzmir- I	28,552	28,695	28,838	28,983	29,128	29,273
İzmir- II	28,925	29,070	29,215	29,361	29,508	29,656
İzmir -III	62,957	63,271	63,588	63,906	64,225	64,546
Eskişehir-I	10,068	10,118	10,169	10,220	10,271	10,322
Denizli-I	14,093	14,164	14,234	14,306	14,377	14,449
Çanakkale-I	11,137	11,193	11,249	11,305	11,362	11,419
Yozgat-I	25,586	25,714	25,843	25,972	26,102	26,232
Ordu-I	4,154	4,175	4,196	4,217	4,238	4,259
Manisa-I	101,108	101,614	102,122	102,632	103,146	103,661
Erzurum-I	13,948	14,017	14,087	14,158	14,229	14,300
Balıkesir-I	6,651	6,684	6,717	6,751	6,785	6,819
Balıkesir-II	42,976	43,191	43,407	43,624	43,842	44,062
Balıkesir-III	56,650	56,934	57,218	57,504	57,792	58,081
Kayseri-I	9,947	9,997	10,047	10,097	10,147	10,198
Kayseri-II	20,291	20,392	20,494	20,597	20,700	20,803
Trabzon-I	41,614	41,822	42,031	42,241	42,452	42,665
Van-I	83,263	83,679	84,097	84,518	84,940	85,365
Gümüşhane-I	10,736	10,790	10,844	10,898	10,953	11,008

Moreover, to reach to the subscriber number, we had to find out the average residents in households in the relevant cities. Higher number of residents would mean lower number of buildings in the town which entails lower number of subscribers, lower investment need and could mean lower natural gas consumption per capita on overall. The related numbers of household residents are obtained from address-based population registration system (Appendix-B) [32]. While these residency numbers would not totally reflect the actual figures of the townships that we base our calculations, it is only data we have for estimating the total household numbers and therefore, potential subscriber numbers. Keeping in mind that remote regions are constantly under pressure of losing migration to bigger cities and leaving older people to live by themselves in their houses, the residents per household figures should be much lower than the crowded and expensive housing cities. This lower residency in remote regions would affect the natural gas investments in two folds: (1) houses without kids and babies tend to consume less energy for heating, therefore, making them reluctant to move onto natural gas over coal, wood, and fuel-oil, (2) lower residents in any household would mean more potential subscriber/building per population which increases the service line investments; but decreases the efficient use of gas investments and operational expenditures.

Due to lower number of residents and probably older age groups residing in the buildings, the heating need would be much lower, and they will be reluctant to move on using natural gas. This will end up in decrease in subscriber penetration (the rate at which houses start using natural gas) and decrease in natural gas consumption. Decline in average natural gas consumption would mean investment costs will be higher per natural gas consumed. In this regard, we can say that our calculation is again biased towards natural gas investments over solar energy by making use of higher number of residents per household.

As a result, to reach the number of potential subscribers in an expanded city, population estimation is divided into number of households related to the relevant city. In this study, it was assumed that DSOs could reach only 60% of potential customers and sensitivity analysis was performed for two different percentages, 50% and 70%.

Table 5: Potential Subscribers

Towns	Potential Subscribers	Towns	Potential Subscribers
Aydın- I	4,287	Ordu-I	826
Aydın- II	4,360	Manisa-I	19,725
Adana - I	13,101	Erzurum-I	2,150
Adana- II	1,251	Balıkesir-I	1,476
İzmir- I	5,779	Balıkesir-II	9,535
İzmir- II	5,854	Balıkesir-III	12,568
İzmir -III	12,742	Kayseri-I	1,725
Eskişehir-I	2,245	Kayseri-II	3,520
Denizli-I	2,828	Trabzon-I	7,852
Çanakkale-I	2,568	Van-I	9,628
Yozgat-I	4,809	Gümüşhane-I	1,908

Moreover, consumption in 2016 has been accepted as the base consumption for the annual subscriber average consumption. This, too, make our calculation biased towards natural gas use, because (1) it does not consider the fact that remote natural gas users are more able and free of regulation to switch back to old consumption patterns (coal, wood, and fuel-oil), (2) it does not take into account that remote areas are growingly populated by older people and impoverished residents which causes their consumption to be lower than those of bigger cities.

3.1.2 CAPEX Calculations

In this chapter, the term of CAPEX is used to cover the grid investments made by the company for the respective district expansions. It is calculated based on the kilometers (kms) of steel, polyethylene, and service lines. Also relevant capital expenditures such as excavation, license and fees, line covering, Geographical Information System (GIS) applications, cathodic protection and other expenses (expropriation, supervisory control and data acquisition (SCADA) etc.) are also included based on the kilometer parameters of relevant line investments.

Furthermore, if found necessary, costs of small and/or big regulating and measuring stations (RMS) are taken into consideration. The investment period is taken as six years because the general time frame expectation for these expansion investments is six years. It should be emphasized that these CAPEX calculations only includes the investments that is/will be made by the distribution companies. In other words, the investments regarding the transmission lines are not included. So, it can be said that those calculated CAPEX values are less than or equal to the necessary investments to supply these regions with gas. The fact that some of the regions will also need Petroleum Pipeline Company (BOTAŞ) investments that operates transmission lines in order to cope up with increased consumption and length of natural gas transmission. These upstream investments can be of significant quantities that are not reflected in the natural gas sales price of BOTAŞ to the remote regions. Therefore, one can conclude that calculations are favoring natural gas in this aspect.

Each town requires different kilometers of steel, polyethylene, and service line investments due to the difference in distance to the transmission line. The assumed investment realization rates, in other words pipeline investment completion rates of the DSO's in order to feed the city by years is given in Table-6.

Table 6: Investment Realization Rates

Years	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Rates	40%	20%	20%	10%	5%	5%

When calculating the length of the steel pipelines to be built, the distances between the city where the investment will be made and the place where the closest natural gas line is present are taken into consideration.

In order to find the length of polyethylene pipelines that need to be built to feed the city is calculated by the below formula;

$L_t = RR_t * PS_{2037} * \beta$ where;

L_t : Length of polyethylene pipeline that will be built at year t, **RR_t :** Realization rate of investment at year t, **PS_{2037} :** Number of potential customers as of year 2037, **β :** Coefficient factor (length of PE line for each subscriber (meter/subscriber)).

As seen from the formula, the number of potential consumers in the relevant city are taken as of year 2037. It has been regarded so based on the assumption that the investment plans will at least cover the potential customers for 20 years, those customers that DSOs are planning to reach as of 2037. The coefficient factor for polyethylene pipelines shows the length of the line investment for a subscriber. When service lines[2] are considered, the length of service line is calculated by the below formula;

$L_t = RR_t * PS_{2022} * PR * \alpha$ where;

L_t : Length of service line that will be built at year t, **RR_t :** Realization rate of investment at year t, **PS_{2022} :** Number of subscribers planned to be connected as of year 2022, **PR:** Penetration Rate, **α :** Average service line length.

As seen from the formula, the number of subscribers, 60% of potential customers in the relevant city is taken in our base calculations, are taken as of year 2022. Moreover, 50% and %70 of potential customers are also examined as sensitivity calculations as mentioned earlier. So far, natural gas penetration (subscribers / potential customers) in big cities where natural gas use is somewhat mandatory due to city laws could not reach 80% in many cities. Therefore, it is reasonable to consider a 60% penetration ratio in a remote region, if not ambitious. Average service line length is taken as 10.0 metres. When calculating the service line cost, not only the line cost but service box, meter and installation costs are also included in the calculations.

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[2] Service line is defined as the pipeline and service box connecting the distribution network to the subscriber service box or the pressure reducing and metering station.

In addition to line costs, excavation, license and fees, line covering, Geographical Information System (GIS) applications, cathodic protection and other expenses (expropriation, scada etc.) and, if necessary, regulation and measuring stations (RMS) costs are added separately to the CAPEX calculation. While converting 2017 prices into 2019, the formula below is used:

$P_{2019} = P_{2017} * (PPI_{2019}/PPI_{2017})$ where;

P_{2019}: Price at the year 2019, **P_{2017}:** Price at the year 2017, **PPI_{2019}:** Domestic Producer, Price Index at the year 2019, **PPI_{2017} :** Domestic Producer Price Index at the year 2017.

Table 7: Total Natural Gas Distribution Investments

Town	Total Investment (TL – prices as of start of 2017)	Total Investment (TL – mid-2019 prices)
Aydın- I	21,734,555	34,864,975
Aydın- II	17,373,995	27,870,086
Adana - I	58,573,032	93,958,550
Adana- II	14,275,776	22,900,150
İzmir- I	30,106,824	48,295,153
İzmir- II	35,126,000	56,346,546
İzmir -III	58,138,496	93,261,500
Eskişehir-I	29,103,454	46,685,620
Denizli-I	17,517,736	28,100,663
Çanakkale-I	17,720,830	28,426,452
Yozgat-I	31,747,953	50,927,732
Ordu-I	22,800,553	36,574,971
Manisa-I	84,691,560	135,855,972
Erzurum-I	17,321,883	27,786,491
Balıkesir-I	14,685,785	23,557,856
Balıkesir-II	40,842,309	65,516,229
Balıkesir-III	46,081,482	73,920,525
Kayseri-I	16,197,065	25,982,140
Kayseri-II	27,221,785	43,667,185
Trabzon-I	30,160,708	48,381,590
Van-I	54,795,185	87,898,406
Gümüşhane-I	16,005,769	25,675,277

3.1.3 OPEX Calculations

After CAPEX estimations, OPEX values are estimated which includes personnel costs, maintenance, office expenses, legally mandatory expenses, outsourced expenses, etc.

Personnel costs are composed of personnel dealing with investment planning, customer center, emergency response, RMS personnel (if any), maintenance and repair personnel. For each town, it has been assumed that 1 investment personnel, 2 maintenance and repair personnel, 4 RMS personnel (if any RMS), 4 emergency response personnel and 2 customer center personnel will be employed in each year. Moreover, maintenance costs have also been included which depends on the kilometers of the investment to be made. In addition, building, vehicle, and software rental expenses, energy and communication expenses such as office heating, electricity, and water costs, telephone, internet and SCADA expenses, office stationery expenses, legally mandatory costs like taxes, fees, and charges and notary expenses are also included. Moreover, outsourced service expenses such as costs related to metering operations, call center and insurance expenses are also considered. OPEX is calculated for 20 years which is equal to PV's lifetime, and which is also the payback period that is considered in tariff calculations (Table-8).

Table 8: Operational Expenditures for 20 Years

Towns	OPEX (TL) (mid-2019 prices)	Towns	OPEX (TL) (mid-2019 prices)
Aydın- I	26,020,245	Ordu-I	18,262,796
Aydın- II	21,044,882	Manisa-I	42,898,326
Adana - I	28,705,940	Erzurum-I	26,979,402
Adana- II	18,569,210	Balıkesir-I	26,370,893
İzmir- I	22,583,141	Balıkesir-II	26,195,757
İzmir- II	22,691,322	Balıkesir-III	28,921,471
İzmir -III	28,736,485	Kayseri-I	19,084,204
Eskişehir-I	27,109,279	Kayseri-II	20,769,082
Denizli-I	27,516,518	Trabzon-I	22,848,493
Çanakkale-I	27,296,001	Van-I	34,393,986
Yozgat-I	29,374,045	Gümüşhane-I	26,883,954

3.2 Externality of Natural Gas Use in Remote Regions

The concerns over external costs of fossil fuel use in heating should also be inserting pressure against the consumption of natural gas in remote regions. In our study, we did not tread on the externality caused by natural gas infrastructure investments in countrysides and limited our core study on the financial cost benefit analysis of a certain energy generation output from solar energy and natural gas investments. Should the externality costs due to use of natural gas be added on top of the prices of natural gas investment and consumption, it would obviously weigh the scales to the advantage of renewable solar energy generation. Yet in reality of Turkish energy market, the realization of externality costs is always non-existent. Keeping this fact in mind, this study has left out the externality costs intentionally from its core calculations in order to prove the eligibility of solar PVs as a strong and formidable alternative over natural gas to the concerned parties e.g., policy makers, economic shareholders, and even consumers. All in all, this research aims to place the question and suspicion that it would have been better to introduce the remote regions with solar energy generation and relevant renewable systems in the mind of those parties in question.

On the other hand, it is always of paramount value to show the externality costs because they are always overlooked. Although, the most pressing matter in today’s World is the immense cost that our economic activities inflict upon the environment. For this reason, it is better to attempt to include externality aspect of natural gas investments in our calculations.

There is no market present for carbon pricing in Turkey. This leaves us to search for insightful studies to quantify environmental costs that accompanies fossil energy use. Therefore, SHURA report in which the low-end (conservative) estimates of Turkish heating sector external costs have been studied can be refered [33]. This study is unique in directly addressing Turkish heating sector, along with power generation and transport. The total cost based on 2018 figures for buildings is found out to be 1.6 billion Euros/year. Moreover, natural gas share in external costs that are subject to the SHURA study's scope is 11%. Another important overall finding is that the air pollution accounts for the 60% of all externalities, and 40% of which is accounted by carbon dioxide emissions, followed by nitrogen oxides and particulate matters.

In its methodology report, regional natural gas consumption figures, relevant emission factors of gas consumption per Terajoule, and calculated greenhouse gas emission data per 1 ton household gas consumption are as given below [34].

Table 9: Regional Gas Consumption Figures and Relevant Emissions [34]

Residential Gas Use (million Sm3)		**Aegean**	**Black Sea**	**Anatolia Central**	**Anatolia Eastern**	**Marmara**	**Mediterranean**	**South Eastern Anatolia**
		1.048	846	2.485	554	6.560	477	655
Annual GHG Emission (Tons)								
Annual GHG Emission = Gas Use (million Sm3) * Gross Calorific Value (TJ/million Sm3) * Emission Factor (ton/TJ)								
Pollutant / GHGs	**Emission Factor (kg/TJ)**	**Aegean**	**Black Sea**	**Anatolia Central**	**Anatolia Eastern**	**Marmara**	**Mediterranean**	**South Eastern Anatolia**
CH_4	5	181	146	429	96	1.133	82	113
CO	31	1.122	906	2.661	593	7.025	510	702
CO_2	54.300 – 58.300	2.029.985	1.640.178	4.815.178	1.073.747	12.712.117	923.402	1.269.888
N_2O	1.02	37	30	88	19.557	232	17	23
NO_x	57	2.063	1.666	4.892	1.091	12.916	938	1.290
SO_x	0.5	18	15	43	10	113	8	11
NMVOC	10.5	380	307	901	201	2.379	173	238

In their detailed analysis, upon which this SHURA report has been built, emission factors per gas consumption, externality costs of greenhouse gases for Turkey, and regional gas use data are given. With the help of these figures, we can try to estimate the externality that would arise due to gas consumption in the supplied region. In our analysis, we have estimates for natural gas consumption of each region. By incorporating these data within the SHURA's methodology, a sensible and conservative externality measure can be reached. It has to be pointed out that neither in SHURA methodology nor in ours the externality cost that is associated with direct emission of natural gas itself to the air during distribution operation is not included in the study. It is a well-known fact that these direct emissions of natural gas pose great concern for the environment and often overlooked in most studies, because it is hard to determine the level of unburned natural gas in both upstream and downstream operations.

Table 10: Externality Cost (€/ton) of Pollutant [34]

Pollutant	Pollutant External Cost (€ / ton)	Pollutant	Pollutant External Cost (€ / ton)
CH_4	49	**PM**	5.316
CO	367	**PM_{10}**	6.861
CO_2	10	**$PM_{2.5}$**	7.760
N_2O	726	**SO_x**	3.884
NO_x	4.657	**VOC via ozone**	336

Their findings suggest that external costs of pollutant are as shown in Table-10, albeit, their estimates for pollutant costs are rather conservative. Using the emission factors from natural gas use in residential areas (Table-9) and the pollutant external cost we can derive each consumer's annual related emission amounts and their externality in Euros.

In Table-11, it is found out that annual emission externality from natural gas use in the remote towns are ranging between 14 to 28 Euros. It is important to point out that even annual solar radiation is somewhat similar in Adana and Van cities, the excess heating need in Van causes much emission and externality compared to Adana city. Same discrepancy can be observed between cities with middle radiation in our analysis. In coastal cities the need for heating decreases and the total externality decreases due to natural gas use. While in central regions, we see an increase in externality costs from 14 Euros per year coastal externality to 23 Euros (64% increase) central externality.

Table 11: Annual Emission Cost per User in Euros for Each User

In EUROS	CH_4	CO	CO_2	N_2O	NOx	SOx	NMVOC	ANNUAL Externality
Ordu	0.01	0.29	14.37	0.02	6.77	0.05	0.09	22
Trabzon	0.01	0.32	15.61	0.02	7.36	0.05	0.10	23
Balıkesir-I	0.01	0.31	15.23	0.02	7.18	0.05	0.10	23
Balıkesir-II	0.01	0.31	15.23	0.02	7.18	0.05	0.10	23
Balıkesir-III	0.01	0.31	15.23	0.02	7.18	0.05	0.10	23
Çanakkale	0.01	0.27	13.52	0.02	6.37	0.05	0.08	20
Aydın-I	0.00	0.19	9.47	0.01	4.46	0.03	0.06	14
Aydın-II	0.00	0.19	9.47	0.01	4.46	0.03	0.06	14
Eskişehir	0.01	0.27	13.40	0.02	6.32	0.05	0.08	20
Gümüşhane	0.01	0.41	20.34	0.03	9.59	0.07	0.13	31
İzmir-I	0.01	0.26	12.91	0.02	6.08	0.04	0.08	19
İzmir-II	0.01	0.26	12.91	0.02	6.08	0.04	0.08	19
İzmir-III	0.01	0.26	12.91	0.02	6.08	0.04	0.08	19
Manisa	0.01	0.29	14.57	0.02	6.87	0.05	0.09	22
Yozgat	0.01	0.28	13.95	0.02	6.58	0.05	0.09	21
Kayseri-I	0.01	0.31	15.35	0.02	7.24	0.05	0.10	23
Kayseri-II	0.01	0.31	15.35	0.02	7.24	0.05	0.10	23
Erzurum	0.01	0.30	14.93	0.02	7.04	0.05	0.09	22
Denizli	0.01	0.27	13.47	0.02	6.35	0.05	0.08	20
Adana-I	0.00	0.23	11.15	0.01	5.26	0.04	0.07	17
Adana-II	0.00	0.23	11.15	0.01	5.26	0.04	0.07	17
Van	0.01	0.38	18.56	0.02	8.75	0.06	0.12	28

3.3 PV Investment Calculations

In order to find residential PV investment costs, first, average subscriber consumption, in terms of kWh, is found by converting the average natural gas consumption per consumer that is used in natural gas calculations. The following formula is used for this conversion:

$ACC_{kwh} = ACC_{m3} * 10.64 * E_c$ where ACC is Average Consumer Consumption[3] and Ec is Efficiency of combi boiler which is taken as 0.8.

On the other hand, electricity produced by a solar panel (kWh/year) differs from region to region due to the difference in solar irradiation. For example, in Çanakkale, it is 7,231 kWh/year, in Adana 8,664 kWh/year for a 5 kWp capacity of solar panel [30]. Therefore, to calculate required installed capacity per consumer corresponding to the energy level that is acquired with natural gas consumption, it is essential to determine the amount of electricity produced in each region.

In Table-12, electricity produced by a 5 kWp solar panel is given. By using the data available from Table-12, required installed capacity per consumer has been calculated by dividing average consumer energy need of each township to the electricity generation from 1 kWp solar panel in each township.

Table 12: Electricity Produced by 5 kWp Panels in Relevant Regions [30]

	City	El. produced by 5 kWp panel (kWh/year)	Electricity Produced (kWh/kWp-year)
Northern	Artvin	6,455.0	1,291.0
	Istanbul	6,760.0	1,352.0
	Canakkale	7,231.0	1,446.2
Center	Eskisehir	7,559.0	1,511.8
	Yozgat	8,048.0	1,609.6
	Denizli	8,313.0	1,662.6
Southern	Van	8,511.0	1,702.2
	Adana	8,664.0	1,732.8
	Antalya	8,881.0	1,776.2

For initial investment cost of solar panels, Duman et. al. done calculations by using National Renewable Energy Laboratory’s (NREL) recently released product HOMER Grid software results. In the model, the polycrystalline PV modules cost have been estimated. NREL’s assumptions are adopted into Turkish conditions considering much lower labor costs. Finally, HOMER Grid simulation results of 5

[3] The average natural gas consumption per consumer has been taken as the consumption in 2016.

kWp rooftop systems are estimated and the initial capital cost of 5 kWp rooftop PV system with 4 kWp inverter is estimated as $6,350 [30]. It is well known that these costs have plummeted by the time of this analysis and by the time that these townships have gasified with natural gas. Whereas it is our duty to take the costs as is at the time of relevant natural gas investment decisions were made. In retrospect, the solar investment was the more valuable decision rather than introducing natural gas to remote regions where fuel switch is more likely to occur any given time due to price shocks and dire economic conditions. Another important point is that penetration of natural gas in remote areas are deemed to be low keeping in mind that penetration in cities like Konya or Antalya was very low even in first 7 years of natural gas supply.

In Sindh Solar Energy Project for Pakistan done by The World Bank, OPEX is assumed as 2% of CAPEX [35] while in IRENA Global Atlas Spatial planning techniques seminar, project annual OPEX is assumed as 1.5% of CAPEX in worked example of Grid-tied PV in Tanzania and [36]. In this study, solar panel operational expenditures are assumed as $127 per annum, which is 2% of capital cost in each year and is added into calculations for 20 years matching the time frame of natural gas calculations. Since full-scale investment of solar PV generation in remote regions will reasonably drive the prices down and increase the technical capacity of Turkey in this field, 10% discount is taken into consideration. Related calculations are given in Table-13. Residential rooftop solar PV cost is found by multiplying total cost with the necessary installed capacity. The average USD rate in 2019 is taken as 5.67 TL [37].

Table 13: CAPEX and OPEX Structure of Solar Panels

Cost $/kWp (CAPEX)	1,143.00
OPEX ($/kWp) (2% of CAPEX)	457.20
TOTAL ($/kWp)	1,600.20
$/TL	5.67
Cost (TL/kWp)	6480.81

One can argue that since many townships will have solar panel investments, the capital expenditure for solar panels and operational expenditures for sustaining solar panels would be much lower than assumed in our study. We can claim that, yet again, our study is biased towards natural gas use in cost estimation for solar panels.

CHAPTER 4

RESULTS AND DISCUSSION

In this chapter, the results and outcomes of the calculations given in Chapter 3 will be discussed. Thus, the answer to which investment (solar PV or natural gas) is reasonable for the natural gas district expansions will be investigated.

4.1 Outcomes and Results

The results of solar PV and natural gas investment costs are given in Figure-8 for customer penetration rate of 60%. Blue bars represent townships in the northern part of the country, while the yellow ones are in center regions and orange ones are in southern part.

According to these results, there is no distinctive outcome for either of the three (northern, center, and southern) regions of Turkey. In other words, it is not clear and obvious to conclude that solar PV investments are more feasible than natural gas investments in one region when compared to other, eg, northern to southern. This may be due to the difference in number of potential consumers. If the number of potential consumers is low, investment in that region becomes more unreasonable. Another reason of this may be the investments that has already been carried out by either distribution companies or BOTAŞ in the region which decreases the investment amount to be made by DSOs. One has to be reminded of the fact that our analysis does not cover the transmission level investments that was or will be carried out by the BOTAŞ in order to supply selected provinces with natural gas. Furthermore, our analysis does not take into account the natural gas price subsidization for the residential sector which favors the natural gas use in this analysis. Not limited to this fact, our analysis does not incorporate the governmental subsidy for solar PV investments. If these subsidies were to be included, it is obvious that solar PV will surpass natural gas in feasibility.

At 2019 level PV costs, in Ordu, Balıkesir-I, Aydın-I, Eskişehir and Adana-II's selected provinces, PV investments are more feasible than natural gas investments. In Aydın-II, Kayseri-I, Erzurum and Denizli, PV investments are on equal terms with natural gas investments.

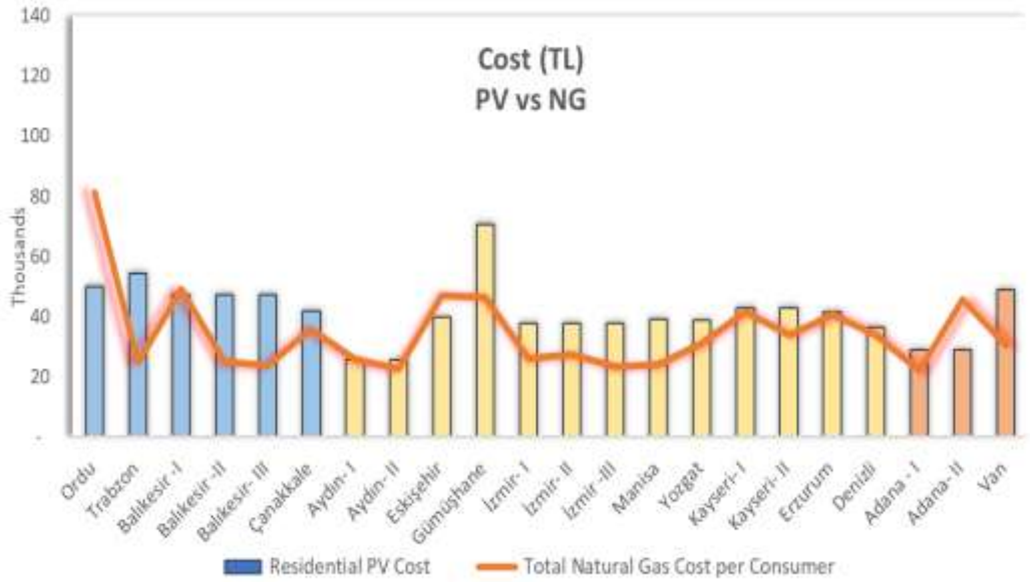

Figure 8: Solar PV and Natural Gas Total Costs

There is also disparity between towns of the same city. While PV investments seem more reasonable in Balıkesir-I, natural gas investment has made more sense in Balıkesir II and Balıkesir III, although, both are being exposed to the same solar radiation which is worth to analyze (Figure-9). These differences in natural gas costs could be attained to the stark difference between CAPEX investment requirements and penetrated subscriber amounts in those townships.

Although, total natural gas expenditure in the second and third town of Balıkesir is two times greater than the first, the customer base is more than six times greater. This causes natural gas to be feasible in the second and third towns, while makes PV investments reasonable in the first town for.

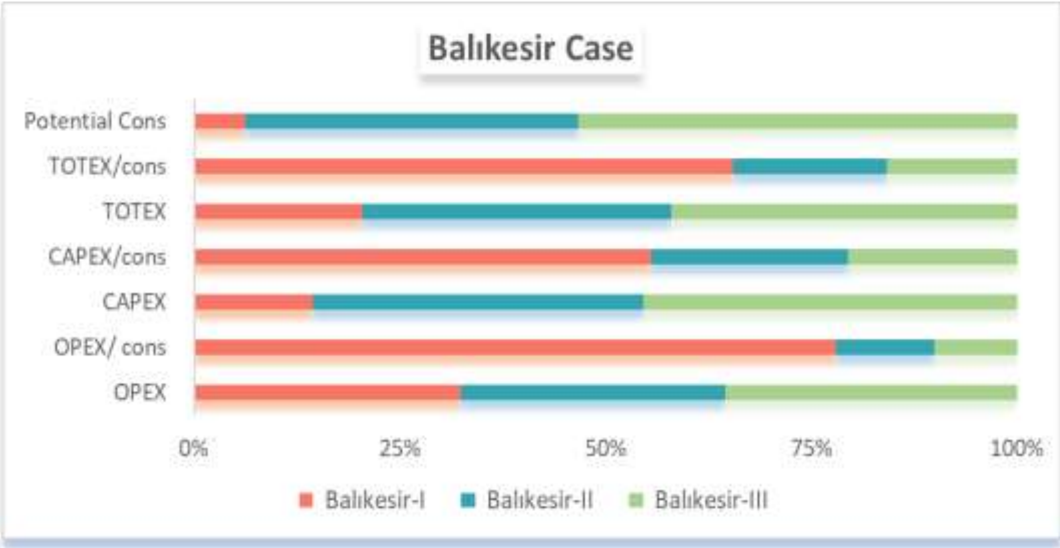

Figure 9: Comparison of Townships of Same Cities (Balıkesir Case)

These stark differences lead us to realize that for a profitable and feasible plan of natural gas infrastructure investments in provinces, regulatory authorities and distribution companies should choose to invest in crowded towns with high number of potential customers and look for other renewable solutions for towns that are scarcely resided.

4.2 Sensitivity Analysis

It is obvious that the initial investment cost of solar PV is decreasing day by day. So, it is considered that it would be beneficial to perform an additional analysis based on this expected fall in PV prices. With an assumption of a 20% decrease in solar PV costs from 2019 levels, PV investment is feasible in Ordu, Balıkesir -I, Çanakkale, Aydın- I, Aydın- II, Eskişehir, Yozgat, Kayseri- I, Erzurum, Denizli and Adana- II. With this cost reduction in PVs, İzmir II, Kayseri II and Adana I equals the solar energy investments to natural gas investment cost (Figure-10).

Since solar prices have come down dramatically in recent years [9], a sensitivity analysis has also done in order to find at which point PV investments are preferable over natural gas. This shows how much should the price of photovoltaics decrease, in order to allow for each township to adopt solar PV generation (Figure-11).

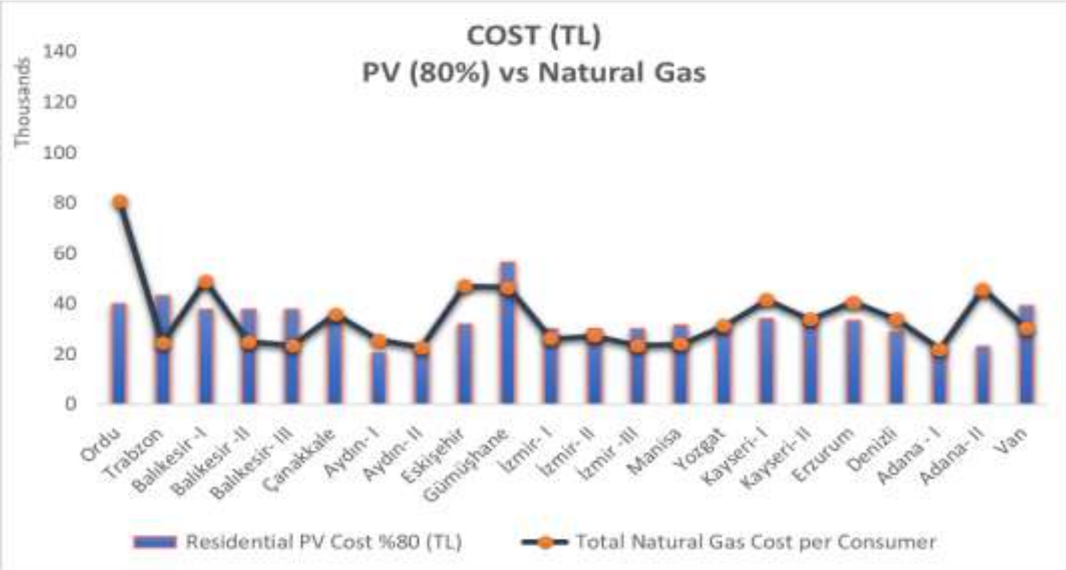

Figure 10: Natural Gas Total Costs and Solar PV Costs with 20% Reduction

In Erzurum and Kayseri I up to 3% decrease in costs is enough to make PV more feasible. If there is a 20% reduction in the solar installation costs, PV investment makes more sense in Denizli, Aydın- II, Çanakkale and Yozgat, a 35% reduction in PV investment will make Kayseri II, Adana I, İzmir- II, İzmir I and Gümüşhane feasible in terms of PV investment.

Figure 11: PV Cost Sensitivity Analysis

It should be emphasized that these calculations given above has been done with an assumption 60% customer penetration rate. So far, natural gas penetration (subscribers / potential customers) in big cities where natural gas use is somewhat mandatory due to city laws could not reach 80% in many cities. Therefore, it is reasonable to consider a 60% penetration ratio in a remote region, if not ambitious. On the other hand, since this penetration rate influence directly the result of these calculations, 50% and 70% penetration rates has also examined as sensitivity analysis (Figure-12).

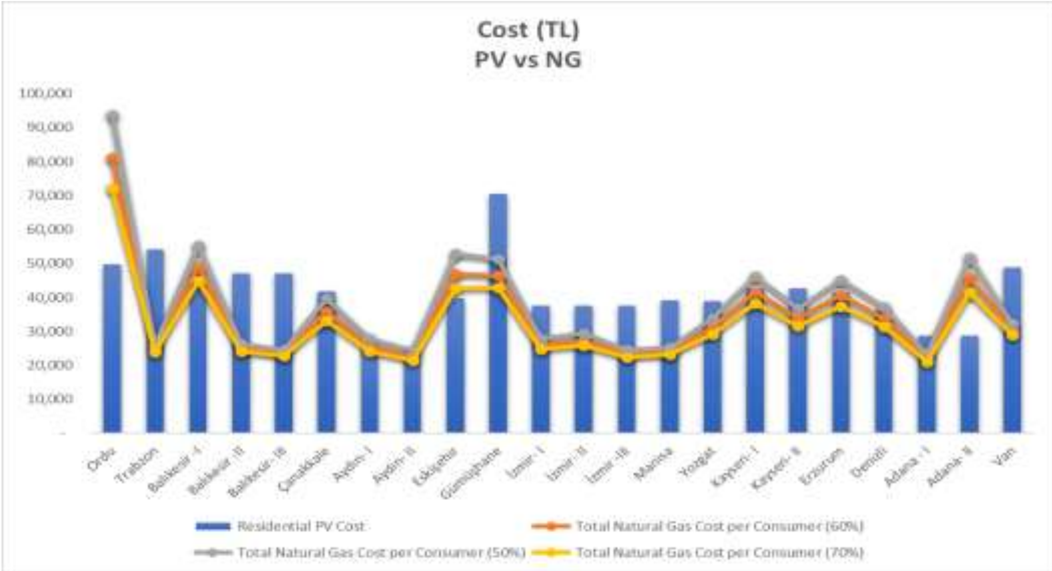

Figure 12: Effect of Subscriber Penetration Rate

As seen from the figure above, PV investment is still more feasible in Ordu, Eskişehir and Adana-II regardless of the penetration rate. On the other hand, in Balıkesir I, and Aydın I, 70% penetration rate makes natural gas investments become more feasible. However, if the investing company can only reach 50% of the potential subscribers, then PV investments in Kayseri I, Denizli and Erzurum will make more sense.

Moreover, two types of break-even analyses have been made for each region; first, required decrease in PV cost figures for break-even for 60% penetration rate and second, the required subscription rate (Table-14).

Table 14: Break-even Points for PV Cost and Subscription Rate

Districts	PV cost reduction for break-even (at the subscription rate of 60%)	Subscription rate for break-even
Ordu	-	Not Possible
Trabzon	48.9%	10.8%
Balıkesir -I	-	71.5%
Balıkesir -II	40.9%	14.9%
Balıkesir- III	44.0%	11.6%
Çanakkale	8.1%	50.7%
Aydın- I	-	73.0%
Aydın- II	4.1%	53.1%
Eskişehir	-	89.7%
Gümüşhane	28.8%	32.6%
İzmir- I	24.3%	29.9%
İzmir- II	21.0%	33.9%
İzmir -III	31.5%	21.0%
Manisa	31.9%	19.1%
Yozgat	12.8%	43.8%
Kayseri- I	-	65.0%
Kayseri- II	14.2%	42.8%
Erzurum	-	65.7%
Denizli	-	60.4%
Adana - I	16.5%	34.0%
Adana- II	-	Not Possible
Van	30.7%	23.2%

The point that is important to emphasize in this table is that, unlike our previous sensitivity analysis, calculations were made in this table by taking into account the extra cost of externality which is explained below. As seen from the table, at 60% subscription penetration rate, up to 30% reduction in PV cost Çanakkale, Aydın-II, Gümüşhane, İzmir I and II, Yozgat, Kayseri II, Adana-I and Van districts become more feasible for PV investments in addition to the provinces that are currently more feasible for PV investments. On the other hand, the subscriber penetration rate required for natural gas and PV investments to be at par is also given in that Table. For example, in Eskişehir's district if the DSO can reach almost 90% penetration rate, then natural gas investments will make sense. While in Trabzon's district if the DSO can only achieves less than 10.8% penetration rate, then PV will only make sense.

4.3 Externality Estimation

Emissions externality cost due to natural gas combustion in these selected provinces are calculated by using the emission factors and emission costs determined in the SHURA report. The emission externality costs in that report were very conservative estimates, and it is seen that these emission figures do not have much effect on the total cost of natural gas use. All in all, total externality costs over 20 years add 4-12% to the total gas investment cots, averaging 9% for all municipalities in question. While this difference seems not much, it gives solar PV costs an advantage over natural gas so that it is now more competitive in the comparisons, making PV more desirable in few regions that needed this push as we have realized in Aydın II, Kayseri I, Erzurum and Denizli.

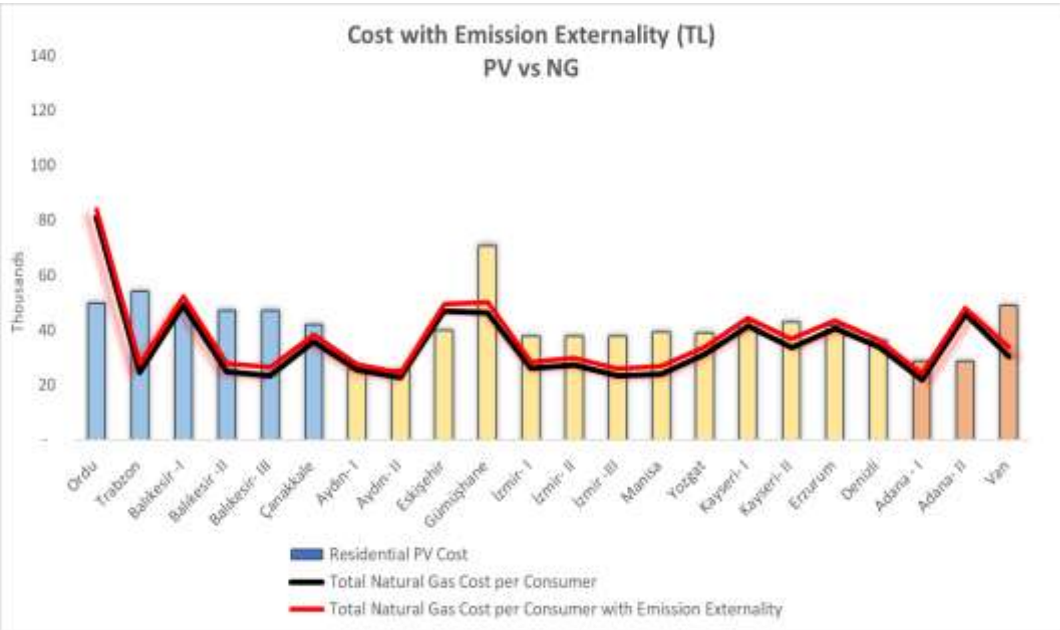

Figure 13: Effect of Externality Cost of Natural Gas Use on Total Expenditures

Externality calculations show that rather conservative externalities can have big effect on decision making processes favoring renewable energies more.

4.4 Limitations of the Study

It is obvious that certain limitations to our study were present throughout our research. While we tried to minimize and account for those, however, they are still affecting to an extent. On the other hand, it should be stated that these limitations do not change the apparent conclusions that we have derived. The need for incorporating sustainable and renewable solutions to any regulated sector by the regulatory bodies is of paramount value. A simple cost benefit analysis of all possible energy alternatives can be easily accomplished, and regulators can lead energy companies to follow up on the tracks of sustainability aiming for the higher benefit of society, state, environment, and the World.

As for limitations, we have lacked to pin down real capital and operational expenditures to run the natural gas distribution system in these selected provinces. The author has expertise in valuation of natural gas investments and operational costs, yet real data from the field would have been beneficial in pinpointing the true cost structure for each township.

Another important limitation was to estimate the subscriber penetration in each town. There is no reliable research on the willingness of residents in these selected regions to switch to the natural gas use. Wood burning, coal and fuel-oil use are strong alternatives in these regions which are both customary and price competitive. While they are dirtier than natural gas use, remote regions, on contrary to city dwellers, are not much affected by decrease in air quality due to coal and fuel-oil use. Furthermore, natural gas use requires high initial investment that would bring about a big burden for an impoverished remote area. We also do not know if natural gas acceptance would be affected by the conservative and nostalgic mindset of remote regions who would want to carry on the old ways of their ancestors and would prefer to sit beside a coal and wood burning stove and have their meals cooked and teas brewed on top of that very same stove.

Author also accepts that merely comparing the solar PV investment requirement for a certain level of gas consumption would not totally account for the heating needs of the households. Use of electricity as a reasonable heating source may require excess electricity provision from electricity lines which will mostly be generated by generation plants other than solar. Therefore, it is obvious that any functioning solar PV solution would require integration to electricity distribution and transmission networks. The outcome of this need is not incorporated within the calculations.

CHAPTER 5

CONCLUSION

It is inevitable that the use of natural gas, which has gained popularity in Turkey since the 1980s, will be replaced by renewable energy with the approach of energy transition, due to the rapidly decreasing reserves and climate change concerns. Although it is a very clean energy source compared to coal use, the fact that domestic production is almost negligible compared to consumption necessitates natural gas imports which cause a noteworthy problem: budget deficit. In the face of all these negativities, Turkey's strategy of delivering natural gas to even the most remote corners bring to mind a simple question: Is there another way?

In this thesis, while investigating the answer to this question, it was focused on electrical energy, and an answer was sought to the question of what would happen if solar energy was used instead of natural gas investments to be made in districts since solar potential in Turkey is relatively high due to its geographic location.

Considering that the structure of the natural gas market in Turkey should be explained thoroughly in order to reach a reasonable conclusion; First of all, the share of domestic production in consumption was researched and it was seen that its share in the total supply was only 0.91% which is the most prominent indicator of natural gas dependency of Turkey to the foreign countries. Second, the tariff structure was tried to be explained in order to show that each investment should bring enough consumption to be feasible and distribution companies should be compelled to invest in regions where consumption gains are enough to account for the increase in revenue requirement base.

After examining both Turkey's natural gas market structure and the current situation in solar energy, an economic analysis was conducted to find an answer to the question of what would happen if solar energy was used instead of natural gas investment in small towns. For individual households, the answer to this question is not difficult since they simply compare the cost of both options based on the cost and efficiency figures of the alternative options as well as their current energy demand. While the general attitude when doing this type of feasibility analysis is to focus on the solar potential of the area, the cost of traditional alternatives is often based on a simple aggregation of cost items. However, this study reveals the complex nature of natural gas investment cost calculations with an assumed reference company model for 22 districts within the scope of Turkey's natural gas expansion plan. Those districts were selected, in the north, south and center since they have different solar irradiation, It is explicitly shown that natural gas investments consist of a large number of components such as steel pipes, polyethylene pipes, service lines, personnel, maintenance, office expenses, renting costs, fees, insurance, etc. In other words, both OPEX and CAPEX calculations were made by estimating the potential subscriber numbers for the districts in question. To summarize the content of the economic analysis done in this study, first, the total costs of rooftop PVs are calculated for an average household based on the average energy demand and solar potential in the region. Next, the total costs of being a natural gas subscriber are determined using the detailed cost components particular to the region under a subscription level of 60%. Moreover, a sensitivity analysis is conducted over different subscription levels. On top of these, two types of break-even analyses have been made for each region, i.e., 1) required decrease in PV cost figures for break-even, 2) required subscription rate for break-even.

Since, the average consumption in the region, the number of existing subscribers and the number of new subscribers directly affect the average cost, the usual expectation that the higher the solar radiation potential, the higher the feasibility of PV modules will be, depending on the levels of the above-mentioned indicators, will not be met. That’s why the result of the analysis show that there is no distinctive outcome for either of the three (northern, center, and southern) regions of Turkey which may be due to the low number of potential consumers. To put it more clearly, if the number of potential consumers is low, investment in that region becomes more unreasonable.

As a result of these similar results in cost comparison of PV and natural gas investments, the policy decisions to invest in natural gas for remote regions should always include a detailed analysis. This also shows that contrary to the past experiences and convictions that natural gas was believed to be environmentally friendly and redeemed as increasing social welfare a lot, policy makers now have more responsibility and pressure to carry out cost benefit analysis and should be inclined to opt for renewable alternatives over natural gas.

It should be included that the investments that has already been carried out by either distribution companies or BOTAŞ in the region which decreases the investment amount to be made by DSOs would be another reason.

The results of our study show that at 2019 level PV costs, Ordu, Balıkesir-I, Aydın-I, Eskişehir and Adana-II's selected areas, PV investments are more feasible than natural gas investments. In Aydın-II, Kayseri-I, Erzurum and Denizli, PV investments are on equal terms with natural gas investments. Another important result was that two different districts of the same city gave different results despite being exposed to the same solar radiation. In Balıkesir-I, PV investments seem reasonable, in Balıkesir II and Balıkesir III natural gas investment is more feasible which is due to the inconsistency between the CAPEX investment requirements and the subscriber volumes penetrated. To explain in more detail, although total natural gas expenditure in the second and third town of Balıkesir is two times greater than the Balıkesir I, the customer base is more than six times greater which causes PV investments reasonable in the first town while natural gas in the second and third towns. This result clearly reveals the necessity of making natural gas investments only in provinces where consumption, in other words number of potential subscribers, will be high. In order to show the effect of the consumption, sensitivity analysis was performed for 50% and 70% potential subscriber rates in addition to 60% subscriber penetration rate. The results put forth that PV investment is still more feasible in Ordu, Eskişehir and Adana-II regardless of the penetration rate. However, in Balıkesir I, and Aydın I, 70% penetration rate makes natural gas investments become more feasible. On the other hand, if the investing company can only reach 50% of the potential subscribers, then PV investments in Kayseri I, Denizli and Erzurum will make more sense.

Moreover, another sensitivity analysis has been done due to the tendency of PV initial investment costs to decrease day by day. According to the results of the sensitivity analysis study, which also included the externality, at 60% subscription penetration rate, up to 30% reduction in PV cost Çanakkale, Aydın-II, Gümüşhane, İzmir I and II, Yozgat, Kayseri II, Adana-I and Van districts become more feasible for PV investments in addition to the provinces that are currently more feasible for PV investments. On the other hand, the subscriber penetration rate required for natural gas and PV investments to be at par is also examined. As an example, in Eskişehir's district if the DSO can reach almost 90% penetration rate, then natural gas investments will make sense. While in Trabzon's district, if the DSO can only achieves less than 10.8% penetration rate, then PV will only make sense.

It is obvious that more detailed research has to be done in order to show the true costs and benefits of this comparison. Nevertheless, this research is covering a lot of aspects of it. Some more factors to include could be: (1) the foremost one is about natural gas investment calculations that could be revised such that required BOTAS investment costs are included, (2) country specific subsidies are not included in this study, PV solar has many subsidies in place, (3) intermittency, supply security and detailed environmental risks can be included for a different set of analyses on this subject.

To emphasize more, BOTAŞ investments may drastically change the equation in favor of PVs. Secondly, since this analysis is done with an economics perspective, it does not include PV subsidies and cross subsidy of natural gas investments between existing natural gas customers and newcomers. This also requires a different analysis which could be very interesting to conduct.

Third, in Turkish natural gas market, fuel price is not totally directed to households, on the contrary subsidized by electricity generators. Whereas the natural gas prices that are reflected to households are used in this calculation. The subsidy in natural gas is another risk and a problem for the analysis. Another aspect of it could be incorporating electricity prices as solar PVs excess generation could have been sold to the electricity market. Furthermore, seasonal and daily time differences between natural gas consumption need and solar energy generation could be evaluated more. Another important fact to conduct a research on is the security of supply issue and the total affect in current account deficit of natural gas use. While we have tried to include a small and limited emission externality cost analysis, the true effect on environment could be taken into consideration for further studies.

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APPENDICES

A. Population Estimation on the Selected Provinces of Expansion

Towns	2012	2013	2014	2015	2016
Aydın- I	20,250	20,351	20,453	20,555	20,658
Aydın- II	20,597	20,700	20,803	20,908	21,012
Adana - I	78,587	78,980	79,375	79,772	80,171
Adana- II	7,504	7,542	7,579	7,617	7,655
İzmir- I	27,849	27,988	28,128	28,269	28,410
İzmir- II	28,213	28,354	28,496	28,638	28,782
İzmir -III	61,406	61,713	62,022	62,332	62,643
Eskişehir-I	9,820	9,869	9,918	9,968	10,018
Denizli-I	13,746	13,815	13,884	13,953	14,023
Çanakkale-I	10,863	10,917	10,972	11,027	11,082
Yozgat-I	24,956	25,081	25,206	25,332	25,459
Ordu-I	4,052	4,072	4,093	4,113	4,134
Manisa-I	98,618	99,111	99,607	100,105	100,605
Erzurum-I	13,604	13,672	13,740	13,809	13,878
Balıkesir-I	6,487	6,519	6,552	6,585	6,618
Balıkesir-II	41,918	42,128	42,338	42,550	42,763
Balıkesir-III	55,255	55,531	55,809	56,088	56,368
Kayseri-I	9,702	9,751	9,799	9,848	9,898
Kayseri-II	19,791	19,890	19,989	20,089	20,190
Trabzon-I	40,589	40,792	40,996	41,201	41,407
Van-I	81,212	81,618	82,026	82,436	82,848
Gümüşhane-I	10,472	10,524	10,577	10,630	10,683

B. Subscriber Estimation

	Years								
Provinces	2008	2009	2010	2011	2012	2013	2014	2015	2016
Adana	4.2	4.2	4.1	4.1	4.0	3.9	3.9	3.8	3.8
Aydın	3.3	3.3	3.2	3.2	3.1	3.1	3.0	3.0	3.0
Balıkesir	3.1	3.1	3.0	2.9	2.9	2.9	2.8	2.8	2.8
Çanakkale	2.9	2.9	2.8	2.8	2.8	2.7	2.7	2.7	2.7
Denizli	3.4	3.4	3.3	3.2	3.2	3.1	3.1	3.1	3.1
Erzurum	5.0	4.9	4.8	4.7	4.6	4.4	4.2	4.1	4.0
Eskişehir	3.2	3.2	3.0	3.0	2.9	2.8	2.8	2.8	2.8
Gümüşhane	4.0	3.9	3.7	3.6	3.4	3.4	3.2	3.2	3.5
İzmir	3.4	3.4	3.3	3.2	3.2	3.1	3.1	3.1	3.0
Kayseri	4.2	4.1	3.9	3.9	3.8	3.7	3.6	3.6	3.5
Manisa	3.5	3.4	3.4	3.3	3.3	3.2	3.2	3.2	3.2
Ordu	3.9	3.8	3.7	3.6	3.4	3.3	3.2	3.2	3.1
Trabzon	3.9	3.9	3.7	3.6	3.5	3.4	3.4	3.3	3.3
Van	6.9	7.1	7.0	6.7	6.4	6.0	5.8	5.5	5.3
Yozgat	4.2	4.1	4.0	3.8	3.7	3.6	3.4	3.3	3.3

Average size of households by provinces. 2008-2016