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Multifaceted Feasibility Analysis of PV Solar Application in Northern Cyprus

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Abstract-This paper first reviews the current state of Photovoltaic (PV) cell technology, and comparatively analyzes the cost of electricity generated from different PV technologies against electricity produced at the main thermal power plant in Northern Cyprus. The comparison has been done with and without externality costs, and thus incorporates sustainability principles. The analysis is extended to investigate suitable solar cell technologies for an on-campus PV farm at Middle East Technical University Northern Cyprus Campus, with and without substantial storage support. The estimated economical break-even points of the PV system with battery storage as opposed to current fossil fuel based energy are approximately 15 and 17 years respectively for mono-crystalline silicon (Si) and multi-crystalline Si technology. Assuming the produced electricity can be stored to the grid through bi-directional power delivery, the economical break-even point can be reduced to 6 to 7 years depending on utilized technology. The electricity generation cost of grid-tied PV system at university with multi-crystalline Si technology has already become competitive against that of the grid electricity in Northern Cyprus. Therefore PV electricity production can be expected to significantly contribute to electricity production in Northern Cyprus in near future based on the analysis in this paper.

Keywords-Renewable energy, photovoltaic technology, Northern Cyprus, PV feasibility.

1. Introduction

Photovoltaic (PV) electricity production is a widely known technology to be environmentally clean or “green”. Although PV industry is experiencing rapid growth, the technology has generally been accepted as not yet competitive with traditional energy resources such as fossil fuels because of its high cost. The recent drastic cost reduction in the production of photovoltaic (PV) pave the way for enabling this technology to become cost competitive with fossil fuel. However, the electricity generation cost of PV mainly depends on the region. Numerous studies have been done to suggest the feasibility of building PV farms or power plants for the generation of electricity.

E. Al-Ammar and E. Al-Ammar studied the feasibility of design and construction of solar power plant using photovoltaic cells in Saudi Arabia from the geographic, economic and technical perspective. Based on the analysis, Saudi Arabia has a capacity of 35 GW and it is suggested to increase the capacity by 72 GW. The cost of electricity for PV power plants in Saudi Arabia was estimated to be between 0.216 $/kWh and 0.24$/kWh[1].

The study performed by Myers et.al discussed about the use of PV to generate electricity in Wisconsin regarding interaction with substation, economics and emissions associated. The results indicate that solar PV can have a maximum of 20% contribution in the total electricity generation capacity of Wisconsin. Even a 20% contribution did not prove to be economically feasible. The unsubsidized cost of electricity associated with the installation of PV power plant proved to be \$0.614/kWh, which is quite high[2].

Bob van der Zwaan et.al.[3]have calculated the electricity generation cost of off-grid PV system and grid-tied PV system for three different PV technologies. According to this calculation, electricity generation cost of off-grid PV system with single crystalline Si(c-Si) and multi crystalline Si (mc-Si) technologies is \$0.23/kWh, while it is \$0.18/kWh for thin film Si. For grid-tied system, this value becomes \$0.14/kWh and \$0.09/kWh for c-Si or mc-Si and thin film Si technologies respectively.

There are few important technical parameters to be considered, however, in PV feasibility analysis associated with a particular geography, before healthy investment decisions can be made. It is a common mistake to miss or ignore one or more of these parameters, which leads to falsified conclusions. Firstly, there are few PV technologies in production with different associated development and cost trends. One should not be blind to the gradual evolutionary changes and step advancements associated with different technologies. Secondly, geography specific yearly solar irradiation data should be evaluated. Due to large global variations, resource characterization done in northern Europe will not apply to a location in Mediterranean for example, even though the two geographies may seem close. Third, the cost of the available traditional energy sources in the geography under scrutiny requires careful consideration before a fair comparison can be done. This cost is in general high on islands like Cyprus where fossil fuels are imported. Finally, externality costs, such as environmental effects, can no longer be ignored in the twenty-first century when the global warming increasingly continues to be a big concern.

In geographies with plentiful solar resource, like Northern Cyprus, Photovoltaic electricity generation and use have been proposed in the past as an attractive option. The designing of the PV and a PV-Wind standalone energy system to power a household application in Nicosia, North Cyprus and Nice, France was carried out by Panayiotou et.al [4].This study revealed that PV system is a better solution for Nicosia, North Cyprus. Phillips et.al.[5] investigated the feasibility of using PV to reduce electricity generation from fossil fuels in North Cyprus. In this work, it was proposed to use photovoltaic systems to power heating and cooling systems in household units, and it was found that this is economically feasible. The calculation showed a simple payback time of 8 years, and if every household in North Cyprus uses PV systems for heating and cooling as proposed in this paper, the CO_2, SO_x and NO_x production would be reduced by 2.827 ton/year,15.8kg/year and 7.98 kg/year respectively per household unit. However, a thorough technology specific analysis, and comparison against current fossil fuel based electricity supply, in terms of both internal and external costs, has been missing in all the aforementioned studies.

In this work, a comprehensive and comparative feasibility analysis is provided for the application of PV technology in Northern Cyprus, specifically Middle East Technical University Northern Cyprus Campus (METU-NCC) site, where solar irradiation data has been collected for three years. The next section will briefly review the state of the art PV cell technologies and market trends. The feasibility analysis of a PV farm at METU-NCC will be provided as a case study in Section 3 and 4. The comparison against the current fossil fuel based electricity production is provided in the same section, with and without externality costs. Storage options are also discussed as part of the PV farm. Finally, Section 5 summarizes the results and conclusions from this work.

2. Status of PV Technology

After the temporary silicon shortage between 2004 and 2008, silicon prices fell dramatically and the cost of wafer-based silicon solar cells decreased very rapidly. In 2012, 89% of photovoltaic production is based on crystalline form (c-Si)[6]. Even though the panels based on this technology are durable, cost of manufacturing process is very high. This is the background for the strong research interest in thin-film solar cell. Thin film devices represent the second generation of photovoltaic technology, with crystalline silicon-based devices considered part of the first generation. In current thin-film technologies, solar cells are fabricated using amorphous silicon, cadmium telluride, Copper indium gallium (di) selenide (CIGS), and copper indium disulfide ($CuInS_2$). In 2005, for the first time, production of thin film solar modules reached more than 100 MW per annum. The market share of thin film increased from 6% to 10% from 2005 to 2007 and became 20% in 2009. Since then, the thin-film share has been slowly decreasing as the ramp-up of new production lines did not follow that of wafer-based silicon [7].

2.1. PV World Market

Worldwide solar photovoltaic (PV) market installations reached a record high of 28.1 GW in 2012[6]. Although remarkable, this is far from constituting a notable contribution to the world energy consumption. Excluding the very specific space industry, there are two major market sectors:

i. Grid-tied systems: Power is delivered directly to the grid through conversion of generated DC energy into AC through inverters. Such systems incur the additional cost of the inverters.

ii. Off-grid systems: Such systems supply power to decentralized systems and small-scale consumer products with no connectivity to the grid. Such systems often require separate storage units due to the intermittency of the PV energy.

At present, both of the above markets in general need subsidies. The world wide PV growth represents in Fig.1.

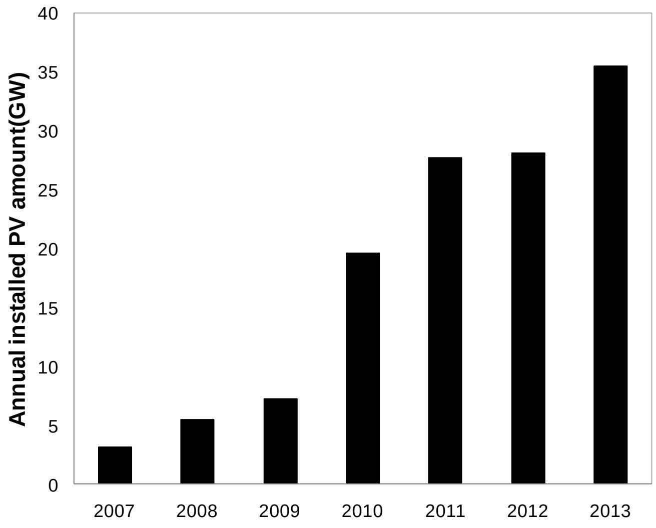

Fig. 1. Theworld wide PV growth from 2007-2013 [6]

Crystalline silicon still dominates the market and probably will continue to do so in the immediate future. As can be seen from the graph at the left the solar industry has seen a remarkable rebound from the 2009 recession. The five year growth rate from 2007 to 2012 was approximately 55% per year. The growth rate from 2009 to 2010 was 172%. The growth rate for 2011 was a more modest 40%, but still very good for an entire industry. The reason for the growth rate of only 1.6% in 2012 was due to major reductions of incentives in several European countries, namely Italy and Germany [6].

2.2. PV System Cost

The cost of a PV module is measured in dollars-per-peak-watt ($/Wp), where "peak watt" is defined as the power obtained from full sunlight at sea level on a clear day. Modules are rated using standard test conditions of 1000 W/m^2 and air mass of 1.5 at 25°C.The cost depends on efficiency, materials and area of the cells that make up the modules, and can be reduced by decreasing the manufacturing cost and improving the module efficiency [8].

Table 1. The PV panel cost, CO$_2$content, and efficiency for different PV technologies [[9], [10]]

PV technology	PV panel cost($/kW$_{peak}$)	CO$_2$ content(kg/m^2)	Efficiency (%)(η_{PV})
Si(c-Si)	1280	193.5	14.3
Si(mc-Si)	1140	135.2	13.9
Thin-film Si	1150	67.8	8.6

PV electricity generation mainly requires panels, inverters, and finally battery storage if it is part of a standalone system.

PV system cost ($) = PV panel cost + Inverter cost + Battery storage cost (1)

3. PV Feasibility Case Studies

3.1. Introduction

The variation of the annual solar irradiation at North Cyprus (at latitude 35^o) is shown in Fig. 2.It can be calculated that the annual solar irradiation is 1823 kWhm^{-2} from Fig. 2.

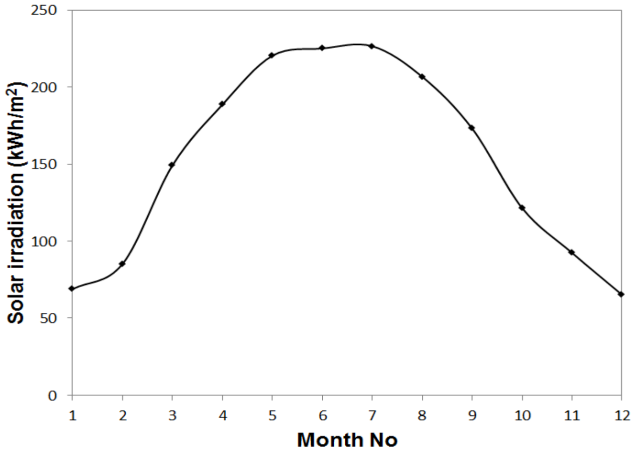

Fig.2. Variation of the annual solar irradiation in North Cyprus (at latitude 35^o)

The latest PV panel cost, efficiency and CO$_2$ content produced in the production stage for different PV technologies are shown in Table 1.Due to the lack of data of year 2012 on solar irradiation, 2011 data was used for both solar irradiation and energy demand. The average electricity demand of METU-NCC in 2011 is shown in Fig.3. The total electricity requirement can be calculated by using Fig.3 as approximately 6,443,720kWh. The grid electricity cost is approximately $1,431,938/year. Grid electricity price in North Cyprus is equal to $0.22/kWh (0.4TL/kWh). The Life time (T_{Life}) of the PV systems and PV module including battery storage and inverter is assumed to be 20 years.

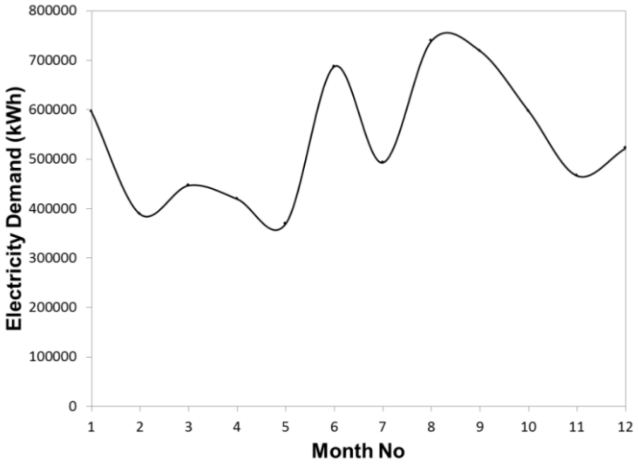

Fig.3. Average electrical energy demand at METU-NCC in 2011

3.2. Design Methodology and Cost Analysis Model

A model has been developed to design and analyze the two types of PV systems in order to supply the energy requirement for METU-NCC with three different PV technologies. One of the two system types is an off-grid PV system, which consists of PV panels, storage system, and an inverter. The other one is grid-connected PV system which consists of PV panels and an inverter. In this system, excess electrical power can be delivered to the grid and power deficit can be drawn from the grid through a bi-directional meter. The analysis was performed through the following steps:

a. Calculate the peak sun hours (T_{peak}) in the day for different months;

b. Choose the suitable design month to calculate the PV panel size (and battery storage size if included),

c. Calculate the size and cost of PV panels for different PV technologies, inverters and battery storage,

d. Determine the externality costs due to CO_2 emission of PV (production stage), and grid electricity,

e. Calculate the grid electricity generating cost including:

   i. Fuel,
   ii. Transmission,
   iii. Capital (CAP) and operation-maintenance cost (O&M),

f. Calculate the electricity generating cost of the grid and different PV technologies with and without externalities,

g. Calculate the economical break-even points of the PV systems with different PV technologies as opposed to traditional electricity generation in North Cyprus.

3.2.1.Peak sun hours (T_{peak})

The average daily solar irradiation in units of kWh/ m^2 per day is sometimes referred to in "peak sun hours" unit. The term "peak sun hours" refers to the number of hours which a particular location would have received it's maximum solar irradiance value of 1000 W/m^2[11], which would amount to the same amount of received energy through the actual insolation over a longer duration of time.

T_{peak} (hr) = (Solar irradiation per month(Whm^{-2})/Number of days in the month (N))/1000(Wm^{-2}) (2)

The peak sun hours at METU NCC will be presented in Section 4.

3.2.2.Size and the cost of PV panels, inverter and battery storage

Size of the PV panel and the cost can be estimated using equations (3) and (4).The critical design month can be chosen by using the energy demand curve in a particular location.

Size of the PV panel (kW) =E_g (D.M)/ (T_{peak} x η_s x N) (3)

where E_g (D.M) =Electricity demand in designed month (kWh),η_s=Efficiency of the PV system (%),N=Number of days in the month. It follows that:

Cost of the PV panel ($) =Size of the PV panel (kW) x PV panel cost ($/kW). (4)

The inverter size should be chosen based on the peak power (P_{peak}) usage during the year. The cost for the inverter can be calculated by using equation (5):

Cost of the inverter ($) =$P_{peak}$ (kW) x Inverter cost ($/kW) (5)

In order to avoid more than 50% discharge of the batteries, they must be able to store twice the amount of used energy. One day worth of storage system size can be estimated using equation (6):

Actual 1 day storage (kWh) =2xE_g (D.M)/ (η_Ix (1-L_I) x N), (6)

where η_I=Inverter efficiency (%) and L_I= losses between inverter and load (%). Then,

Cost of the battery storage=Actual 1 day storage (kWh) x price of the battery ($/kWh) (7)

3.2.3.Annual Electricity generation from the PV systems

The electricity generation for each month and annual electricity generation can be calculated through equations (8) and (9):

Electricity generation (kWh, month) =W (kWh, month) =P_{PV} x T_{peak} x η_s x N, (8)

where P_{PV}=Power of the PV system. Also,

Annual Electricity generation (kWh) =W_{Annual}=$\sum$W(kWh,month) (9)

3.2.4. Electricity generation cost in Teknecik Power Plant

The grid electricity cost can be divided into the following parts: Fuel cost, transmission cost, capital (CAP) cost, operation-maintenance cost (O&M), and externality cost. From KIBTEK [12], El-Kordy et.al. [13] and Teknecik Power Plant staff [14] the following data is obtained:

Fuel type: No 6. Heavy oil (H/C=1.5)
Fuel usage : 250 g of oil to produce 1 kWh electricity
Total transmission cost in 2008 : $44,000,000
CO2 tax : $0.018/kg(which is constant over 20 years)

$$4C_2H_3+11O_2 \rightarrow 8CO_2+6H_2O \quad (10)$$

From the equation (10) and the above data, the electricity generation cost at Teknecik Power Plant with and without externality cost can be calculated. The results from this exercise will be presented in Section 4.1.By considering the CO_2 emission in the production stage of the PV module, the cost due to CO_2 tax ($/kWh) for PV can be calculated using equation (11):

Cost due to CO_2 tax ($/kWh) = ($CO_2$ content x CO_2 tax)/ (E_{Annual} x η_{PV} x T_{Life}), (11)

Where E_{Annual}=Annual solar irradiation ($kWhm^{-2}$), η_{PV}=Efficiency of the PV module (%), and T_{Life}=Life time of the PV module.

The transmission cost of the grid electricity is obtained using equation (12):

Transm. cost ($/kWh) =Total Transm. cost in 2008($)/Total energy production in 2008(kWh) (12)

Grid electricity price based on billing data at the university averages approximately to 0.22$/kWh. Therefore, electricity production cost can be calculated using the following equation:

Grid electricity cost ($/kWh) =Bus bar cost ($/kWh) + Transmission cost ($/kWh), (13)

where Bus bar cost=Capital and Maintain cost + Fuel cost

3.2.5. Electricity generating cost and economical break event point of the PV system

Present value (PVA) $$P_i$ spent n years from now is represented in the equation (14):

$$PVA=P_i\,(1+i_I)^n/\,(1+i_R)^n \qquad (14)$$

where i_I=Inflation rate (%), and I_R=Rate of return (%) {For North Cyprus, i_I=10% [15], I_R=18% [15]}

Annual Capital cost of the PV system (A) can be calculated from the following equation:

$$PVA_{CAP}=\sum_{n=0}^{t} A(1+i_I)^n/(1+i_R)^n=A(1-\alpha^{T_{Life}})/(1-\alpha) \quad (15)$$

where PVA_{CAP} is the present value of the capital cost and $\alpha=(1+i_I)/(1+i_R)$.

Similarly, the Present value of O&M cost ($PVA_{O\&M}$) and present value of total revenue (PVA_{PR}) can be calculated. The equivalent sales revenue (PR) can be obtained using following equation:

$$PR=W_{Annual}\text{x } COE, \qquad (16)$$

where COE=Cost of electricity generation ($/kWh) and W_{Annual}=Annual electricity generation.

For an investment to make sense, Net Present Value (NPVA) ≥ 0. Thus, NPVA = PVA_{PR}– PVA_{cost}, where PVA_{cost} is present value of cash outflow. In this model NPVA is set to zero in order to avoid financial losses. Therefore, $PVA_{PR}=PVA_{CAP}+PVA_{O\&M}$. By substituting the present values of sales revenue, operation-maintenance cost, and capital cost into this equation, COE can be obtained as:

$$COE(\$/kWh)=(A+P_{O\&M})/W_{Annual}\ , \qquad (17)$$

where $P_{O\&M}$ is annual maintenance cost ($/year).For this model, it was taken as 2% of the capital cost of the system [13].A is annual capital cost of the PV system.

The break-even occurs when present value of the grid electricity cost is equal to the present value of the PV investment[16]. Therefore, economical break-even point can be calculated using the following equation:

$$PVA_{CAP}=A_E(1-\alpha^T)/(1-\alpha) \qquad (18)$$

where A_E=Annual grid electricity cost ($),T is the economical break-even (year).

4. Results and Discussion

Results and discussion section consists of four parts: The grid electricity generation cost with and without externality will be discussed in the first part. The calculated externality cost of PV with different technologies will also be presented in this part. In the second part, PV farm feasibility at METU-NCC will be discussed. Different types of storage options for the stand alone system in the university are discussed in the third section. Cost and policy aspects of the PV will be presented in the final section.

4.1. Bus Bar Cost of Grid Electricity and the Externality Cost of PV and Grid Electricity

The cost of grid electricity, produced by the main thermal plant (Teknecik) in North Cyprus, and externality cost of PV and grid electricity are calculated according to the model explained in the 3.2.4.The results are presented in Table 2 and 3.

Table2. Grid electricity cost breakdown.

Grid electricity cost(including transmission cost)	$0.22/kWh
Bus bar (electricity generation cost) without externality(and without transmission cost)	$0.18/kWh
Transmission cost	$0.04/kWh
Annual fuel cost	$0.16/kWh
Cost to grid electricity due to CO_2 tax(externality cost)	$0.015/kWh
Bus bar cost(electricity generating cost) with externality	$0.195/kWh

Table 3. Externality cost for different PV technologies due to CO_2 emissions during production.

PV technology	Single crystalline Si(c-Si)	Multi crystalline Si(mc-Si)	Thin film Si
Externality cost ($/kWh)	0.0007	0.0005	0.0004

It is obvious from Table 2 and Table 3 that the externality cost of PV is negligible compared with that of the grid electricity generation. Therefore, the externality cost of PV will not be considered in the next analyses.

4.2. PV Farm Feasibility at Middle East Technical University Northern Cyprus Campus (METU-NCC)

4.2.1. Peak sun hours (T_{peak}) at METU-NCC

The calculated peak sun hours and the monthly solar irradiation at METU-NCC are shown in Fig.4 and Fig.5 respectively.

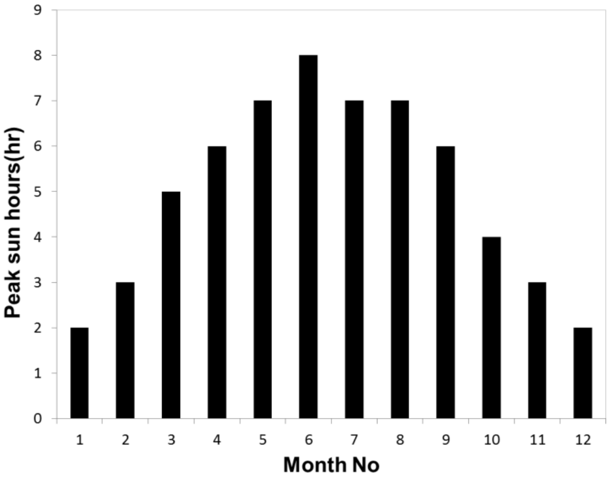

Fig.4. Peak sun hours in different months in METU-NCC in 2011

4.2.2.Off-grid PV system (Stand-alone PV system)

PV array size, battery storage requirement, PV system cost, electricity generation cost and break-even point for different PV technologies as opposed to thermal power based grid electricity can be calculated under the following assumptions.

1. Externality cost for PV system is negligible (as discussed in Section 3).

2. Storage system is designed for 1 day, and provides the minimum energy demand.

3.Critical month is assumed to be August to estimate the PV panel size, since it has maximum energy demand (Fig. 3) with peak sun hour of 7 (Fig. 4).

4. Life time of the whole system is 20 years (including batteries and inverters).

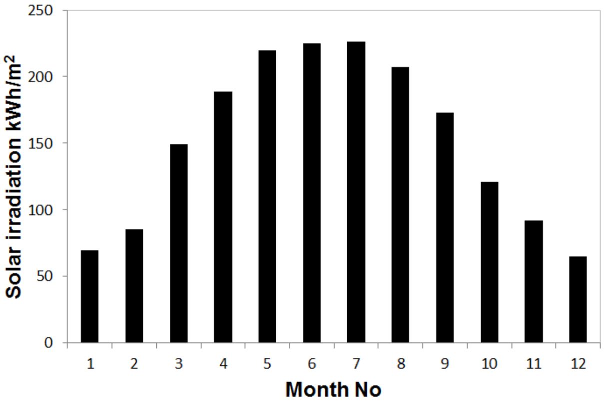

Fig. 5. Monthly solar irradiation in METU, NCC in 2011

The calculation was carried out according to the model explained in 3.2.2, 3.2.3 and 3.2.5.The following input parameters are considered:

1. η_s=50%[17], η_I=94%, L_I=2 %[11] , P_{peak}=1000kW (Fig.4 data)
2. Inverter cost =$711/kW [9], price of the batteries=$213/kWh [9]
3. Eg(D.M)(to estimate the PV panel size)= 739,000kWh(Fig.4),N=31
4. Eg(D.M)(to estimate the battery storage)= 369,680kWh(Fig.4),N=31

PV system size has been estimated according to equation (3), and is approximately 6,811 kW. The calculated values for the actual energy storage and cost for the battery storage system are 25,351kWh and $5,399,786 respectively. The estimated values are shown in the Table 4.

According to Table 4, there is not much system cost difference among the different PV technologies. The minimum electricity generation cost for off-grid PV system is approximately $0.24/kWh (without externality cost), which is 1.3 times higher than grid electricity cost.

Table 4. Estimated cost and break-even points for different PV technologies applied at METU-NCC with storage.

PV Technology	PV panel cost ($)	Battery storage cost($)	Inverter cost ($)	PV system price ($)	Break-even point (year)	COE($/kWh)
c-Si	8,718,080	5,399,786	711,000	14,828,866	17.2	0.25
mc-Si	7,764,540	5,399,786	711,000	13,875,326	15.2	0.24
Thin film- Si	7,832,650	5,399,786	711,000	13,943,436	15.4	0.24

The electricity generation cost gap between the grid electricity and the off-grid PV system is approximately $0.06/kWh. However in this analysis, the life time of the battery storage is assumed to be 20 years for simplicity. In practice, batteries have life time of approximately 6 years, and would need to be renewed three times during the plant's life time. Therefore, the actual electricity generation cost from the off grid PV system and break event points will be higher than the calculated values. On the other hand, the current economical break-even point is 15 to17 years depending on the PV technology, which is close to the system's life time. Hence, the system is only profitable for approximately three years.

According to Table 4, single-crystalline Si (c-Si) PV technology has the highest expected cost. The difference between the cost of c-Si and mc-Si, and the difference between the cost of c-Si and thin film Si technologies are $ 953,540 and $ 885,430 respectively. Most of the expenses for PV system have been allocated to the battery storage. Battery disposal is also a problem. For these reasons, PV systems using batteries for sustained electricity production are unsuitable, and alternate energy storage systems need to be considered. Hence, grid-tied PV system is proposed and analyzed in the next section.

4.2.3.Grid-tied PV system

In addition to the assumptions outlined in the previous section, the following assumptions are made in order to estimate the PV array size, PV system cost, electricity generation cost and break-even points for different grid-tied PV technologies as opposed to the conventional grid electricity from Teknecik power plant:

1. The excess electricity production is sold to the government at same rate as the grid electricity cost,
2. The deficit electricity requirement is supplied from the grid electricity,

The calculation was carried out according to the model explained in 3.2.2, 3.2.3 and 3.2.5.The following input parameters are considered:

i. η_s=60%[17], P_{peak}=1000kW(Fig. 3),
ii.Inverter cost =$711/kW [9],
iii.E_g(D.M)(to estimate the PV panel size)= 739,000kWh(Fig. 3),N=31(same as in the previous case).

PV system size is estimated using equation (3) as approximately 5,675 kW. However, the generated electricity is not enough to cover the required energy demand of the METU-NCC. According to the equations (8) and (9), the annual electricity generation is 6,224,340kWh. Therefore, additional energy of 219,380kWh is required to cover the total energy demand of the University. As a result, university should pay additional amount of $48,264/year for the grid electricity which is not profitable for the investor. Hence, it is better to increase the PV panel size in order to meet the energy demand. The estimated new PV panel size is approximately 5,875kW which can produce 6,443,700kWh electricity, reducing the net grid electricity bill to only $4/year, a negligible amount.

Table 5 represents the electricity generation and demand, extra electricity energy requirement or production and extra income/expense for each month of the year. The calculations denote the sign of the energy drawn from the grid as negative, and energy supplied to the grid as positive. Estimated cost, and break-even points for different PV technologies tied to the grid at METU-NCC are depicted in Table 6.

The electricity generation and demand curve at METU-NCC is shown in Fig. 6.

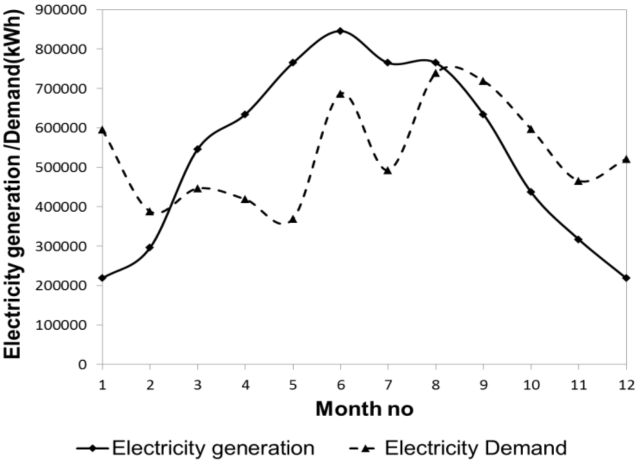

Fig.6. The electricity generation and demand curve at METU-NCC in 2011

According to Table 6, the economical break-even point and electricity generation cost for the grid-tied PV system are reduced to 6 to 7 years and 0.13 to 0.14 cents/kWh respectively, depending on utilized technology.

Table 5. Estimated electricity generation, excess electricity energy production or deficit requirement, and extra income/expenses in each month from grid-connected PV system.

Month	Electricity Generation (kWh)	Electricity Demand (kWh)	Energy excess(+) / deficit (-) (kWh)	Income /Expense($)
January	218,550	595,480	-376,930	-82,925
February	296,100	388,680	-92,580	-20,368
March	546,375	446,800	99,575	21,907
April	634,500	419,280	215,220	47,348
May	764,925	369,680	395,245	86,954
June	846,000	687,400	158,600	34,892
July	764,925	492,920	272,005	59,841
August	764,925	739,000	25,925	5,704
September	634,500	718,960	-84,460	-18,581
October	437,100	597,320	-160,220	-35,248
November	317,250	466,200	-148,950	-32,769
December	218,550	522,000	-303,450	-66,759
Total				-4

Table 6. Estimated Cost and Break-even points for different technologies applied at METU-NCC without storage.

PV Technology	PV panel cost ($)	Inverter cost ($)	PV system price ($)	Break-even point (year)	COE($/kWh)
c-Si	7,520,000	711,000	8,231,000	7	0.14
mc-Si	6,697,500	711,000	7,408,500	6.2	0.13
Thin film-Si	6,756,250	711,000	7,467,250	6.2	0.13

This is an interesting result, because electricity generation cost from grid-tied PV system is less than that of the current grid electricity generation cost associated with the thermal power plant. Therefore, grid-tied PV systems have evidently started to compete against conventional grid electricity generation in Northern Cyprus. Government and private industry should consider this opportunity, and take positive steps to build grid-tied PV systems.

The cost difference of grid-connected c-Si based PV against mc-Si and against thin film Si technologies is $822,500 and $763,750 respectively.

The cumulative cost of the PV panels and the inverter is the most important factor when PV competes with fossil fuel for grid-tied PV system. Due to difference in efficiency of the PV modules, peak power of mc-Si is higher than that of the thin film Si with the same area. Therefore, mc-Si is better compared to the thin film Si for the time being, even though the electricity generation costs are same. The installation area can be reduced by choosing mc-Si over the thin film Si PV technology. Considering the economic aspects of different PV technologies, multi-crystalline Si technology has a lower cost. Therefore, the grid-connected system with mc-Si PV technology is the most suitable option for the university PV farm.

4.3. *Storage Options*

Solar irradiation varies during the day and based on seasons. Therefore, the output of the PV system cannot sustain its maximum power. Thus, having the storage option is advantageous. As demonstrated through calculations in the previous section, battery storage is inhibitingly expensive. Since the campus (METU-NCC) is located at a relatively high altitude, pumped hydropower system can be proposed as an alternate energy storage system for PV generation. Analysis toward such alternatives is not included here.

4.4. *Cost and Policy Aspects*

Over the last 15 years, global photovoltaic (PV) installations have shown an average annual growth rate of 45%. When a constant learning rate of about 20% is considered, this leads to relatively steep reduction of PV installation costs. The growth rate of the PV industry is strongly dependent on the public subsidies [18] in many parts of the world. According to results obtained from the section4.2.3, the grid-tied PV system can already compete against grid electricity in Northern Cyprus, and island country. Therefore, new policies and investments are required from government and private industries to turn PV into the main alternative energy supply in Northern Cyprus. For example, the governments of Japan and Germany pay 0.5 EUR to investors for each kWh produced by PV, as an incentive program. Due to such incentive programs, the PV technology is the leading renewable energy technology in Germany and Japan, and has achieved a tremendous growth rate in recent years [19]. The government in Northern Cyprus can evidently drive PV forward with less effort than these countries, based on results reported in this paper, due to the abundant solar resources, and high cost of fossil fuel imports. The framework for a new energy law has just been approved by parliament in Northern Cyprus, which is a big step to promote environmentally friendly electricity production. The PV systems produce CO_2 free electricity compared to the fossil fuel based electricity generation. Therefore, they have additional market value for the government. The government can sell CO_2 credit to another country, and can provide incentives for investments to PV power plants.

Enabling PV solar power as the main alternative energy supply requires strong, consistent and balanced policy support. The four main areas of policy intervention should include the following [8]:

i. Creating a policy framework for PV market deployment, including incentive schemes for investors to accelerate market competitiveness,
ii. Providing educational and awareness programs about PV technology and its advantages for the public,
iii. Supporting continuing technology development and sustained R&D efforts to advance the cost and efficiency improvements for PV technology,
iv. Increasing tax for nonrenewable energy production.

5. Conclusion

Analysis in this paper shows that the electricity generation cost of grid-tied PV power plant in Northern Cyprus is cheaper than that of the grid electricity generation of the Teknecik fuel-oil based thermal power plant. Therefore, in the near future grid-tied PV system will become the second main electricity generation resource in North Cyprus. The PV electricity generation cost of university off-grid PV system is approximately 1.8 times higher than that of the grid-connected PV electricity generation, due to the high cost of battery storage system. Calculated break-even points of the off-grid PV system with main technologies available in the market are approximately two times greater than that of the grid-connected PV system. For that reason, off-grid PV system is not currently suitable for large scale applications. The cost of the PV system heavily depends on the PV technology as well as the peak solar hours. However, present cost gaps among Silicon based

PV technologies are small. In the future, the material availability and the cost will play an important role in the PV industry, and will continue to drive the competitiveness of technologies. Considering economic, environmental, technological aspects, the multi-crystalline Si is currently the most suitable solution for the university PV farm, even though its CO_2 emission is relatively high during the manufacturing process compared to other PV technologies. The study reveals that externality cost due to greenhouse emission of the oil-fired plant in North Cyprus is thirty seven, thirty, twenty one times larger than externality cost due the life-time greenhouse emission of thin-film Si, multi-crystalline Si, and mono-crystalline Si technologies respectively. The externality cost of Silicon based PV technologies is negligible in general, compared with that of the conventional energy generation technologies. On-campus PV farm feasibility for METU-NCC can be summarized as follows:

PV technology	Multi-crystalline Si(mc-Si)
PV system price for off-grid PV system, rounded to next 500 ($)	14,000,000
PV system price for grid-connected PV system($)	7,500,000
Break-even point with battery storage(year)	15
Break-even point without battery storage(year)	6
Electricity generation cost of off-grid PV system ($/kWh)	0.24
Electricity generation cost of grid–connected PV system ($/kWh)	0.13
Electricity generation cost of conventional grid electricity without externality($/kWh)	0.18
Electricity generation cost of conventional grid electricity with externality($/kWh)	0.195

Due to the high altitude of the university campus, and high cost for the battery storage system, a pumped hydropower system can be proposed as alternative energy storage for PV electricity generation. The analysis of this option was left to another study. A large number of new PV concepts and materials are still in the research stage. Some of them may lead to much higher efficiency and lower cost in the upcoming decades. The thin film technology with amorphous Silicon is expected to be the next dominant technology that can compete against the fossil fuel. The growth of the PV market will inevitably reduce the PV module price. Therefore, new policies are required from the governments. Photovoltaic technology has already become a truly cost-competitive energy supply. The timing of a large-scale transition may depend on the level of research investments, the level of national, international and multinational cooperation, and the increasing cost of non-renewable energy supplies. Our case study concerning METU-NCC campus confirms the feasibility of grid-connected PV generation in Cyprus, with break-even time far shorter than the life expectation of a PV farm.

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