DETERMINATION OF APPROPRIATE TARGET AUDIENCE FOR DISTRIBUTED SOLAR GENERATION AMONG US RESIDENTIAL AND COMMERCIAL CUSTOMERS

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ABSTRACT
This study tries to determine the appropriate target audience for small-scale distributed solar generation in 30 big cities across the US. Residential customers are divided into subgroups according to floor space of a housing unit. Commercial customers are divided into subgroups according to the sector of service they are in. Consumption data of residential and commercial customers are gathered from selected variables of The Residential Energy Consumption Survey (RECS) from 2009 and The Commercial Buildings Energy Consumption Survey (CBECS) from 2003 respectively. Typical hourly solar radiation data, which is required to compute annual solar energy generation, is obtained from the average of the hourly solar radiation data from the 3-year span from 2003-2005 as reported by the US Government. The most appropriate target groups are found by using a comparison of consumption and generation per sq.ft. data. The results are illustrated in eight figures for four census divisions.

Religious and warehouse establishments are identified as the entities that stand to benefit the most in the commercial sector from distributed generation (DG) in all census divisions. Housing units having between 1,000 and 1,500 square feet are found as the most likely to benefit in the residential sector. Implications for tailored DG policy and marketing interventions are discussed in relation to the findings of this study.

KEY WORDS
Solar Distributed Generation, Solar Policies, Target Audience

1. Introduction
Although photovoltaic (PV) efficiency has increased significantly in recent years and there are a lot of federal support campaigns to encourage solar generation, the public and investor support couldn't reach the expected results until now. The primary reason for that failure is mainly the misguided public idea of solar power being known as an expensive investment [1]. However, it's a fact that, high initial investment for a large-scale central solar energy plant and long investment return time prevent business people from investing in that industry. But there is a new opinion at this point.

Lots of small-scale distributed generation facilities, instead of a large central plant may satisfy the required capacity with low initial investment per facility. In other words, the total money to build the same amount of capacity would be divided amongst lots of people. To achieve that goal, the appropriate target audience has to be on board in order to encourage them to invest in solar DG. The term “appropriate target audience” refers to a residence or business that has the ability to generate, with low initial investment, some amount of energy annually that is greater or equal to its total amount of annual energy consumption as shown in Table 1 by select customer groups.

<table>
<thead>
<tr>
<th></th>
<th>Commercial</th>
<th>Residential 0 - 499 sq. ft</th>
<th>Residential 1000-1499 sq. ft</th>
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<tbody>
<tr>
<td>Atlanta, GA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Annual Consumption per sq.ft.</td>
<td>58.69</td>
<td>49.82</td>
<td>50.53</td>
</tr>
<tr>
<td>Annual Generation per sq.ft.</td>
<td>52.38</td>
<td>52.38</td>
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</tr>
<tr>
<td>Status</td>
<td></td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Chicago, IL</td>
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<tr>
<td>Annual Consumption per sq.ft.</td>
<td>44.36</td>
<td>27.64</td>
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<td>Annual Generation per sq.ft.</td>
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This study is prepared to compare electricity consumption with solar generation for residential and commercial customers in 30 selected cities across the US.

Firstly, the analysis part of the study covers the data sets of residential and commercial electricity consumption from RECS '09 (most recent at the time of this study) and CBECS '03 (most recent published data at the time of this study), which is conducted by the Energy Information Administration (EIA) every four years. The consumption for four census divisions (South, West, Midwest, and Northeast) in reference to total square footage (area) or sector of the customer are identified and illustrated in the figures in the results section. Residential customers are divided into groups classified by total square footage of the housing unit because a study reported that residential area predicts the largest proportion of variance in electricity consumption [2]. Also, a recent study that was done examines the underlying patterns of residential electricity consumption in the US associated with socio-demographic variables, such as housing size, number of household members, and income. Its results also confirmed a strong relationship between annual electricity consumption and housing size [3]. Therefore, this paper takes this strong relationship into consideration to determine the best target audience for solar DG among US residential customers.

Secondly, typical hourly solar radiation data, which is needed to compute annual solar energy generation, is obtained from the average of the hourly solar radiation data from the 3-year span from 2003-2005 as reported by the US Government. The hourly annual data sets collected of solar radiation are measured and approved by the National Renewable Energy Laboratory (NREL) at thirty cities across the US, which are selected due to their high population. The population of the area covered is around 60 million people, which is 20% of US population. Furthermore, the typical hourly temperature data sets collected by NREL for the selected cities are used to determine the cell temperature because of the temperature effects on the output power of PV module. By this method, it is possible to accurately compute the solar generation intensities from the selected cities. This data is also shown in the figures in the results section.

Illustrating the average electricity consumption and the average generation on the same figure for either residential or commercial customers makes the required information easier to obtain. The fourth section of this paper summarizes the results of the charts provided. The fifth section of this paper discusses the policy and marketing interventions in relation to the results. However, there is a technical constraint considered during the study and is important to note here:

The required instantaneous power for either residential or commercial customers varies every second; therefore, generating what is exactly needed becomes a challenge due to the intermittency of solar PV modules. Because of that reason, small-scale solar projects should not be designed as a dispersed system but as a distributed system. A distributed system is a grid connected system that gives an opportunity to the owner to sell surplus power back to the grid in accordance with a contract with the local utility. This study will focus on generating equal or greater amounts of energy than consumption for either residential or commercial purposes during a year period and will not discuss instantaneous power requirements.

2. Background

In the beginning of the electricity era, the grid was formed by a local central generating plant and wires that brought service to local customers; however there was no connection among two different generating plants. Until the 1930s, the concept of the electrical grid stayed almost the same; therefore, most of the cities in the US had their own local electric power generation, transmission, and distribution systems. Years passed and the benefits of electricity interconnection had become to be understood correctly, hence leading to the design concept of the energy grid of today.

Interconnection of different types and sizes of generators allowed the total system operation cost to decrease because the new grid permitted customers to receive power from cheaper generators. Another important effect of interconnection of generators was the reserve capacity. After interconnection, they didn't need to hold as high a reserve as before; therefore, they were able to increase their generating capacity. This evolution in the industry reduced the risk and the time for the companies to return their investment.

After more than 80 years, the concept of the electrical grid is still the same. However, public and technological support during those years has made electricity indispensable for consumers. For example, electricity outages today cause people to lose money, time, and even life in extreme cases. The recent outage that happened in Washington, DC in May’12 could only be restored completely after 4 days of work, causing economic impact estimated at over $100M.

Today, we are in the beginning of a new era. The idea of advanced energy concepts started out being called “Exotics” at the beginning of the 1970s [4], then progressed to being called “Renewable Energy Sources” at the end of 1980s, and now with the integration of computers, the new era is called “Smart Grid”. It is the unpreventable future that the power grid and the information grid will be more and more intertwined.

Smart grid provides an opportunity for everyone in the industry, i.e. generator owners, energy provider utilities, and end-users, to access real-time information. To achieve all the benefits of a smart grid; cheap and renewable sources have to be deployed all around the US. Therefore, this study is a response to help determine best prospective investors to support renewable energy generation and a sustainable World.
3. Method

3.1 Residential and Commercial Electricity Consumption Data

The RECS is conducted by the Energy Information Administration (EIA) every four years. It is the only survey that provides accurate and precise comparisons of energy consumption between households and between areas of the country. A measurement of the two-dimensional area of the housing unit that is enclosed from the weather is considered as total square footage of the housing unit in RECS. This is also the area where residential energy-consuming activities occur. Total square footage consists of four areas: attic, basement, garage, and the rest of the home. In 2009, there were 113.78 million occupied housing units in the US [5]. 12,100 of them were selected for RECS interviews in 2009. The EIA produces estimates of end uses of energy by modeling the data from the interviews [6]. In this study, selected variables from the 2009 RECS identify the average annual electricity consumption of residential consumers by subgroups which are defined according to total square footage of the housing unit among four census divisions.

CBECs is conducted quadrennially by the EIA. The CBECs ‘03 was the eighth and the last survey in the series at the time of this study. The commercial sector encompasses a vast range of building types such as retail stores, hotels, hospitals, as well as schools and religious organizations. In 2009, the total floor space of surviving commercial units was around 78 billion square feet and they purchased 4.46 quadrillion BTU’s of electricity energy in 2009 [7]. The EIA produces estimates of end usage of electricity by modeling the actual monthly electricity consumption data gathered from about 1,500 selected commercial buildings around the US [8]. Select variables from the CBECs ‘03 identify the average annual electricity consumption of commercial consumers by their sector among four census divisions.

3.2 Hourly Temperature And Solar Radiation Data

Typical hourly temperature data sets for the 30 selected cities around the US were produced by the National Renewable Energy Laboratory's Electric Systems Center under the Solar Resource Characterization Project [9]. The data sets of hourly meteorological elements are for a one-year period and they represent typical “dry bulb” temperature rather than extreme conditions. These hourly temperature data sets were used to estimate the cell temperature value for sixty-minute periods in this study.

The annual solar radiation data sets were produced by the National Renewable Energy Laboratory from 2003 to 2005 for the 30 selected cities [10]. The last 3-year increment of governmentally approved data sets was selected. Even though the daily solar radiation changes, annual solar radiation is almost the same for each year. Therefore, the average of three-year data was accepted as the typical solar radiation set of that region. The data sets do not represent the measured solar radiation, instead, they represent global solar radiation, in other words, total amount of direct and diffuse solar radiation, (SUNY-modeled) received on a horizontal surface during the 60-minute period ending at the timestamp.

All data sets were selected carefully from the available Class I sites because of their high accuracy. The station receives a Class I designation, if less than 25% of the data for the 15-year period of record exceeds an uncertainty of 11% [11].

3.3 Solar Energy Generation

Accurate prediction of the amount of possible solar energy generation for the future is not possible. One of the unpredictable changes in the output power is caused by the degradation of the material of the PV module. After 10 years of use of the PV modules, the output power performance of the module may decrease to 90%. Some other equipment like inverters, diodes, DC and AC wiring, etc., may also cause power drops. Furthermore, there are mismatch and dirt factors decreasing the output power based on the design of the PV system.

Only one type of commercially available PV module on the market is chosen to be used during the study to compare the amount of possible solar generation between the 30 cities accurately. To select the best suitable PV module on the market; the medium level products of the top three North American solar cell manufacturers, which are Solarworld, First Solar, and Suniva due to their market share [12], are compared based on their generation capacity per square meter under the same annual solar radiation data set. The results are given in Table 2. The highest generation per square meter is reached with the product from the company, Suniva, model number MVP-245-60-5-401. Nominal electrical information can be found from the product datasheet directly online [13].

<table>
<thead>
<tr>
<th>Solar World SW 225 mono</th>
<th>FirstSolar FS 280</th>
<th>Suniva MVP 245</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under Typical January Radiation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy generated in a month per module (kWh/mo-module)</td>
<td>12.44</td>
<td>4.45</td>
</tr>
<tr>
<td>Energy generated in a month per m². (kWh/month-m²)</td>
<td>7.42</td>
<td>6.19</td>
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<tr>
<td>Under Typical July Radiation</td>
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<tr>
<td>Energy generated in a month per module (kWh/mo-module)</td>
<td>20.23</td>
<td>7.73</td>
</tr>
<tr>
<td>Energy generated in a month per m². (kWh/month-m²)</td>
<td>12.07</td>
<td>10.73</td>
</tr>
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</table>

Table 2: The amount of energy generation for three modules
Hourly temperature data is used to estimate the real temperature of the cell in order to adjust the output ratings of the PV cells because cell temperature affects the efficiency of the module. When the cell temperature is higher than 25°C, power losses of the module increase for each degree. In other words, the DC rated power of the module changes according to the cell temperature.

To compute AC power output, an inverter that has a constant efficiency coefficient is needed to convert the power from DC to AC. 95% inverter efficiency is used during the study. Lastly, there are two factors that affect the AC power output; mismatch and dirt factors.

The mismatch factor is a result of the manufacturing process of modules. It is unlikely to have the same power capacity for every module manufactured in the same factory. In other words, each product has a power tolerance that represents the rated power variation. When the modules are connected in series and/or parallel, the voltage difference causes power output to decrease. The other factor, the dirt factor, affects the power output in a more detrimental way. Dirt prevents the solar radiation from reaching the PV cell; therefore, it causes the power output to decrease.

### 3.4 Modeling Approach

In today’s solar cell market, most of the PV product datasheets cover the data under standard test conditions, which is under 1-sun, 1.5 Air Mass, and 25°C cell temperature. That means, given data for the solar cell is accurate when the cell temperature is 25°C degree. However, a new approach for testing which is PVUSA’s (Photovoltaics for Utility Scale Applications) Test Calculation (PTC) methodology gives a more accurate result for real designs. For rerating a PV array using the PTC; equation 1 [14] is used, where, $T_{cell}$ is the actual cell temperature, $T_{amb}$ is the actual air temperature, NOCT is module nominal operating cell temperature, and $S$ is 1 kW/m² insolation.

$$ T_{cell} = T_{amb} + \left( \frac{NOCT - 20}{0.8} \right) \times S \quad \text{(Eq.1)} $$

Any difference in cell temperature either above or below 25°C degree causes a drop in output power. The power-temperature coefficient for the selected product is -0.47%/C and is used along with the calculated cell temperature to correct the DC rated power of the PV module during the study.

Hourly solar radiation data sets of 2003, 2004, and 2005 for the 30 selected cities are combined with calculated hourly AC output power of a module to compute AC energy generation during an hour period. Having each energy value for 8,761 hours in a year for the same location represents the annual energy generation of a PV module. The average generation over 3 years' is considered as the typical annual solar energy generation at that location.

To find the annual energy generation of a PV module (kWh/sq.ft.); the annual energy generation (kWh) is divided by the square footage of a module, 17.51 sq.ft in this case.

### 4. Figures and Results

#### 4.1 Midwestern United States

The average solar generation in the Midwestern US is approximately 47.22 thousand BTU/sq.ft. The highest generation occurred at Kansas City, MO, which is 10% more than the average and the lowest generation occurred at Minneapolis, MN. Minneapolis is the northernmost location selected in the region so it is expected to have the lowest solar radiation.

Fig. 1 illustrates the comparison for residential customers. The inappropriate targets for solar DG in this region are the housing units having less than 1,000 sq.ft. Almost all of those units have only one story. In addition, there is a strong relationship between square footage and household income [5]. On the other hand, the most appropriate target structures are units having more than 2,000 sq.ft. in Minneapolis and Detroit, and more than 1,500 sq.ft. in the rest of selected cities. Combining two or more units having more than 1,000 sq.ft. may improve the efficiency of DG and also decrease the initial investment per household in the selected cities.

Fig. 2 illustrates the comparison for commercial customers. Because of similar generation values among the selected cities, the results are given in general for this region, not city by city. The average commercial consumption in the Midwest is 49.75 thousand/sq.ft. The most relevant target audiences for solar DG by sector are religious worship, education, and warehouse structures. Religious establishments have at least three times more generation capability than their consumption in the region. Secondly, educational buildings have a minimum of 35% less consumption than generation. Lastly, most of the warehouses in the region have only one floor and a flat roof [8], which is an advantage to build a rooftop PV array easily. Thus, distributed generation can generate more energy annually than what these buildings consume annually.
4.2 Western United States

The average solar generation in the Western US is 54.58 thousand BTU/sq.ft. The highest generation occurred in Phoenix, AZ, which is 20% more than the average and the lowest generation occurred at Seattle, WA. Seattle is the farthest northern city selected in the region so it is expected to have the lowest solar radiation; however, it is worth noting that, the west coast side of the United States, Washington and Oregon, have totally different solar radiation patterns than the rest of the states. The region in general has the highest solar availability and income rate among the other regions. Therefore, it is the best target region for solar DG campaigns.

Fig. 3 illustrates the comparison for residential customers. Average residential electricity consumption in the region is 19.46 thousand BTU/sq.ft [5]. The appropriate target audiences are units having more than 1,000 sq.ft in Seattle and Portland. Combining three neighboring units having more than 1,500 sq.ft. each is the optimal solution for using the land most efficiently and also decreasing the initial investment per household in the selected cities except Seattle and Portland.

4.3 Northeastern United States

The average solar generation in the Northeastern US is 46.74 thousand BTU/sq.ft. The highest generation occurred at Portland, ME, which is 2% more than the average and lowest generation occurred at Buffalo, NY. Even though Portland is the northernmost city selected in the region, annual solar radiation for that part of the region is higher than the rest. The region in general has the lowest solar radiation availability among the others but it has one of the highest wind power rate along the Atlantic coast.

Fig. 5 illustrates the comparison for residential customers. Average residential electricity consumption in the region is 15.89 thousand BTU/sq.ft [5]. Because of the low electricity consumption in the region as discussed in section 5 in detail, all housing units fall in to the qualified target audience. Combining three neighboring units having more than 1,500 sq.ft. each is the optimal solution to use the land most efficiently for solar DG and also decrease the initial investment per household in the Northeast. But, high natural gas consumption for heating purposes would have been the main issue to solve before electricity generation or consumption.

Fig. 6 illustrates the comparison for commercial customers. Average commercial consumption in the Northeast is 34.51 thousand BTU/sq.ft. Low electricity consumption in the region also provides benefits to all commercial sectors. The most relevant target audiences for solar DG are religious worship structures, warehouse, service, and educational buildings. Religious worship structures have five times more generation capability than...
their consumption in this region. That roughly means that, surplus power generated may also be used for heating purposes during cold days instead of natural gas. Also, solar investments in the education sector have already started, even in the Buffalo area, which is one of the lowest solar generating locations available. The University at Buffalo has recently installed and commissioned a solar array with a power capacity of 0.75MW. Health care facilities and office buildings would only generate half of the energy they consume annually even if they use all available space to build solar PV arrays.

4.4 Southern United States

The average solar generation in the Southern US is 53.27 thousand BTU/sq.ft. The highest generation occurred at Miami, FL, which is 7% more than the average and the lowest generation occurred at Washington, DC. The region in general has the second highest solar power availability rate among the others and at the same time, it has the highest electricity consumption rate, mostly related to cooling purposes.

Fig. 7 illustrates the comparison for residential customers. Average residential electricity consumption in the region is 29.66 thousand BTU/sq.ft [6]. It is the highest consumption rate and is almost double that of the Northeast’s average consumption.

Fig. 8 illustrates the comparison for commercial customers. The average commercial consumption in the South is 53.43 thousand BTU/sq.ft. The high electricity consumption opposes high solar generation being an advantage in the region. The high consumption rate even at religious worship structures is not expected data. However, the most relevant target audiences for solar DG in the region are religious worship structures and warehouses. Food sales and food service businesses consume more than double the office, public assembly, and lodging businesses. Therefore, the possible energy generation rate is only around 33% of the energy consumption rate for food sales and the service industry. On the other hand, retail stores, education, and service industry have opportunity to generate almost equal amount of energy consumed during a year.

5. Discussion

5.1 Policy Implementations

The basis of this paper is to find the optimal area to design and implement a distributed solar generation project because solar energy needs the largest area to generate enough energy in comparison to other renewable sources [15]. The following are intuitively known; that the electricity consumption of a housing unit is less than the possible electricity generation if a distributed solar generation system is built on the rooftop for that housing unit. In other words, available total area on the rooftop to build PV array is much higher than the area needed to generate the amount of energy consumed. However, the electricity consumption of a building complex, including housing units and businesses like a university campus, is higher than the amount of possible electricity generation even though a solar system is built on the rooftop of each building. In other words, available total area of the rooftops at that complex is less than the area needed to generate the same amount of energy consumed annually. Consequently, if we have a minimum and a maximum value, that means we have an optimal middle point between them.

This study proves that the stated hypothesis is true for both housing units having more than 1,000sq.ft. and commercial buildings, like warehouses and service industries. That leads us to a result that, instead of supporting the idea of each business owner having their own solar generation, it is more efficient and worthwhile to encourage them to have a solar PV array joint with the company next to them. In that case, the initial investment per business may decrease significantly and the area would be used efficiently.
The primary audience of this paper is intended to be electrical design engineers and energy policy makers. The illustrated figures may give an idea about the average consumption to a design engineer so that they may suggest solar arrays to their customers. In the beginning of an electrical design project for generation, the initial information an engineer has is the sector and the location of the company. The instantaneous power need has not been accurately known yet so that the ability to compute precisely the capacity of generation needed is not there, but illustrated figures can give some rough information in order to understand the importance of distributed solar generation project.

The findings of this paper provide information to determine the right target groups for solar DG. This tool may help policy makers think about developing new types of campaigns to target specific groups. The benefits of distributed generation on stability and reliability of the energy grid were discussed in many scientific articles. The only obstacle preventing us from making it the public support. However, as mentioned in the first section of this paper, the public’s misconception of seeing solar power as an expensive investment for today ought to be changed as soon as possible. Results of this study show that 95% of residential housing units may produce electricity equal to or more than their consumption annually; therefore, they might be considered as target audience for solar DG. On the other hand, only 46% of commercial buildings are appropriate target audience in the US. The highest rate among the census division is 53% in the Midwestern US. That means, distributed generation is not suitable with its full potential for every business in the US, but for suitable customers; its benefits shouldn’t be disregarded or understated. The future federal or state campaigns on DG should target the correct audience describing the advantages and subsidies of distributed generation. A more recent example of creative energy campaigns shows Germany's feed-in tariff system which integrates residential and community energy producers with federal systems showing significant progress on renewable energy generation and distributed systems.

5.2. Electricity Consumption and Expenditures

Comparison of the annual energy consumption by state shows that; consumption of the northern states of the US is more than the US average. The term energy refers here the total amount of energy by electricity, natural gas, oil, wood, etc. However, comparison of the annual electricity consumption by state only shows that; consumption of the southern states of the US is more than the US average. The high energy consumption rate is mainly caused by natural gas consumption at the northern half of the US for heating purposes during the winter. On the other hand, the high electricity consumption rate in the Southern US is mainly caused by the cooling needs related to the hot weather. Although there is high electricity consumption in the Southern US due to the high temperature, high temperature is related to high solar radiation and high solar generation. Therefore, high solar power generation can compensate for high electricity consumption in this region.

The decision making process to invest in solar PV modules is most related to the energy expenditure of the customer. The cost of electricity in the US has increased consecutively during the past years. A fair assumption in finance is; if the cost increases, demand is expected to decrease. However, recent studies show that real spending on electricity was increasing [16-17]. In other words, the consumption had increased while cost was increasing. But since 2005, consumption began to decrease, while cost continued to increase. The future expectations show that consumption is going to decrease due to the high cost of electricity; furthermore, lower consumption will decrease life quality. Distributed generation, solar or wind is the first and wise option to stop that future trend.

It is also an important fact to note that; although the electricity consumption rate in the Northeastern US is lower than the average, the highest electricity bills for residential consumption is seen in the same region. Conversely, customers in the Southern US pay less money even though they consume significantly more energy than the Northeastern US.

6. Conclusion

This paper is prepared to determine the appropriate target audience for distributed solar generation projects among US residential and commercial customers. The results include valuable information for electrical design engineers considering having solar power arrays on their projects. The calculated solar generation capability and gathered values of electricity consumption for the 30 selected cities are illustrated in eight different figures for both residential and commercial customers in four census divisions. The study covers 20% of US population directly and 60% indirectly.

Religious worships structures are identified as the sector that stands to benefit the most from distributed generation in the 4 census divisions. Houses having between 1,000 and 1,500 square feet stand to benefit the most amongst the residential customers from distributed generation. The most noteworthy analysis of this paper is increasing the efficiency of PV modules by using the optimal area. Solar energy needs the largest area to generate similar levels of energy in comparison to other renewable sources; therefore, determination of optimal land usage discussed in this study is the beginning of a new idea in distributed solar generation research.

Until recently, real spending on electricity has trended upwards; however, beginning in 2005, real spending on electricity has declined. The upward trend in the price of electricity is predicted to stabilize for the near future. That means, the price is going to increase but we are going to use less and less energy. If we consider the strong relationship between energy consumption and life quality, it will be hard to keep life quality stable for people not having energy independence. Distributed
generation gives a chance to those people to have an energy independent residence or business for the next 30 years after construction.

The required instantaneous power for either residential or commercial customers varies every second. Because of that reason, small scale solar projects should be designed as a distributed (grid-connected) system. Consequently, these systems have the ability to sell unrequired instantaneous power generated back to grid and buy power when required. This study covers the data of annual energy generation and consumption in a residential or commercial building; however, future works will cover the relationship between the instantaneous power consumption and instantaneous power generation.

References


