TECHNICAL POTENTIAL OF ROOFTOP SOLAR PHOTOVOLTAIC FOR ANKARA: A PRELIMINARY STUDY

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ELİF CEREN KUTLU

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TECHNICAL POTENTIAL OF ROOFTOP SOLAR PHOTOVOLTAIC FOR ANKARA: A PRELIMINARY STUDY

submitted by **ELİF CEREN KUTLU** in partial fulfillment of the requirements for the degree of **Master of Science** i**n Earth System Science, Middle East Technical University** by,

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, **Physics, METU** ____________

Prof. Dr. Uğur Soytaş
Co-Supervisor, **Business Administration, METU** ____________

Examining Committee Members:

Prof. Dr. Ramazan Sarı
Business Administration, METU ____________

Prof. Dr. Bülent Gültekin Akınoğlu
Physics, METU ____________

Asst. Prof. Dr. Talat Özden
Electrical Engineering Gümüşhane University ____________

Date: 21.09.2020

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 : Elif Ceren, Kutlu

Signature :

ABSTRACT

TECHNICAL POTENTIAL OF ROOFTOP SOLAR PHOTOVOLTAIC FOR ANKARA: A PRELIMINARY STUDY

Kutlu, Elif Ceren
Master of Science, Earth System Science
Supervisor: Prof. Dr. Bülent Gültekin Akınoğlu
Co-Supervisor: Prof. Dr. Uğur Soytaş

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Cities are responsible for over two-thirds of total energy consumption due to the population's externalities. The buildings in the urban areas cause half of this energy consumption. 250 cities have 100% renewable energy target worldwide, including nineteen metropolitans such as London, Los Angeles, Tokyo, and Paris. Besides, these metropolitans aim at zero emissions in new buildings by 2030 and in the existing ones by 2050. By year of 2018, as a developing country, Turkey has a dependency ratio of 73.8 % for overall energy and 51.11% for electricity. In order to overcome problems like population-based pressure in cities and energy security, Turkey requires effective and realistic renewable energy solutions that can combat climate change. As policymakers emphasize, more decentralized solutions as city-wide and municipality-based policies, would provide faster and more effective results to reach renewable energy targets. The renewable energy potential is not the same for all cities. Although there are some rooftop technical solar PV potential studies in country-wide, one of the main motivations of this study is to focus on both building types and roof types to generalize for a city. We develop an accurate methodology to determine the rooftop technical PV potential reliable and applicable to every type of roofs. City of Ankara is a convenient starting point for this study due to its relatively high solar irradiance, high number of public buildings and increasing energy demand. In the study, buildings in Ankara divided into three categories: residential, public, and commercial (shopping mall). After the manual selection, the methodology is applied using a well-known Helioscope software program and suitable area constants (access factors) are determined for the three categories. Constant value method was used to generalize the constants to all buildings. The results indicate that the Mono-Si module application is the optimum one for both pitched-roof and flat-roof apartments. Bifacial modules have better results for detached houses, public buildings, and shopping malls, and the amount of energy production might be increased by row-spacing arrangement specifically to the building.

Keywords: Rooftop PV, solar energy, solar potential, building solar potential, bifacial

ÖZ

ANKARA ÇATI ÜSTÜ GÜNEŞ TEKNİK FOTOVOLTAİK POTANSİYELİ: ÖN ÇALIŞMA

Kutlu, Elif Ceren
Yüksek Lisans, Yer Sistem Bilimleri
Tez Yöneticisi: Prof. Dr. Bülent Gültekin Akınoğlu
Ortak Tez Yöneticisi: Prof. Dr. Uğur Soytaş

Eylül 2020, 145 sayfa

Şehirler, nüfus kaynaklı toplam enerji tüketiminin üçte ikisinden sorumludur. Şehir merkezlerindeki binalar ise bu enerji tüketiminin yarısını oluşturur. Dünya genelinde, Londra, Los Angeles, Tokyo ve Paris gibi on dokuz metropoliten şehrin de içinde bulunduğu iki yüz elliden fazla şehir %100 yenilenebilir enerji hedefi koymuştur. Bu metropoliten şehirler, 2030 itibariyle yeni binalar için, 2050 itibariyle de var olan binalar için 0 emisyon hedefi koymuştur. 2018 yılı itibariyle, gelişmekte olan ülkelerden olan Türkiye, toplam enerjide %73.8, elektrikte ise %51.11 dışa bağımlıdır. Hem şehirlerdeki nüfus artışının yarattığı enerji baskısının hem de enerji arz ve güvenliğinin üstesinden gelebilmek için Türkiye iklim değişikliğiyle mücadele ederek etkili ve gerçekçi yenilenebilir enerji çözümleri geliştirmelidir. Politikacıların da vurguladığı gibi, şehir ve belediye bazlı politikalar yenilenebilir enerji hedeflerine ulaşmada lokal yapılaşmaları sayesinde daha hızlı ve etkili çözümler sağlamaktadır. Her şehrin yenilebilir enerjisi potansiyeli eşit değildir. Bu çalışmanın en önemli motivasyonlarından biri çatı üstü güneş fotovoltaik teknik potansiyeli için Türkiye geneli çalışmalar olsa da bina ve çatı tiplerine göre genellemeye odaklanan şehir bazlı bir çalışma yapılmamıştır. Bu çalışmada çatı üstü

teknik PV potansiyelinin belirlenebilmesi için her çatı tipine uygulanabilir ve güvenilir bir metot geliştirilmiştir. Güneş ışınımının Türkiye ortalamasından yüksek olması, başkent olması nedeniyle yüksek oranda kamu binası bulundurması ve artan enerji ihtiyacını gidermek için doğal motivasyonunun olması Ankara'yı başlangıç için uygun bir şehir kılmaktadır. Bu çalışmada Ankara'daki binalar konut, kamu ve ticari binalar (alışveriş merkezleri) olarak üçe ayrılmıştır. Seçilen binalara manuel örnekleme metoduyla Helioscope programı uygulanmış olup, elde edilen FV modül uygulanabilir alan oranı (erişim katsayıları) sabit değer metoduyla diğer binalar için genellenmiştir. Sonuçlar hem eğik çatılı hem düz çatılı apartmanlar için Monokristal panellerin daha verimli olduğunu göstermiştir. Öte yandan, müstakil binalar, kamu binaları ve alışveriş merkezleri için ise çift taraflı paneller daha iyi sonuç vermiştir. Aynı zamanda, paneller arası boşluk hesaplarının o binaya özel olarak ayarlanmasının, üretilen enerji miktarını yüksek oranda artırabildiği gözlemlenmiştir.

Anahtar Kelimeler: Çatı üstü FV, güneş enerjisi, güneş enerjisi potansiyeli, bina güneş potansiyeli, çift taraflı panel

To all who are fair to nature

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CHAPTER 1

INTRODUCTION

Cities are responsible for over two-thirds of total energy consumption due to the population's externalities. Furthermore, it is stated that the buildings in urban areas cause half of this energy consumption (Couture et al., 2019). Worldwide, 250 cities, which nineteen of them metropolitans, including London, Los Angeles, Tokyo, and Paris have 100% renewable energy target. Besides, these metropolitans aim at zero emissions in new buildings by 2030 and, for the existing ones by 2050 (Scott, 2018). As a developing country, Turkey is a net fossil fuel-dependent country. By year of 2018, Turkey imported its 73.8 % of the overall energy (Eurostat, 2020) and 51.11% of its electrical energy (TEIAS, 2019).

Moreover, as the rate of urbanization is above the world average, the energy pressure in the cities is increasing. Fossil fuel dependency, high urbanization rates, and their externalities push Turkey to make sustainable solutions. To overcome problems such as population-based pressure in cities, energy security and climate change, Turkey requires effective and realistic renewable energy solutions to combat also global warming. As policymakers emphasize, city-wide, municipality-based policies that refer to more decentralized solutions provide faster and more effective results to reach renewable energy targets. The renewable energy potential is not the same for all cities; Turkey needs to shift the decentralized solution to supply the increasing electricity demand in urbanized areas. As the capital of Turkey, Ankara receives considerable solar energy, in this study, the rooftop PV Potential of Ankara is calculated as divided into three types of buildings: residential, public, and commercial (shopping mall).

1.1 Background of the Study

As the end of 2018, Turkey's electricity production was sourced 20.67 % by imported coal, 30.34% natural gas, 14.79% lignite, 0.11 % fuel oil, 1.70 % coal and asphaltite, 13.44 % hydro with a dam, 6.54% wind, 6.22% lake and river, 2.56% solar, 2.44 % geothermal, 1.19 % renewable waste and total electricity production was 304801.9 GWh. In terms of renewable energy, hydro with dams was leading with 41.90 % and followed by 20.40% wind, 19.39% lake and river, 7.98% solar, 7.60% geothermal, and 2.73 % renewable waste (TEIAS, 2019). In 2000, the part of fossil fuels in gross available energy was 80.6% for EU-28 countries and 86.6% for Turkey; in 2018, the part of the amount decreased to 72.4% in EU-28 countries; however, it increased to 87.2 % for Turkey, respectively. Moreover, although Turkey had a better part of the amount of renewable energy with 24.9 % while EU-28 countries had 13.9% in 2000, Turkey increased to 32.2 % in 18 years, whereas EU-28 countries reached to 32.4% (Eurostat, 2020). Turkey has huge geological and technical potential of solar energy compared with other European Countries. This advantage is now used to install photovoltaic (PV) power plants in the last few years.

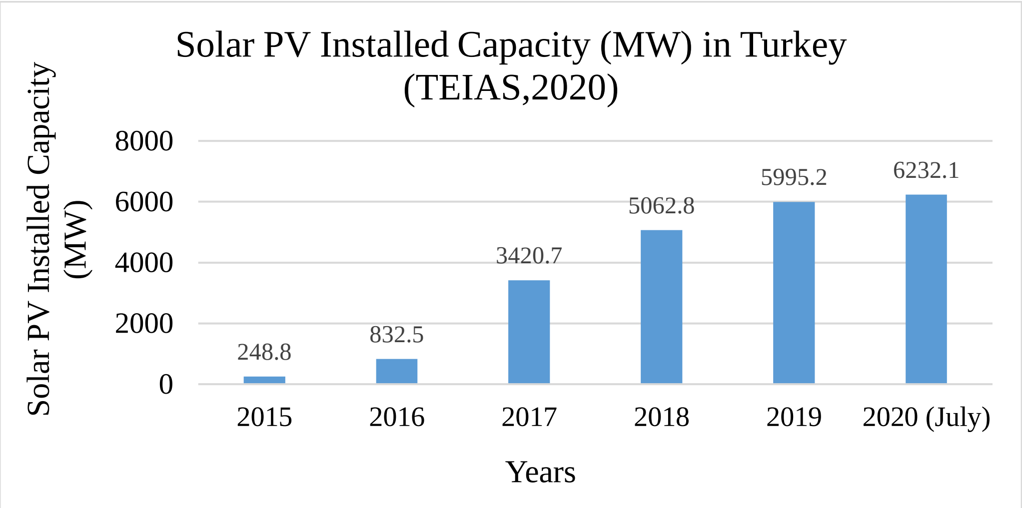

Figure 1: Solar PV Installed Capacities (MW) in Turkey according to years (TEIAS, 2020)

Figure 1 shows the increasement of Solar PV installation in Turkey for the years between 2015 and 2020 July. After 2016, installations increased faster. For solar sourced electricity generation according to primary sources of Turkey for the end of July 2019 and the end of July 2020, there is also an increasement from 5837 GWh to 6866 GWh and installed capacities for the same period are 5513 MW and 6166 MW, respectively. With the increased ratio of 17.63% in electricity production, solar has the highest rate (GUYAD, 2020).

As mentioned above Turkey and henceforth Ankara have high solar potential. Figure 2 shows the global horizontal irradiance (KWh /m^2) of some cities, which are mostly mentioned in the Literature Review part. It shows that the global horizontal irradiation of Ankara is higher than the European cities.

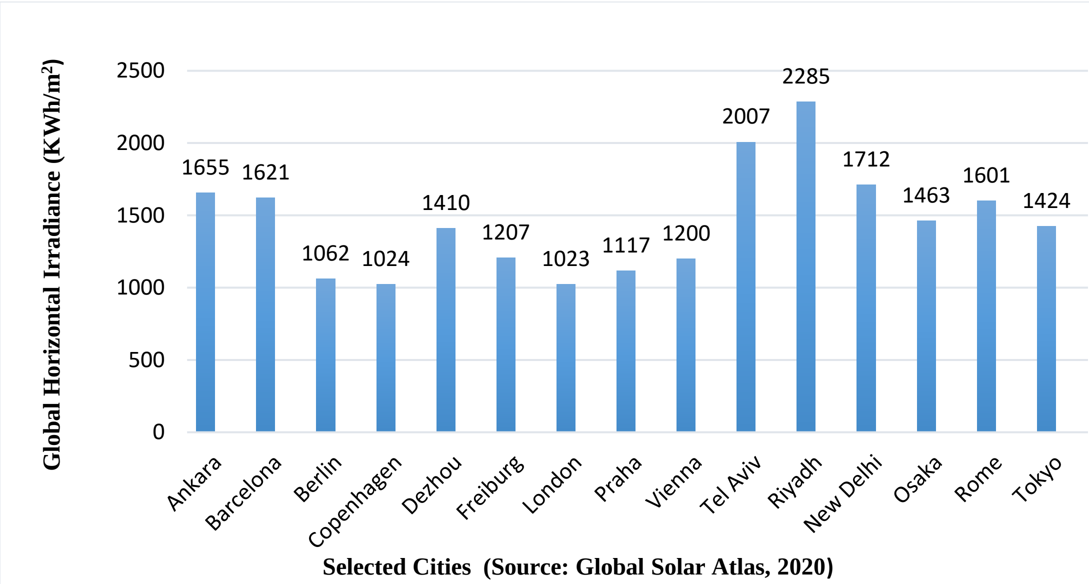

Figure 2: Global Horizontal Irradiance (KWh /m^2) of selected cities (Global Solar Atlas, 2020)

1.2 Background of Energy Policies in Turkey

Turkey has a different statue since the Kyoto Protocol in 2004. Although Turkey was included in both Annex 1 and Annex 2 countries list, she tried to be removed from both of the lists, because she is not a developed country for providing financial support for non-Annex 1 countries and also she is a non-industrialized country that doesn't have an emission reduction target because of her historical responsibility. However, the name is only deleted from Annex 2 countries' list, and it has a different statue from other Annex 1 countries. Hence, it is not clear that Turkey must need emission reduction targets.

Furthermore, although the renewable energy policy is relatively young, it aimed to set strategic and ambitious goals for implementation in Turkey. The law on Utilization of Renewable Energy in Electricity generation was enacted in May 2005, and after that, amendments were made in January 2011. Following these amendments, The Ministry of Energy and Natural Sources and Energy Market Regulatory Authority (EMRA) promulgated new regulations which are the one on Certification and Support of Renewable Energy Support Mechanism and the other, on Domestic Manufacturing of Components used in Renewable Energy Electricity Generation Facilities (Basaran S.,Dogru A.,Balcik F.,Ulugtekin N.,Goksel C.,Sozen S., 2015). Moreover, the amended law includes increasing the scale of unlicensed projects, higher tariffs, and enlarging the guarantee period to ten years and varied tariffs according to different sources (Ari & Yikmaz, 2019).

In April 2016, Turkey signed but not ratified the Paris Agreement. However, through the Paris Agreement, Turkey announced its INDC (Intended National Determined Contributions), and it is stated up to a 21% decline in Green House Gas (GHG) emission from Business as Usual scenario by 2030. Moreover, as stated in INDC, GHG emissions could be reduced to 926 million tons of CO_2 equivalent by 2030 sources (Ari & Yikmaz, 2019).

Turkey has 2023 targets in renewable total installed capacities as: 1 GW Geothermal Power, 34 GW Hydropower, 5 GW Solar PV (which is already reached) and 20 GW Wind Energy (Couture et al., 2019).

Recent regulations of solar energy are entered into force by the Regulation of Unlicensed Electricity Production in Electricity Market #30772 in May 2019. In this regulation, only rooftop and façade Solar PV applications were included and opened the way for selling of excess electricity production without any license and compulsory of incorporation. By limitation of 10 KW for residential and 5 MW for public and businesses, production and consumption are going to be measured hourly, and net-metering will be applied monthly. Furthermore, the previous 1 MW limitation for industry, commercial, and lightening consumers is also removed from rooftop and façade solar PV applications (EPDK, 2019).

1.3 Significance of the Study

In 1970, the net electricity consumption was 7,308 GWh, and it increased to 46,820 GWh in 1990, 98,296 GWh in 2000, and 258,232 GWh in 2018. Because of the electricity demand and consumption increases swiftly, Turkey's fossil fuel dependency increases. Between the years of 2004 and 2014, energy imports include 21% of total imports. Moreover, between these years, energy import constitutes 85% of the current account deficit (Uysal, Yılmaz, & Taş, 2015). Both the economic and environmental situation is a natural incentive for Turkey for a transition to renewable energy.

Furthermore, Figure 3 shows the sectoral sharing of energy consumption for the years 1997-2018. Households have between 20-25 % of this consumption, public buildings have 3-5% in the last 30 years, and commercials have % 9-20.5 in the previous 20 years. For Ankara, the best option is solar energy due to geological position. However, in solar energy terms, for the installment of 1 MW, 10,098 m^2 area is required (Karaveli, 2014), and the land requirement has externalities such as finding a suitable location and land cost. Hence, in this study, it is aimed to calculate the potential of electricity produced in rooftops of buildings since consumption and production will take place within the same building (prosumer).

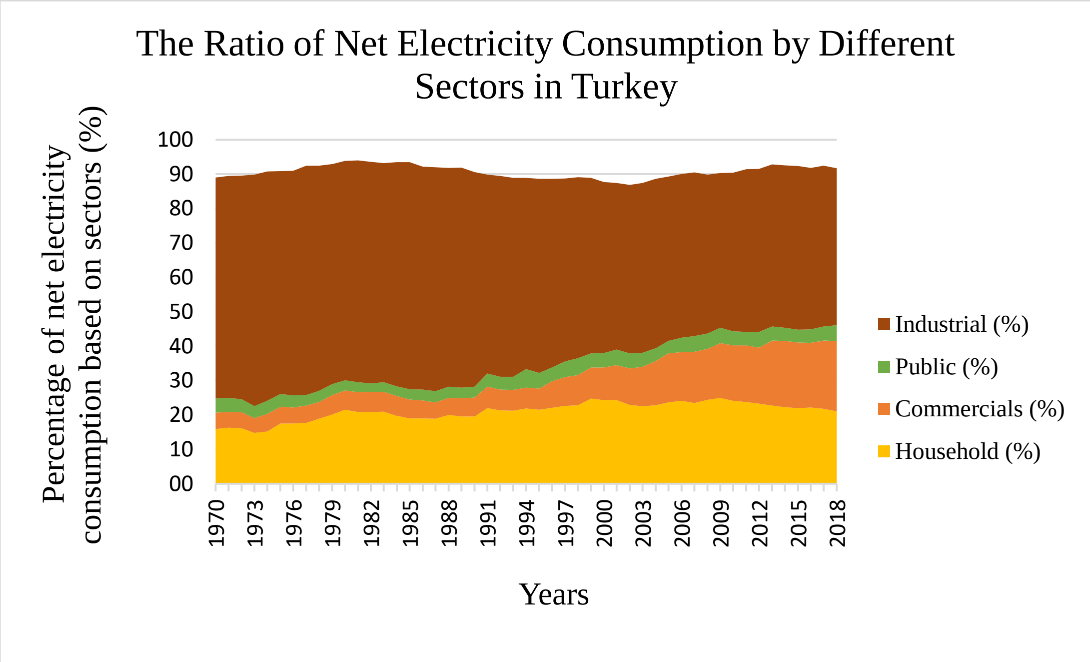

Figure 3: The Ratio of Net Electricity Consumption by Different Sectors in Turkey for the years 1970-2018 (TUIK,2019)

Moreover, Figure 4 and Figure 5 show that Turkey has the 3rd place in solar water heating collector capacity and also after China has the highest rate in solar water heating collector installations.

	1	2	3	4	5
POWER					
Renewable power capacity (including hydropower)	**China**	United States	Brazil	India	Germany
Renewable power capacity (not including hydropower)	**China**	United States	Germany	India	Japan
Renewable power capacity *per capita* (not including hydropower)[3]	**Iceland**	Denmark	Germany/Sweden		Finland
Bio-power generation	**China**	United States	Brazil	Germany	India
Bio-power capacity	**China**	United States	Brazil	India	Germany
Geothermal power capacity	**United States**	Indonesia	Philippines	Turkey	New Zealand
Hydropower capacity[4]	**China**	Brazil	Canada	United States	Russian Federation
Hydropower generation[4]	**China**	Canada	Brazil	United States	Russian Federation
Solar PV capacity	**China**	United States	Japan	Germany	India
Solar PV capacity *per capita*	**Germany**	Australia	Japan	Belgium	Italy
Concentrating solar thermal power (CSP) capacity	**Spain**	United States	South Africa	Morocco	India
Wind power capacity	**China**	United States	Germany	India	Spain
Wind power capacity *per capita*	**Denmark**	Ireland	Germany	Sweden	Portugal
HEAT					
Solar water heating collector capacity[5]	**China**	United States	Turkey	Germany	Brazil
Solar water heating collector capacity *per capita*	**Barbados**	Austria	Cyprus	Israel	Greece
Geothermal heat output[6]	**China**	Turkey	Iceland	Japan	Hungary

Figure 4: The Rank of Total Capacity as of End-2018 (Couture et al., 2019)

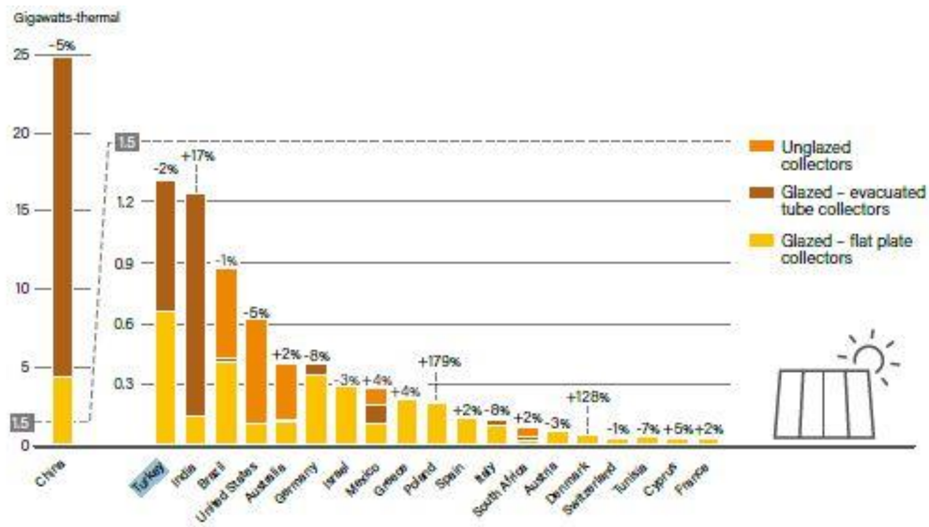

Figure 5: Solar Water Heating Collector Additions, Top 20 Countries for Capacity Added (Couture et al., 2019)

As can be seen in Figure 6, municipal and city-wide applications are more powerful to set targets and applicability. They have a direct mechanism to reach energy consumers, energy producers, regulators, facilitators, and urban planners. Cities' actions might provide significant information and impact national-level decisions while providing essential case studies for cities (Couture et al., 2019).

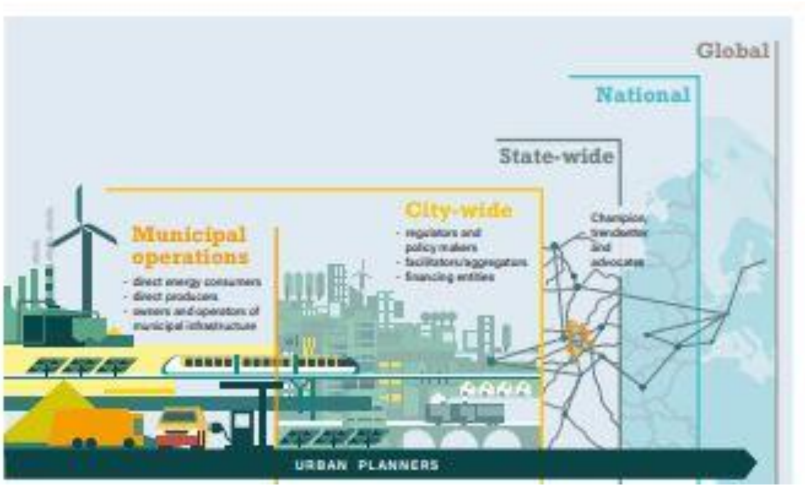

Figure 6: City Roles in Advancing Renewables Across Different Levels of Governance (Couture et al., 2019)

In this concept, this study focused on city-wide applications for Ankara. There is no previous study in the literature that focuses on rooftop PV potentials directly in Turkey's city level. Although there are some studies country-wide, there is no specific study to focus on building types and generalization. This study aims to develop and propose a free, reliable, open-sourced, and applicable methodology for everybody.

1.4 Studied City: Ankara

Ankara is the capital city of Turkey, which is located at 39.93 °N and central Anatolia. Ankara has more than 5 million capita, and the annual population growth rate is reached to 2.45% between 2018 and 2019.

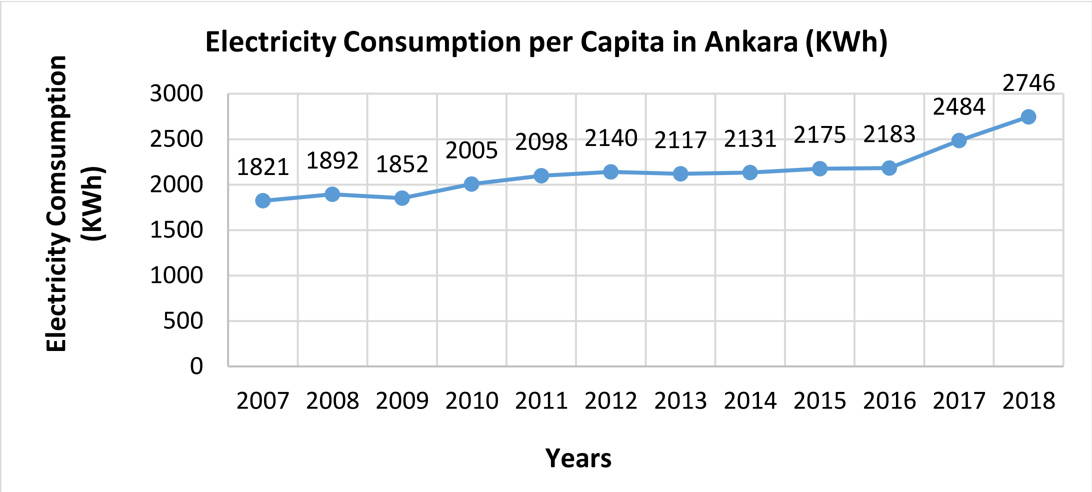

Figure 7: Electricity Consumption per Capita in Ankara between the years 2007-2018 (TUIK, 2020b)

Figure 7 shows an increasing trend in electricity consumption per capita in Ankara. After 2016, the rate of increase is higher; hence energy demand is increasing. Ankara belongs to the 3rd Climate Region in Turkey.

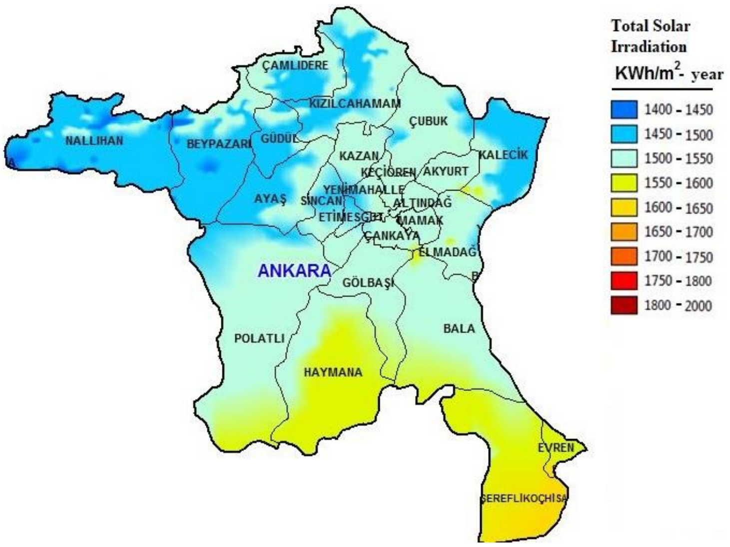

Figure 8: Total Solar Irradiation (KWh/m^2.year) of Ankara according to districts (YEGM, 2020)

Figure 8 shows the total solar irradiation of Ankara districts. Although irradiation varies between south and north districts, solar irradiation values are between 1400 KWh/m^2.year and 1650 KWh/m^2.year, which is higher than the average of the European cities. Although in YEGM (2020) report yearly solar irradiation values are as above, in Figure 2, the Ankara city's value is given as 1655 kWh/m^2.year as it is stated before. In this thesis, 1650 kWh/m^2.year is used.

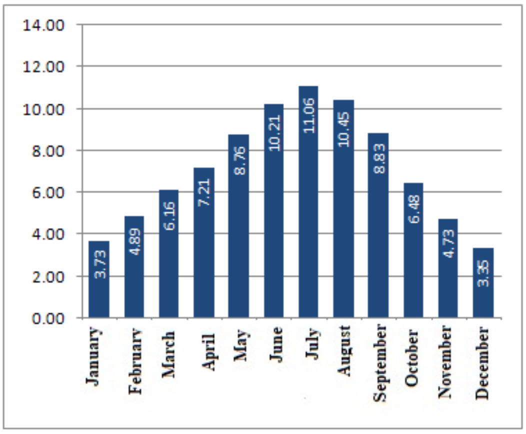

Figure 9: Ankara Sunshine Duration (hr) (YEGM, 2020)

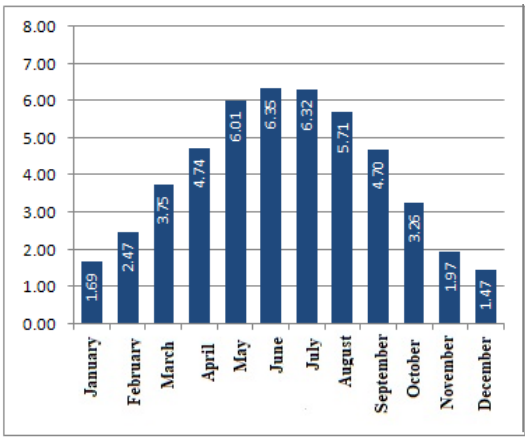

Figure 10: Ankara Global Horizontal Irradiation (KWh/m^2. day) (YEGM, 2020)

Figure 9 shows the average sunshine duration of Ankara according to months, and December is the least with 3.35 hours. July has the highest duration, with 11.06 hours. Figure 10 shows Ankara's daily average global horizontal irradiation monthly. In June, Ankara has the highest irradiation amount, and the value in July is also so close to the June amount. (Melikoglu, 2016) states that Turkey receives around 3.6 KWh/m^2.day. On the other hand, Ankara receives around 4.04 KWh/m^2.day hence, higher than the average of Turkey.

KOÇER, Şevik, & GÜNGÖR (2016) found that the optimum tilt angle is 1° in June, 67° in December and also between 15° and 56° in six-month terms in Ankara. Hence, in this study, 32° is selected as an optimum tilt angle for Ankara.

Ankara is an appropriate choice for the starting location to identify rooftop solar technical potential due to its relatively high solar irradiance, owning many public buildings for being a capital city, should meet the increasing energy demand.

1.5 Applied Software Selection

PV modules are the main components of PV Power systems, which convert Sun's energy to electricity directly. However, since the Sun's energy is intermittent and varies over time, how the amount of solar irradiation is converted into electricity efficiently should be estimated. These estimations can be made by software programs which use surface irradiation measurements or satellite data and calculate performance estimations (Özden, Karaveli, & Akınoğlu, 2020). In this study, software results are applied to all the same categorized buildings. Hence, to select the best suitable software option is highly important to reach better results. (Ceylan & Taşdelen, 2018) made a comparison of software programs PV*SOL, Helioscope, PolySun, and PVGIS by on-site measurement in Isparta, Turkey. Helioscope application is selected as the most accurate software, with a 1.2% standard deviation. Also, it is stated that Helioscope has advantages such as flexibility, considering the technical features of selected modules, the changeability of alignment and orientation of modules and allows inverter interference. Furthermore, in (Özden et al., 2020), a comparison is carried out for different software using on-site measurements in Ankara. They found that although PV*Sol and PVsyst estimates are acceptable, the best performance is provided by Helioscope.

Since different PV sub-technologies are also compared for the same building in this study, technical features of modules are also important. Helioscope is selected in this study both of its flexibility and previous study results for the same city.

1.6 Module Selection

Solar PV systems are attractive for investors due to recent increases in efficiency, increased unit electricity price of conventional power plants, and a decrease in cost due to the latest developed technologies and economic scale effect. In the laboratory, for Mono-Si Crystalline Cell 26.7% is reached, and for the Mono-Si Crystalline module, 24.4 % efficiency is measured. Also, for Multi-Si Crystalline cell 22.3%, for Multi-Si Crystalline Module 19.9% is reached, respectively (Fraunhofer Institute for Solar Energy Systems, 2020).

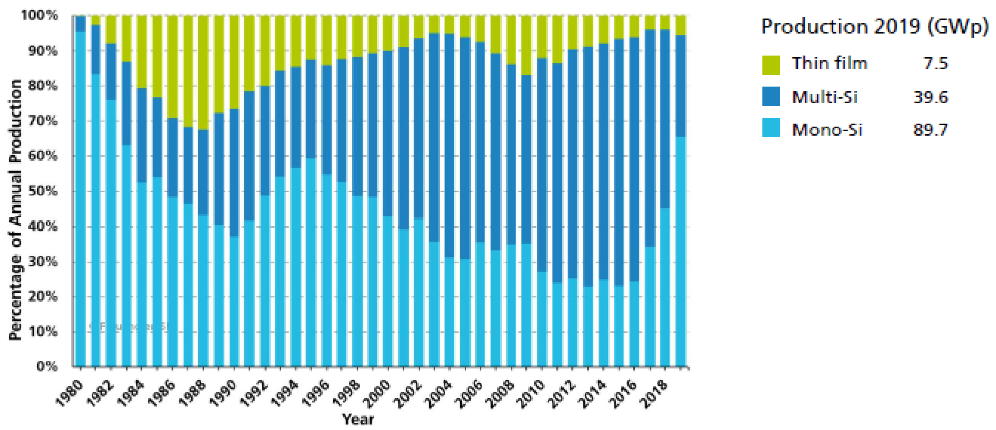

Figure 11: Percentage of Annual Production of Modules (Fraunhofer Institute for Solar Energy Systems, 2020)

Figure 11 shows the sharing percentages of the annual production of three different PV technologies as thin-film, Multi-Silicon Crystalline, and Mono-Silicon Crystalline Panels. As can be seen, although their sharing ratio varies according to years, Silicon Crystalline Modules dominates. Hence, both Mono-Si and Poly-Si modules are applied in this study for the same building.

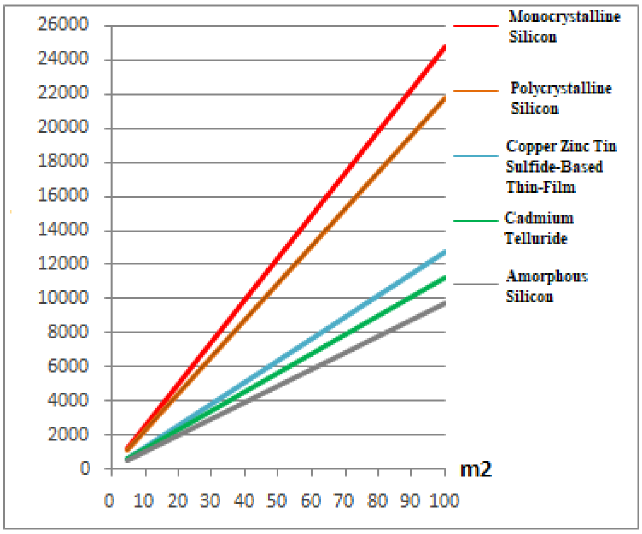

Figure 12: Ankara PV Potential based on the area (KWh /year) (YEGM,2020)

Furthermore, Figure 12 shows the estimated energy production per m^2 according to different module types for Ankara. Mono-Si and Poly-Si are determined to have the highest energy production, as stated in (YEGM, 2020).

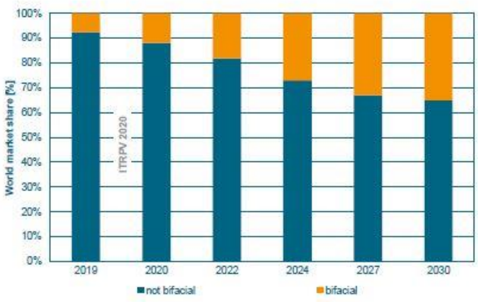

Figure 13: Market share ratio of Bifacial Modules in Years (ITRPV, 2019)

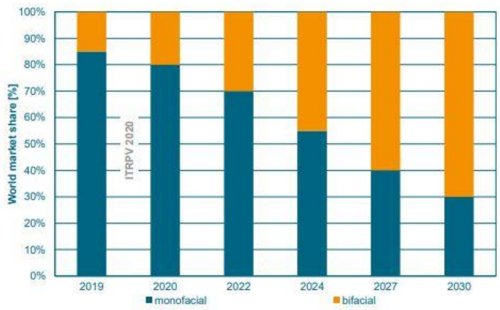

Figure 14: Market share comparison of Bifacial Modules and Monofacial Modules in Years (ITRPV, 2019)

Moreover, Figure 13 and Figure 14 show how the bifacial module increases its market share. It is projected as the market share of bifacial modules will continue to increase in the 2020s. Thus, bifacial modules are also considered in this study.

CHAPTER 2

LITERATURE REVIEW

Figure 15 shows the hierarchical order of the estimation of renewable energy potentials. In this study, the city-based technical potential of rooftop PV is estimated. Brief definitions can be followed by the insets of the figure.

Figure 15: Types of Renewable Energy Potentials (Gagnon, Margolis, Melius, & Phillips, 2016)

2.1 Similar Studies in Literature

As described in the above figure, system and topographic constraints, land-use constraints, and system performance should be known to reach technical potential. “Access Factor” is a term that includes land-use constraints like shadings and orientation. In this section, different terminologies are used for constants. NREL (2008) used the “PV access factor” for different shadings and orientation (Paidipati, Frantzis, Sawyer, & Kurrasch, 2008). For the same calculation, Ordóñez, Jadraque, Alegre, & Martínez (2010) used the “Relation coefficient” term and Izquierdo, Rodrigues, & Fueyo (2008) used “available roof area.” On the other hand, in this study, besides shading and orientation, module space, space for access wiring, and inverters are also considered and defined as “suitable area constant.” For this term, M. Khan, Asif, & Stach (2017) and Mainzer et al. (2014) used “Utilization constant /factor” and Tripathi (2014) used the “Useful area constant” term. Furthermore, in NREL (2008) report, it is stated that to reach a suitable area constant, the PV access factor is combined with Packing Factor, which is calculated as 1.25 for residential and commercial (Paidipati et al., 2008). On the other hand, (Lise et al., 2018) defined two constants as “ weighted average ratio of usable area” and “penetration factor” to reach usable area constant.

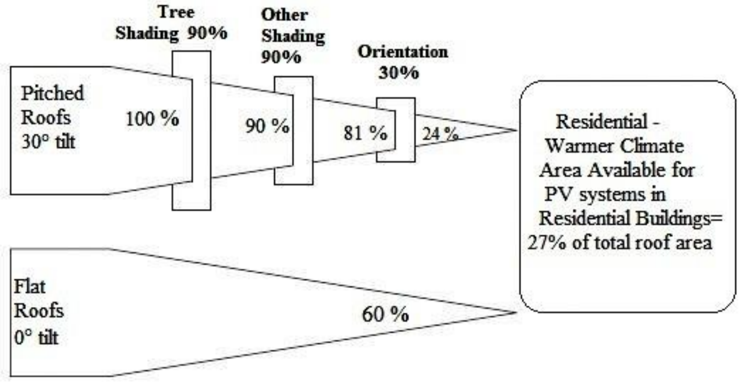

Figure 16: PV Access Factor for Residential Buildings in Warmer Climates (Paidipati et al., 2008)

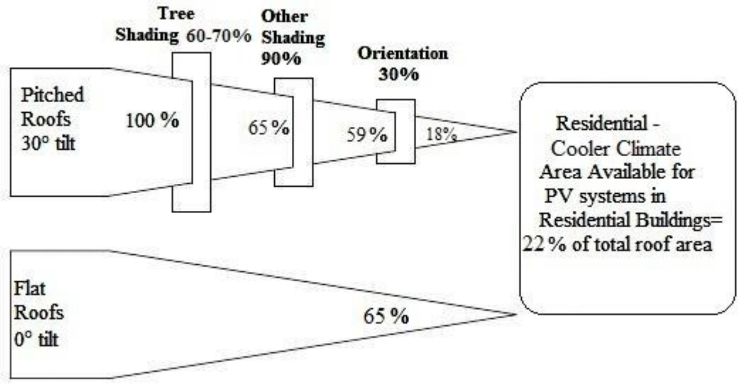

Figure 17: PV Access Factor for Residential Buildings in Cooler Climate (Paidipati et al., 2008)

Figure 16 and Figure 17 show PV access factors for residential buildings in a warmer and cooler climate, respectively. In both of the climate types, pitched roofs are assumed as 92% of the total buildings. The average PV access factor is estimated as 27 % of total roof area for warmer-climate residential and 22% for cooler-climate residential.

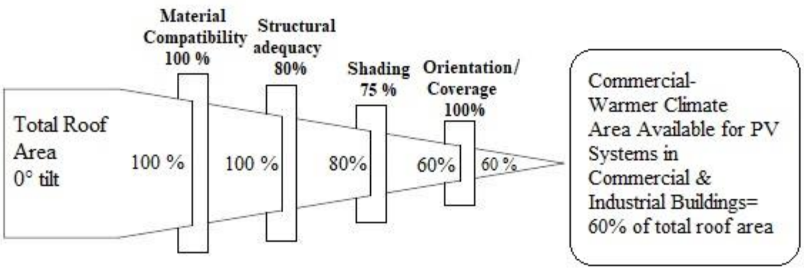

Figure 18: PV Access Factor for Commercial Buildings in Warmer Climate (Paidipati et al., 2008)

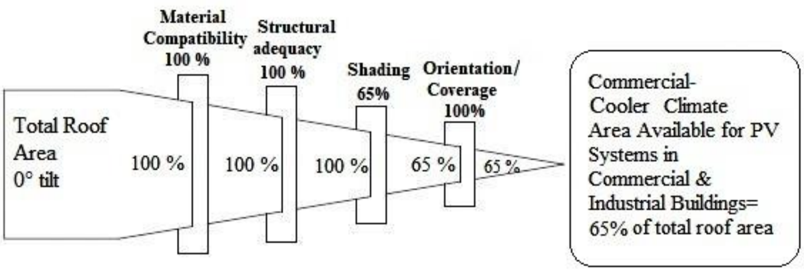

Figure 19: PV Access Factor for Commercial Buildings in Cooler Climate (Paidipati et al., 2008)

Moreover, Figure 18 and Figure 19 show the same study for commercial buildings, which is assumed as all flat roofs. The PV access factor is estimated as 60% of total roof area for the warmer climate and 65 % for cooler climate one, respectively. On the other hand, the packing factor, which is estimated as 1.25 for residential and commercial buildings, modifies the suitable area constant by taking into account space required for the system like space for wiring, inverters and access between modules. Also, it is stated that the technical potential of the rooftop PV potential increases because of two reasons: the increasement in system efficiency and growing of the rooftop area over time (Paidipati et al., 2008).

Melius, Margolis, & Ong (2013) stated that the methods to estimate the suitable rooftop area have both advantages and disadvantages. Firstly, although the constant value method is good as a starting point since it is quick and easy to compute, results are difficult to validate. Secondly, despite the manual selection methods being detail-specific and making more realistic assumptions, it is a time-intensive method that is not applicable for wide and multiple regions. Thirdly, GIS-based methods are also detail-specific and applicable for wide/ multiple regions, yet it is time-intensive and intense computer-resource required. Furthermore, according to revised studies by constant value method, suitable PV area varies between 15-30% for residential, and 15-65% for commercials. It varies between 1.31-33% for pitched roofs and 1.31-55% for flat roofs when the manual selection method is selected. The suitable area constant varies between 6.5-59% by GIS-based method used studies. Moreover, in constant-value method studies, 8% of all residential buildings and 63% of all commercial building rooftops are assumed as flat for the U.S. In the validation part, it is stated that although GIS tools like Solar Analyst underestimates the solar potential, constant-value methods overestimate the energy potential.

Vardimon (2011) studied Israel's photovoltaic electricity production based on a complete GIS dataset for the whole country. By analyzing the orthophotos of all town's buildings, buildings were classified according to the usage of purpose, and ArcGIS software is applied. After calculating the total roof area by GIS application, a PV access factor is calculated using constant-value methods based on literature values. The results are calculated in 2 scenarios: "Total Potential Scenario" and "Economic Scenario" where all rooftops are accounted in the total potential scenario and the PV access factor is assumed as 30% for all rooftops; on the other hand, in Economic Scenario, only the roofs which are larger than 800 m^2 are taken into account. For this scenario, the PV access factor is assumed as 50%. The module efficiencies are taken as 16% for Total Potential Scenario and 10% for Economic

Scenario. Yearly production potential is calculated as 15.9 TWh for Total Potential and 3.3 TWh for Economic Potential.

Ordóñez, Jadraque, Alegre, & Martínez (2010) analyzed the photovoltaic solar energy capacity of residential rooftops in Andalusia (Spain) by starting from usage of gross roof surface area statistics for each building type from the Spanish Ministry of Development. Buildings are divided into three parts: detached/semi-detached houses, town/row houses, and high-rise buildings. To reach a suitable roof area, urban maps are provided from Google Earth and scaled with the AutoCAD. Obstacle constants such as HVAC system, antennas, shaded area calculated by AutoCAD application. Two types of installation are done, and different modules from the same brand are applied. Relation coefficients for the suitable area, free of obstacles, calculated as 0.740 for flat roof and 0.974 for the pitched roof in detached and semi-detached houses, 0.796 for flat and 0.983 for pitched roofs in town/row houses and 0.654 for flat, 0.789 for the pitched roof in high-rise buildings. After installations, coefficients are decided for flat roofs: 54.9% in detached houses, 53.72% in townhouses, 51.83% in high-rise buildings, then it is found as 21.12% detached houses, 20.19% for townhouses and 16.83% in high-rise buildings with pitched roofs.

Izquierdo, Rodrigues, & Fueyo (2008) emphasized that no study includes the rooftop area as direct input data; hence there should be a method to estimate the roof area, which is reliable, low cost, efficient, and flexible for unforeseen aspects. The formula is suggested to calculate the available roof area, including the built-up area, the void fraction coefficient, the shadowing coefficient, and the facility coefficient. The method is applied for 8320 municipalities with 40,727,624 capita in Spain, and the portion of the coefficient is calculated as 19.45% for Spain. Moreover, it is indicated that some cities have higher potential, although the lower solar irradiation, because of the availability of the roof area.

Khan, Asif, & Stach (2017) studied the rooftop PV Potential in the Residential Sector of the Kingdom of Saudi Arabia by different methods. In this paper, the mean floor area of different residential types is analysed, then the total rooftop area is calculated by multiplying average area with the number of buildings. For usable area, balustrade shadows, the inter-row gap between the modules and other obstacles such as satellite dishes and air-conditioning units, staircase room, and commercial shadows are also considered. To calculate the utilization constants, The King Fahd University of Petroleum and Minerals (KFUPM) is carried out a case study. It is stated that all of the roofs are flat, and the total roof area is calculated by ArcGIS software and utilization constant is estimated as 30%. They calculated, 30% of total residential electricity demand can be met.

Yuan, Farnham, Emura, & Lu (2016) studied potential of rooftop photovoltaic power generation in Osaka City, Japan, by using aerial photo data of Osaka and pixel analysis techniques with the C++ Program. In the study, 24 regions, which are 1 km^2, selected, and their annual solar radiation is calculated. Then, a suitable area for PV installation is estimated for all the samples. After estimating the average annual PV power generation of samples, it is applied to the whole city. It is assumed that all useful roof area can be utilized. Suitable area ratios are calculated according to the selected region, not according to the roof.

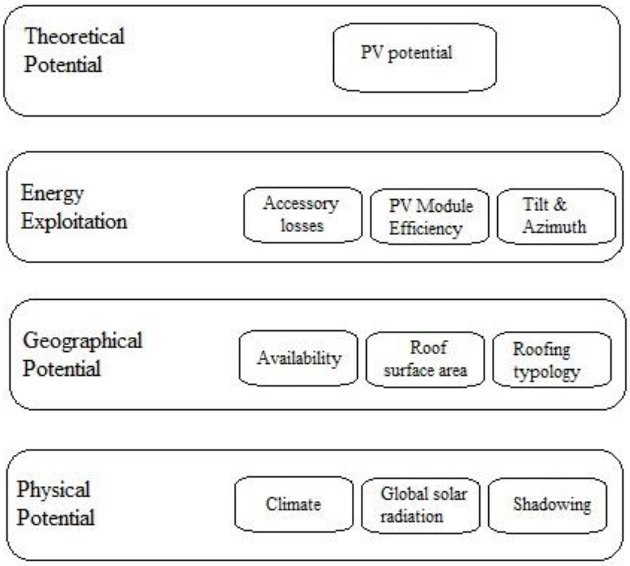

Figure 20: Scheme of the hierarchical methodology to obtain the theoretical PV Potential (Bergamasco & Asinari, 2011)

Bergamasco & Asinari (2011) studied photovoltaic solar energy potential assessment based on available roof surface areas in the Piedmont Region (Italy). Figure 20 shows the suggested methodology for obtaining the theoretical PV Potential and maps studied by ESRI ArcGIS 9.3 and then performed in MATLAB. In Piedmont Region, the slope varies 30-45%; hence inclination angle of pitched roofs is assumed as 20°. Then, for a suitable area, constants are determined. It is assumed as only one side of pitched roofs are usable; hence roof-type coefficient assumed as 0.5, corrective feature coefficient, consider occupied area by a chimney, windows, antennas, etc., assumed as 0.7, solar thermal coefficient assumed as 0.9, covering index coefficient, the ratio of module surface divided by the total suitable roof area, assumed as 0.45 and shadowing coefficient assumes as 0.46. While considering the inclination angle 20 ° for residential and 30 ° for industrial buildings, the total coefficient is found to be 0.065 for residential and 0.304 for industrial buildings. The results are analyzed in 3 scenarios: different module technologies, mono-crystalline only, and thin-film only and applied all municipalities.

Both Izquierdo, Rodrigues, & Fueyo (2008) and Bergamasco & Asinari (2011) indicated that some cities have higher potential although having lower solar irradiation, because of the availability of the roof area.

Huang, Mendis, & Xu (2019) studied the urban solar utilization mapping of Wuhan, China, via deep learning technology. In this study, instead of LIDAR or CAD open-source satellite imagery is used for 2D information for the rooftop area and it is stated that there is an insignificant error in roof recognition because of machine learning recognition, shadings and reflections due to neighboring building and Python is used as a programming language. Although urban density results are parallel with real urban density, solar irradiation results show 9.51 % error, and it is stated that future research should be focused on determining the shading factor.

Jahanfar, Sleep & Drake (2017) analyzed net energy and emission factors for green-roof, PV, and GR-PV roof systems. To overcome the uncertainty in design parameters, a probabilistic approach is applied. For comparison, embodied energy,

energy savings, and energy production are estimated for GR, PV and their combination. Then, it is stated that the GR-PV roof system has much higher energy reduction than separate GR or PV systems. In the conclusion part of the study, it is predicted that the installation of combined systems can reduce electricity demand by 28 %.

Mainzer et al. (2014) studied the technical potential for residential roof-mounted PV systems in Germany and compared the results with previous ones for the same federal states. To calculate the technical PV potential, firstly a suitable area, then a combination of suitable area, local solar radiation, and the energy conversion processes' efficiency are applied. For single-family buildings average available roof area is assumed as 141.4 m^2 for flat roof and 113.7 m^2 for pitched roof, for double-family buildings 143.9 m^2 for flat roof and 130.2 m^2 for pitched roof and for multi-family buildings 135.7 m^2 for flat roof and 207.3 m^2 for a pitched roof. The utilization factor is estimated as 27% for flat roof and 58% for a pitched roof. However, it is stated that the utilization factor for pitched roofs (58%) is around twice the previous studies. Previous studies in Germany estimated the utilization factors between 23-33% for flat roofs and between 15-34% for a pitched roof.

Tripathi et al. (2014) studied India's technical and economic potential and first calculated the land use ratios. It is estimated that 40% of the land is used by residential, 2% by commercial buildings and 3% by industrial buildings. They reached the useful rooftop area constants using 3 scenarios: Pessimistic, realistic, and optimistic. According to these scenarios, the pessimistic constant is estimated at 10%, the realistic constant estimated at 20%, and the optimistic constant is estimated as 30% for residential buildings. Furthermore, commercial buildings constants are estimated at 20%, 30% and 40%, respectively.

(Lise et al., 2018) published a report Rooftop Solar PV Market assessment of Turkey and calculated the usable rooftop areas of seven cities of Turkey and 909 polygons selected in these cities. The total area for rooftop PV is estimated as 1.1 billion m^2 which includes 596 million m^2 for residentials, 499 million m^2 for commercial and industrial buildings and 42 million m^2 for public buildings by a weighted average ratio of usable area is which is 47% for residential, 57% for commercials, 45% for public buildings. Then, to reach the technical potential useful area is reached by applying penetration factor, which is 0.39 for residentials, 0.43 for commercial and industrials, and 0.49 for public buildings. Solar potential (GW) is reached 23.3 for residentials, 21.46 for commercials, and 2.06 for public buildings. To validate, 18 building samples are used, and 8 of the samples located in Ankara. Table 1 shows the selected samples and their features from Ankara.

Table 1: Selected Ankara Samples and their features (Lise et al., 2018) *

The Samples	**Building Type**	**Roof Angle (°)**	**Total Area (m^2)**	**Useful Area (m^2)**	**Useful Area Ratio (%)**
Angora A2 Block	4-Floor Multi-Dwelling Residential	20	450	150	33
Angora	Detached House	25	450	150	33
Atlantis City (Batikent)	24 floors Multi-Dwelling Residential	0	700	560	80
Atlantis AVM	Commercial	0	12,000	6000	50
Ulusoy Plaza	Commercial	5	900	720	80
Ikizler Building Technocity	Commercial	0-10	3450	2800	81.16
Angora Fine Arts High School	Public	10	4000	1600	40
METU EEE	Public	0	2000	1600	80

*Table 4-2 and Table 4-3 obtained from (Lise et al., 2018) and combined, and the ratio is added after calculation.

Acar et al.,(2020) published a very new report which focused on Rooftop PV Potential in Buildings in Turkey. In the study, the buildings built after 1970 are considered, and building numbers according to building types are analysed. To estimate the useful area, average building areas are used. In consequence of Stakeholder interviews, for multi-family residential building area estimated as 150-

250 m^2, for one-dwelling residentials 80-120 m^2, for commercial and public buildings the value estimated as 350-650 m^2 and for shopping malls it is estimated as 1100-1500 m^2; also it is stated that for all building types 25% of roof area is suitable for PV installations. It is stated that if modules are settled only in south-faced roof segments, the technical potential is calculated as 55 GW; on the other hand, if modules are settled using a PV access factor of 0.25, the technical potential is estimated to be 14.9 GW. According to technical potential results, multi-dwelling residentials have a higher share with 13.2 TWh/year. Commercial, public and Industrial buildings follow this with 5.1 TWh/year and one-dwelling residentials have 2 TWh/year potential.

2.2 City Applications

As mentioned before, a lot of cities and municipalities make a regulation in city based. In this section, literature about some of these cities will be given.

2.2.1 Vienna (Austria)

The new roof program is understated in the Governmental Agreement between the Green party ÖPV for the years 2020 to 2024, and it is stated that 1 million photovoltaic roofing will be added inclusive of the program. Any kind of properties such as car parking units will be funded, and it is stated that 27 TWh additional energy production is possible from renewables. 11 TWh of this production is assumed to come from photovoltaics until 2030. Today, Austria produces 1.4 TWh from renewables, which covers 2.5% of Austrian energy demand (Emanuela Barbiroglio, 2020).

The capital city of Vienna is planning a CO2- neutral city as soon as possible. Industrial buildings in Vienna already have a photovoltaic obligation, and now the municipality expands these regulations as adding obligation to new residential and educational buildings. One and two-dwelling buildings will be excluded from the new PV system obligation. By this regulation, schools and other educational buildings and multi-dwelling residentials will be equipped with solar PV systems. In this concept, to produce more green electricity will be encouraged to feed the part of the Vienna power grid's electricity. The limit of installation amount of obligation is calculated according to electricity produced and consumed in residential buildings, directly (SPIEGEL, 2020). The obligation will be applied from 2021 for new buildings, and also along with new obligations, Vienna municipality invests 1.2 billion euros for the expansion of renewables until 2030 (KONTRAST, 2020).

2.2.2 Freiburg (Germany)

Germany has one of the biggest solar PV markets, and around 65% of this capacity comes from Rooftop Solar PV (RSPV). Germany promotes the Self-Consumption model for RSPV in the national solar market. There is no requirement for local permits, inspections, and no permit fees for small residential RSPV systems (Lise et al., 2018).

Freiburg is a solar city that is leading the green energy of revolution in Germany. In 1986, after Chernobyl, Freiburg focused on solar energy as the main energy source. By 2010, Freiburg put on regulation that required the city to obtain 10% of electricity from renewable energy, and for all new residential, energy standard is required (Evans, 2015). Furthermore, Freiburg contains the Vauban district, which is the most sustainable town in Europe. Vauban's settlement is the first community globally as an amount of produced energy more than the consumed amount. As shown in Figure 21 and Figure 22, these buildings generate more renewable energy than others, known as plus-energy buildings. This energy is mostly sourced by the rooftop solar panels on residential and municipal buildings. Moreover, the rooftop PV panels are combined with the local biomass plant, and excess energy is sold back to the municipality's utility company (Braff, 2020).

Figure 21: Residential in Vauban City

Figure 22: Residential in Vauban City

2.2.3 Dezhou (China)

The local government of Dezhou announced a Development Plan which centralizes solar technology research and development in 1997. After the developed solar energy industry, The National Renewable Energy Law entered into force by establishing the Dezhou Solar City Plan. The local government reduced the barriers to entry of new solar initiatives. In 2008, The Million Roof Project was launched, aiming for all new residential buildings in urban to be equipped with solar thermal facilities. This project stated that residential buildings with less than 12 floors should install thermal rooftop facilities, and higher than 12 floors should install wall-mounted or centralized solar thermal equipment. Furthermore, in the context of this project, the renovation of existing buildings is also included. On the other hand, for rural residential, The Thousand Bathroom Project was launched in the same year to supply a solution to the scarcity of hot water in winter (Yong, 2012).

2.2.4 Barcelona

Barcelona is the first EU city that establishes a Solar Thermal Ordinance (STO). By this ordinance, the obligation of using solar energy for the supply of 60% of hot water in all new buildings, renovated commercials and renovated more than 16 dwellings residentials are applied. The application is carried out as a part of Barcelona Energy Plan and adopted by the municipality. This application between the 2000-2011 solar thermal collectors' surface increased from 1.1 m^2 /1000 capita to 59 m^2 /1000 capita (Schio, 2012). After this success, more than 70 municipalities have also followed the Barcelona case for theirs. In 2006, Spain came the first country to enact building codes that included solar water heaters by installing solar panels of both electricity and hot water in new buildings and renovating large buildings. As a consequence of these policies, the number of solar water heaters has increased to forty-fold (Jacobson, 2012).

CHAPTER 3

METHODOLOGY

3.1 Data Collection

There is no direct recorded data for the rooftop area for Turkey. Hence, as a starting point, TUIK data are used to reach the buildings' number and floor base for residential buildings. Google Earth is also used to calculate the total roof area of selected samples, all public and commercial buildings. In this study, by the Manual Selection Method, access factor in selected buildings is determined, and then, by Constant Value Method, access factors are applied for all buildings. However, it is necessary to make assumptions since there is a lack of information.

Assumptions and Limitations

- Since there is no additional information about apartments and detached houses, buildings with one and two dwellings are assumed as detached houses.
- Since TUIK data classified according to floor numbers and the buildings with ten floors and higher labeled as 10+, these buildings assumed ten floors.
- Because of the floor base area used as a roof area, all terraces are assumed as closed terraces.
- Although all public building addresses are checked from official web pages, since there are a lot of changes between public buildings, such as the transferring of The Ministry of Health from Mithatpasa Street to Eskisehir Road and the transferring of Governorship of Ankara to the old Ministry

building or closure and transferring of Prime Ministry, there might be a mistake in naming if not updated.

- As shown below, Figure 23, Figure 24 and Figure 25 show the rooftops of different parts of Ankara. Hence, roof directions in Ankara are accepted as random.

Figure 23: Etlik Rooftops

Figure 24: Buyukesat Rooftops

Figure 25: Erdemkent Rooftops

- According to Ankara Building Bylaws (Ankara Büyükşehir Belediyesi, 2013.), roofs' slope cannot exceed 40%. Hence the angle of the roofs is assumed as constant and 20 °.
- Some of the public buildings have both flat-roof and pitched roof buildings on their campus. e.g., MIT building has 44392.7 m^2 pitched roof and 45578.5 m^2 flat roof; hence to ease of calculation, all roofs are assumed as a flat roof (the one which has a higher ratio).
- As can be seen in Figure 26, Google Earth cannot find some addresses accurately. These addresses are mentioned as “n.f.” (not found).
- Also, some roofs are measured roughly because of the low resolution of Google Earth in some regions, such as Figure 27.

Figure 26: Haymana Teacherage and Evening Art School

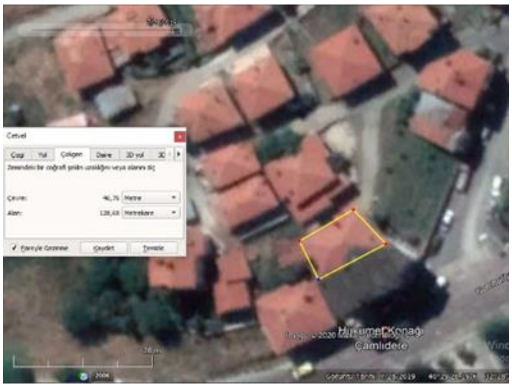

Figure 27: Camlidere Government Office

3.1.1 TUIK Data Revision

In this thesis, residential buildings are studied in three categories: Pitched-roof apartments, flat-roof apartments, and detached houses. For all residential types, TUIK building data for the years between 2000 and 2019 is used because of the Communique of Mandatory Standards put in force in 2000.

Table 2: Apartment Building Data of 2019 (TUIK, 2020)

Number of floors	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10+**	**Total**
Number of buildings	7	46	121	662	640	261	136	114	513	2500
Total area (m^2)	5939	28136	120492	922456	1165306	580336	366739	427453	3603094	7219951
Base area (m^2)	2970	9379	30123	184491	194218	82905	45842	47495	360309	957732

As shown in Table 2, the total base area is reached by dividing the total area (m^2) by the number of floors for applying all numbered floors. Also, the same calculation applied for detached houses is shown in Table 3.

Table 3: Detached House Data of 2019 (TUIK, 2020a)

Number of floors	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**Total**
Number of buildings	176	335	480	20	1	0	0	1012
Total area (m^2)	26669	96060	171750	12298	847	0	0	307624
Base area (m^2)	26669	48030	57250	3074.5	169.4	0	0	135192.9

Table 4: Apartment data for the years between 2000-2019 (TUIK, 2020a)

Apartments / **Years**	**Total Number of Buildings**	**Total Floor Base Area (m^2)**
2019	2500	957731.73
2018	3522	1224816.00
2017	3753	1368806.28
2016	3609	1184517.45
2015	4070	1332671.10
2014	4608	1624286.34
2013	4873	1647141.06
2012	4235	1325785.33
2011	4362	1339204.00
2010	4021	1274079.51
2009	3894	1164194.13
2008	3315	954253.54
2007	3972	1183340.32
2006	4297	1226124.94
2005	3994	1188127.28
2004	2103	592208.89
2003	2051	584517.04
2002	2085	570502.54

Table 4: Apartment data for the years between 2000-2019 (TUIK, 2020a) (cont'd)

2001	3194	678062.24
2000	3449	648267.71
Total	**71907**	**22068637**

Table 5: Detached house data for the years between 2000-2019 (TUIK, 2020a)

Detached House / Years	**Total Number of Buildings**	**Total Floor Base Area (m^2)**
2019	1012	135192.90
2018	1599	223195.24
2017	1596	219998.00
2016	1750	246428.23
2015	1610	211142.58
2014	2273	295073.67
2013	2704	310234.05
2012	1442	154285.07
2011	1757	227142.90
2010	1957	169511.63
2009	1069	121184.62
2008	1107	111164.18
2007	1501	171541.75
2006	1265	117889.53
2005	1188	115297.93
2004	817	94159.40
2003	1212	116550.65
2002	818	84075.33
2001	1797	120065.15
2000	1001	69032.28
Total	**29475**	**3313165**

Table 4 and Table 5 show the total floor base area (m^2) based on years, which are assumed as floor area is equal to the roof area. According to these tables, the total roof area (both apartment and detached houses) is found as 25,381,802.53 m^2 for 19 years.

3.1.2. Google Earth Data Revision

In this thesis, Google Earth Pro polygon ruler is used to measure the roof area of residential samples, all public and commercial buildings (shopping malls), by considering "Assumptions and Limitations" part.

3.2 Application of Helioscope

3.2.1 Application in Residential Buildings

For calculation of the suitable area coefficients, the Helioscope software program is used. 14 apartment-type houses with different floor numbers and different locations and 3 detached houses are selected as a sample.

Table 6: Selected Residential Buildings

Samples	**Location**	**Roof Type**	**Number of Floors**	**Number of dwellings**	**Roof Area (m^2) (Google Earth)**
#1 Yesiloz Apt.	Pursaklar	Pitched	3	12	470.62
#2 Hacı Tahsin Apt.	Etlik	Pitched	3	14	656.72
#3 Kocak Apt.	Etlik	Pitched	3	8	384.6
#4 Kilic Apt.	Birlik	Pitched	4	8	340.84
#5 Beyler Apt.	Kecioren	Pitched	4 (3+1) *	9	379.06
#6 Işık Apt.	Etlik	Pitched	5 (4+1) *	18	527.28
#7 Beyaz Apt.	Ovecler	Pitched	6 (4+2) *	16	461.74

Table 6: Selected Residential Buildings (cont'd)

#8 Kivanc Apt.	Ayranci	Pitched	6 (3+3) *	20	528.92
#9 Emcag Site	Batikent	Pitched	6 (5+1) *	10	262.68
#10 Cem Koc Apt.	Mamak	Pitched	7 (5+2) *	20	367.94
#11 Birlik Konutlari	Birlik	Flat	7 (6+1) *	14	262
#12 Altinel Park	Umitkoy	Pitched	10	40	879.77
#13 Eryaman Evleri	Etimesgut	Pitched	13	52	749.38
#14 Okyanus Plaza	Eryaman	Flat	31 (29+2)	98	700.69
#15 Serpme Evler	Yasamkent	Pitched	4	1	205.41
#16 Gozde Evler	Konutkent	Pitched	-	1	80.30
#17 Alacaatli Bahceci Konaklari	Alacaatli	Pitched	-	1	330

***shows cellar floor**

As can be seen in Table 6, although the floor numbers are the same in two buildings, their roof area is not close to each other. Hence buildings cannot be classified according to their number of floors for their roof areas.

By the Helioscope software, 3 types of modules (Mono-Si, Poly-Si and Bifacial) are applied for residential buildings.

3.2.1.1 Application of Mono-Si Panels to Pitched-Roof Residential Buildings

Mono-Si modules are applied as both vertical and horizontal, and the more practical orientation is selected based on samples since the module-covered area is the same. Table 7 shows the features of selected Mono- Si panel.

Table 7: Features of selected Mono-Si panel model

Description	**Data**
PV Panel Model	1 Soltech 1-STH 320 M
Power	320.0 W
Number of cells	80 cells
Dimensions	1.327 m x 1.614 m
Area of a panel	2.14 m^2
Efficiency of Module	14.94%

For Mono-Si application,

- Every facade of the roof is selected as different field segments.
- Racking is selected as "flush mount racking."
- Azimuth Angle is determined differently by Helioscope for every field segments.
- Orientation is applied for both Portrait (Vertical) and Landscape (Horizontal).
- Since racking is selected as flush mount racking, row spacing is determined as 0 m, and module spacing is determined as 0.1 m to interfere for any inconvenience.
- The setback is determined as 0.8 m according to Roof Mounted PV Setbacks and Conduit Requirements (City of American Canyon, 2018).
- Alignment is selected as centered, although it might decrease the number of panels. It is selected as centered because of the unforeseen shadings such as new neighbor buildings or trees. For sample 3, centered alignment leads to a decrease in the number of modules from 48 to 39.
- Keepouts are marked, and their setbacks and heights are selected roughly according to shadow shade.
- Module shading cutoff is selected as 10%, and the modules which have more than 10% shading are removed (IDAE & CENSOLAR, 2011).
- As a weather data set, Meteonorm is selected.
- Helioscope, itself applied inverter installment.
- Applied Condition Set 1 is shown in Figure 28.

Condition Set	
Description	Condition Set 1
Weather Dataset	TMY, 10km Grid, meteonorm (meteonorm)
Solar Angle Location	Meteo Lat/Lng
Transposition Model	Perez Model
Temperature Model	Sandia Model

Temperature Model Parameters	Rack Type	a	b	Temperature Delta
	Fixed Tilt	-3.56	-0.075	3°C
	Flush Mount	-2.81	-0.0455	0°C

Soiling (%)	J	F	M	A	M	J	J	A	S	O	N	D
	2	2	2	2	2	2	2	2	2	2	2	2

Irradiation Variance	5%
Cell Temperature Spread	4° C
Module Binning Range	-2.5% to 2.5%
AC System Derate	0.50%

Figure 28: Applied Condition Set by Helioscope Software

3.2.1.2 Application of Poly-Si Panels to Pitched Roof Residential Buildings

Poly-Si modules are applied as Landscape (horizontal) oriented. The application is made the same way with the Mono-Si Module application, except orientation is selected only Landscape (horizontal). Table 8 shows the features of the selected Poly-Si panel model.

Table 8: Features of selected Poly-Si panel model for pitched roof

Description	**Data**
PV Panel Model	1 Soltech 1 STH-320 (Horizont)
Power	320.0 W
Number of cells	80 cells
Dimensions	1.306 m x 1.652 m
Area of a panel	2.158 m^2
Module Efficiency	14.85%

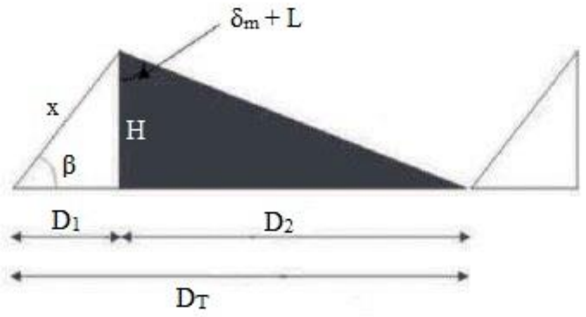

Figure 29: Triangle shadow method for the computation of the row spacing of the system (Karaveli, 2014)

To use the rooftop area efficiently, row spacing is highly important to eliminate the shading effect. Hence, the triangle shadow method (Figure 29) is used to reach the most efficient module distance (row spacing). In there,

$D_1 = X * \cos \beta$ (eqn. I)

$H = X * \sin \beta$ (eqn. II)

$D_2 = H * \tan (\delta_m + L)$ (eqn. III)

$D_T = D_1 + D_2$ (eqn. IV) (Karaveli, 2014)

and β is tilt angle of modules, δ_m is declination and L is latitude.

3.2.1.3 Application of Mono-Si and Poly-Si Panels to Flat Roof Residentials

In flat roof residential buildings,

- Racking is selected as “fixed-tilt.” The tilt angle is taken as 32°, which is the optimum angle for Ankara.
- Azimuth Angle is determined differently by Helioscope Software for every roof.
- Orientation is applied as Portrait (Vertical).

For the Mono-Si application, 1-Soltech 1 STH 320 M (Table 7) and for Poly-Si application Trina Solar TSM-PD14 320 (Table 10) are selected.

Since racking is selected as fixed-tilt, row spacing is determined according to module size, explained in Figure 29. Row spacing is determined as 1.889 m for Mono-Si application, shown in Table 9, 2.295 m for Poly-Si application, shown in Table 11, below.

Table 9: Row Space Calculation of Soltech 1-STH-320M Module

β	cosβ	X (mm)	D1	δm	L (Ankara)	H(mm)	δm+L	tan (δm+L)	D2	DT (m)
32	0.848	1614	1346.44	23.45	39.93	890	63.38	0.61	543.39	1.8898

Table 10: Features of selected Poly-Si panel model

Description	**Data**
PV Panel Model	Trinasolar TSM-PD14 320
Power	320.0 W
Number of cells	72 cells
Dimensions	0.992 m x 1.960 m
Area of a panel	1.944
Efficiency of Module	16.5%

Table 11: Row Space Calculation Trinasolar TSM-PD14 320 Module

β	cosβ	X (mm)	D1	δm	L (Ankara)	H(mm)	δm+L	tan (δm+L)	D2	DT (m)
32	0.848	1960	1635.078	23.45	39.93	1080.80	63.38	0.611	659.889	2.295

- Module spacing is determined as 0.1 m to interfere for any inconvenience.
- The setback is determined as 1.21 m, which is suggested by Helioscope software itself.
- Alignment is selected as centered.

- Keepouts are marked, and their setbacks and heights are selected roughly according to shadow shade.
- Module shading cut-off is selected as 10%, and the modules which have more than 10% shading are removed (IDAE & CENSOLAR, 2011).
- As a weather data set, Meteonorm is selected.
- Helioscope, itself applied inverter installment.
- The applied Condition Set 1 is shown in Figure 28.

3.2.1.4. Application of Bifacial Panels to Residential Buildings

For the bifacial module application,

- Every facade of the roof is selected as different field segments.
- The selected module features are presented in Table 12.
- Racking is selected as “fixed-tilt.” The tilt angle is taken as 32°, which is the optimum angle for Ankara.
- Azimuth Angle is determined differently by Helioscope for every field segments.
- Orientation is applied as Portrait (Vertical).
- Since racking is selected as fixed-tilt racking, row spacing is determined as 2.3067 m, which calculation is explained in Figure 29 and showed in Table 13.
- Module spacing is determined as 0.1 m to interfere for any inconvenience.
- The setback is determined as 0.8 m according to Roof Mounted PV Setbacks and Conduit Requirements (City of American Canyon, 2018) for pitched roof and 1.21 m for the flat roof.
- Alignment is selected as centered.
- Keepouts are marked, and their setbacks and heights are selected roughly according to shadow shade.
- Module shading cutoff is selected as 10%, and the modules which have more than 10% shading are removed (IDAE & CENSOLAR, 2011).
- As a weather data set, Meteonorm is selected.
- Helioscope, itself applied inverter installment.

- The applied Condition Set 1 is shown in Figure 28.

Table 12: Features of selected Bifacial panel model

Description	**Data**
PV Panel Model	Silfab SLA-X 350 Bifacial
Power	350.0 W
Number of cells	72 cells
Dimensions	0.99 m x 1.97 m
Area of a panel	1.95 m^2
Efficiency of module	18%

Table 13: Row Space Calculation for Silfab SLA-X 350 Bifacial Module

β	**cosβ**	**X (mm)**	**D1**	**δm**	**L (Ankara)**	**H(mm)**	**δm+L**	**tan (δm+L)**	**D2**	**DT (m)**
32	0.848	1970	1643.42	23.45	39.93	1086.31	63.38	0.611	663.25	2.3067

Helioscope Program allows us to enter only one tilt angle for every project. However, for bifacial module application in a pitched roof, there is no option for given both roof angle and module tilt angle. Hence, to see the differences, rear side mean annual irradiation is calculated for both 12°, which is a difference of optimum tilt angle (32°) and roof angle (20 °), and 32 °, which illustrated in Figure 30 for sample 15.

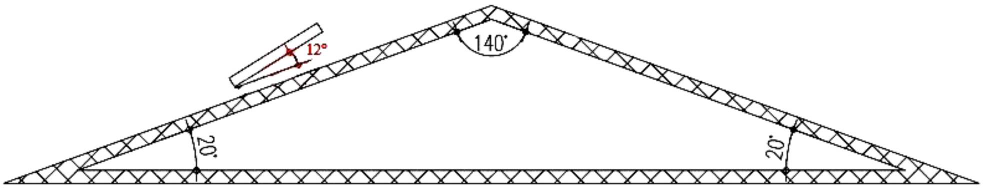

Figure 30: Illustration of Application of Bifacial Module in Pitched Roof

For front side:

$$I_T = I_b*R_b + I_d\left(\frac{1+\cos\beta 1}{2}\right) + I*\rho_g*\left(\frac{1-\cos\beta 1}{2}\right)$$ (eqn. V) (Liu, 1963)

For rear side:

$$I_{T,back} = I_b*R_{b,back} + I_d\left(\frac{1-\cos\beta 2}{2}\right) + 0.33*I*\rho_g*\left(\frac{1+\cos\beta 2}{2}\right)$$ (eqn. VI) (Durusoy, Ozden, & Akinoglu, 2020)

Table 14: Irradiation data set for sample #15 on 4th September 2021

	Beam H.I (W/m^2)	**Diffuse H.I. (W/m^2)**	**Global H.I. (W/m^2)**	**I, tilted front (W/m^2)**	**Rb**	**Rb, back**	**I, tilted rear (32°) (W/m^2)**	**I, tilted rear (12°) (W/m2)**
5:00	0.00	0.00	0.00	0.00	1.93	1.12	0.00	0.00
6:00	0.00	5.62	5.62	5.28	0.21	1.00	0.77	0.43
7:00	60.07	74.27	134.33	130.69	1.00	0.00	13.84	9.58
8:00	150.88	140.42	291.30	302.79	1.12	0.00	28.44	20.55
9:00	225.02	217.12	442.13	468.90	1.16	0.00	43.46	31.24
10:00	262.83	290.03	552.87	587.52	1.18	0.00	55.76	39.26
11:00	320.47	318.92	639.38	687.00	1.19	0.00	63.23	45.23
12:00	399.25	287.00	686.25	753.49	1.20	0.00	63.66	47.94
13:00	405.68	270.45	676.13	799.66	1.33	0.00	61.79	47.09
14:00	314.65	305.10	619.75	667.94	1.20	0.00	60.98	43.79
15:00	283.32	236.55	519.87	564.72	1.19	0.00	49.68	36.52
16:00	185.10	197.00	382.10	406.95	1.18	0.00	38.27	27.10
17:00	90.65	133.25	223.90	231.90	1.16	0.00	23.78	16.07
18:00	26.63	50.80	77.43	77.88	1.12	0.00	8.58	5.61

Table 14: Irradiation data set for sample #15 on 4th September 2021 (cont'd)

19:00	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.00
20:00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	0.00
21:00	0.00	0.00	0.00	0.00	0.00	1.12	0.00	0.00

In there, global horizontal irradiance and diffuse horizontal irradiance are taken from Helioscope hourly report for Sample 15. Since albedo values differ from 0.2 and 0.4, it is taken as 0.2 as a constant. For the front side, β_1 is taken as 32°, and for the rear side calculation, β_2 is taken as both 32° and 12°. In Table 14, Eqn (V) and Eqn (VI) is used for a sample-specific day: 4th September 2021.

While applying the dataset for a year, $I_{T,\ front}$ is calculated as 1588558.25 Wh/ m^2 from eqn (V) $I_{T,\ back}$ with 32° tilt angle, is calculated as 137396.7 Wh/m^2 and $I_{T,\ back}$ with 12° tilt angle, is calculated as 103243 Wh/m^2 from eqn (VI). To compare energy output per area, eqn (VII) is calculated.

(E/A): PR * h* η_{nom} (eqn. VII) (Baumgaertner, 2016)

In there, E is energy (Wh), A is area (m^2), PR is Performance Ratio, h is a yearly sum of irradiance (Wh/ m^2), η_{nom} is nominal module efficiency. PR is taken as 82.5% from the Helioscope report, and nominal module efficiency is taken as 17.1 % according to selected module SILFAB SLA-X 350.

Then, for 32° tilt angle case, the energy output is found as 243489.09 Wh/$m^{2,}$ and in 12° tilt angle case, it is found as 238670.9 Wh/m^2. Since Sample #15 includes 24 modules and module area is 1.95 m^2, shown in Table 12, the annual energy yield is found as 11.41 MWh in 32° tilt angle case and 11.18 MWh for 12 ° tilt angle case. So, it is found that the application of the Helioscope software program for bifacial modules in the pitched roof is acceptable.

3.2.2 Application in Public Buildings

For calculation of suitable area ratio (access factor), the Helioscope software is used. 5 Public Buildings are selected as samples. Samples are selected considering both their resolution and ability of 3D Building versions in Google Earth to get more accurate roof size and keepout heights.

Table 15: Selected Public Buildings

Samples	Roof Type	Roof Area (m^2)
The Department of Revenue	Flat	1110
Turkish Petroleum (TPAO)	Flat	1134.85
The Ministry of Foreign Affairs	Flat	3668.11
Turkish Air Force	Flat	2552.57
The Ministry of Culture and Tourism	Flat	4104.39

Although all public building samples have flat-roof, some of the Ministries have a lot of residential-type pitched roof additional buildings. Hence, for the ones with a pitched roof, the same way application is made with pitched roof residential.

3.2.2.1 Application of Mono-Si Panels to Public Buildings

For Mono-Si application,

- The features of the selected module are shown in Table 7.
- Racking is selected as “fixed-tilt,” and the tilt angle is taken as 32°, which is the optimum angle for Ankara.
- Azimuth Angle is determined by Helioscope individually to the sample.
- Orientation is applied as Portrait (Vertical).

- Since racking is selected as fixed-tilt racking, row spacing is determined as 1.8898 m, shown in Table 9, and module spacing is determined as 0.1 to interfere for any inconvenience.
- The setback is determined as 1.21 m, which is suggested by the Helioscope program.
- Alignment is selected as centered.
- Keepouts are marked, their setbacks and heights are selected roughly according to shadow shade and 3D building pictures.
- Module shading cutoff is selected as 10%, and the modules which have more than 10% shading are removed (IDAE & CENSOLAR, 2011).
- As a weather data set, Meteonorm is selected.
- Helioscope, itself applied inverter installment.
- The applied Condition Set 1 is shown in Figure 28.

3.2.2.2 Application of Poly-Si Panels to Public Buildings

For the Poly-Si module application, the same way of application is done with Mono-Si Panels. The selected module features shown in Table 10, and the row spacing is given as 2.295 m, shown in Table 11.

3.2.2.3 Application of Bifacial Panels to Public Buildings

In this part, steps are repeated in the same way with other public building applications according to the Bifacial module features, which shown in Table 12 with row space is given as 2.3067 m, which is shown in Table 11.

3.2.3 Application in Commercial Buildings

In this thesis, as commercial buildings, only shopping malls are included. As samples, CEPA and Armada are selected.

Table 16: Selected Shopping Malls

Samples	**Roof Type**	**Roof Area (m^2) (Google Earth)**
CEPA	Flat	22227.21
ARMADA	Flat	6970

For application in Commercial Buildings, the same modules are used with the same row spacing with Public Buildings part. Solely, setbacks are taken as 2 m since the roof area is wider, and obstacles are more complex such as aeration units.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Residential Buildings Application Results

4.1.1 Mono-Si Panel Applications in Residential Buildings

As mentioned in the Methodology Part, Mono-Si Panels are installed in both vertical and horizontal orientation. Since the total module area is the same, the most efficient orientation is selected. In Table 17, the Helioscope application results are given. The number of modules and annual energy (MWh) are taken from the Helioscope, and according to these results, the usable area first, then its ratio, is calculated for all samples.

Table 17: Determination of Usable Area Ratio for Mono-Si Modules in Residential Buildings

Pitched Roof Apartments	# of modules	Annual Energy (MWh)	Module area (m^2)	Usable Area (m^2)	Ratio (%)	Efficient Position
Yesiloz Apt	47	17.55	2.14	100.66	21.39	V
Hacı Tahsin Apt.	69	26.5	2.14	147.78	22.5	V
Kocak Apt.	38	14.08	2.14	81.39	21.16	H
Kilic Apt.	49	19.64	2.14	104.95	30.79	H
Beyler Apt.	35	12.89	2.14	74.96	19.78	V
Isik Apt.	60	22.24	2.14	128.51	24.37	V
Beyaz Apt.	56	19.82	2.14	119.94	25.98	V
Kivanc Apt.	53	23.9	2.14	113.51	21.46	V=H
Emcag Sitesi	17	5.78	2.14	36.41	13.86	V
Cem Koc Apt.	35	12.66	2.14	74.96	20.37	V
Altınel Park Konutlari	77	30.16	2.14	164.92	18.75	V

Table 17: Determination of Usable Area Ratio for Mono-Si Modules in Residential Buildings (cont'd)

Eryaman Evleri	88	30.46	2.14	188.48	25.15	H
Average					**22.13**	
Detached Houses	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**	**Efficient Position**
Yasamkent 3068.sk	18	6.75	2.14	38.55	18.77	H
Gözde Evler	7	2.83	2.14	14.99	18.67	V=H
Alacaatlı Bahceci Konaklari	22	7.73	2.14	47.12	14.28	V
Average					**17.24**	
Flat Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**	
Birlik Konutları	22	9.49	2.14	47.12	17.98	
Okyanus Plaza	49	21.16	2.14	104.95	14.98	
Average					**16.48**	

As shown in Table 17, the usable area is calculated by the number of modules given by Helioscope results multiplied with the module area. A suitable area is then divided into the total roof area, which is measured by Google Earth. According to these results, the usable area ratio is 22.13% for pitched roof residential buildings, 16.48% for flat-roof residential buildings and 17.24% for detached houses. Then, according to Helioscope's annual energy results, average annual energy yields of modules are calculated (Table 18).

Table 18: Average Annual Energy Production per Mono- Si Module

Samples	**STH-320M, 1 Soltech (Mono- Si)**		
Pitched Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**1 module/year (MWh/year)**
Yesiloz Apt	47	17.55	0.37
Hacı Tahsin Apt.	69	26.5	0.38
Kocak Apt.	38	14.08	0.37

Table 18: Average Annual Energy Production per Mono- Si Module (cont'd)

Kilic Apt.	49	19.64	0.40
Beyler Apt.	35	12.89	0.37
Isik Apt.	60	22.24	0.37
Beyaz Apt.	56	19.82	0.35
Kıvanç Apt	53	23.9	0.45
Emcag Sitesi	17	5.78	0.34
Cem Koc Apt.	35	12.66	0.36
Altınel Park Konutlari	77	30.16	0.39
Eryaman Evleri	88	30.46	0.35
Average			**0.38**
Flat Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**1 module /year (MWh/ year)**
Birlik Konutları	22	9.49	0.43
Okyanus Plaza	49	21.16	0.43
Average			**0.43**
Detached Houses	**# of modules**	**Annual Energy (MWh)**	**1 module/year (MWh/ year)**
Yasamkent 3068.sk	18	6.75	0.38
Gözde Evler	7	2.83	0.40
Alacaatlı Bahceci Konaklari	22	7.73	0.35
Average			**0.38**

As shown in Table 6, 12 buildings have pitched roofs, and 2 buildings have flat-roof in apartments; hence, flat-roof residential buildings are assumed as 1/7 of total residential high-rise buildings (apartments). In Table 18, both the number of modules and their production yield (MWh) and then using these numbers, the energy production of a module per year is calculated. A single Mono-Si module in pitched-roof apartments produces 0.38 MWh / year, 0.43 MWh/year in flat roofs and 0.38 MWh/year in detached houses, averagely.

Table 19: Annual Energy Yield by Mono-Si Modules in Residential Buildings

	Total	# of buildings	Total Area (m^2)	Mono-Si Panel (usable area, m^2)	# of modules	Annual Energy (MWh/yr)
Pitched roof Apartments	71703	61460	18915975	4186105.17	1956124	735502.59
Flat roof apartments *according to samples 1/7 of total buildings		10243	3152662.43	519558.77	242784	104397.32
Pitched roof detached house	29475		3313165.09	571189.66	266911	101426.20
Total						**941326.12**

In Table 19, (TUIK, 2020a), building data is revised. As mentioned before, flat-roof apartments assumed as 1/7 of total apartments; hence, 1/7 of the total floor base area accounted for flat-roofs. Then, suitable area constants are applied for pitched-roof and flat-roof, separately. The number of the modules which can be placed is calculated and multiplied by module energy yields, which are found in Table 18. The total amount of energy production is found 941,326.12 MWh per year for residential by applying Mono-Si Modules.

4.1.2 Poly-Si Panel Applications in Residential Building

In Table 20, the number of modules and annual energy (MWh) shows the Helioscope application results, and according to these results, the usable area and its ratio are calculated for all samples. As mentioned in the Methodology part, since used Poly-Si modules are different, the module area differs, too. According to these results, the usable area ratio is calculated as 21.13% for pitched roof apartments, 10.93 % for flat roof apartments and 15.69 % for detached houses.

Table 20: Determination of usable area ratio for Poly-Si Modules in Residential Buildings

Pitched-Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**
Yesiloz Apt	46	17.14	2.158	99.25	21.09
Hacı Tahsin Apt.	63	24.17	2.158	135.92	20.70
Kocak Apt.	39	14.35	2.158	84.14	21.88
Kilic Apt.	47	18.76	2.158	101.40	29.75
Beyler Apt.	34	12.7	2.158	73.36	19.35
Isik Apt.	52	19.19	2.158	112.19	21.28
Beyaz Apt.	56	19.62	2.158	120.82	26.17
Kivanc Apt.	52	23	2.158	112.19	21.21
Emcag Sitesi	13	4.401	2.158	28.05	10.68
Cem Koc Apt.	32	11.33	2.158	69.04	18.76
Altınel Park Konutlari	71	27.59	2.158	153.18	17.41
Eryaman Evleri	88	30.31	2.158	189.86	25.34
Average					**21.13**
Detached Houses	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**
Yasamkent 3068.sk	15	5.63	2.158	32.36	15.76
Gözde Evler	8	3.22	2.158	17.26	21.49
Alacaatlı Bahceci Konaklari	15	5.384	2.158	32.36	9.81
Average					**15.69**
Flat-Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**
Birlik Konutları	19	8.26	1.944	36.94	14.10
Okyanus Plaza	28	12.21	1.944	54.44	7.77
Average					**10.93**

According to Helioscope's annual energy results, average annual energy yields of modules are calculated and presented in Table 21. A single Poly-Si module in pitched-roof apartments produces 0.37 MWh / year, 0.44 MWh/year in flat roofs and 0.38 MWh/year in detached houses, averagely.

Table 21: Average Annual Energy Production per Poly-Si Module

Samples	**1 STH-320 (Horizont) 1 Soltech (Pitched roof) / TrinaSolar (Flat roof)**		
Apartments	**# of modules**	**Annual Energy (MWh)**	**1 module /year (MWh/ year)**
Yesiloz Apt	51	18.88	0.37
Hacı Tahsin Apt.	63	24.17	0.38
Kocak Apt.	39	14.35	0.37
Kilic Apt.	47	18.76	0.40
Beyler Apt.	34	12.7	0.37
Isik Apt.	52	19.19	0.37
Beyaz Apt.	56	19.62	0.35
Kıvanç Apt	52	23	0.44
Emcag Sitesi	13	4.401	0.34
Cem Koc Apt.	32	11.33	0.35
Altınel Park Konutlari	71	27.59	0.39
Eryaman Evleri	88	30.31	0.34
Average			**0.37**
Flat_roof apartments	**# of modules**	**Annual Energy (MWh)**	**1 module /year (MWh/ year)**
Birlik Konutları	19	8.26	0.43
Okyanus Plaza	28	12.21	0.44
Average			**0.44**
Detached Houses	**# of modules**	**Annual Energy (MWh)**	**1 module /year (MWh/ year)**
Yasamkent 3068.sk	15	5.634	0.38

Table 21: Average Annual Energy Production per Poly-Si Module (cont'd)

Gözde Evler	8	3.22	0.40
Alacaatlı Bahceci Konaklari	15	5.384	0.36
Average			**0.38**

In below, Table 22 shows the total annual energy yield by Poly-Si modules in residential buildings with the same application steps in the Mono-Si case. The total amount of energy production is found 860,382.97 MWh per year for residential by application of Poly-Si Modules.

Table 22: Annual Energy Yield by Poly-Si Modules in Residential Buildings

<table>
<tr><th></th><th>Total</th><th># of buildings</th><th>Total Area (m^2)</th><th>Poly-Si Panel Usable Area (m^2)</th><th># of modules</th><th>Annual Energy (MWh/yr)</th></tr>
<tr><td>Pitched roof Apartments</td><td rowspan="2">71703</td><td>61460</td><td>18915975</td><td>3996945.43</td><td>1852153</td><td>690852.94</td></tr>
<tr><td>Flat roof apartments *according to samples 1/7 of total buildings</td><td>10243</td><td>3152662.43</td><td>344586.00</td><td>177256</td><td>77992.72</td></tr>
<tr><td>Pitched roof detached house</td><td colspan="2">29475</td><td>3313165.09</td><td>519835.60</td><td>240888</td><td>91537.32</td></tr>
<tr><td>Total</td><td></td><td></td><td></td><td></td><td></td><td>860382.97</td></tr>
</table>

4.1.3 Bifacial Panel Applications in Residential Building

In below, Table 23 shows the founded usable area ratios by Helioscope results. Due to the application, the usable area ratio is found as 17.59% for pitched roof apartments, 15.63% for detached houses and 10.83% for flat roof apartments.

Table 23: Determination of usable area ratio for Bifacial Modules in Residential Buildings

Pitched-Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**
Yesiloz Apt	63	24.3	1.95	122.87	26.11
Hacı Tahsin Apt.	55	20.13	1.95	107.27	16.33
Kocak Apt.	31	12.89	1.95	60.46	15.72
Kilic Apt.	53	19.22	1.95	103.37	30.33
Beyler Apt.	42	15.85	1.95	81.91	21.61
Isik Apt.	45	17.84	1.95	87.76	16.64
Beyaz Apt.	48	18.53	1.95	93.61	20.27
Kivanc Apt.	29	13.08	1.95	56.56	10.69
Emcag Sitesi	13	5.205	1.95	25.35	9.65
Cem Koc Apt.	29	10.52	1.95	56.56	15.37
Altınel Park Konutlari	75	29	1.95	146.27	16.63
Eryaman Evleri	45	16.57	1.95	87.76	11.71
Average					**17.59**
Detached Houses	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area**	**Ratio (%)**
Yasamkent 3068.sk	24	10.01	1.95	46.81	22.79
Gözde Evler	7	2.939	1.95	13.65	17.00
Alacaatlı Bahceci Konaklari	12	4.686	1.95	23.40	7.09
Average					**15.63**
Flat-Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**
Birlik Konutları	19	8.792	1.9503	37.0557	14.14
Okyanus Plaza	27	12.57	1.9503	52.6581	7.52
Average					**10.83**

According to Helioscope's annual energy results, the average annual energy yields of modules are calculated below, Table 24. For the Bifacial module application, the average module energy yield per year is found as 0.39 MWh in pitched roof residential, 0.46 MWh in flat roof residential and 0.40 MWh in detached houses.

Table 24: Average Annual Energy Production per Bifacial Module in Residential Buildings

Samples	**SLA-X 350 Bifacial, Silfab**		
Pitched Roof Apartments	**# of modules**	**Annual Energy (MWh)**	**1 module/year (MWh/ year)**
Yesiloz Apt	51	19.68	0.39
Hacı Tahsin Apt.	55	20.13	0.37
Kocak Apt.	31	12.89	0.42
Kilic Apt.	53	19.22	0.36
Beyler Apt.	33	12.28	0.37
Isik Apt.	45	17.84	0.40
Beyaz Apt.	48	18.53	0.39
Kıvanç Apt	29	13.08	0.45
Emcag Sitesi	13	5.205	0.40
Cem Koc Apt.	29	10.52	0.36
Altınel Park Konutlari	75	29	0.39
Eryaman Evleri	45	16.57	0.37
Average			**0.39**
Flat roof apartments	**# of modules**	**Annual Energy (MWh)**	**1 module /year (MWh/ year)**
Birlik Konutları	19	8.792	0.46
Okyanus Plaza	27	12.57	0.47
Average			**0.46**
Detached Houses	**# of modules**	**Annual Energy (MWh)**	**1 module/year (MWh/ year)**
Yasamkent 3068.sk	14	5.397	0.42
Gözde Evler	4	1.545	0.39

Table 24: Average Annual Energy Production per Bifacial Module in Residential Buildings (cont'd)

Alacaatlı Bahceci Konaklari	12	4.686	0.39
Average			**0.40**

In Table 25, it has shown that applying the same procedures with Mono-Si and Poly-Si modules, 849,576.78 MWh can be produced annually by application of bifacial modules.

Table 25: Annual Energy Yield by Bifacial Modules in Residential Buildings

	Total	**# of buildings**	**Total Area (m^2)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh/yr)**
Pitched roof Apartments	71703	61460	18915975	3327319.93	1706318	665464
Flat roof apartments *according to samples 1/7 of total buildings		10243	3152662.43	341433.34	175094	80543.25
Pitched roof detached house	29475		3313165.09	517847.70	265563	103569.54
Total						**849576.78**

Table 26: Summary Table for Determination of Suitable Area Constants (%)

	Mono-Si Module	**Poly-Si Module**		**Bifacial Module**
Residentials	**STH-320 M, 1 Soltech**	**1-STH-320 Horizont**	**Trinasolar**	**Silfab SLA-X 350**
Pitched roof apartments	22.13	21.13		17.59
Flat roof apartments	16.48		10.93	10.83
Pitched roof detached houses	17.24	15.69		15.63

Table 26 summarizes the suitable area constants for different modules, which will be applied to all residential buildings. Mono-Si Modules have a higher suitable area ratio for pitched roof apartments and detached houses because of the flush mount setting; row spacing is not required.

Table 27: Summary of Average Annual Energy Yield per module (MWh/yr) in Residential Buildings

	Mono-Si Module	**Poly-Si Module**		**Bifacial Module**
Residentials	**STH-320 M, 1 Soltech**	**1 Soltech 320 (Horizont)**	**TrinaSolar**	**Silfab SLA-X 350**
Pitched Roof Apartments	0.38	0.37		0.39
Flat Roof Apartments	0.43		0.44	0.46
Pitched-Roof Detached Houses	0.38	0.38		0.40

Table 27 shows that apart from suitable area ratios, the bifacial module is the most efficient one while using the same number of modules, as expected.

Table 28: Summary of Annual Energy Yield Calculations for Different Type of Modules Scenarios in Residential Buildings

Mono-Si Module Scenario (MWh/yr)	**Poly-Si Module Scenario (MWh/yr)**	**Bifacial Module Scenario (MWh/yr)**
941,326.12	860,382.97	849,576.78

As can be seen in Table 28, although the bifacial modules produce more energy per module, according to the size of the roofs and the row spacing, less module is settled, so energy is produced in the Bifacial scenario.

As can be seen in Figure 29, the required row spacing is calculated. However, by doing small revisions in-row spacing, the number of modules might be increased according to the roof's location and size since the shading ratio is limited by 10%. The Ministry of Family, Labor and Social Services includes four buildings. By applying Silfab SLA-X 350 (Bifacial module, oriented vertically) (350W), as shown in Figure 31, 108 modules are settled by 2.3067 m row spacing 58.45 MWh is produced.

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Portrait (Vertical)	32°	158.713°	2.3 m	1x1	21	18	6.30 kW
Field Segment 2	Fixed Tilt	Portrait (Vertical)	32°	156.641°	2.3 m	1x1	26	26	9.10 kW
Field Segment 3	Fixed Tilt	Portrait (Vertical)	32°	158.407°	2.3 m	1x1	18	15	5.25 kW
Field Segment 4	Fixed Tilt	Portrait (Vertical)	32°	157.863°	2.3 m	1x1	49	49	17.2 kW

Figure 31: The number of settled modules in The Ministry of Family, Labor and Social Services with fixed 2.3067 m row spacing (Bifacial module application)

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Portrait (Vertical)	32°	158.713°	2.8 m	1x1	48	45	15.8 kW
Field Segment 2	Fixed Tilt	Portrait (Vertical)	32°	156.641°	3.0 m	1x1	26	26	9.10 kW
Field Segment 3	Fixed Tilt	Portrait (Vertical)	32°	158.407°	2.7 m	1x1	18	15	5.25 kW
Field Segment 4	Fixed Tilt	Portrait (Vertical)	32°	157.863°	2.8 m	1x1	64	64	22.4 kW

Figure 32: The number of settled modules in The Ministry of Family, Labor and Social Services with varied row spacing (Bifacial module application)

However, when the row spacing is revised, such as in Figure 32, the total module number increases to 150 from 108, and annual production increases to 82.14 MWh from 58.45 MWh. Furthermore, for the same ministry also 1-Soltech 1 STH-320 M (Mono Si, oriented vertically) is applied. Figure 33 shows that when 1.8898 m row spacing is strictly applied, 130 modules are settled, and 64.40 MWh is produced.

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Portrait (Vertical)	32°	158.713°	1.9 m	1x1	35	33	10.6 kW
Field Segment 2	Fixed Tilt	Portrait (Vertical)	32°	156.641°	1.9 m	1x1	25	25	8.00 kW
Field Segment 3	Fixed Tilt	Portrait (Vertical)	32°	158.407°	1.9 m	1x1	33	30	9.60 kW
Field Segment 4	Fixed Tilt	Portrait (Vertical)	32°	157.863°	1.9 m	1x1	42	42	13.4 kW

Figure 33: The number of settled modules in The Ministry of Family, Labor and Social Services with fixed 1.8898 m row spacing (Mono- Si application)

On the other hand, when the revised row spacing values applied, in Figure 34, the total module numbers increased to 169, and annual production increased to 84.04 MWh.

Field Segments

Description	Racking	Orientation	Tilt	Azimuth	Intrarow Spacing	Frame Size	Frames	Modules	Power
Field Segment 1	Fixed Tilt	Portrait (Vertical)	32°	158.713°	1.9 m	1x1	35	33	10.6 kW
Field Segment 2	Fixed Tilt	Portrait (Vertical)	32°	156.641°	1.9 m	1x1	25	25	8.00 kW
Field Segment 3	Fixed Tilt	Portrait (Vertical)	32°	158.407°	2.0 m	1x1	40	37	11.8 kW
Field Segment 4	Fixed Tilt	Portrait (Vertical)	32°	157.863°	1.5 m	1x1	74	74	23.7 kW

Figure 34: The number of settled modules in The Ministry of Family, Labor and Social Services with varied row spacing (Mono- Si application)

Hence, when the row spacing is explicitly defined to the roof, the number of modules will increase, and the produced energy amount will increase. Figure 35 and Figure 36 show the Helioscope application results for Sample #1, Yesiloz Apt, which have a 4-segmented pitched roof. As can be seen, although flush mount settling does not require space between modules, 5 modules settled more in the Bifacial scenario due to the north-facing roof area.

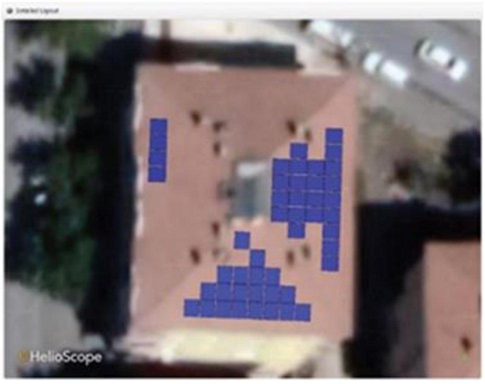

Figure 35: Sample #1 Mono-Si Module Application

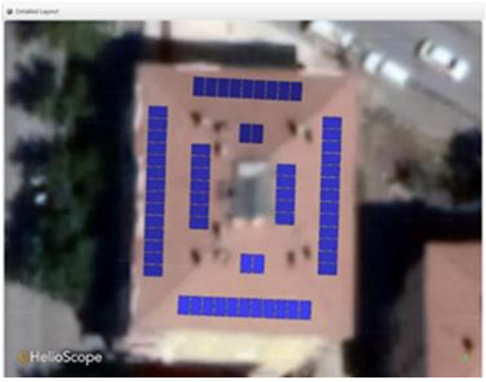

Figure 36: Sample #1 Bifacial Module Application

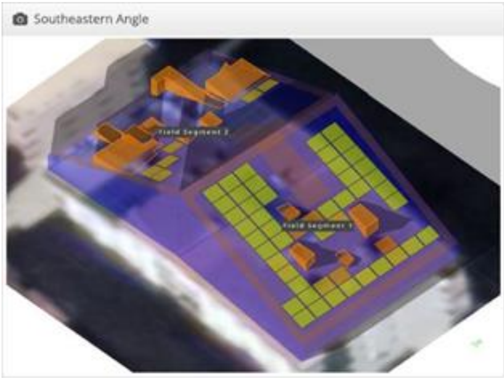

Figure 37: Sample #7 Mono-Si Module Application

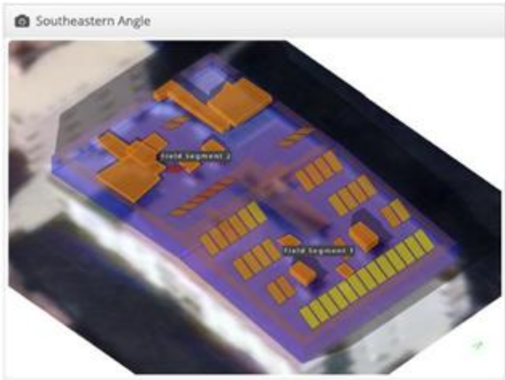

Figure 38: Sample #7 Bifacial Module Application

In the above, Figure 37 and Figure 38 show the Helioscope application in Sample #7, Beyaz Apt, which has 2-segmented pitched roof. Since the roof orientated in East-West direction, Mono-Si modules 8 more settled by a flush mount. Furthermore below, Figure 39 and Figure 40 show the shading results of sample #15, a detached house with a 2-segmented pitched roof. In Bifacial application, 8 modules settled more due to the North-South direction of the roof. Moreover, since detached houses' roof area is less than apartments, row spacing does not affect the module numbers as much as apartments.

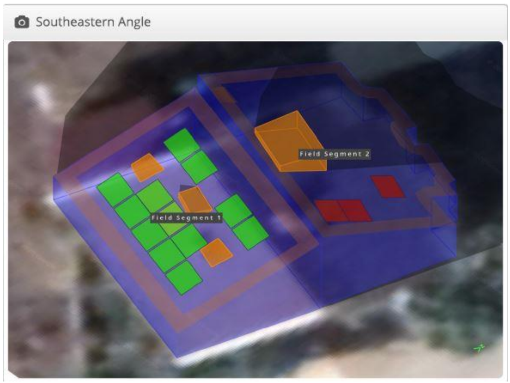

Figure 39: Sample #15 Mono-Si Module Application

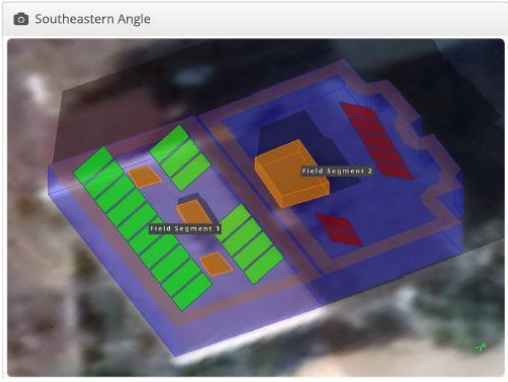

Figure 40: Sample #15 Bifacial Module Application

4.2 Public Buildings Application Results

As mentioned in the Methodology part, 5 Public buildings are selected, and the Helioscope program is applied for 3 different types of modules. Although these samples are all flat roofs, it is observed that a lot of public buildings also have residential type pitched roof apartments as additional buildings. Hence, residential building constants (i.e., usable area ratio and energy production per module) are used for pitched roof ones. The detailed building features are shown in Appendices.

4.2.1 Mono-Si Panel Applications in Public Buildings

In below, Table 29 shows the Helioscope application results for Mono-Si modules are settled. Suitable area ratios are found between 10.86 % and 15.27 %, and the average suitable area of the samples found as 12.43.

Table 29: Determination of usable area ratio for Mono-Si Modules in Public Buildings

Samples	# of modules	Annual Energy (MWh)	Module area (m^2)	Usable Area (m^2)	Ratio (%)
The Department of Revenue	56	27.13	2.142	119.94	10.81
Turkish Petroleum (TPAO)	59	24.42	2.142	126.36	11.13
The Ministry of Foreign Affairs	186	78.05	2.142	398.37	10.86
Turkish Air Force	182	88.14	2.142	389.80	15.27
The Ministry of Culture and Tourism	270	134.2	2.142	578.28	14.09
Average					**12.43**

Moreover, Table 30 shows the average energy production of Mono-Si modules in Public buildings. The average annual energy yield per module is found as 0.46 MWh averagely.

Table 30: Average Annual Energy Production per Mono- Si Module in Public Buildings

Samples	# of modules	Annual Energy (MWh)	1 module/year (MWh/yr)
The Department of Revenue	56	27.13	0.4845
Turkish Petroleum (TPAO)	59	24.42	0.4139
The Ministry of Foreign Affairs	186	78.05	0.4196
Turkish Air Force	182	88.14	0.4843
The Ministry of Culture and Tourism	270	134.2	0.4970
Average			**0.460**

4.2.2 Poly-Si Panel Applications in Public Building

In below, Table 31 shows the Helioscope application results for Poly-Si modules are settled. Suitable area ratios are found between 9.81 % and 15.92 %, and the average suitable area of the samples is 12.80%.

Table 31: Determination of usable area ratio for Poly-Si Modules in Public Buildings

Samples	# of modules	Annual Energy (MWh)	Module area (m^2)	Usable Area (m^2)	Ratio
The Department of Revenue	56	27.81	1.944	108.89	9.81
Turkish Petroleum (TPAO)	64	27.01	1.944	124.44	10.97
The Ministry of Foreign Affairs	232	98.33	1.944	451.08	12.30
Turkish Air Force	197	97.07	1.944	383.03	15.01
The Ministry of Culture and Tourism	336	167.2	1.944	653.29	15.92
Total					**12.80**

Furthermore, in Table 32, it is shown that the average energy production of Poly-Si modules in Public buildings. The average annual energy yield per module is found as 0.467 MWh, averagely.

Table 32: Average Annual Energy Production per Poly-Si Module in Public Buildings

Samples	# of modules	Annual Energy (MWh)	1 module/year (MWh/yr)
The Department of Revenue	56	27.81	0.497
Turkish Petroleum (TPAO)	64	27.01	0.422
The Ministry of Foreign Affairs	232	98.33	0.424
Turkish Air Force	197	97.07	0.493

Table 32: Average Annual Energy Production per Poly-Si Module in Public Buildings (cont'd)

The Ministry of Culture and Tourism	336	167.2	0.498
Average			**0.467**

Table 33: Comparison of Settlement of Two Different Poly-Si Modules in Public Buildings

Samples	Module Type	# of Modules	Module area (m^2)	Usable Area (m)	Ratio (%)
The Department of Revenue	Suntech STP280-24/Vd	56	1.94	108.64	9.79
	Canadian Solar CS6K-280P	73	1.637	119.501	10.77
Turkish Petroleum (TPAO)	Suntech STP280-24/Vd	63	1.94	122.22	10.77
	Canadian Solar CS6K-280P	83	1.637	135.871	11.97
The Ministry of Foreign Affairs	Suntech STP280-24/Vd	232	1.94	450.08	12.27
	Canadian Solar CS6K-280P	252	1.637	412.524	11.25
Turkish Air Force	Suntech STP280-24/Vd	226	1.94	438.44	17.18
	Canadian Solar CS6K-280P	242	1.637	396.154	15.52
The Ministry of Culture and Tourism	Suntech STP280-24/Vd	293	1.94	568.42	13.85
	Canadian Solar CS6K-280P	371	1.637	607.327	14.80

Table 33 shows the application of two Poly-Si modules (Suntech and Canadian Solar) in public buildings. More modules are settled in all the samples in Canadian

Solar settlement due to the module area. However, the usable area ratio varies because of the differences in settled module numbers. Furthermore, in below Table 34 shows the annual energy production (MWh) and annual average energy production per module (MWh/year) for different modules. Although both modules, Suntech and Canadian Solar, have the same output (280 W), the produced energy amount is different. It shows that although the module type and output are the same, the number of settled modules and energy production varies by the size of the modules, row spacing and module efficiency. Hence, in this study, Trinasolar TSM-PD 14 320 W is used since it is the most commercial and has average results between Suntech and Canadian Solar.

Table 34: Average Annual Energy Production per Different Poly-Si Module in Public Buildings

Samples	Module Type	# of modules	Annual Energy (MWh)	1 module/ yr (MWh/ yr)
The Department of Revenue	Suntech STP280-24/Vd	56	24.33	0.434
	Canadian Solar CS6K-280P	73	31.62	0.433
	Trinasolar TSM PD-14 320	56	27.81	0.497
Turkish Petroleum (TPAO)	Suntech STP280-24/Vd	63	23.21	0.368
	Canadian Solar CS6K-280P	83	30.27	0.365
	Trinasolar TSM PD-14 320	64	27.81	0.422

Table 34: Average Annual Energy Production per Different Poly-Si Module in Public Buildings (cont'd)

The Ministry of Foreign Affairs	Suntech STP280-24/Vd	232	86.1	0.371
	Canadian Solar CS6K-280P	252	92.96	0.369
	Trinasolar TSM PD-14 320	232	98.33	0.424
Turkish Air Force	Suntech STP280-24/Vd	226	97.81	0.433
	Canadian Solar CS6K-280P	242	104.3	0.431
	Trinasolar TSM PD-14 320	197	97.07	0.493
The Ministry of Culture and Tourism	Suntech STP280-24/Vd	293	128.2	0.438
	Canadian Solar CS6K-280P	371	162.4	0.438
	Trinasolar TSM PD-14 320	336	167.2	0.498

4.2.3 Bifacial Panel Applications in Public Buildings

In below, Table 35 shows the Helioscope application results for Bifacial modules are settled. Suitable area ratios are found between 10.66 % and 14.68 %, and the average suitable area of the samples is found at 12.56 %.

Table 35: Determination of usable area ratio for Bifacial Modules in Public Buildings

Samples	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio**
The Department of Revenue	61	32.3	1.95	118.97	10.72
Turkish Petroleum (TPAO)	62	28.56	1.95	120.92	10.66

Table 35: Determination of usable area ratio for Bifacial Modules in Public Buildings (cont'd)

The Ministry of Foreign Affairs	231	106.7	1.95	450.52	12.28
Turkish Air Force	189	101.4	1.95	368.61	14.44
The Ministry of Culture and Tourism	309	168.9	1.95	602.64	14.68
Total					**12.56**

Furthermore, in Table 36, it is shown that the average energy production of Bifacial modules in Public buildings. The average annual energy yield per module is found as 0.507 MWh, averagely.

Table 36: Average Annual Energy Production per Bifacial Module in Public Buildings

Samples	**# of modules**	**Annual Energy (MWh)**	**1 module/year (MWh/yr)**
The Department of Revenue	61	32.3	0.529
Turkish Petroleum (TPAO)	62	28.56	0.461
The Ministry of Foreign Affairs	231	106.7	0.462
Turkish Air Force	189	101.4	0.537
The Ministry of Culture and Tourism	309	168.9	0.547
Average			**0.507**

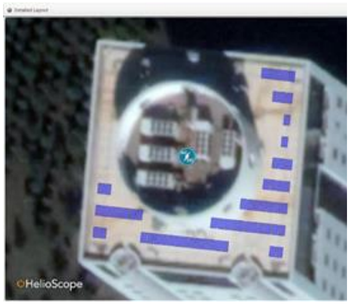

Figure 41: The Department of Revenue Bifacial Application

Figure 42: The Department of Revenue Poly-Si Module Application

Figure 43: The Department of Revenue Mono-Si Application

In the above, Figure 41, Figure 42 and Figure 43 show the different module applications in the same public building, The Department of Revenue. Due to the different sizes of the modules and the row spacing, the number and orientation of the settled modules are varied. In Figure 42 and Figure 43, 56 modules are settled; however, in Figure 41, 61 modules are settled.

Figure 44: TPAO Bifacial Module Application

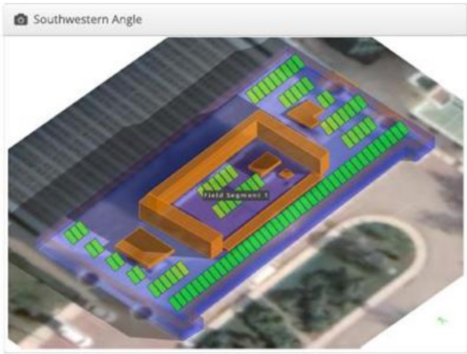

Figure 45: TPAO Bifacial Module Application Shaded Version

Besides, Figure 44 and Figure 45 show the same Bifacial module application with different versions. As can be seen, the obstacles and their shadows limit the suitable roof area highly.

In below, in Table 37, the Helioscope application results are shown for three module types. It is found that 44,343.54 MWh annual energy production is possible by Mono-Si Scenario, 45,428.04 MWh by Poly-Si Scenario and 46,593.07 MWh by

Bifacial Scenario. On the other hand, since some public buildings have pitched roofs, the produced energy amount is higher in Mono-Si Scenario for these buildings. The detailed application results in Public Buildings are shown in the Appendix.

Table 37: Results of Application of the Helioscope Software in Public Buildings

		Bifacial Module Scenario (Bifacial Silfab SLA-X 350)			Mono-Si Module Scenario (Soltech 1 STH-320M)			Poly-Si Module Scenario (1-STH 320 (Horizont) /Trinasolar)		
Buildings	**Roof Area (m^2)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
The Ministry of Justice	201425.08	33404.40	17130	6984.46	40623.53	18965	7392.15	42561.12	18431	7076.58
Council of State	11707.9	1470.51	754	382.33	1442.41	673	309.76	1498.61	771	360.01
Court of Cassation	10935.37	1749.86	897	375.99	2081.30	2385	1035.23	2023.04	960	377.25
Ministry of Family, Labor and Social Services	43934.41	7222.10	3704	1520.22	8735.90	4078	1596.07	9283.34	3979	1536.56
The Ministry of Culture and Tourism	24570.74	3548.15	1820	825.57	3928.28	1834	767.68	3910.26	1912	805.86
The Ministry of Environment and Urban Planning	26775.98	3558.75	1825	884.22	3680.46	1718	758.23	3751.40	1888	844.65

Table 37: Results of Application of the Helioscope Software in Public Buildings (cont'd)

The Ministry of Energy and Natural Resources	40607.91	5760.27	2954	1359.21	6289.93	2936	1242.34	6290.68	3095	1320.54
The Ministry of Youth and Sports	3781.02	474.90	244	123.47	465.82	217	100.04	483.97	249	116.26
The Ministry of Education	27442.59	4661.00	2390	957.09	5749.00	2684	1035.10	5523.47	2581	976.10
The Ministry of Treasury and Finance	54860.83	7401.85	3796	1817.19	7756.09	3621	1581.62	7868.97	3938	1742.62
The Ministry of Interior	131821.17	19415.23	9957	4448.19	21815.28	10185	4215.19	21606.96	10502	4364.76
The Ministry of National Defense	20105.27	3300.40	1693	695.46	3988.79	1862	729.23	3857.21	1818	702.66
The Ministry of Health	428516.79	59196.79	30357	14263.36	63276.28	29541	12705.52	63751.63	31642	13761.99
The Ministry of Industry and Technology	26479.01	3585.66	1839	877.74	3769.10	1760	766.72	3819.72	1909	842.51
The Ministry of Commerce	25860.12	3248.03	1666	844.49	3185.97	1487	684.19	3310.10	1703	795.17
The Ministry of Agriculture and Forestry	61981.95	9796.29	5024	2125.01	11558.91	5396	2151.81	11264.62	5364	2164.14

Table 37: Results of Application of the Helioscope Software in Public Buildings (cont'd)

The Ministry of Transportation and Infrastructure	11884.3	1539.06	789	390.42	1554.61	726	326.24	1598.01	812	376.62
The Ministry of Foreign Affairs	69975.81	10683.96	5479	2198.96	11657.96	5443	2106.13	10746.97	5034	1960.15
Institutions and Organizations Affiliated to the Presidency	159778.93	21790.45	11175	5304.16	23043.60	10758	4665.68	23303.81	11619	5100.65
Turkish Court of Accounts	6600	828.96	425	215.53	813.12	380	174.62	844.80	435	202.94
Total	**1389045.18**	**202636.61**	**103916**	**46593.07**	**225416.34**	**106650**	**44343.54**	**227298.68**	**108641**	**45428.04**

4.3 Commercial Buildings Application Results

As mentioned in the Methodology part, shopping malls are considered as a commercial building. For the Helioscope application, two shopping malls are selected: CEPA and ARMADA.

4.3.1 Mono-Si Applications in Commercial Buildings

In below, Table 38 shows the application results of the Mono-Si Module in CEPA and ARMADA. The suitable area constants are determined by 20.94% for CEPA and 19.79% for ARMADA. Hence, the suitable area constant for shopping malls is determined as 20.36%.

Table 38: Determination of usable area ratio for Mono-Si Modules in Commercial Buildings

Samples	**# of modules**	**Annual Energy (MWh)**	**Module area (m^2)**	**Usable Area (m^2)**	**Ratio (%)**
CEPA	2173	923.5	2.14	4654.08	20.94
Armada	644	260	2.14	1379.31	19.79
Average					**20.36**

Therefore, the average energy production per module is found as 0.414 MWh/yr in the Mono-Si module application, shown in Table 39.

Table 39: Average Annual Energy Production per Mono- Si Module in Commercial Buildings

Samples	# of modules	Annual Energy (MWh)	1 module /year (MWh/yr)
CEPA	2173	923.5	0.425
Armada	644	260	0.404
Average			**0.414**

4.3.2 Poly-Si Applications in Commercial Buildings

In below, Table 40 shows the application results of the Poly-Si Module in CEPA and ARMADA. The suitable area constants are determined by 20.25% for CEPA and 17.60 % for ARMADA. Hence, the suitable area constant for shopping malls is determined as 18.93 %.

Table 40: Determination of usable area ratio for Poly-Si Modules in Commercial Buildings

Samples	# of modules	Annual Energy (MWh)	Module area (m^2)	Usable Area (m^2)	Ratio (%)
CEPA	2315	993.7	1.94	4501.10	20.25
Armada	631	257.9	1.94	1226.87	17.60
Average					**18.93**

Furthermore, the average energy production per module is found as 0.419 MWh/yr in the Poly-Si module application, shown in Table 41.

Table 41: Average Annual Energy Production per Poly- Si Module in Commercial Buildings

Samples	**# of modules**	**Annual Energy (MWh)**	**1 module /year (MWh/yr)**
CEPA	2315	993.7	0.429
Armada	631	257.9	0.409
Average			**0.419**

Table 42: Different Poly-Si Module Applications in CEPA

Module Name	**Output (W)**	**Module Area (m^2)**	**Module Efficiency (%)**	**Row Spacing (m)**	**# of Modules**	**Produced Energy (MWh)**	**1 module/year (MWh/yr)**
Suntech STP280-24 /Vd	280	1.94	14.4	2.29	2462	921.4	0.374
Canadian Solar Inc CS3K-280P 1500V	280	1.644	16.85	1.961	2962	1038	0.350
Canadian Solar CS6K-280P	280	1.637	17.11	1.932	3023	1338	0.443
AE Solar AE280 SMP6-60	280	1.66	17.26	1.96	2970	1117	0.376
Trinasolar TSM-PD14 320	320	1.944	16.5	2.295	2315	993.7	0.429

As can be seen in Table 42, to see the effect of module brands, five different Poly-Si modules are settled. The number of settled modules and produced energy varies throughout the ones with the same output (280 W). Although the modules have similar features, a settled number of modules and produced energy highly depend on row spacing and module efficiency. Although Canadian Solar Inc CS3K-280P 1500

V and AE Solar AE280 SMP6-60 have the same row spacing (1.96 m), in AE Solar AE280 SMP6-60 module application, 79 MWh extra energy produced and energy production per module is increased from 0.35 MWh/yr to 0.376 MWh/yr due to the difference between the efficiencies. On the other hand, although Canadian Solar CS6K-280P has less efficiency (17.11%) than AE Solar AE280 SMP6-60 (17.26%) produced more energy, due to the number of modules.

4.3.3 Bifacial Applications in Commercial Buildings

Figure 46: Helioscope Bifacial Module Settlement in CEPA

Figure 47: Helioscope Bifacial Module Settlement in ARMADA

In the above, the Bifacial module application in CEPA is shown in Figure 46, and the Bifacial module application in ARMADA is shown in Figure 47. As can be seen in there, although shopping malls have relatively wide and flat roof areas, since balustrades, obstacles, and their shadows cover a large area, the suitable area constant is not as higher as expected.

In below, Table 43 shows that the average suitable area constant is selected 19.78% for shopping malls.

Table 43: Determination of usable area ratio for Bifacial Modules in Commercial Buildings

Samples	# of modules	Annual Energy (MWh)	Module area (m^2)	Usable Area (m^2)	Ratio (%)
CEPA	2511	1180	1.95	4897.20	22.03
Armada	626	279.3	1.95	1220.89	17.52
Average					**19.78**

Furthermore, the average energy production per module is found as 0.458 MWh per year for Bifacial modules.

Table 44: Average Annual Energy Production per Bifacial Module in Commercial Buildings

Samples	# of modules	Annual Energy (MWh)	1 module /year (MWh/yr)
CEPA	2511	1180	0.469
Armada	626	279.3	0.446
Average			**0.458**

Moreover, Table 45 shows the application results of shopping malls in three scenarios: The Bifacial scenario, the Mono-Si scenario and the Poly-Si scenario. By applying Mono-Si modules, energy production is calculated as 10,621.74 MWh/year; 11,017.50 MWh/year by Poly-Si module application and 12,598.82 MWh/year by the Bifacial module application.

Table 45: Results of Application of Helioscope to All Shopping Malls

		Bifacial Module Scenario (Bifacial Silfab SLA-X 350)			Mono-Si Module Scenario (Soltech 1 STH-320M)			Poly-Si Module Scenario (Trinasolar TSM-PD14)		
Shopping Malls	**Roof Area (m^2)**	**Suitable Area(m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Arcadium	8156.77	1612.95	827	378.84	1660.72	775	320.98	1544.08	794	332.80
Gordion	19593.01	3874.40	1987	909.99	3989.14	1862	771.01	3708.96	1908	799.41
Kentpark	22715.77	4491.91	2304	1055.02	4624.93	2159	893.89	4300.10	2212	926.82
Karum	5500.29	1087.65	558	255.46	1119.86	523	216.44	1041.20	536	224.42
Panora	20014.94	3957.83	2030	929.58	4075.04	1902	787.61	3788.83	1949	816.62
Podium	34369.45	6796.35	3485	1596.27	6997.62	3267	1352.48	6506.14	3347	1402.30
Ankamall	42571.62	8418.28	4317	1977.22	8667.58	4046	1675.25	8058.81	4145	1736.95
Taurus	12046.47	2382.12	1222	559.49	2452.66	1145	474.04	2280.40	1173	491.51
Optimum AVM	15960.00	3155.99	1618	741.25	3249.46	1517	628.05	3021.23	1554	651.18
Kızılay AVM	3078.96	608.85	312	143.00	626.88	293	121.16	582.85	300	125.62
Acity Premium Outlet	25715.77	5085.14	2608	1194.36	5235.73	2444	1011.95	4868.00	2504	1049.22
Bilkent Center	23788.52	4704.04	2412	1104.85	4843.34	2261	936.11	4503.17	2316	970.59
FTZ AVM	3305.64	653.67	335	153.53	673.03	314	130.08	625.76	322	134.87
Arsia AVM	3028.72	598.91	307	140.67	616.65	288	119.18	573.34	295	123.57
Total	239845.93			11139.52			9438.24			9785.90

Table 45: Results of Application of Helioscope to All Shopping Malls (cont'd)

Samples										
CEPA	22227.21	4897.20	2511	1180	4654.08	2173	923.5	4501.10	2315	993.7
ARMADA	6970	1220.89	626	279.3	1379.31	644	260	1226.87	631	257.9
TOTAL	**269043.14**	**53546.18**	**27459**	**12598.82**	**54866.02**	**25615**	**10621.74**	**51130.80**	**26301**	**11037.50**

4.4 Comparison with Previous Studies

In this part, the comparison will be done between this study's results and the studies mentioned in the LITERATURE REVIEW part.

Table 46: Previous Studies' results mentioned in the Literature Review

Studies	Methods	Study Area	Findings
(Ordóñez et al., 2010)	Manual Selection Method	Spain	**Suitable Area Constants** Pitched Roof : Detached Houses: 21.12% High Rise: Buildings 16.83% Flat Roof: Detached Houses: 54.97% High Rise: Buildings 51.83%
(Bergamasco & Asinari, 2011)	GIS	Piedmont, Italy	**Suitable Area Constants** Residential: 6.5% Industrial: 30.4%
(Mainzer et al., 2014)	GIS	Germany	**Suitable Area Constant:** Pitched roof residential: 58% Flat Roof residential: 27%
(Vardimon, 2011)	Constant Value Method	Israel	**PV Access Factors:** Pitched Roof: 20% Flat Roof: 50-70 % 30% averagely.
(Tripathi, 2014)	GIS	India	**Suitable Roof Area:** Residential: 20% Commercial: 30% Industrial: 40%

Table 46: Previous Studies' results mentioned in the Literature Review (cont'd)

(Izquierdo et al., 2008)	Constant Value Method	Spain	**PV Access Factor** 19.45 %
(Khan et al., 2017)	GIS	Saudi Arabia	**Suitable Area Constant:** -All roofs are flat. 30%
(Yuan et al., 2016)	Manual Selection Method	Osaka, Japan	-
(Acar et al., 2020)	Constant Value Method	Turkey	0.25 for all types of buildings, averagely.
(Lise et al., 2018)	GIS - Manual Selection Method	Turkey	**Usable area constants (*)** Residential: 18.31% Public: 22.15% Commercial/ Industrial: 49.68%
(Paidipati et al., 2008)	Constant Value Method	U.S	**PV Access Factors:** Residential: Pitched Roof: 24% (warmer Climate) 18% (cooler climate) Flat Roof: 60% (warmer climate) 65% (cooler climate) Commercial: 60-65% **Suitable Area Constants (*):** Residential: Pitched Roof: 19 % (warmer Climate) 14% (cooler climate) Flat Roof: 48% (warmer climate) 52% (cooler climate) Commercial: 48-52%

Table 46 summarizes the results of previous studies. For simplicity, the “relation coefficient” and “available roof area” are named “PV Access Factor” which means shading and orientation effects on the roof. On the other hand, “utilization constant,” “useful rooftop area” and “useful area constant” are merged under the name of “useful area constant” which also includes space between modules, inverters and wiring. Furthermore, (*) means these constants are not given directly but calculated by the constants given in the paper. As mentioned in Literature Review Part, Lise et al., (2018) stated two different constants: Weighted average ratio of usable area and penetration factor. By multiplying these two constants, a suitable area constant is reached. Therefore, NREL (2008) stated PV Access Factors directly. Then, it is stated that the packing factor is determined as 1.25 for the requirement of space for access modules, wiring, and inverters (Paidipati, Frantzis, Sawyer, & Kurrasch, 2008). Hence, the suitable area constants are reached by dividing the PV access factor into the packing factor.

Table 47: Summary of Suitable Area Constants in the Study

	Pitched Roof Apartments (%)	**Flat Roof Apartments (%)**	**Detached Houses (%)**	**Public Buildings (%)**	**Commercial Buildings (%)**
Mono-Si	22.13	16.48	17.24	12.43	20.94
Poly-Si	21.13	10.93	15.69	12.80	18.93
Bifacial	17.59	10.83	15.63	12.56	19.78

As can be seen in Table 47, the results are similar to the previous studies in pitched roof buildings. On the other hand, in most studies, it is estimated that 50-70% suitability in flat-roof buildings. Only in two studies, they are founded as 27% in Germany (Mainzer et al., 2014) and 30 % in Saudi Arabia (Khan et al., 2017), relatively low to the other studies. Hence, it can be said that flat roofs are highly dependent on the structure and shading effects like balustrades, ventilation units, etc. Although flat roofs are more efficient for solar PV applications in many cities, it is not a case for Ankara.

Table 48: Energy Production (MWh/yr) in Buildings

Scenario	Residential	Public	Commercial
Mono-Si	941,326.12	44,343.54	10,621.74
Poly-Si	860,382.97	45,428.04	11,037.50
Bifacial	849,576.78	46,593.07	12,598.82
Optimum	943,469.45*	46,593.07	12,598.82

*In Optimum Scenario, Mono-Si modules are selected for apartments (both Pitched roof and Flat roof), and Bifacial modules are selected for detached houses.

In Table 48, the results of the study are presented. As a consequence of the results, annual energy production is estimated as 943,469.45* MWh by settling of Mono-Si modules to a pitched roof and flat roof apartments and Bifacial modules to detached houses. By settling Bifacial modules in public buildings and commercial buildings, the best values are 46,593.07 MWh/year and 12,598.82 MWh /year, respectively. By taking mean sunlight duration 8 hours and capacity factor as 0.17; technical potential estimated as 1.9 GW for residentials, 93.86 MW for public buildings and 25.38 MW for shopping malls. To compare the studies carried out for Turkey, there are also differences in calculations and results. First of all, Acar et al. (2020) has taken into account the buildings built after 1970. However, since the regulation changed after ‘1999 Earthquake’ and the stability criteria for buildings are renewed, this study has considered buildings built after 2000. Hence, building numbers and the total rooftop area are not the same. Second of all, to reach the total rooftop area, Acar et al. (2020) had made a calculation based on the average available roof area per building type. However, this study shows that although multi-dwelling buildings are categorized in the same class, their roof area varies between 262 m^2 and 880 m^2.

Moreover, although sample #2 and sample #3 are located in the same street and have the same features as 3-floored, their roof areas are almost a half. Third of all, as Table 1 shows samples of Lise et al., (2018) located in Ankara, the usable area ratio varies between 33-80%. The assumed constants are found overestimated compared to this study since the samples' features are very similar. Besides, Lise et al. (2018) estimated the rooftop solar PV technical potentials as 23.3 GW residential, 21.46 GW commercial, 2.06 GW public (46.8 GW totally), and Acar et al. (2020) estimated as 15.2 TWh residential and 5.1 TWh commercial, public and industrial. On the other hand, in this study 943,469.5 MWh for residentials, 46,593.07 MWh for public buildings and 12598.82 for commercial buildings are estimated. Ankara includes 6% of Turkey’s total population, and the energy outcomes equal to 4.94% of Acar et al. (2020) 4% of Lise et al. (2018) report results.

CHAPTER 5

CONCLUSION

Developing economy, urbanization, and increasing population cause an increase in energy demand. As an energy-intense country, Turkey supplies her energy demand gap by importing fossil fuels and externalities, both economic and environmental. As the whole developed and developing countries do, Turkey needs to shift its energy policy to sustainable, renewable, and safe energy sources. Renewable energy potential is not the same for all cities in Turkey; Turkey needs to shift the decentralized solution to supply the increasing electricity demand in urbanized areas to combat climate change and secure their energy. This study focused on the city, Ankara, to suggest a reliable, free, easily applicable, and open-sourced method to calculate rooftop solar PV's technical potential in three types of buildings: residential, public and commercial (shopping mall).

The main findings of the study are as follows:

- The PV system's efficiency in the rooftops is highly dependent on the building type and roof type.
- Mono-Si modules are determined as the optimum one for pitched-roof apartments due to flush-mount settling does not require row-spacing between the modules as in bifacial modules in the limited roof area. Bifacial modules have better efficiency than Poly-Si modules. In Mono-Si Scenario, pitched roof-apartments' total energy production was 735,502 MWh annually; 690,852 MWh in Poly-Si Scenario 665,464 MWh in the Bifacial Module scenario, respectively. The main reason for less energy production in Bifacial Scenario is that fewer number of module’s settlement.
- For flat-roof apartments, Mono-Si modules are determined as the optimum one, as well. Although all modules are settled with a 32 ° fixed tilt angle in flat roofs, the results show that module sizes and row spacing, which are determined according to module type, are significantly essential. In the study, the determined row spacing between Mono-Si modules is found as 1.89 m, the determined row spacing between Poly-Si modules is found as 2.295 m and 2.306 m for Bifacial modules. Although the average amount of energy production per

module is almost the same such as 0.43 MWh/year in Mono-Si Scenario, 0.44 MWh in Poly-Si Scenario, and 0.46 MWh/year in the Bifacial scenario, respectively; total energy production differs due to the number of the oriented modules. In Mono-Si Scenario, the total energy production in flat-roof apartments is 104,397 MWh annually; 77,992 MWh in Poly-Si 80,543 MWh in Bifacial Scenario. Under the usual conditions, the energy production per module for Poly-Si Modules cannot exceed the Mono-Si Modules while applying in the same number and same orientation. However, in this study, since the roof area is limited and row spacings are different, modules are settled in different amounts. Hence, the shading amount and average energy production per module vary.

- For detached houses, the results are varied according to the number of roof segments. Although Mono-Si and Poly-Si Modules are settled as flush mount and are not affected by row spacing, they are settled mainly in the south-east and south-west segments of the 2-segmented pitched roofs; on the other hand, bifacial modules are settled to both segments in this type of roof. However, for 4-segmented pitched roofs, the flush mount is applied more efficiently. In overall, the bifacial modules are determined as the optimum one. In the Mono-Si Scenario, detached houses' total energy production was found 101,426 MWh/year; in the Poly-Si scenario, 91,537 MWh/year and 103,569 MWh/year in the Bifacial Scenario, respectively.
- For public buildings, the Bifacial modules are determined as the optimum one. In the Mono-Si scenario, the total energy production is found as 44,343 MWh/year; in the Poly-Si scenario, 45,428 MWh/year and in the bifacial scenario, it is found as 46,593 MWh/year, respectively. However, as can be seen in Appendices, public buildings include a high amount of pitched-roof additional buildings. Hence, by applying bifacial modules to the flat-roof public buildings and Mono-Si module application to the pitched-roof public buildings will be able to increase the amount of energy production. Moreover, the average energy production per module is 0.460 MWh/year for Mono-Si modules, 0.467 MWh/year for Poly-Si modules, and 0.507 MWh/year for Bifacial modules, so in the case of the same amount of module application, Bifacial modules are more efficient options in public buildings.
- For commercial buildings, the bifacial modules are determined as the optimum one, again. In the Mono-Si scenario, the total energy production is found as 10,621 MWh/year; in the Poly-Si scenario, 11,037 MWh/year and in the bifacial scenario, it is found as 12,598 MWh/year, respectively.

- For flat roof commercial and public buildings, Poly-Si modules give better results than Mono-Si modules, unexpectedly. So, to analyze the difference, two more Poly-Si modules (Suntech STP280/Vd with 280W output and 14.4% efficiency and Canadian Solar CS6K-280P with 280W output and 17.11% efficiency) are settled. The results show that the produced energy amount depends on the features of the module brand; moreover, the average annual energy production per module is mostly dependent on module output. On the other hand, although the selected Poly-Si module brand has the same output as the selected Mono-Si module since the efficiency of Trinasolar (16.5%) is higher than 1-Soltech STH (14.94%), overall energy production in flat roofs is higher in the Poly-Si scenario.
- The technical rooftop solar PV potential of Ankara is found as 1,002.66 GWh (1,002,661.34 MWh) annually for the residential, which built-in 2000-2019, public buildings, and shopping malls.
- The amount of energy production might be increased by row spacing arrangement to the buildings individually.
- Regarding the annual total electricity per capita in Ankara is 2746 KWh, the energy production sourced by solar rooftop PV panels are able to provide electricity for 365,135 capita.

To conclude, the suitable area ratio for PV application for all types of buildings differs between 10.83%-22.13 %. This is caused by obstacles such as balustrades, chimneys, antennas, and aeration units, and their shadows, mostly. By regarding the fact that more than 2500 buildings are adding to Ankara every year, new buildings should be designed by considering PV systems. Furthermore, Ankara includes 1833 public, 3159 private educational buildings (private primary and secondary education buildings, training centers, driving courses, etc.) and 22 universities. This study might be extended with the addition of these educational buildings, industrial buildings, car parking lots, and even the addition of façade applications. One of the most crucial externalities of PV application is a land requirement due to finding a suitable area and land cost. By the usage of roofs, this externality can be eliminated. Today, many countries make research to apply PV installation in highways and roads and make regulations on compulsory rooftop solar PV installment to reach zero-emission buildings. However, as Bayraktar M. (2020) stated in ZeroBuild Forum 2020, there is no exact data for Turkey's building stock. The average energy consumption of buildings and energy efficiency comparison between the buildings located in the same city is unknown, so energy statistics deficiencies should be improved.

Furthermore, as discussed in Scaling Up Rooftop Solar Photovoltaics in Turkey Workshop (2019) by Worldbank, Turkey needs prudential and supportive regulations, such as an increase in 10 KW residential limitations, which is not enough home charger for an electrical car. In conclusion, Turkey requires decentralized and environmental-friendly solutions to provide its energy requirement. Both lack of land requirements and the chance of on-site production-consumption directly in buildings are significant by applying the rooftops and practical starting point in the energy transition.

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APPENDICES

A. Application Results in Public Buildings

Table A.1: The Ministry of Justice Application Results

Ministry of Justice	**F: Flat Roof P: Pitch Roof**		**Bifacial Module Scenario (Bifacial Silfab SLA-X 350)**			**Mono-Si Module Scenario (Soltech 1 STH-320M)**			**Poly-Si Module Scenario (1 STH 320 (Horizont) /Trinasolar)**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	2716.39	P	477.81	245.03	95.56	601.14	280.64	106.64	573.97	265.97	98.41
Additional Building	676.08	F	84.92	43.55	22.08	83.29	38.89	17.89	86.54	44.52	20.79
High Council of Judges and Prosecutor (HSYK) (Department of Internal Auditing Unit)	2513.16	F	315.65	161.87	82.07	309.62	144.55	66.49	321.68	165.48	77.28
General Directorate of Enforcement Offices	4722.68	P	830.72	426.01	166.14	1045.13	487.92	185.41	997.90	462.42	171.10
Department of Corrections and Institutions of Detention house	541.11	F	67.96	34.85	17.67	66.66	31.12	14.32	69.26	35.63	16.64

Table A.1: The Ministry of Justice Application Results (cont'd)

General Directorate of Prisons and Detention Houses	206.98	F	26.00	13.33	6.76	25.50	11.90	5.48	26.49	13.63	6.36
General Directorate of Law Services	404.29	P	71.11	36.47	14.22	89.47	41.77	15.87	85.43	39.59	14.65
General Directorate of IT	2311.1	P*	406.52	208.47	81.30	511.45	238.77	90.73	488.34	226.29	83.73
Total	14091.79		2280.70	1169.59	485.81	2732.26	1275.57	502.83	2649.62	1253.52	488.95
General Courts											
Ankara Regional Administrative Court	4813.6	F	604.59	310.05	157.19	593.04	276.86	127.36	616.14	316.94	148.01
Ankara Regional Administrative Court: Kizilay Additional Building	341.76	F	42.93	22.01	11.16	42.10	19.66	9.04	43.75	22.50	10.51
Total	5155.36		647.51	332.06	168.35	635.14	296.52	136.40	659.89	339.45	
Courthouses **											
Ankara Main Building	11986.26	F	1505.47	772.04	391.42	1476.71	689.41	317.13	1534.24	789.22	368.57
Additional Building_ Sogutozu	1755.94	F	220.55	113.10	57.34	216.33	101.00	46.46	224.76	115.62	53.99
Additional Building_ Cevizlidere	1014.35	F	127.40	65.33	33.12	124.97	58.34	26.84	129.84	66.79	31.19
Additional Building_ Etlik	2221.69	P	390.80	200.41	78.16	491.66	229.53	87.22	469.44	217.54	80.49
West Courthouse	8790.3	F	1104.06	566.19	287.06	1082.96	505.59	232.57	1125.16	578.79	270.29
Regional Administrative Court	537.32	F	67.49	34.61	17.55	66.20	30.90	14.22	68.78	35.38	16.52

Table A.1: The Ministry of Justice Application Results (cont'd)

Administrative and Tax Courts	644.46	F	80.94	41.51	21.05	79.40	37.07	17.05	82.49	42.43	19.82
Court of Conflicts	6462.5	F	811.69	416.25	211.04	796.18	371.70	170.98	827.20	425.51	198.72
Justice Academy of Turkey	1472.34	P	258.98	132.81	51.80	325.83	152.11	57.80	311.11	144.16	53.34
Total	34885.16		4567.39	2342.25	1148.53	4660.24	2175.65	970.27	4773.01	2415.44	1092.92
Penal Institutions											
Sincan Closed Prison	18988.46	P	3340.07	1712.86	668.01	4202.15	1961.79	745.48	4012.26	1859.25	687.92
Sincan No:2 F Type High Security Prison	16656.48	P	2929.87	1502.50	585.97	3686.08	1720.86	653.93	3519.51	1630.91	603.44
Sincan No:1 F Type Prison	17732.16	P	3119.09	1599.53	623.82	3924.13	1831.99	696.16	3746.81	1736.24	642.41
Sincan T Type Prison	15088.73	P	2654.11	1361.08	530.82	3339.14	1558.89	592.38	3188.25	1477.41	546.64
Sincan No:1 L Type Prison	26087.17	P	4588.73	2353.20	917.75	5773.09	2695.19	1024.17	5512.22	2554.32	945.10
Sincan No:2 L Type Prison	25880.35	P	4552.35	2334.54	910.47	5727.32	2673.82	1016.05	5468.52	2534.07	937.61
Directorate of Prison Campus Nursery	23514.96	P	4136.28	2121.17	827.26	5203.86	2429.44	923.19	4968.71	2302.46	851.91
Personal Education Center	2346.66	P	412.78	211.68	82.56	519.32	242.44	92.13	495.85	229.77	85.02

Table A.1: The Ministry of Justice Application Results (cont'd)

Personal Education Center_2	997.8	P	175.51	90.01	35.10	220.81	103.09	39.17	210.84	97.70	36.15
Total	147292.77		25908.80	13286.56	5181.76	32595.89	15217.50	5782.65	31122.96	14422.13	5336.19
Ministry of Justice Total	**201425.08**		**33404.40**	**17130.46**	**6984.46**	**40623.53**	**18965.23**	**7392.15**	**42561.12**	**18430.54**	**7076.58**

P* shows that the roof is originally U shape steel roof, but it is assumed as typical pitched roof.
** Golbası Courthouse is permanently closed. Hence, it is not included in calculations.

Table A.2: The Ministry of Family, Labor and Social Services Application Results

The Ministry of Family, Labor and Social Services	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario (Bifacial Silfab SLA-X 350)			Mono-Si Module Scenario (Soltech 1 STH-320M)			Poly-Si Module Scenario (1 STH 320 (Horizont)/ Trinasolar)		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	3065.84	F	385.07	197	100.12	377.71	176	81.11	392.43	202	94.27
Field Service	415.95	F	52.24	27	13.58	51.25	24	11.01	53.24	27	12.79
Total	3481.79		437.31	224.26	113.70	428.96	200.26	92.12	445.67	229.25	107.06
Related and Affiliated Institutions											
Directorate of Training and Research	2272.75	P	399.78	205	79.96	502.96	235	89.23	480.23	223	82.34
State Personnel Administration	443.64	F	55.72	29	14.49	54.66	26	11.74	56.79	29	13.64
Professional Competency Board	665.84	F	83.63	43	21.74	82.03	38	17.62	85.23	44	20.47
Social Security Institution	3904.59	F	490.42	251	127.51	481.05	225	103.31	499.79	257	120.06
Turkish Employment Agency	1318.72	F	165.63	85	43.06	162.47	76	34.89	168.80	87	40.55
Turkish Employment Agency Additional Buildings	3282.9	P	577.46	296	115.49	726.51	339	128.89	693.68	321	118.93
Total	11888.44		1772.64	909.04	402.25	2009.67	938.22	385.66	1984.51	960.95	396.00
Foundation of Social Help and Solidarity											
Akyurt	421.07	P	74.07	38	14.81	93.18	44	16.53	88.97	41	15.25

Table A.2: The Ministry of Family, Labor and Social Services Application Results (cont'd)

Altindağ	960.98	P	169.04	87	33.81	212.66	99	37.73	203.06	94	34.81
Ayas	1134.31	P	199.53	102	39.91	251.02	117	44.53	239.68	111	41.09
Beypazari	1312.27	P	230.83	118	46.17	290.41	136	51.52	277.28	128	47.54
Kizilay	1751.89	P	308.16	158	61.63	387.69	181	68.78	370.17	172	63.47
Cubuk	588.33	P	103.49	53	20.70	130.20	61	23.10	124.31	58	21.31
Elmadag	285.16	P	50.16	26	10.03	63.11	29	11.20	60.25	28	10.33
Etimesgut	1575.53	P	277.14	142	55.43	348.66	163	61.85	332.91	154	57.08
Evren	1048.74	P	184.47	95	36.89	232.09	108	41.17	221.60	103	37.99
Golbasi	737.64	P	129.75	67	25.95	163.24	76	28.96	155.86	72	26.72
Gudul	467.5	P	82.23	42	16.45	103.46	48	18.35	98.78	46	16.94
Haymana	945.93	P	166.39	85	33.28	209.33	98	37.14	199.88	93	34.27
Kahramankazan	1113.44	P	195.85	100	39.17	246.40	115	43.71	235.27	109	40.34
Kuscagiz	492.87	P	86.70	44	17.34	109.07	51	19.35	104.14	48	17.86
Kizilcahamam	995	P	175.02	90	35.00	220.19	103	39.06	210.24	97	36.05
Mamak	1411.88	P	248.35	127	49.67	312.45	146	55.43	298.33	138	51.15
Nallihan	1023.75	P	180.08	92	36.02	226.56	106	40.19	216.32	100	37.09
Polatli	1451.3	P	255.28	131	51.06	321.17	150	56.98	306.66	142	52.58
Pursaklar	577.4	P	101.56	52	20.31	127.78	60	22.67	122.00	57	20.92
Sincan	1552.01	P	273.00	140	54.60	343.46	160	60.93	327.94	152	56.23
Kalecik	645	P	113.46	58	22.69	142.74	67	25.32	136.29	63	23.37
Yenimahalle	572.86	P	100.77	52	20.15	126.77	59	22.49	121.05	56	20.75
Total	21064.86		3705.31	1900	741.06	4661.65	2176.31	827.00	4451.00	2063	763.15
Ankara Provincial Directorate	474.48	P	83.46	43	16.69	105.00	49	18.63	100.26	46	17.19

Table A.2: The Ministry of Family, Labor and Social Services Application Results (cont'd)

Ankara Provincial Directorate Additional Building	772.46	P	135.88	70	27.18	170.95	80	30.33	163.22	76	27.99
Total	1246.94		219.34	112	43.87	275.95	129	48.95	263.48	122	45.17
Directorate of Health and Social Security *SGM											
Ertugrul Gazi SGM	660.52	P	116.19	60	23.24	146.17	68	25.93	139.57	65	23.93
İbni Sina SGM,Kocatepe SGM	1423.86	P	250.46	128	50.09	315.10	147	55.90	300.86	139	51.58
Bahçelievler SGM, Kavaklıdere SGM	531.74	P	93.53	48	18.71	117.67	55	20.88	112.36	52	19.26
Fiscal Service SGM	150.35	P	26.45	14	5.29	33.27	16	5.90	31.77	15	5.45
Total	2766.47		486.62	249.55	97.32	612.22	285.82	108.61	584.56	270	100.22
Social Care Services (SHM)											
Yenimahalle	1301.63	P	228.96	117	45.79	288.05	134	51.10	275.03	127	47.16
Altindağ	128.25	P	22.56	12	4.51	28.38	13	5.04	27.10	13	4.65
Sincan	632	P	111.17	57	22.23	139.86	65	24.81	133.54	62	22.90
Mamak	393	P	69.13	35	13.83	86.97	41	15.43	83.04	38	14.24
Kahramankazan	321.51	P	56.55	29	11.31	71.15	33	12.62	67.94	31	11.65
Cubuk	127.42	P	22.41	11	4.48	28.20	13	5.00	26.92	12	4.62
Etimesgut	181.64	P	31.95	16	6.39	40.20	19	7.13	38.38	18	6.58
Kecioren	156.11	P	27.46	14	5.49	34.55	16	6.13	32.99	15	5.66
Total	3241.56		570.19	292	114.04	717.36	334.90	127.26	684.94	317.40	117.44

Table A.2: The Ministry of Family, Labor and Social Services Application Results (cont'd)

Violence Prevention and Monitoring Center	244.35	F	30.69	16	7.98	30.10	14	6.46	31.28	16	7.51
Ministry of Family, Labor and Social Services Total	**43934.41**		**7222.10**	**3704**	**1520.22**	**8735.90**	**4078**	**1596.07**	**9283.34**	**3979**	**1536.56**

Table A.3: The Ministry of Foreign Affairs Application Results

The Ministry of Foreign Affairs	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320**			**Poly-Si Module Scenario 1-STH 320 (Horizont)/ Trinasolar TSM-PD14**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	5505.24	F	691.46	355	179.78	678.25	317	145.65	704.67	362	169.28
Related and Affiliated Institutions											
Directorate of Foreign Relations and EU Affairs National Agency	1250.49	F	157.06	81	40.84	154.06	72	33.08	160.06	82	38.45
	987.19	F	123.99	64	32.24	121.62	57	26.12	126.36	65	30.36
Turkish Accreditation Agency	506.53	F	63.62	33	16.54	62.40	29	13.40	64.84	33	15.58
Total	8249.45		1036.13	531	269.39	1016.33	475	218.26	1055.93	543	253.66
Representations in Foreign Countries (Embassies)											
1. Islamic Republic of Afghanistan	316.83	P	49.52	25	9.90	54.62	26	9.69	49.74	23	8.76
2. Republic of Albania	263.25	P	41.15	21	8.23	45.38	21	8.05	41.33	19	7.28

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

3. People's Democratic Republic of Algeria	1323.03	P	206.79	106	41.36	228.09	106	40.46	207.72	96	36.58
4. Republic of Angola	206.11	P	32.21	17	6.44	35.53	17	6.30	32.36	15	5.70
5. Argentine Republic	284.36	P	44.45	23	8.89	49.02	23	8.70	44.64	21	7.86
6. Commonwealth of Australia	***										
7. Republic of Austria	807.10	P	126.15	65	25.23	139.14	65	24.68	126.71	59	22.31
8. Republic of Azerbaijan	1595.91	P	249.44	128	49.89	275.13	128	48.81	250.56	116	44.12
9. Kingdom of Bahrain	234.38	P	36.63	19	7.33	40.41	19	7.17	36.80	17	6.48
10. People's Republic of Bangladesh	118.58	P	18.53	10	3.71	20.44	10	3.63	18.62	9	3.28
11. Republic of Belarus	275.05	P	42.99	22	8.60	47.42	22	8.41	43.18	20	7.60
12. Kingdom of Belgium	353.14	P	55.20	28	11.04	60.88	28	10.80	55.44	26	9.76
13. Republic of Benin	415.27	P	64.91	33	12.98	71.59	33	12.70	65.20	30	11.48
14. Bosnia and Herzegovina	237.23	P	37.08	19	7.42	40.90	19	7.26	37.25	17	6.56
15. Federative Republic of Brazil	283.98	P	44.39	23	8.88	48.96	23	8.69	44.58	21	7.85
16. Brunei Darussalam	236.20	P	36.92	19	7.38	40.72	19	7.22	37.08	17	6.53
17. Republic of Bulgaria	645.45	P	100.88	52	20.18	111.28	52	19.74	101.34	47	17.84
18. Burkina Faso	306.73	P	47.94	25	9.59	52.88	25	9.38	48.16	22	8.48
19. Republic of Burundi	115.00	P	17.97	9	3.59	19.83	9	3.52	18.06	8	3.18

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

20. Kingdom of Cambodia	233.40	P	36.48	19	7.30	40.24	19	7.14	36.64	17	6.45
21. Canada	555.65	P	86.85	45	17.37	95.79	45	16.99	87.24	40	15.36
22. Republic of Chad	229.72	P	35.91	18	7.18	39.60	18	7.03	36.07	17	6.35
23. Republic of Chile	440.67	P	68.88	35	13.78	75.97	35	13.48	69.19	32	12.18
24. People's Republic of China	807.41	P	126.20	65	25.24	139.20	65	24.69	126.76	59	22.32
25. Republic of Colombia	277.00	P	43.30	22	8.66	47.75	22	8.47	43.49	20	7.66
26. Republic of the Congo	387.51	P	60.57	31	12.11	66.81	31	11.85	60.84	28	10.71
27. Republic of Costa Rica	428.44	P	66.97	34	13.39	73.86	34	13.10	67.27	31	11.84
28. Republic of Côte d'Ivoire	355.60	P	55.58	29	11.12	61.31	29	10.88	55.83	26	9.83
29. Republic of Croatia						***					
30. Republic of Cuba						***					
31. Czech Republic	509.26	P	79.60	41	15.92	87.80	41	15.58	79.95	37	14.08
32. Democratic Republic of the Congo	305.00	P	47.67	24	9.53	52.58	25	9.33	47.89	22	8.43
33. Kingdom of Denmark						***					
34. Republic of Djibouti	197.16	P	30.82	16	6.16	33.99	16	6.03	30.95	14	5.45
35. Republic of Ecuador	375.75	P	58.73	30	11.75	64.78	30	11.49	58.99	27	10.39
36. Arab Republic of Egypt	355.13	P	55.51	28	11.10	61.22	29	10.86	55.76	26	9.82
37. Republic of Equatorial Guinea	383.17	P	59.89	31	11.98	66.06	31	11.72	60.16	28	10.59

Table A.3: The Ministry of Foreign Affairs Application Results (cont’d)

38. Republic of Estonia	160.00	P	25.01	13	5.00	27.58	13	4.89	25.12	12	4.42
39. Federal Democratic Republic of Ethiopia	391.96	P	61.26	31	12.25	67.57	32	11.99	61.54	29	10.84
40. European Union	***										
41. Republic of Finland	322.06	P	50.34	26	10.07	55.52	26	9.85	50.56	23	8.90
42. French Republic	1309.67	P	204.70	105	40.94	225.79	105	40.06	205.62	95	36.21
43. Gabonese Republic	115.70	P	18.08	9	3.62	19.95	9	3.54	18.16	8	3.20
44. Republic of the Gambia	214.15	P	33.47	17	6.69	36.92	17	6.55	33.62	16	5.92
45. Georgia	820.24	P	128.20	66	25.64	141.41	66	25.09	128.78	60	22.68
46. Federal Republic of Germany	518.78	P	81.09	42	16.22	89.44	42	15.87	81.45	38	14.34
47. Republic of Ghana	165.59	P	25.88	13	5.18	28.55	13	5.06	26.00	12	4.58
48. Hellenic Republic (Greece)	701.84	P	109.70	56	21.94	121.00	56	21.47	110.19	51	19.40
49. Republic of Guatemala	***										
50. Republic of Guinea	366.88	P	57.34	29	11.47	63.25	30	11.22	57.60	27	10.14
51. Hungary	526.66	P	82.32	42	16.46	90.80	42	16.11	82.69	38	14.56
52. Republic of India	505.21	P	78.96	40	15.79	87.10	41	15.45	79.32	37	13.97
53. Republic of Indonesia	257.11	P	40.19	21	8.04	44.33	21	7.86	40.37	19	7.11
54. Islamic Republic of Iran	140.00	P	21.88	11	4.38	24.14	11	4.28	21.98	10	3.87
55. Republic of Iraq	919.14	P	143.66	74	28.73	158.46	74	28.11	144.30	67	25.41

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

56. Ireland	***										
57. State of Israel	***										
57. Italian Republic	2454.00	P	383.56	197	76.71	423.07	198	75.05	385.28	179	67.84
58. Japan	437.33	P	68.35	35	13.67	75.40	35	13.38	68.66	32	12.09
59. Hashemite Kingdom of Jordan	290.00	P	45.33	23	9.07	50.00	23	8.87	45.53	21	8.02
60. Republic of Kazakhstan	525.00	P	82.06	42	16.41	90.51	42	16.06	82.43	38	14.51
61. Republic of Kenya	226.00	P	35.32	18	7.06	38.96	18	6.91	35.48	16	6.25
62. Republic of Korea	225.00	P	35.17	18	7.03	38.79	18	6.88	35.33	16	6.22
63. Republic of Kosovo	430.00	P	67.21	34	13.44	74.13	35	13.15	67.51	31	11.89
64. State of Kuwait	528.00	P	82.53	42	16.51	91.03	42	16.15	82.90	38	14.60
65. Kyrgyz Republic	315.00	P	49.23	25	9.85	54.31	25	9.63	49.46	23	8.71
66. Republic of Latvia	292.00	P	45.64	23	9.13	50.34	24	8.93	45.84	21	8.07
67. Lebanese Republic	320.00	P	50.02	26	10.00	55.17	26	9.79	50.24	23	8.85
68. Libyan Arab Jamahiriya	730.00	P	114.10	59	22.82	125.85	59	22.33	114.61	53	20.18
69. Republic of Lithuania	296.00	P	46.26	24	9.25	51.03	24	9.05	46.47	22	8.18
70. Grand Duchy of Luxembourg	427.00	P	66.74	34	13.35	73.61	34	13.06	67.04	31	11.80
71. Malaysia	345.00	P	53.92	28	10.78	59.48	28	10.55	54.17	25	9.54
72. Republic of Mali	293.00	P	45.80	23	9.16	50.51	24	8.96	46.00	21	8.10
73. Republic of Malta	415.00	P	64.86	33	12.97	71.55	33	12.69	65.16	30	11.47

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

74. Islamic Republic of Mauritania	242.00	P	37.82	19	7.56	41.72	19	7.40	37.99	18	6.69
75. United Mexican States	290.00	P	45.33	23	9.07	50.00	23	8.87	45.53	21	8.02
76. Republic of Moldova	276.00	P	43.14	22	8.63	47.58	22	8.44	43.33	20	7.63
77. Mongolia	320.00	P	50.02	26	10.00	55.17	26	9.79	50.24	23	8.85
78. Montenegro	375.00	P	58.61	30	11.72	64.65	30	11.47	58.88	27	10.37
79. Kingdom of Morocco	507.00	P	79.24	41	15.85	87.41	41	15.51	79.60	37	14.02
80. Kingdom of the Netherlands	762.00	P	119.10	61	23.82	131.37	61	23.31	119.63	55	21.07
81. New Zealand	370.00	P	57.83	30	11.57	63.79	30	11.32	58.09	27	10.23
82. Republic of Niger	288.00	P	45.01	23	9.00	49.65	23	8.81	45.22	21	7.96
83. Kingdom of Norway	***										
84. Sultanate of Oman	2650.00	P	414.20	212	82.84	456.86	213	81.05	416.05	193	73.26
85. Islamic Republic of Pakistan	408.00	P	63.77	33	12.75	70.34	33	12.48	64.06	30	11.28
86. State of Palestine	991.00	P	154.89	79	30.98	170.85	80	30.31	155.59	72	27.40
87. Republic of Panama	***										
88. Republic of Paraguay	***										
89. Republic of Peru	437.00	P	68.30	35	13.66	75.34	35	13.37	68.61	32	12.08
90. Republic of the Philippines	397.00	P	62.05	32	12.41	68.44	32	12.14	62.33	29	10.98
91. Republic of Poland	1100.00	P	171.93	88	34.39	189.64	89	33.64	172.70	80	30.41

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

92. Portuguese Republic	380.00	P	59.39	30	11.88	65.51	31	11.62	59.66	28	10.51
93. State of Qatar	1790.00	P	279.78	143	55.96	308.60	144	54.75	281.03	130	49.49
94. Republic of North Macedonia	353.00	P	55.17	28	11.03	60.86	28	10.80	55.42	26	9.76
95. Romania	320.00	P	50.02	26	10.00	55.17	26	9.79	50.24	23	8.85
96. Russian Federation	3350.00	P	523.61	269	104.72	577.54	270	102.46	525.95	244	92.61
96. Republic of Rwanda	243.54	P	38.07	20	7.61	41.99	20	7.45	38.24	18	6.73
97. Kingdom of Saudi Arabia	920.00	P	143.80	74	28.76	158.61	74	28.14	144.44	67	25.43
98. Republic of Senegal	330.00	P	51.58	26	10.32	56.89	27	10.09	51.81	24	9.12
99. Republic of Serbia	235.00	P	36.73	19	7.35	40.51	19	7.19	36.90	17	6.50
100. Republic of Singapore	250.00	P	39.08	20	7.82	43.10	20	7.65	39.25	18	6.91
101. Slovak Republic	422.00	P	65.96	34	13.19	72.75	34	12.91	66.25	31	11.67
102. Republic of Slovenia	237.00	P	37.04	19	7.41	40.86	19	7.25	37.21	17	6.55
103. Federal Republic of Somalia	306.93	P	47.97	25	9.59	52.91	25	9.39	48.19	22	8.49
104. Republic of South Africa	345.00	P	53.92	28	10.78	59.48	28	10.55	54.17	25	9.54
105. Republic of South Sudan	247.00	P	38.61	20	7.72	42.58	20	7.55	38.78	18	6.83
106. Kingdom of Spain	220.00	P	34.39	18	6.88	37.93	18	6.73	34.54	16	6.08
107. Democratic Socialist Republic of Sri Lanka	297.00	P	46.42	24	9.28	51.20	24	9.08	46.63	22	8.21

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

108. Republic of the Sudan	487.00	P	76.12	39	15.22	83.96	39	14.89	76.46	35	13.46
109. Kingdom of Sweden	350.00	P	54.71	28	10.94	60.34	28	10.70	54.95	25	9.68
110. Swiss Confederation	587.00	P	91.75	47	18.35	101.20	47	17.95	92.16	43	16.23
111. Republic of Tajikistan	245.00	P	38.29	20	7.66	42.24	20	7.49	38.47	18	6.77
112. Tanzania	195.00	P	30.48	16	6.10	33.62	16	5.96	30.62	14	5.39
113. Kingdom of Thailand	405.00	P	63.30	32	12.66	69.82	33	12.39	63.59	29	11.20
114. Republic of Tunisia	1094.00	P	170.99	88	34.20	188.61	88	33.46	171.76	80	30.24
115. Turkish Republic of Northern Cyprus	528.00	P	82.53	42	16.51	91.03	42	16.15	82.90	38	14.60
116. Turkmenistan	396.00	P	61.89	32	12.38	68.27	32	12.11	62.17	29	10.95
117. Republic of Uganda	392.00	P	61.27	31	12.25	67.58	32	11.99	61.54	29	10.84
118. Ukraine	255.00	P	39.86	20	7.97	43.96	21	7.80	40.04	19	7.05
119. United Arab Emirates	860.00	P	134.42	69	26.88	148.26	69	26.30	135.02	63	23.78
120. United Kingdom of Great Britain and Northern Ireland	1409.00	P	220.23	113	44.05	242.91	113	43.09	221.21	103	38.95
121. United States of America	2365.00	P	369.65	190	73.93	407.73	190	72.33	371.31	172	65.38
122. Republic of Uzbekistan	387.00	P	60.49	31	12.10	66.72	31	11.84	60.76	28	10.70
123. State of Vatican City	683.00	P	106.75	55	21.35	117.75	55	20.89	107.23	50	18.88
124. Bolivarian Republic of Venezuela	351.00	P	54.86	28	10.97	60.51	28	10.74	55.11	26	9.70

Table A.3: The Ministry of Foreign Affairs Application Results (cont'd)

125. Socialist Republic of Vietnam	433.00	P	67.68	35	13.54	74.65	35	13.24	67.98	32	11.97
126. Republic of Yemen	250.00	P	39.08	20	7.82	43.10	20	7.65	39.25	18	6.91
127. Zambia	300.10	P	46.91	24	9.38	51.74	24	9.18	47.12	22	8.30
128. Zimbabwe	253.00	P	39.54	20	7.91	43.62	20	7.74	39.72	18	6.99
Total	**61726.36**		**9647.83**	**4948**	**1929.57**	**10641.62**	**4968**	**1887.87**	**9691.04**	**4491**	**1706.49**

*** Embassies are not included to total area because of they are dwells in apartments.
Suitable area constants for detached houses are applied to embassies.

Table A.4: The Ministry of Industry and Technology Application Results

The Ministry of Industry and Technology	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizontal) /Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	6480.05	F	813.89	417	211.61	798.34	373	171.45	829.45	427	199.25
Additional Building	2500.06	F	314.01	161	81.64	308.01	144	66.15	320.01	165	76.87
Scientific and Technological Research Council of Turkey	1620.16	F	203.49	104	52.91	199.60	93	42.87	207.38	107	49.82
Small and Medium Industry Development Organization	2958.62	F	371.60	191	96.62	364.50	170	78.28	378.70	195	90.97
Turkish Patent and Trademark Office	7753.12	F	973.79	499	253.19	955.18	446	205.13	992.40	511	238.40
Turkish Standards Institute	4920	P	865.43	444	173.09	1088.80	508	193.16	1039.60	482	178.24
Turkish Academy of Sciences	247	P	43.45	22	8.69	54.66	26	9.70	52.19	24	8.95
Total	**26479**		**3585.66**	**1839**	**877.74**	**3769.10**	**1760**	**766.72**	**3819.72**	**1909**	**842.51**

Table A.5: The Ministry of Agriculture and Forestry Application Results

The Ministry of Agriculture and Forestry	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320 Mono**			**Poly-Si Module Scenario 1 STH (Horizontal)/ Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Buildings	28942.25	P	5090.94	2611	1018.19	6404.92	2990	1136.26	6115.50	2834	1076.87
Affiliated Institutions											
Atatürk Forest Farm Directorate	517.07	P	90.95	47	18.19	114.43	53	20.30	109.26	51	19.24
General Directorate for State Hydraulic Works (DSI)	5333.84	F	669.93	344	174.18	657.13	307	141.12	682.73	351	164.01
General Directorate of Meteorology	9920.29	P	1744.98	895	349.00	2195.36	1025	389.47	2096.16	971	369.11
General Directorate of Forestry	8881.16	F	1115.47	572	290.02	1094.16	511	234.97	1136.79	585	273.09
Total	24652.36		3621.34	1857	831.39	4061.08	1896	785.86	4024.93	1958	825.45
Related Institutions											
General Directorate of Meat and Milk Board	717.22	F	90.08	46	23.42	88.36	41	18.98	91.80	47	22.05

Table A.5: The Ministry of Agriculture and Forestry Application Results (cont'd)

General Directorate of Agricultural Enterprises	607.53	P	106.86	55	21.37	134.45	63	23.85	128.37	59	22.60
Agriculture and Rural Development Support Institution	675.11	F	84.79	43	22.05	83.17	39	17.86	86.41	44	20.76
Province Coordinatorship	459.21	F	57.68	30	15.00	56.57	26	12.15	58.78	30	14.12
General Directorate of Turkish Grain Board	1251.12	F	157.14	81	40.86	154.14	72	33.10	160.14	82	38.47
Department of Inspection Board	4677.15	F	587.45	301	152.74	576.22	269	123.75	598.68	308	143.82
Total	8387.34		1084.01	556	275.43	1092.92	510	229.69	1124.19	572	261.83
The Ministry of Agriculture and Forestry Total	**61981.95**		**9796.29**	**5024**	**2125.01**	**11558.91**	**5396**	**2151.81**	**11264.62**	**5364**	**2164.14**

Table A.6: The Ministry of Transportation and Infrastructure Application Results

The Ministry of Transportation and Infrastructure	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) /Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	4034.9	F	506.78	259.89	131.76	497.10	232	106.75	516.47	266	124.07
Related and Affiliated Institutions											
General Directorate for Highways	637.22	F	80.03	41.04	20.81	78.51	37	16.86	81.56	42	19.59
General Directorate of Civil Aviation	1416.52	F	177.91	91.24	46.26	174.52	81	37.48	181.31	93	43.56
General Directorate of State Airports Authority	2154.29	F	270.58	138.76	70.35	265.41	124	57.00	275.75	142	66.24
Information Technologies and Communications Authority	2719.16	F	341.53	175.14	88.80	335.00	156	71.94	348.05	179	83.61
Satellite Communications and Cable TV Operations Company	922.21	P	162.22	83	32.44	204.09	95	36.21	194.86	90	39.55
Total	7849.4		1032.27	529	258.66	1057.51	494	219.48	1081.54	546	252.55
The Ministry of Transportation and Infrastructure Total	**11884.3**		**1539.06**	**789**	**390.42**	**1554.61**	**726**	**326.24**	**1598.01**	**812**	**376.62**

Table A.7: The Ministry of Commerce Application Results

The Ministry of Commerce	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Sogutozu Campus	6205.74	F	779.44	400	202.65	764.55	357	164.19	794.33	409	190.82
Eskisehir Road Campus	6414	F	805.60	413	209.46	790.20	369	169.70	820.99	422	197.22
Central Anatolian and Regional Directorate of Trade	12620.53	F	1585.14	813	412.14	1554.85	726	333.91	1615.43	831	388.07
Ankara Provincial Directorate of Trade	619.85	F	77.85	40	20.24	76.37	36	16.40	79.34	41	19.06
The Ministry of Commerce Total	**25860.12**		**3248.03**	**1666**	**844.49**	**3185.97**	**1487**	**684.19**	**3310.10**	**1703**	**795.17**

Table A.8: The Ministry of Health Application Results

The Ministry of Health	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	10902.77	F	1369.39	702	356.04	1343.22	627	288.46	1395.55	718	335.25
Additional Building _Yildiz	965.67	P	169.86	87	33.97	213.70	100	37.91	204.05	95	34.98
Additional Building_Balgat	532.45	P	93.66	48	18.73	117.83	55	20.90	112.51	52	19.29
Turkish Medicines and Medical Devices Agency	1367.55	F	171.76	88	44.66	168.48	79	36.18	175.05	90	42.05
Public Health Center	14142.71	P	2487.70	1276	497.54	3129.78	1461	555.24	2988.35	1385	512.37
Total	27911.15		4292.37	2201	950.94	4973.02	2322	938.69	4875.51	2339	943.94
Public Hospitals											
29 Mayıs	868.08	P	152.70	78	30.54	192.11	90	34.08	183.43	85	31.45
75.Yıl Oral and Dental Health	1257.34	P	221.17	113	44.23	278.25	130	49.36	265.68	123	45.55
Akyurt	2096.18	P	368.72	189	73.74	463.88	217	82.30	442.92	205	75.94
Balgat Oral and Dental Health	473.11	F	59.42	30	15.45	58.29	27	12.52	60.56	31	14.55
Beypazari	6132.63	P	1078.73	553	215.75	1357.15	634	240.76	1295.82	600	222.18

Table A.8: The Ministry of Health Application Results (cont’d)

Beytepe Murat Erdi Eker	3719.02	P	654.18	335	130.84	823.02	384	146.01	785.83	364	134.73
Cubuk Halil Sivgin	5939.73	F	746.03	383	193.97	731.77	342	157.15	760.29	391	182.64
Elmadag Dr.Hulusi Alatas	2152.91	F	270.41	139	70.31	265.24	124	56.96	275.57	142	66.20
Etimesgut Oral and Dental Health	458.93	P	80.73	41	16.15	101.56	47	18.02	96.97	45	16.63
Etimesgut Sehit Sair Erturk	7420.26	F	931.98	478	242.32	914.18	427	196.32	949.79	489	228.17
Gazi Mustafa Kemal	3511.39	P	617.65	317	123.53	777.07	363	137.86	741.96	344	127.21
Golbasi Oral and Dental Health	1016.74	P	178.84	92	35.77	225.00	105	39.92	214.84	100	36.83
Golbasi Sehit Ahmet Ozsoy	3501.32	P	615.88	316	123.18	774.84	362	137.46	739.83	343	126.85
Haymana	2465.11	P	433.61	222	86.72	545.53	255	96.78	520.88	241	89.31
Kahramankazan Hamdi Eris	2185.18	F	274.46	141	71.36	269.21	126	57.81	279.70	144	67.19
Karapurcek Oral and Dental Health	1758.45	F	220.86	113	57.42	216.64	101	46.52	225.08	116	54.07
Kecioren Osmanlı Oral and Dental Health	4629.88	F	581.51	298	151.19	570.40	266	122.50	592.62	305	142.36
Kizilcahamam ***s**	2821.39	P	496.28	255	99.26	624.37	291	110.77	596.16	276	102.21
Mamak Oral and Dental Health	1016.5	F	127.67	65	33.19	125.23	58	26.89	130.11	67	31.26
Meclis	7050.7	F	885.57	454	230.25	868.65	406	186.54	902.49	464	216.80
Occupational and Environmental Diseases	1580	F	198.45	102	51.60	194.66	91	41.80	202.24	104	48.58
Nallihan	2570.31	P	452.12	232	90.42	568.81	266	100.91	543.11	252	93.12

Table A.8: The Ministry of Health Application Results (cont'd)

Polatli Oral and Dental Health	9012.96	F	1132.03	581	294.33	1110.40	518	238.46	1153.66	593	277.14
Sincan Oral and Dental Health	211.39	F	26.55	14	6.90	26.04	12	5.59	27.06	14	6.50
Sincan Dr.Nafiz Korez	2385.79	P	419.66	215	83.93	527.98	246	93.67	504.12	234	86.43
Sereflikochisar	3905.95	F	490.59	252	127.55	481.21	225	103.34	499.96	257	120.10
Gaziler Physical Therapy and Rehabilitation	31026.27	F	3896.90	1998	1013.19	3822.44	1785	820.88	3971.36	2043	954.03
Yenimahalle Training and Research Hospital	6931.1	F	870.55	446	226.34	853.91	399	183.38	887.18	456	213.12
Ankara Training and Research Hospital	7660	P	1347.39	691	269.48	1695.16	791	300.73	1618.56	750	277.51
Ankara Physical Therapy and Rehabilitation	13266.45	P	2333.57	1197	466.71	2935.87	1371	520.84	2803.20	1299	480.62
Ataturk Thoracic Diseases and Thoracic Surgery Center	7930.83	P	1395.03	715	279.01	1755.09	819	311.36	1675.78	777	287.32
Diskapi Yildirim Beyazit	14978.11	P	2634.65	1351	526.93	3314.66	1547	588.03	3164.87	1467	542.63
Dr.Abdurrahman Yurtaslan Oncology ***p**	7107.21	F	892.67	458	232.09	875.61	409	188.04	909.72	468	218.54
Dr.Sami Ulus Maternity and Children Hospital	1071.96	P	188.56	97	37.71	237.22	111	42.08	226.51	105	38.84
Etlik Zübeyde Hanım	11528.43	P	2027.85	1040	405.57	2551.24	1191	452.60	2435.96	1129	417.66
Gülhane	50615.13	F	6357.26	3260	1652.89	6235.78	2911	1339.15	6478.74	3333	1556.36

Table A.8: The Ministry of Health Application Results (cont'd)

Kecioren	7520.85	F	944.62	484	245.60	926.57	433	198.98	962.67	495	231.26
Ulucanlar Eye Hospital	696.35	P	122.49	63	24.50	154.10	72	27.34	147.14	68	25.23
Topraklık Oral and Dental Health	871.17	P	153.24	79	30.65	192.79	90	34.20	184.08	85	31.56
Tepebasi Oral and Dental Health	412.1	P	72.49	37	14.50	91.20	43	16.18	87.08	40	14.93
Ankara City Hospital	158848.43	F	19951.36	10231	5187.35	19570.13	9136	4202.73	20332.60	10459	4884.43
Total	**400605.64**		**54904.42**	**28156**	**13312.42**	**58303.26**	**27219**	**11766.83**	**58876.12**	**29303**	**12818.05**

***s** Kizilcahamam Public hospital has steel U shape roof, assumed as pitched roof.
***p** Dr.Abdurrahman Yurtaslan Oncology includes 3077.8 m^2 Pitched roof, 4029.41 m^2 Flat roof, assumed as totally flat roof.
* Sincan Prison Hospital included in Prisons (The Ministry of Justice) part.

Table A.9: The Court of Cassation Application Results

The Court of Cassation	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Administration Building	2113.42	P	371.75	191	74.35	467.70	218	82.97	446.57	207	76.57
Main Building	565.69	P	99.50	51	19.90	125.19	58	22.21	119.53	55	20.49
Additional Building_Vekaletler	2691.74	P	473.48	243	94.70	595.68	278	105.68	568.76	264	97.52
Additional Building_MilliMudafaa	2111.9	P	371.48	191	74.30	467.36	218	82.91	446.24	207	76.51
Additional Building (TRT)	1485.64	F	186.60	96	48.52	183.03	694	319.05	190.16	98	45.68
Office of Chief Public Prosecutor	1966.98	F	247.05	127	64.23	242.33	918	422.41	251.77	130	60.48
Total	**10935.37**		**1749.86**	**897**	**375.99**	**2081.30**	**2385**	**1035.23**	**2023.04**	**960**	**377.25**

Table A.10: The Ministry of Youth and Sports Application Results

The Ministry of Youth and Sports	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	1700.34	F	213.56	110	55.53	209.48	98	44.99	217.64	112	52.28
Additional Building	592.2	F	74.38	38	19.34	72.96	34	15.67	75.80	39	18.21
General Directorate of Credit and Dormitories Agency	1488.48	F	186.95	96	48.61	183.38	86	39.38	190.53	98	45.77
Total	**3781.02**		**474.90**	**244**	**123.47**	**465.82**	**217**	**100.04**	**483.97**	**249**	**116.26**

Table A.11: The Ministry of Education Application Results

The Ministry of Education	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	1189.29	P	209.20	107	41.84	263.19	123	46.69	251.30	116	43.09
Provincial Directorate for National Education	875.84	P	154.06	79	30.81	193.82	90	34.39	185.06	86	31.73
Total	2065.13		363.26	186	72.65	457.01	213	81.08	436.36	202	74.82
District Directorates of National Education											
Altindağ	971.17	F	121.98	63	31.71	119.65	56	25.69	124.31	64	29.86
Ayas	473	P	83.20	43	16.64	104.67	49	18.57	99.94	46	17.14
Bala	210	P	36.94	19	7.39	46.47	22	8.24	44.37	21	7.61
Beypazari	263	P	46.26	24	9.25	58.20	27	10.33	55.57	26	9.53
Camlidere	1445	P	254.18	130	50.84	319.78	149	56.73	305.33	141	52.35
Cankaya	1331	P	234.12	120	46.82	294.55	138	52.25	281.24	130	48.22
Cubuk	261	P	45.91	24	9.18	57.76	27	10.25	55.15	26	9.46
Elmadag	*n.i										
Golbasi	1500	P	263.85	135	52.77	331.95	155	58.89	316.95	147	54.34
Gudul	366	P	64.38	33	12.88	81.00	38	14.37	77.34	36	13.26
Haymana	335	P	58.93	30	11.79	74.14	35	13.15	70.79	33	12.14
Kalecik	*n.i.										

Table A.11: The Ministry of Education Application Results (cont'd)

Kazan	1084	P	190.68	98	38.14	239.89	112	42.56	229.05	106	39.27
Kecioren	3450	P	606.86	311	121.37	763.49	356	135.45	728.99	338	124.99
Kizilcahamam	*n.i.										
Mamak	362	P	63.68	33	12.74	80.11	37	14.21	76.49	35	13.11
Nallihan	438	P	77.04	40	15.41	96.93	45	17.20	92.55	43	15.87
Polatli	485	P	85.31	44	17.06	107.33	50	19.04	102.48	47	17.57
Sincan	1537	P	270.36	139	54.07	340.14	159	60.34	324.77	150	55.68
Sereflikochisar	2332	F	292.90	150	76.15	287.30	134	61.70	298.50	154	71.71
Yenimahalle	465	P	81.79	42	16.36	102.90	48	18.26	98.25	46	16.85
Akyurt	501	P	88.13	45	17.63	110.87	52	19.67	105.86	49	18.15
Etimesgut	1665	P	292.87	150	58.57	368.46	172	65.37	351.81	163	60.32
Evren	n.i.										
Pursaklar	359	P	63.15	32	12.63	79.45	37	14.09	75.86	35	13.01
Total	19833.17		3322.51	1704	689.39	4065.04	1898	736.35	3915.59	1836	700.43
Teacherage and Evening Art School											
Bala	259.86	P	45.71	23	9.14	57.51	27	10.20	54.91	25	9.41
Beypazari	420.33	P	73.94	38	14.79	93.02	43	16.50	88.82	41	15.23
Cubuk	525.45	P	92.43	47	18.49	116.28	54	20.63	111.03	51	19.04
Golbasi	1140.17	P	200.56	103	40.11	252.32	118	44.76	240.92	112	41.31
Haymana	*n.f										
Kalecik	329.37	P	57.94	30	11.59	72.89	34	12.93	69.60	32	11.93
Kazan	*n.f										
Kizilcahamam	344.32	P	60.57	31	12.11	76.20	36	13.52	72.75	34	12.47

Table A.11: The Ministry of Education Application Results (cont'd)

Nallihan	748.64	P	131.69	68	26.34	165.67	77	29.39	158.19	73	27.12
Polatli	805.44	P	141.68	73	28.34	178.24	83	31.62	170.19	79	29.18
Sincan	531.76	P	93.54	48	18.71	117.68	55	20.88	112.36	52	19.26
Sereflikochisar	438.95	P	77.21	40	15.44	97.14	45	17.23	92.75	43	15.90
Total	5544.29		975.24	500	195.05	1226.95	573	217.67	1171.51	543	200.86
The Ministry of Education Total	**27442.59**		**4661.00**	**2390**	**957.09**	**5749.00**	**2684**	**1035.10**	**5523.47**	**2581**	**976.10**

*n.i Elmadag, Kalecik, Kizilcahamam and Evren buildings are not included in this part since they are the same building with district governorship and already have done.
*n.f Haymana and Kizilcahamam Teacherage and Evening Art Schools could not be found in map.

Table A.12: The Ministry of Treasury and Finance Application Results

The Ministry of Treasury and Finance	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	8194.41	F	1029.22	528	267.60	1009.55	471	216.80	1048.88	540	251.97
Additional Building	1555.04	F	195.31	100	50.78	191.58	89	41.14	199.05	102	47.82
Turkish Tax Inspection Board	6393.72	F	803.05	412	208.79	787.71	368	169.16	818.40	421	196.60
Fund of Bail	614.18	P	108.03	55	21.61	135.92	63	24	130	60	22.25
Public Procurement Authority	1152.95	F	144.81	74	37.65	142.04	66	30.50	147.58	76	35.45
General Directorate of state supply office	4938.4	F	620.26	318	161.27	608.41	284	130.66	632.12	325	151.85
Public Oversight Accounting and Auditing Standards authority	516.66	F	64.89	33	16.87	63.65	30	13.67	66.13	34	15.89
Total	23365.36		2965.58	1521	764.57	2938.86	1372	626.05	3041.93	1558	721.83
Related Institutions											
Department of Revenue_Dikmen	1110	F	139.42	71	36.25	136.75	64	29.37	142.08	73	34.13
Additional Service Building_Diskapi	1676.32	F	210.55	108	54.74	206.52	96	44.35	214.57	110	51.55
Education Center	6783.05	F	851.95	437	221.51	835.67	390	179.46	868.23	447	208.57

Table A.12: The Ministry of Treasury and Finance Application Results (cont'd)

Ankara Directorate of Tax Administration	738.12	F	92.71	48	24.10	90.94	42	19.53	94.48	49	22.70
Total	10307.49		1294.62	664	336.60	1269.88	593	272.71	1319.36	679	316.94
Tax Offices											
Baskent	835.16	F	104.90	54	27.27	102.89	48	22.10	106.90	55	25.68
Beypazari	113.41	P	19.95	10	3.99	25.10	12	4	24	11	4.11
Cankaya	267.74	P	47.10	24	9.42	59.25	28	11	57	26	9.70
Diskapi	137.25	P	24.14	12	4.83	30.37	14	5	29	13	4.97
Dikimevi	295	P	51.89	27	10.38	65.28	30	12	62	29	10.69
Doğanbey	912	F	114.55	59	29.78	112.36	52	24.13	116.74	60	28.04
Etimesgut	2380	P	418.64	215	83.73	526.69	246	93	503	233	86.22
Golbasi	333	P	58.57	30	11.71	73.69	34	13	70	33	12.06
Haymana	285	P	50.13	26	10.03	63.07	29	11	60	28	10.33
Hitit	634	F	79.63	41	20.70	78.11	36	16.77	81.15	42	19.49
Kavaklidere	900	F	113.04	58	29.39	110.88	52	23.81	115.20	59	27.67
Kahramankazan	290	P	51.01	26	10.20	64.18	30	11	61	28	10.51
Kecioren	372	P	65.43	34	13.09	82.32	38	15	79	36	13.48
Kizilbey	475.5	P	83.64	43	16.73	105.23	49	19	100	47	17.23
Maltepe	364	P	64.03	33	12.81	80.55	38	14	77	36	13.19
Mithatpasa	285	P	50.13	26	10.03	63.07	29	11	60	28	10.33
Ostim	880	P	154.79	79	30.96	194.74	91	35	186	86	31.88
Polatli	550	P	96.75	50	19.35	121.72	57	22	116	54	19.93
Segmenler	407	P	71.59	37	14.32	90.07	42	16	86	40	14.74

Table A.12: The Ministry of Treasury and Finance Application Results (cont'd)

Sincan	938	F	117.81	60	30.63	115.56	54	24.82	120.06	62	28.84
Sereflikochisar	635	P	111.70	57	22.34	140.53	66	25	134	62	23.01
Ulus	412	P	72.47	37	14.49	91.18	43	16	87	40	14.93
Tax Office of Inheritance and Fee	679	F	85.28	44	22.17	83.65	39	17.96	86.91	45	20.88
Total	13380.06		2107.18	1081	458.35	2480.50	1158	462.59	2419.19	1153	457.90
Turkish Statistical Institute	4994.87	F	627.36	322	163.11	615.37	287	132.15	639.34	329	153.59
Ankara Regional Directorate	620.14	P	109.08	56	21.82	137.24	64	24	131	61	22.47
General Directorate of The National Lottery	677.05	F	85.04	44	22.11	83.41	39	17.91	86.66	45	20.82
General Directorate of The National Lottery Service Building	320.96	F	40.31	21	10.48	39.54	18	8.49	41.08	21	9.87
Anittepe Service Building	449.31	P	79.03	41	15.81	99.43	46	18	95	44	16.28
Directorate of Privatization Administration	745.59	F	93.65	48	24.35	91.86	43	19.73	95.44	49	22.93
Total	**7807.92**		**1034.47**	**530**	**257.67**	**1066.85**	**498**	**220.27**	**1088.50**	**548**	**245.95**

Table A.13: The Ministry of Interior Application Results

The Ministry of Interior	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	5324.21	P	936.53	480	187.31	1178.25	550	209	1125	521	192.89
Provincial Directorate of Population and Citizenship Affairs	1411.88	P	248.35	127	49.67	312.45	146	55	298	138	51.15
Total	6736.09		1184.88	608	236.98	1490.70	696	264.46	1423.34	660	244.04
General Directorates of Population and Citizenship Affairs	10592.09	P	1863.15	955	372.63	2344.03	1094	416	2238	1037	383.74
District Registry Offices											
Akyurt	1175.54	P	206.78	106	41.36	260.15	121	46	248	115	42.59
Bala	1593.22	P	280.25	144	56.05	352.58	165	63	337	156	57.72
Cayyolu	1156.17	F	145.21	74	37.76	142.44	66	30.59	147.99	76	35.55
Cankaya	316.66	F	39.77	20	10.34	39.01	18	8.38	40.53	21	9.74
Elmadag	480.62	P	84.54	43	16.91	106.36	50	19	102	47	17.41
Kalecik	626.81	P	110.26	57	22.05	138.71	65	25	132	61	22.71
Kecioren	3113.77	P	547.71	281	109.54	689.08	322	122	658	305	112.81
Kizilcahamam	978.93	P	172.19	88	34.44	216.64	101	38	207	96	35.47
Pursaklar	2031.27	P	357.30	183	71.46	449.52	210	80	429	199	73.59
Sincan	321.45	P	56.54	29	11.31	71.14	33	13	68	31	11.65

Table A.13: The Ministry of Interior Application Results (cont'd)

Sincan Civil Registrary	721.23	P	126.86	65	25.37	159.61	75	28	152	71	26.13
Sereflikochisar	1285.78	P	226.17	116	45.23	284.54	133	50	272	126	46.58
Yenimahalle	432.8	P	76.13	39	15.23	95.78	45	17	91	42	15.68
Yenimahalle_Batikent	5285.2	F	663.82	340	172.59	651.14	304	139.83	676.51	348	162.51
Total	19519.45		3093.54	1586	669.64	3656.69	1707	679.81	3561.52	1695	670.13
General Directorate of Law Services	576.14	F	72.36	37	18.81	70.98	33	15.24	73.75	38	17.72
Directorate of Strategy Development	282.32	F	35.46	18	9.22	34.78	16	7.47	36.14	19	8.68
Center for Research and Studies	60.5	P	10.64	5	2.13	13.39	6	2	13	6	2.19
Internal Audit Department	564.6	P	99.31	51	19.86	124.95	58	22	119	55	20.45
General Directorate of Security Affairs	4989.26	F	626.65	321	162.93	614.68	287	132.00	638.63	329	153.41
Ankara Police Office	8716	P	1533.14	786	306.63	1928.85	900	342	1842	853	315.77
General Commandership of Gendarmerie	830.07	P	146.01	75	29.20	183.69	86	33	175	81	30.07
General Commandership of Gendarmerie Additional Building	4258	F	534.80	274	139.05	524.59	245	112.66	545.02	280	130.93
Provincial Gendarmerie Command	6097.22	F	765.81	393	199.11	751.18	351	161.32	780.44	401	187.48
Turkish Coast Guard Command	1436.33	F	180.40	93	46.90	176.96	83	38.00	183.85	95	44.17
General Directorate of Migration Administration	2482	F	311.74	160	81.05	305.78	143	65.67	317.70	163	76.32

Table A.13: The Ministry of Interior Application Results (cont'd)

Department of Training	3039.87	F	381.81	196	99.27	374.51	175	80.43	389.10	200	93.47
Total			4698.15	2409	1114.17	5104.33	2383	1012.10	5113.79	2521	1080.67
Disaster and Emergency Management Presidency (AFAD)	11043.28	F	1387.04	711	360.63	1360.53	635	292.18	1413.54	727	339.57
Ankara Provincial Disaster and Emergency Directorate	3896.12	P	685.33	351	137.07	862.21	403	153	823	381	141.15
Governorship of Ankara	2943.47	P	517.76	266	103.55	651.39	304	116	622	288	106.64
Total	17882.87		2590.12	1328	601.25	2874.13	1342	560.70	2858.75	1397	587.36
Municipalities											
Ankara	9028	F	1133.92	581	294.82	1112.25	519	238.86	1155.58	594	277.60
Akyurt	1287.35	P	226.44	116	45.29	284.89	133	51	272	126	46.64
Altindag	3238.64	F	406.77	209	105.76	399.00	186	85.69	414.55	213	99.58
Ayas	507.52	P	89.27	46	17.85	112.31	52	20	107	50	18.39
Bala	341.08	P	60.00	31	12.00	75.48	35	13	72	33	12.36
Beypazari	429.18	P	75.49	39	15.10	94.98	44	17	91	42	15.55
Camlidere	522.45	P	91.90	47	18.38	115.62	54	21	110	51	18.93
Cankaya	2591.19	F	325.45	167	84.62	319.23	149	68.56	331.67	171	79.68
Cubuk	529.13	P	93.07	48	18.61	117.10	55	21	112	52	19.17
Elmadag	1330	P	233.95	120	46.79	294.33	137	52	281	130	48.18
Etimesgut	955.57	F	120.02	62	31.21	117.73	55	25.28	122.31	63	29.38

Table A.13: The Ministry of Interior Application Results (cont'd)

Evren	216.5	P	38.08	20	7.62	47.91	22	8	46	21	7.84
Golbasi	3244.9	F	407.56	209	105.97	399.77	187	85.85	415.35	214	99.78
Gudul	290	P	51.01	26	10.20	64.18	30	11	61	28	10.51
Haymana	345.09	P	60.70	31	12.14	76.37	36	14	73	34	12.50
Kalecik	270.75	P	47.62	24	9.52	59.92	28	11	57	27	9.81
Kahramankazan	2278.54	F	286.18	147	74.41	280.72	131	60.28	291.65	150	70.06
Kecioren	4130.22	F	518.76	266	134.88	508.84	238	109.28	528.67	272	127.00
Kizilcahamam	801.25	P	140.94	72	28.19	177.32	83	31	169	78	29.03
Mamak	2695.81	F	338.59	174	88.03	332.12	155	71.32	345.06	178	82.89
Nallihan	258.02	P	45.39	23	9.08	57.10	27	10	55	25	9.35
Polatli	992.94	P	174.66	90	34.93	219.74	103	39	210	97	35.97
Sereflikochisar	606.14	P	106.62	55	21.32	134.14	63	24	128	59	21.96
Sincan	1001.13	P	176.10	90	35.22	221.55	103	39	212	98	36.27
Yenimahalle	3801.96	F	477.53	245	124.16	468.40	219	100.59	486.65	250	116.91
Pursaklar	2065	F	259.36	133	67.43	254.41	119	54.63	264.32	136	63.50
Total	43758.36		5985.40	3069	1453.53	6345.40	2962	1282.28	6411.46	3193	1398.83
The Ministry of Interior Total	**131821.17**		**19415.23**	**9957**	**4448.19**	**21815.28**	**10185**	**4215.19**	**21606.96**	**10502**	**4364.76**

Table A.14: The Ministry of Environment and Urban Planning Application Results

The Ministry of Environment and Urban Planning	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	17163.26	F	2155.71	1105	560.48	2114.51	987	454.10	2196.90	1130.09	527.75
Ankara Provincial Directorate	1410.95	F	177.22	91	46.08	173.83	81	37.33	180.60	92.90	43.39
General Directorate of State Hydraulic Works	1211.42	F	152.15	78	39.56	149.25	70	32.05	155.06	79.76	37.25
Total	19785.63		2485.08	1274	646.12	2437.59	1138	523.48	2532.56	1303	608.39
Related and Affiliated Institutions											
General Directorate of Land Registry and Cadastres	3172.19	P	557.99	286	111.60	702.01	328	124.54	670.28	311	114.92
Housing Development Administration of Turkey	2074.78	F	260.59	134	67.75	255.61	119	54.89	265.57	136.61	63.80
General Directorate of Provincial Bank	1025.1	F	128.75	66	33.48	126.29	59	27.12	131.21	67.50	31.52
Participation Bank	718.28	P	126.35	65	25.27	158.96	74	28.20	151.77	70	26.02
Total	6990.35		1073.68	551	238.10	1242.87	580	234.75	1218.84	585	236.26
The Ministry of Environment and Urban Planning Total	**26775.98**		**3558.75**	**1825**	**884.22**	**3680.46**	**1718**	**758.23**	**3751.40**	**1888**	**844.65**

Table A.15: The Ministry of Culture and Tourism Application Results

The Ministry of Culture and Tourism	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	4104.39	F	515.51	264	134.03	505.66	236	108.59	525.36	270	126.21
Department of Inspection Board	634.23	P	111.56	57	22.31	140.36	66	24.90	134.01	62	22.98
Directorate for Internal Auditing Unit	969.47	F	121.77	62	31.66	119.44	56	25.65	124.09	64	29.81
Turkish Cooperation and Coordination Agency (TIKA)	1674.7	F	210.34	108	54.69	206.32	96	44.31	214.36	110	51.50
General Directorate for Foundations	553.32	F	69.50	36	18.07	68.17	32	14.64	70.82	36	17.01
Radio and Television Supreme Council (RTUK)	2212.82	F	277.93	143	72.26	272.62	127	58.55	283.24	146	68.04
Atatürk Supreme Council for Culture, Language and History	922.25	P	162.22	83	32.44	204.09	95	36.21	194.87	90	33.41
General Directorate of State Opera and Ballet	386.06	P	67.91	35	13.58	85.44	40	15.16	81.57	38	13.99

Table A.15: The Ministry of Culture and Tourism Application Results (cont'd)

General Directorate of State Theatres	2031.63	P	357.36	183	71.47	449.60	210	79.76	429.28	199	73.60
General Directorate of Fine Arts	1904.24	F	239.17	123	62.18	234.60	110	50.38	243.74	125	58.55
General Directorate of Law Services	2638.15	F	331.35	170	86.15	325.02	152	69.80	337.68	174	81.12
General Directorate of Libraries and Publications	1739.77	P	306.03	157	61.21	385.01	180	68.30	367.61	170	63.03
General Directorate of Copyrights	309.98	P	54.53	28	10.91	68.60	32	12.17	65.50	30	11.23
Institute of Yunus Emre	437.36	P	76.93	39	15.39	96.79	45	17.17	92.41	43	15.84
Administration for Turks Living Abroad and Related Communities	1327.5	F	166.73	86	43.35	163.55	76	35.12	169.92	87	40.82
General Directorate of Cinema	2724.87	P	479.30	246	95.86	603.01	282	106.98	575.77	267	98.72
The Ministry of Culture and Tourism Total	**24570.74**		**3548.15**	**1820**	**825.57**	**3928.28**	**1834**	**767.68**	**3910.26**	**1912**	**805.86**

Table A.16: The Ministry of Energy and Natural Resources Application Results

The Ministry of Energy and Natural Resources	**F: Flat Roof P: Pitched Roof**		**Bifacial Module Scenario Silfab SLA-X 350**			**Mono-Si Module Scenario Soltech 1 STH-320M Mono**			**Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar**		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Buildings	4370	F	548.87	281	142.71	538.38	251	115.62	559.36	288	134.37
Related and Affiliated Institutions											
General Directorate of Mineral Research and Exploration (MTA)	3645.84	P	641.30	329	128.26	806.82	377	143.13	770.37	357	132.08
Middle Anatolian III. Regional Directorate Kizilcahamam	219.08	P	38.54	20	7.71	48.48	23	8.60	46.29	21	7.94
Turkish Atomic Energy Authority	2067.18	F	259.64	133	67.51	254.68	119	54.69	264.60	136	63.56
Secretariat of Ankara Research and Education Centre	1351.2	P	237.68	122	47.54	299.02	140	53.05	285.51	132	48.95
Department of Radiation and Accelerator	466	P	81.97	42	16.39	103.13	48	18.29	98.47	46	16.88

Table A.16: The Ministry of Energy and Natural Resources Application Results (cont'd)

General Directorate of Mining and Petroleum Affairs	2239.2	P	393.88	202	78.78	495.53	231	87.91	473.14	219	81.12
Electricity Generation Company (EUAS)	2883.11	F	362.12	186	94.15	355.20	166	76.28	369.04	190	88.65
Turkish Electricity Transmission Corporation (TEIAS)	1599.11	P	281.28	144	56.26	353.88	165	62.78	337.89	157	57.93
General Directorate	1557.43	F	195.61	100	50.86	191.88	90	41.21	199.35	103	47.89
Petroleum Pipeline Company (BOTAS)	2113.76	F	265.49	136	69.03	260.42	122	55.92	270.56	139	65.00
Turkish Petroleum (TPAO)	2318.64	F	291.22	149	75.72	285.66	133	61.35	296.79	153	71.30
General Directorate of Turkish Coal	2236.8	F	280.94	144	73.04	275.57	129	59.18	286.31	147	68.78
General Directorate ETI Mine Works	637	F	80.01	41	20.80	78.48	37	16.85	81.54	42	19.59
General Directorate of Electromechanic Industry (TEMSAN)	1828.7	P	321.67	165	64.33	404.69	189	71.79	386.40	179	66.25
Energy Market Regulatory Authority (EMRA)	7460	F	936.98	481	243.61	919.07	429	197.37	954.88	491	229.39

Table A.16: The Ministry of Energy and Natural Resources Application Results (cont'd)

The National Boron Research Institute (BOREN)	1770.48	P	311.43	160	62.29	391.81	183	69.51	374.10	173	64.14
Rare Earth Elements Research Institute (NATEN)	1844.38	F	231.65	119	60.23	227.23	106	48.80	236.08	121	56.71
Total	**40607.91**		**5760.27**	**2954**	**1359.21**	**6289.93**	**2936**	**1242.34**	**6290.68**	**3095**	**1320.54**

Table A.17: The Ministry of National Defence Application Results

The Ministry of National Defence	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Main Building	13125.53	P	2308.78	1184	461.76	2904.68	1356	515.30	2773.42	1285	475.52
Department of National Mine	426.43	P	75.01	38	15.00	94.37	44	16.74	90.10	42	15.45
Department of Employee Recruitment	798.6	P	140.47	72	28.09	176.73	83	31.35	168.74	78	28.93
Mechanical and Chemical Industry Corporation	1090	F	136.90	70	35.60	134.29	63	28.84	139.52	72	33.52
General Directorate of Mapping	1060.44	P	186.53	96	37.31	234.68	110	41.63	224.07	104	38.42
Fuel Supply and NATO Pol Facilities Operating Agency	1051.7	F	132.09	68	34.34	129.57	60	27.83	134.62	69	32.34
Turkish Air Force	2552.57	F	320.60	164	83.36	314.48	147	67.53	326.73	168	78.49
The Ministry of National Defence Total	**20105.27**		**3300.40**	**1693**	**695.46**	**3988.79**	**1862**	**729.23**	**3857.21**	**1818**	**702.66**

Table A.18: The Turkish Court of Accounts and The Council of State Application Results

	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320M Mono			Poly-Si Module Scenario 1 STH 320 (Horizont) / Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Turkish Court of Accounts	6600	F	828.96	425	215.53	813.12	380	174.62	844.80	435	202.94
The Council of State	11707.9	F	1470.51	754	382.33	1442.41328	673	309.76	1498.61	771	360.01

Table A.19: Institutions and Organizations Affiliated to the Presidency Application Results

Institutions and Organizations Affiliated to the Presidency	F: Flat Roof P: Pitched Roof		Bifacial Module Scenario Silfab SLA-X 350			Mono-Si Module Scenario Soltech 1 STH-320 Mono			Poly-Si Module Scenario 1 STH (Horizont)/ Trinasolar		
Buildings	**Roof Area (m^2)**	**Roof Type**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**	**Suitable Area (m^2)**	**# of modules**	**Annual Energy (MWh)**
Directorate of State Archives	13813	P	2429.71	1246	485.94	3056.82	1427	542.29	2918.69	1352	500.42
Directorate of Religious Affairs	18180	F	2283.41	1171	593.69	2239.78	1046	481.00	2327.04	1197	559.02
Turkish Armed Forces General Staff	1075	P	189.09	97	37.82	237.90	111	42.20	227.15	105	38.95
General Secretariat of The National Security Council	6199	F	778.59	399	202.43	763.72	357	164.01	793.47	408	190.61
National Intelligence Organization	89971	F	11300.36	5795	2938.09	11084.43	5175	2380.41	11516.29	5924	2766.52
Directorate of Defence Industries	4789	F	601.50	308	156.39	590.00	275	126.71	612.99	315	147.26
Grand National Assembly of Turkey	18063.55	P	3177.38	1629	635.48	3997.46	1866	709.17	3816.83	1769	654.41

Table A.19: Institutions and Organizations Affiliated to the Presidency Application Results (cont'd)

Grand National Assembly of Turkey *Additional Service Building	1287.38	P	226.45	116	45.29	284.90	133	50.54	272.02	126	46.64
Grand National Assembly of Turkey *PR Building	6401	F	803.97	412	209.03	788.60	368	169.35	819.33	421	196.82
Institutions and Organizations Affiliated to the Presidency Total	**159778.93**		**21790.45**	**11175**	**5304.16**	**23043.60**	**10758**	**4665.68**	**23303.81**	**11619**	**5100.65**

B. Comparison of Terminology Used in Literature Review and the Study

References	The Terminology used in References	The Terminology used in This Study	Extent
(Paidipati et al., 2008)	PV Access Factor *	PV Access Factor	PV Access Factor term does not include the required space for access between modules, wiring and inverters. Also, row spacing for shading is neglected.
(Ordóñez et al., 2010)	Relation Coefficient	PV Access Factor	
(Izquierdo et al., 2008)	Available roof Area	PV Access Factor	
(Khan et al., 2017)	Utilization Constant	Suitable Area Constant	Suitable Area Constant term includes settling requirements such as space for access between modules, wiring and row spacing are included.
(Mainzer et al., 2014)	Utilization Factor	Suitable Area Constant	
(Tripathi, 2014)	Useful rooftop area	Suitable Area Constant	
(Bergamasco & Asinari, 2011)	Corrective coefficient	Suitable Area Constant	
(Lise et al., 2018)	Realizable area**	Suitable Area Constant	

*Although Paidipati et al. (2008) used PV Access Factor term, it is stated that by “the packing factor,” the suitable area constant is computable.

** Lise et al., (2018) does not directly mention the realizable area constant. It is found as a multiplication of weighted average ratio of usable area and penetration factor.

C. The Summary Table of Results

Module Types		Pitched Roof Apartments	Flat Roof Apartments	Detached Houses	Total Residential	Public Buildings	Commercial Buildings
Mono-Si Modules	The Ratio of Usable Area	22.13%	16.48 %	17.24 %		12.43%	20.94%
	Energy Production per Module (MWh/yr.module)	0.38	0.43	0.38		0.460	0.414
	Energy Production (MWh)	735,502.59	104,397.32	101,426.20	941,326.12	44,343.54	10,621.74
Poly-Si Modules	The Ratio of Usable Area	21.13%	10.93%	15.69%		12.80%	18.93%
	Energy Production per Module (MWh/yr.module)	0.37	0.44	0.38		0.467	0.419
	Energy Production (MWh)	690,852.94	77,992.72	91,537.32	860,382.97	45,428.04	11,037.50

C. The Summary Table of Results (cont'd)

Bifacial Modules	The Ratio of Usable Area	17.59 %	10.83%	15.63%		12.56%	19.78%
	Energy Production per Module (MWh/yr.module)	0.39	0.46	0.40		0.507	0.458
	Energy Production (MWh)	665,464	80,543.25	103,569.54	849,576.78	46,593.07	12,598.82
Optimum	Energy Production (MWh)				943,469.45*	46,593.07	12,598.82

*Optimum shows total energy production by Mono-Si Module application in pitched roof and flat roof apartments and Bifacial Module application in detached houses.