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Sustainability of Grid-tie Micro-generation System

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***Abstract-* Both the outcomes of technical and economical feasibility analysis of a renewable based power system should be positive to achieve sustainability. Energy production or Renewable Energy Feed-in-Tariff (REFIT) cost should be lower or higher respectively than the existing grid electricity cost. As the renewable energy sources are variable and where REFIT is also applicable for the system connected to the grid, the detailed hourly time series analysis is very important. Based on this issue, in this paper, a techno-economic feasibility analysis has been performed for a PV based micro-generation system to find out the possible ways to make the micro-generation (µGen) system sustainable in low irradiation region. As a case study, the city of Dublin, Ireland has been chosen for the detailed analysis. Analysis shows how the technological improvement can help to popularize the µGen system in Ireland. The procedure can be followed by other countries as well.**

***Index Terms*—Renewable energy, PV system, micro-generation, techno-economic analysis, REFIT,**

I. INTRODUCTION

Developing renewable energy sector is an important part of Ireland's energy sustainability and climate change strategy. Three energy policy goals are met with RE sources such as; energy security, cost competitiveness and protection of the environment through the reduction of greenhouse gas emission. Under EU Renewable Energy Directive 2009/28/EC, Ireland's target is, at least 16% of all energy in the state will be consumed from renewable energy with a sub-target of 10% in the transport by 2020 [1]. Ireland also wants to achieve the target of 20% reduction of Green House Gas (GHG) emission by 2020 [2]. To achieve these targets between the timeline, first step should be maximizing penetration of Renewable/Green Energy (RE) in the energy sector. Photovoltaic (PV) system is a technology to produce electricity from solar energy which is becoming popular in many countries with high solar irradiation. Though Ireland is comparatively a low GHI (global horizontal irradiation) region, future of PV based micro-generation system can become a promising option in energy sector with some technological and economical improvement in the system.

Aim of the present work is to figure out few possible ways to reduce the energy production cost to make the PV system as a sustainable or viable micro-generation solution for Ireland. Therefore, some technical analysis has been done here a) to increase the energy production and b) to reduce the produced cost of energy. Increase of energy production is related to the implemented technology and optimum placement of the system based on geographical and environmental condition. Ireland is one of the countries in low irradiation region. Till now, very few researches/efforts have been made to popularize the PV based µGen system [3, 4]. Findings of these research work show that till now analysis has been done for 53 degree tilt fixed axis PV system and based on the current market price and REFIT policy, this system is not viable.

Therefore the following technical issues have been considered in this paper and analysed in details to improve the technical performance as well as increase the energy production of the system. This will help to reduce the cost of produced energy (COE) below the purchased grid electricity cost or the REFIT cost to make it sustainable. The considered issues are;

1. Optimum placement (tilted angle) of PV panel for a fixed axis system
2. Auto tracking system – (a) One axis (b) Two axis

II. METHODOLOGY

A simple PV based µGen system is presented in Fig 1. A methodology has also been prepared, as shown in Fig 2, to normalize the procedure for techno-economical analysis of a system (i) to improve the technical performance and (ii) to make it economically sustainable. Technical information of the system, economical information of the components and system installation, load demand of the end user and the geo-resource information of the location are used as the input to calculate the cost of energy (COE) of the proposed system. It is then compared with the present or existing base system (in this case - grid electricity cost). Technological improvements are then applied to achieve the sustainability. HOMER, powerful software for techno-economical analysis of renewable based power generation system [5, 6], has been used in the paper for partial analysis of the system. One of the main advantages of the software is that it deals with the hourly time series data and performs the analysis hourly. Therefore, hour-by-hour technical performance of the system can be observed.

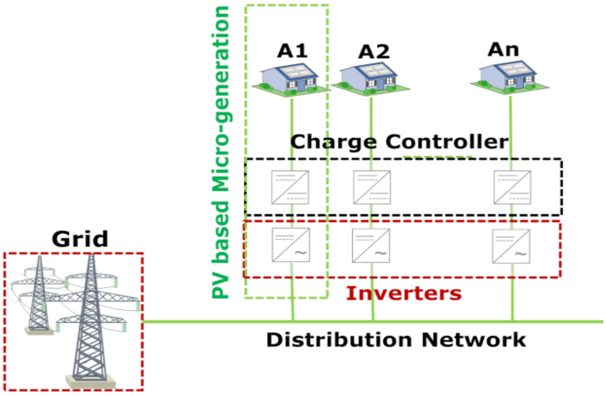

Fig 1: PV based µGen system

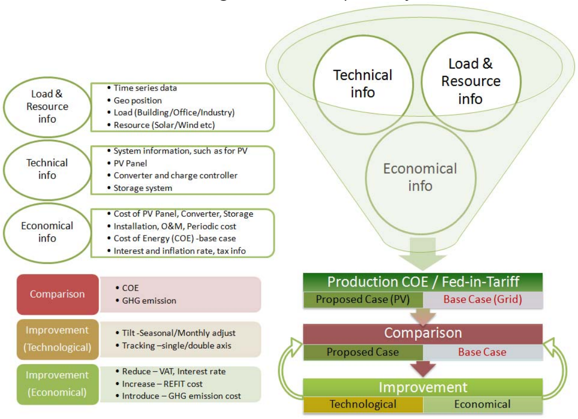

Fig 2: Methodology for techno-economic analysis

III. µGEN SCENARIO IN IRELAND

According to Irish electricity board ESB Network Micro-generators are defined as grid connected generation up to maximum rating of 11 kW when connected to the 3 phase distribution grid (400V) and 6 kW when connected to the single phase distribution grid (230V) [7]. Following this definition In Ireland, at the end of 2010 nearly 2 MW micro-generation system are grid connected among which solar PV installed capacity is 120.78 kW [7]. And the share of the µGen system in the total energy production is less than 1% [8]. Irish Government has introduced incentives for µGenerators from early 2009 and these are free export/import meter, 9c/kWh for all exported electricity, 10c/kWh for the first 3000 kWh exported [8]. But still PV micro-generator is not yet economically feasible in Ireland [3] and based on the market condition in 2011 and the prediction of PV systems price reduction, grid electricity cost escalation, PV based µGen can become feasible after 2016 [4]. Fig 3 shows the percentage of prominent renewable energy (RE) systems in total Irish electricity production [2]. Fig 4 shows grid-connected micro solar PV systems installed from January to October 2010, where it is observed that 80% of the systems have capacity upto 3 kW peak, may be result of restricted roof size, larger capital cost and long payback period of the system [3].

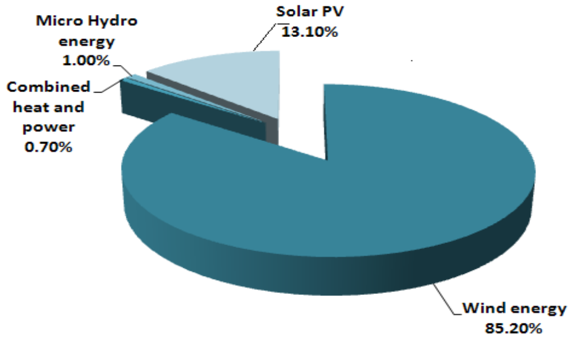

Fig 3: Share of RE system in total Irish electricity production

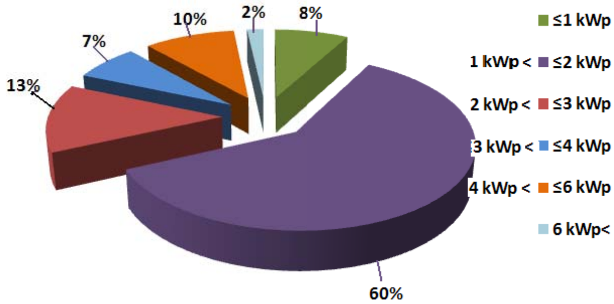

Fig 4: Grid connected micro-PV systems in Ireland

IV. SUN-TRACKING SYSTEMS

In conventional fixed PV systems, the modules are oriented in such a position (tilt and azimuth) that ensures the highest solar irradiation. Position of the sun changes continuously over the time, therefore fixed angle tilted PV systems cannot get optimum solar radiation. This is one of the reasons for introducing tracking technology in the system. The racks that allow the collectors to track along the movement of the sun are quite costly. If the obtained solar radiation by the tracking system is not significant enough, the COE can increase. Sun-tracking systems can be classified into two categories.

A. One axis tracking system:

The system tracks the sun either in azimuth or in altitude angle. Single or one axis tracking is almost always done with a mount having manually adjustable tilt angle along north-south axis and a tracking system that rotates the collector array from east to west. The equation of one axis tracking system is as follows [9],

$$I_{BC} = I_B \cos \delta$$

$$I_{DC} = CI_B \left[\frac{1 + \cos(90° - \beta + \delta)}{2}\right]$$

$$I_{RC} = \rho(I_{BH} + I_{DH}) \left[\frac{1 + \cos(90° - \beta + \delta)}{2}\right]$$

I_{BC} = Beam radiation
I_{DC} = Diffuse radiation
I_{RC} = Reflected radiation
I_{DH} = Horizontal diffuse radiation
I_{BH} = Horizontal beam radiation
C = Sky diffuse factor

I_B = Direct beam radiation
β = Tilt angle
δ = Declination

B. Two axis tracking system

The system tracks the sun in both azimuth and altitude angles so that the collectors are always pointing directly to the sun. The equation of two axis tracking system is as follows [9],

$$I_{BC} = I_B$$

$$I_{DC} = CI_B\left[\frac{1+\cos(90°-\beta)}{2}\right]$$

$$I_{RC} = \rho(I_{BH}+I_{DH})\left[\frac{1+\cos(90°-\beta)}{2}\right]$$

C. Energy gain in sun-tracking system:

Existing studies show that introducing tracking systems in solar PV modules can achieve 30-40% gain in the annual radiation comparing to the same installation of fixed modules [10, 11]. The city of Dublin in Ireland is located at 53 degree angle latitude, so the fixed solar panel systems are normally installed at that angle for better performance. Monthly averaged global horizontal irradiation (GHI) has been collected from [12]. Monthly averaged available radiation on a fixed tilt and tracking surface has been calculated. Fig 5 shows the ratio of solar radiation on tilted and horizontal (G_β/G_H) along with the tracking surface. It indicates how much solar radiation can improve from fixed axis to one or two axis tracking system for Dublin location. It is observed from Fig 5 that, maximum G_β/G_H is found to be 17% more than with a tilt angle of 38° compared to no tilt. At 53°tilt, this ratio is 15% which is commonly practiced in Dublin. Further improvement can be possible by introducing tracking system. With 1-axis tracking at 38°tilt it can improve maximum 45% whereas with 2-axis tracking it increases to 49%.

Table I shows the monthly average solar radiation values for these selected position and tracking systems, as shown in Fig 5. As a part of manual tracking system, monthly optimum (maximum radiation obtained at each month at a specific tilt angle) values can also be calculated, but this topic is beyond the area of this paper. It is observed that in case of fixed system, tilt at 53 degree can give better performance in winter months whereas 38 degree could be suitable for summer months (shown by the green colour). Annual average value for 38 and 53 degree angle is 3.06 and 3.00 kWh/m², therefore it can be stated that PV panel at 38 degree angle can produce more electricity.

On the other hand solar radiation improves significantly for 1-axis and 2-axis tracking system. In case of 1-axis system, both tilt at 38 and 53 degree show comparatively healthier improvement in the obtained radiation. Therefore, it can summarize that in case of Dublin, sun tracking PV system can achieve 40% – 50% more solar energy annually compared to fixed axis system.

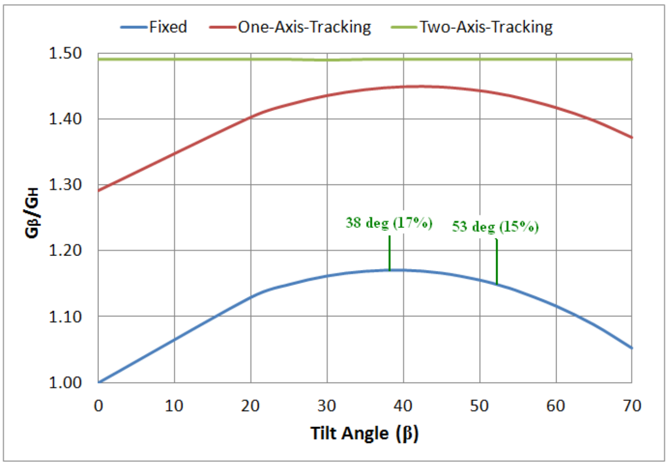

Fig 5: Ratio of solar radiation on Tilted (G_β) and Horizontal (G_H) surface in Dublin, Ireland

TABLE I

GLOBAL RADIATION (G), IN kWh/m^2/day, ON HORIZONTAL (H) AND TILTED (β) SURFACE IN DUBLIN, IRELAND

Month	Fixed			Tracking		
	Tilt Angle, β (degree)			One axis		Two Axis
	0	38	53	38	53	
Jan	0.71	1.49	1.67	1.71	1.87	1.94
Feb	1.31	2.14	2.28	2.54	2.66	2.67
Mar	2.86	3.98	4.07	5.10	5.17	5.16
Apr	3.31	3.65	3.50	4.47	4.37	4.47
May	4.75	4.77	4.43	6.28	6.06	6.42
Jun	4.92	4.71	4.30	6.04	5.78	6.27
Jul	4.70	4.59	4.22	5.90	5.66	6.07
Aug	3.61	3.80	3.59	4.62	4.48	4.65
Sep	2.40	2.84	2.79	3.30	3.27	3.28
Oct	1.39	1.98	2.05	2.27	2.33	2.32
Nov	0.81	1.61	1.67	1.84	1.86	1.90
Dec	0.54	1.10	1.38	1.26	1.55	1.62
Ave	**2.62**	**3.06**	**3.00**	**3.79**	**3.76**	**3.90**
Annual kWh/m^2	955	1118	1095	1382	1373	1423
G_β/G_H	**1.0**	**1.17**	**1.15**	**1.45**	**1.44**	**1.49**

V. Analysis

For the overall analysis, technical and economical information of the system have been given in Table II and III respectively. Load information (load profile and per capita energy consumption) has been collected from the local authority [13]. PV Panel, tracking system and inverter cost information have been collected from different sources [14, 15, 16].

Fig 6 shows the load profile (kW/h) of a single home user for four months (January, April, July, October) in Dublin, Ireland with solar radiation availability on those consecutive months. It is found that load consumption is relatively high (>1.2 kW/h) in winter months at time (17:00 pm—22:00 pm).

In those months the available solar radiation (<0.2 kWh/m²) during the time (8:00 am – 17:00 pm) is not sufficient enough to produce electricity. In summer months, peak load demand is (<1.0 kW/h) at the time (17:00 pm – 22:00 pm). Solar radiation in those months is relatively high and suitable for electricity production. In both cases, the solar radiation and load demand pattern does not match at peak load hours.

TABLE II

TECHNOLOGICAL INFORMATION

Peak Load	1.7 kWp/day per house (single user)
Annual consumption	5000 kWh/year
PV panel capacity	1 to 6 kW/house
Inverter capacity	1 to 6 kW/house
Fixed axis system	a) 53 degree tilt b) 38 degree tilt
Tracking system	a) 1-axis tracking b) 2 axis tracking

TABLE III

ECONOMICAL INFORMATION

System	Cost
PV panel	1to 4€/Wp
1-axis tracking system	1 €/Wp
2 axis tracking system	1.2 €/Wp
Others (component + installation)	0.5€/Wp
Inverter cost	Calculated from cost curve

Based on the quality and materials, PV panel cost varies. In recent years, PV panel cost is also decreasing dramatically. Therefore, considering the decreasing trend and the possible cost in near future, PV panel cost has been varied from €4.00 to €1.00.

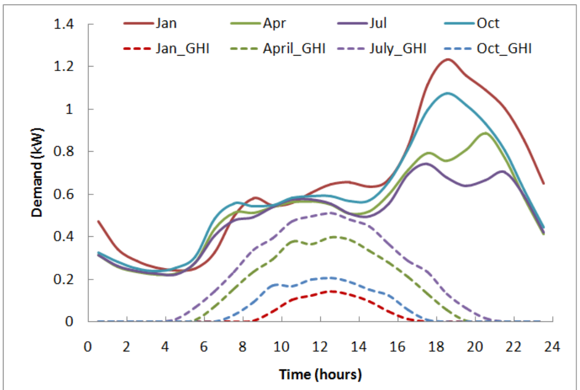

Fig 6: Load profile (-) and solar radiation pattern (--) for 4 months

The cost of converter (€/kW) also varies with the size/capacity. Based on the collected cost information of converter for different size/capacity from different manufacturer, a cost curve has been created, as shown in Fig 7.

Based on this techno-economical information, a grid-connected PV based μGen system has been simulated in HOMER and the hourly performance is analyzed.

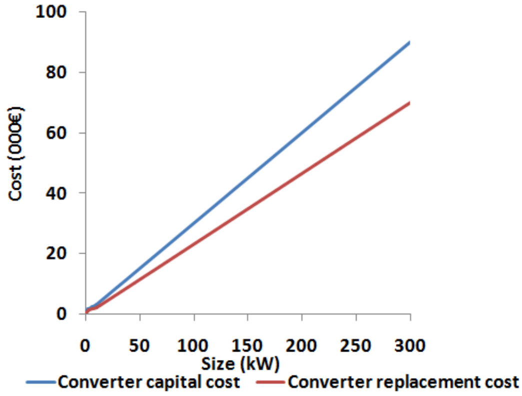

Fig. 7. Converter cost curve

VI. RESULT & DISCUSSION

Result has been discussed here for the installation of maximum capacity (6kW μGen system). Table IV shows the advantages of μGen system. After installation, the household user can sell the additional energy produced by the system and thus can reduce purchasing energy from the grid. Analysis shows that for the fixed tilt at 53 degree, the system can sell more energy to the grid during the winter months. Whereas, tilt 38 degree shows better result for the summer months. Annual sell to the grid also high if the system is placed at 38 degree tilt angle.

Similar result is obtained for the auto tracking systems, as shown in Table V. Here it shows that two axis tracking gives the best output round the year and can sell energy more than that of one axis tracking system.

TABLE IV

ENERGY PURCHASED AND SOLD FOR 6 KW PV BASED μGEN SYSTEM (AT FIXED 53 AND 38 DEGREE ANGLE)

Month	Energy Purchased (kWh)		Energy Sold (kWh)		Net Purchases (kWh)	
	53 Deg	38 Deg	53 Deg	38 Deg	53 Deg	38 Deg
Jan	399	398	180	153	219	245
Feb	295	294	219	194	76	100
Mar	268	267	460	434	-191	-167
Apr	239	235	311	325	-72	-90
May	212	208	432	473	-221	-266
Jun	184	179	385	432	-201	-253
Jul	191	185	386	430	-195	-245
Aug	221	214	322	343	-102	-130
Sep	244	241	254	252	-10	-11
Oct	270	267	164	152	105	115
Nov	307	306	170	146	137	160
Dec	364	363	119	100	245	163
Annual	3,194	3,157	3,404	3,435	-210	-277

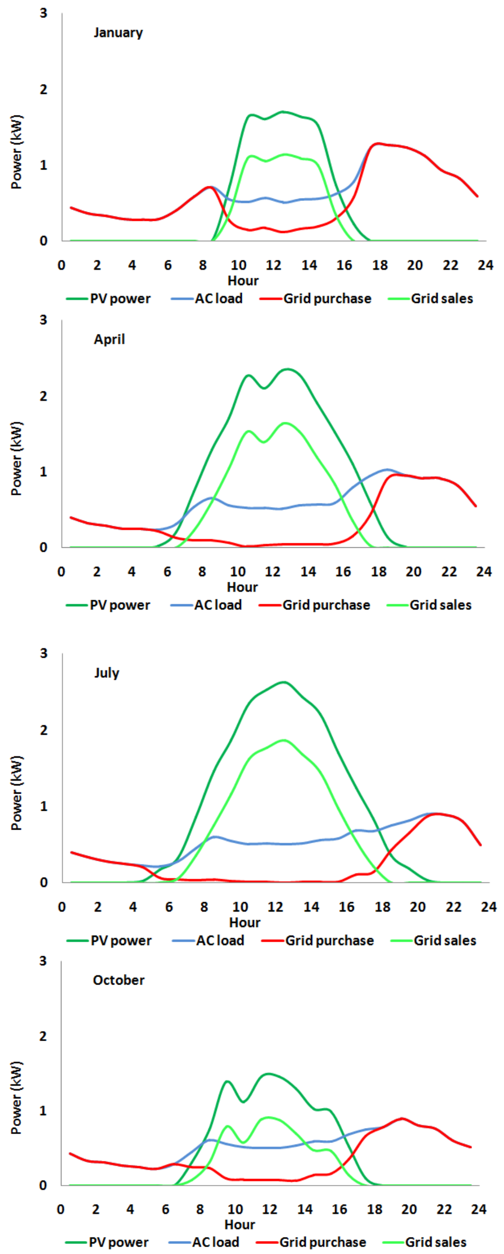

Fig 8: Hourly averaged load profile (AC load), energy production (PV power), sell to (Grid sales) and purchase from grid (Grid purchase) – Fixed axis tilt at 53 degree.

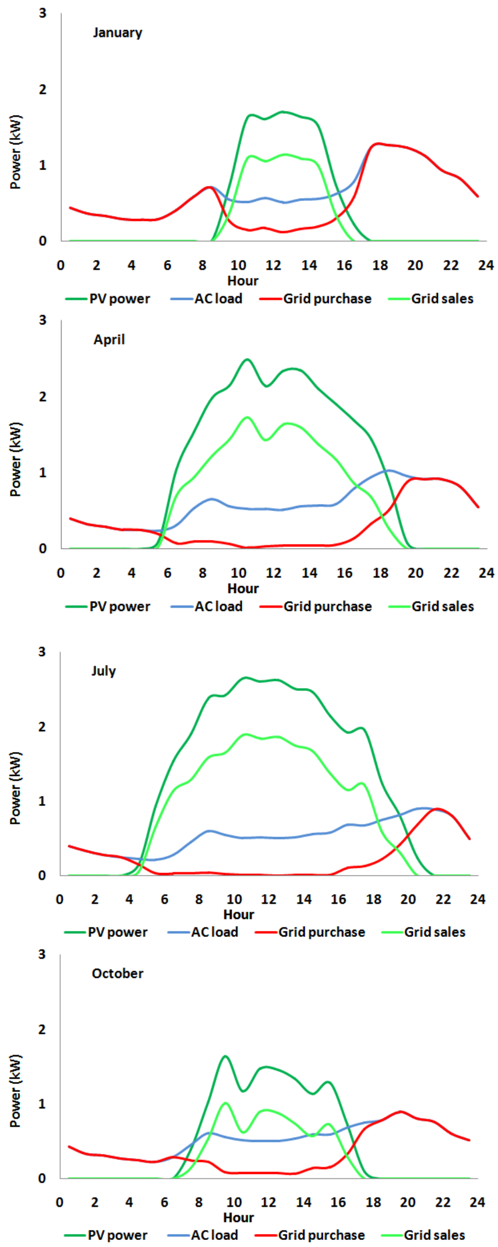

Fig 9: Hourly averaged load profile (AC load), energy production (PV power), sell to (Grid sales) and purchase from grid (Grid purchase) – Two axis tracking system.

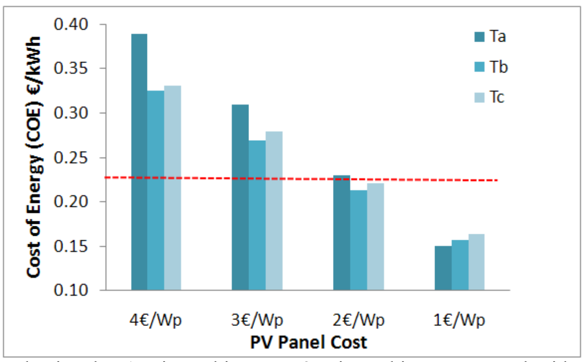

Fig 10: Comparative study of COE for Ta - fixed axis, Tb – 1 axis tracking, Tc - 2 axis tracking system and grid electricity cost - red dotted line

Another finding is that, because of the hourly difference between the load demand and solar radiation availability, user has to purchase the grid electricity every single day. Hourly averaged load profile along with the energy production from the µGen system, energy sell to the grid and energy purchase from the grid is shown in Fig 8 and 9. Both have been given for four months (Jan, Apr, Jul and Oct). Fig 8 represents the performance for fixed axis tilt with 53 degree. Fig 9 reflects the similar performance for two axis tracking system. It shows that for all cases and for any day of the year, the user has to purchase electricity from the grid. There could be a possibility to store the additional sold energy in storage system and use it during the peak demand or solar radiation shortage time. But this storage system can then increase the cost of the system and thus can also increase the COE.

TABLE V
ENERGY PURCHASED AND SOLD FOR 6 KW PV BASED µGEN SYSTEM
(1-AXIS AT 53° ANGLE AND 2 AXIS TRACKING SYSTEMS)

Month	Energy Purchased (kWh)		Energy Sold (kWh)		Net Purchases (kWh)	
	1-axis track	2 axis track	1-axis track	2 axis track	1-axis track	2 axis track
Jan	399	402	189	201	210	201
Feb	294	297	248	259	47	38
Mar	259	261	401	617	-342	-356
Apr	220	222	452	460	-232	-238
May	187	189	692	712	-505	-523
Jun	155	156	635	657	-480	-501
Jul	167	169	620	641	-453	-471
Aug	200	202	487	498	-286	-296
Sep	236	239	335	339	-99	-101
Oct	268	272	199	204	68	67
Nov	307	311	183	193	124	118
Dec	364	367	122	130	242	237
Annual	3,057	3086	4,762	4,910	-1,704	-1,824

Fig 10 shows the COE for a 6kW PV based µGen system for different PV panel cost (1-4 €/Wp). It is observed that for fixed axis system COE is higher than the other two systems when PV panel cost is (2-4 €/Wp). On the other hand COE in 1-axis tracking system is lower than that of 2-axis tracking system. The reasons might be that, (i) in 2-axis tracking system, obtained solar radiation does not improve significantly in Irish climatic condition and (ii) the cost difference between 1-axis and 2-axis tracking system is high compared to the system performance. Therefore, 2-axis system may not be cost effective in Irish environment.

When the panel cost decreases to 2€/Wp then COE in fixed axis system becomes closer to the grid electricity cost. Tracking system becomes sustainable at that condition. When panel cost is lower than 2€/Wp then it is expected that fixed and tracking both systems can become viable.

When panel cost becomes 1€/Wp, fixed axis system can be better than the tracking systems. It happens because of the additional system price in the tracking system which is comparatively higher than the panel cost. It indicates that the tracking system cost should also be decreased in time.

VII. CONCLUSION

This paper deals with the techno-economical analysis of a grid connected PV based µGen system in Irish environment. The goal of this task is to achieve the sustainability of this system through some technical improvement of the existing system. It is found that for fixed axis system the µGen can be placed at 38 degree tilt also. As the summer months have more solar radiation, therefore grid connected µGen with 38 degree tilt could be a better choice. Because of the difference in the additional cost, COE for 1-axis tracking is lower than that of 2 axis tracking system. Based on the present market price and grid electricity cost, both the fixed and tracking systems can become sustainable when the PV panel cost becomes lower then 2€/Wp. If the tracking system cost is not decreased in time, fixed axis system can show better performance when PV panel cost is reduced to 1€/Wp.

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