# Economic Analysis of Stand Alone and Grid Connected Hybrid Energy Systems

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## Abstract

**In this paper, a pilot area has been selected and the renewable energy potential for this region has been evaluated making energy cost analysis. The study evaluates the feasibility of utilizing solar and wind energy with hydrogen as storage to meet the electricity requirements of the pilot region in conjunction with the conventional grid based electricity.**

**In order to simulate the operation of the system and to calculate the technical and economic parameters, micropower optimization program HOMER (NREL, US) has been used. HOMER requires some input values such as technological options, cost of components, resource compliance and the program ranges the feasible system configurations according to the net present cost (system cost) using these inputs.**

**The pilot region where the renewable based energy will be used is determined to be Electrics& Electronics faculty, Istanbul Technical University.**

## 1. Introduction

The goal throughout the modeling is to identify the optimum renewable energy based system design with respect to source availability (wind, solar energy) –which is obtained by varying some pre-defined border conditions-,cost variations and load state by using different input values.

HOMER decides whether renewable energy sources can or cannot satisfy electric demand or not for every hour of the year. If these sources are inadequate, it ensures the other sources like generator and grid to have an active state for satisfying the demand. The program simulates the operation of a system by making energy balance calculations for each of the 8,760 hours in one year. For every hour of the year, this optimization model compares the electric energy demand to the energy that the system can supply in that hour and also calculates the related energy flow towards and from each component of the system.

HOMER expresses the economics of controllable energy sources with two values: fixed cost per hour and energy cost per kWh. These costs express the required cost for generating energy at any time for a power source. HOMER searches for the combination of sources meeting the load and then finds the system achieving the goal with minimum cost by using these cost parameters. [1]

The purpose of this study is analyzing the energy generation via renewable energy sources and also defining the limitations of its competitiveness to traditional systems in its measure of values and rivalry state. As well as defining these limitations, the integration of hydrogen with unstable renewable energy sources –not practically seen in the applications- will be analyzed with an economical perspective.

## 2. System and Components

The sample area where the system will be set up and the economic optimization is to be performed is Electrics& Electronics Faculty of Istanbul Technical University in Ayazaga campus. The energy system feeding the load rate is presented in Figure 1.

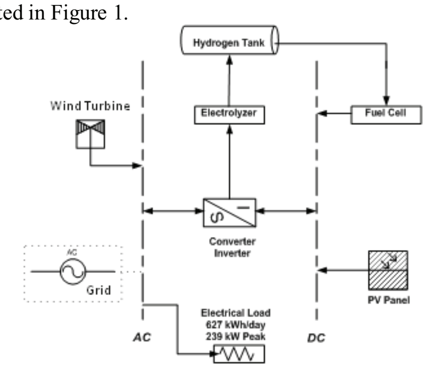


**Fig. 1.** System diagram to be simulated

The excess energy in the system, which has been supplied via photovoltaic panels (PV) and wind turbines (WT), will be used to produce hydrogen by means of electrolysis (ELC) the hydrogen to be obtained will be stored in hydrogen tanks (HT). This stored hydrogen is planned to be converted back into electricity by means of fuel cells (FC) in case of a need (peak load). The characteristics of components WT and FC in utilization are shown Figure 2 and Figure 3. The cost analysis of the system equipments is specified in Tables 1-5.

Furhlander 30 WT has been chosen from the library of HOMER, with 13 m rotor diameter and 26 m of tower height, for the calculation. The initial cost has been taken as 78000$.

Table 1 shows the economical cost values of some WT brands, including the brand that is chosen.[2]

**Table 1.** Turbine costs with respect to WT manufacturers.

| Manufacturer (Model) | Power (kW) | Hub Height (m) | Cost ($/kW) |
|---|---|---|---|
| Bergey Excel-S | 10 | 30 | 5000 |
| Fuhrlander FL 30 | 30 | 27 | 4400 |
| Fuhrlander FL 100 | 100 | 35 | 3100 |
| Fuhrlander FL 250 | 250 | 50 | 2500 |
| Entegrity EW15 | 50 | 25 | 4000 |
| Enertech E48 | 600 | 60 | 2100 |
| General Electric GE1.5 | 1500 | 80 | 1600 |

| Wind Speed (m/s) | Power Output (kW) |
|---|---|
| 0 | 0 |
| 1 | 0 |
| 2 | 0 |
| 3 | 0,5 |
| 4 | 1,6 |
| 5 | 3,5 |
| 6 | 7 |
| 7 | 12 |
| 8 | 17 |
| 9 | 22 |
| 10 | 26 |
| 11 | 28 |
| 12 | 30 |
| 13 | 30,5 |
| 14 | 31 |
| 15 | 32 |

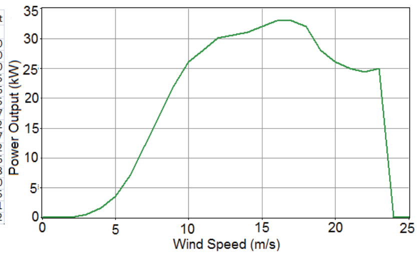


**Fig. 2.** WT power values and the related curve

**Table 2.** Turbine costs in the literature [3,4,5,6,7,8]

| Wind Turbine | | | |
|---|---|---|---|
| **Size** | **ICC** | **Replacement Cost** | **O&M Cost** |
| 1 kW | \$ 1500-\$2250 | %10 ICC | %5 ICC |
| 1 kW | \$1.200 | | |
| 600 kW | \$575.000 | \$400.000 | \$13.000 |
| 75 kW | \$19.400 | \$15.000 | 75\$/year |
| 1800kW | \$3.500.000 | | %2 ICC |
| 50 kW | \$147.000 | | 4400\$/year |
| 1 kW | \$1.350 | | |

**Table 3.** PV costs in the literature [9,10,3,11,4,7,12,13]

| PV | | | |
|---|---|---|---|
| **Size** | **ICC** | **Size** | **ICC** |
| 1 kW | \$6.750 | 1kW | \$10.200 |
| 1 kW | \$8000-\$12000 | 1 kW | \$10.000 |
| 1kW | \$4200-\$6000 | 75W | \$355 |
| 1kW | \$7.500 | 1 W | \$5,3 |

PV cost is determined to be \$5000 per kWh (with zero O&M cost) regarding the market research and literature values

**Table 4.** Electrolyzer costs in the literature [9,6,14,4,8]

| Electrolyzer | | | |
|---|---|---|---|
| **Size** | **ICC** | **Replacement Cost** | **O&M Cost** |
| 1 kW | \$2.184 | %10 ICC | %2 ICC |
| 1 kW | \$1500-\$3000 | \$1125-\$2250 | \$1,5-\$30 |
| 1 kW | \$740 | %30 ICC | %5 ICC |
| 1 kW | \$1.500 | | |
| 1 kW | \$1.450 | | |

Regarding the analysis in Table 4, ELC cost values of the system have been determined as \$3128/kWh while the replacement and maintenance costs are determined to be 1/2 and 1/20 of capital cost, respectively.

**Table 5.** Fuel cell costs in the literature [10,9,4,12,13]

| Fuel Cell | | | |
|---|---|---|---|
| **Size** | **ICC** | **Replacement Cost** | **O&M Cost** |
| 1 kW | \$4.000 | | %1 ICC |
| 1 kW | \$3000-\$6000 | | |
| 1 kW | \$3.000 | \$2.500 | 0,02\$/h |
| 1 kW | \$1.840 | | |
| 1 kW | \$4.000 | | |
| 1W | \$7 | | |

FC cost value of the system is determined to be \$5000 per kWh; and the maintenance cost is determined to be 0,1 \$/hour. FC power and efficiency curves are developed as shown in Figure 3.[8,15,16]

| Output Power (kW) | Fuel Consupmtion (kg/hour) |
|---|---|
| 0.100 | 0.011 |
| 0.200 | 0.016 |
| 0.230 | 0.019 |
| 0.500 | 0.113 |
| 0.700 | 0.138 |
| 3.500 | 0.231 |
| 5.870 | 0.354 |
| 8.375 | 0.474 |
| 12.750 | 0.749 |
| 15.870 | 0.957 |
| 23.500 | 1.460 |
| 31.750 | 2.044 |
| 36.620 | 2.350 |

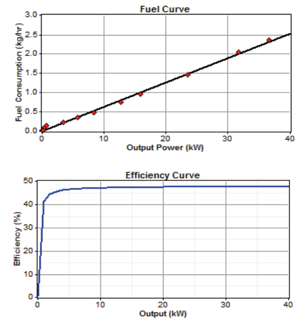


**Fig. 3.** FC power and efficiency curves

Hydrogen tank and storing costs for 3,2 kg is determined to be \$2288 while the replacing cost is determined to be \$195 and maintenance cost is 9 \$/year for the system. Convertor, capital, replacement and maintenance costs are determined to be \$1000, \$1000 and 100 \$/year per kWh, respectively.

### 3. Load and Energy Characteristics of the Region

The load profile has been formed by using the past electricity demand figures of the faculty. The load characteristic is critically important for the system optimization; if big energy demand occurs on the evening time, or in convenient weather conditions, then the stored energy (hydrogen in this system) must be used. [3] The load characteristics of the pilot region have been specified in Figure 4.

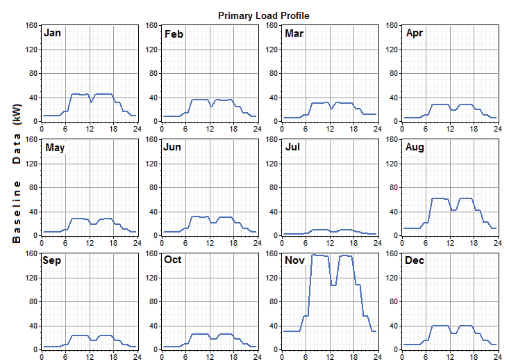


**Fig. 4.** Load profile of the region

The solar and wind energy characteristics of the region are summarized in Table 6, Figures 5 and 6.

**Table 6.** Solarization values of the region

| Months | Clearnes Index | Dailiy Radiation Wh/m2/g | Months | Clearnes Index | Dailiy Radiation Wh/m2/g |
|---|---|---|---|---|---|
| *Jan* | 0.383 | 1.550 | *Jul* | 0.661 | 7.450 |
| *Feb* | 0.390 | 2.130 | *Agu* | 0.650 | 6.540 |
| *Mar* | 0.431 | 3.220 | *Sep* | 0.602 | 4.920 |
| *Apr* | 0.498 | 4.750 | *Oct* | 0.499 | 3.020 |
| *May* | 0.562 | 6.180 | *Nov* | 0.415 | 1.810 |
| *Jun* | 0.619 | 7.180 | *Dec* | 0.372 | 1.350 |
| *Avg.* | 0.541 | 4.186 | | | |

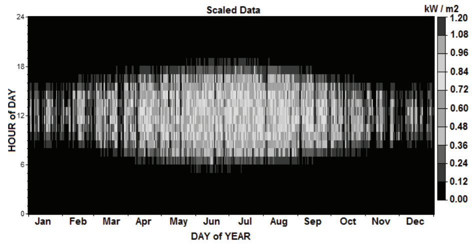


**Fig. 5.** Global solar radiation of the region

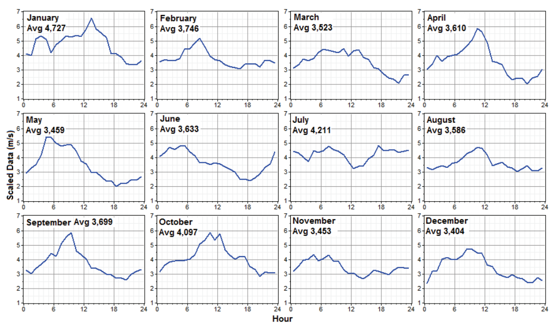


**Fig. 6.** Monthly average wind speed and the profile of the region

## 4. Optimum Hybrid System

### 4.1. Stand Alone System (SA)

The quantity HOMER uses to represent the life-cycle cost of the system is the total system cost (SC). This single value includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The SC includes the initial capital cost (ICC) of the system components, the cost of any component replacements that occur within the project lifetime, the cost of maintenance and fuel, and the cost of purchasing power from the grid.

The optimum system (system with minimum SC) for the stand alone power system includes 250 kW Photovoltaic Panel (PV), 10 Wind Turbines (WT) 250 kW Fuel Cell (FC) 250 kW converter (CON), 100 kW electrolyzer (ELC) and 2250 kg $H_2$ tank (HT). The ICC of the whole system is $ 5.451.617. The total SC is $ 8.724.232 while the cost of energy (EC) is calculated as 3,391$/kWh. The component costs are shown in the Table 7.

**Table 7.** Component costs of the stand alone system

| Component | Capital | Replacement | O&M |
|---|---|---|---|
| *PV* | 1.250.000 | 0 | 0 |
| *WT* | 780.000 | 0 | 247.399 |
| *FC* | 1.250.000 | 1.522.341 | 891.762 |
| *CON* | 250.000 | 85.679 | 281.135 |
| *ELC* | 312.867 | 114.129 | 175.916 |
| *HT* | 1.608.750 | 0 | 71.162 |
| *SYS* | 5.451.617 | 1.722.148 | 1.667.375 |

The cash flow detail of the system over the project life time is shown in Figure 7. On the other hand, it is observed that the replacement and O&M costs belonging to FC and ELC equipments raises the SC over the project life time.

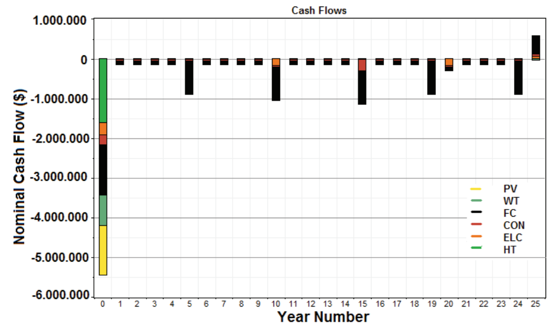


**Fig. 7.** Cash flow details of the SAS

In this stand alone power system, 33% of the electricity demand is produced from solar panels with 378.740 kWh/yr, while 59% and 7% of the energy requirement is supplied from WT with 674.252 kWh/yr and from FC with 80.405 kWh/yr, respectively. Monthly average electric production of the entire system is shown in Figure 8.

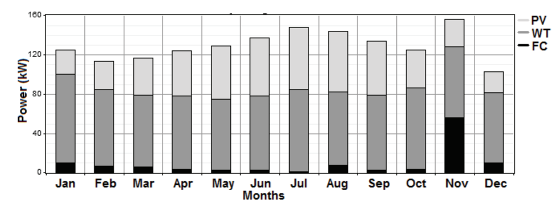


**Fig. 8.** Monthly average electrical production rates of SAS

The output operation values of system components are calculated as specified in Table 8 and Table 9.

**Table 8.** PV and WT outputs for SAS

| PV | | | WT | | |
|---|---|---|---|---|---|
| **Quantity** | **Value** | **Units** | **Quantity** | **Value** | **Units** |
| Rated capacity | 250 | kW | Total rated capacity | 330 | kW |
| Mean output | 43 | kW | Mean output | 77 | kW |
| Mean output | 1.038 | kWh/d | Capacity factor | 23,3 | % |
| Capacity factor | 17,3 | % | Total production | 674.252 | kWh/yr |
| Total production | 378.740 | kWh/yr | Maximum output | 330 | kW |
| Maximum output | 291 | kW | Wind penetration | 295 | % |
| PV penetration | 165 | % | Hours of operation | 5.591 | hr/yr |
| Hours of operation | 4.378 | hr/yr | Levelized cost | 0,136 | $/kWh |
| Levelized cost | 0,293 | $/kWh | | | |

**Table 9.** FC outputs for SAS

| FC | | | | | |
|---|---|---|---|---|---|
| **Quantity** | **Value** | **Units** | **Quantity** | **Value** | **Units** |
| Hours of operation | 3.172 | hr/yr | Min. electrical output | 0,0481 | kW |
| Number of starts | 536 | starts/yr | Max. electrical output | 250 | kW |
| Operational life | 4,73 | yr | Hydrogen consumption | 5239 | kg/yr |
| Capacity factor | 3,67 | % | Specific fuel consumption | 0,065 | kg/kWh |
| Fixed generation cost | 75 | $/hr | Fuel energy input | 174.635 | kWh/yr |
| Electrical production | 80.405 | kWh/yr | Mean electrical efficiency | 46 | % |
| Mean electrical output | 25,3 | kW | | | |

#### 4.1.1. Effects of component costs to the system

The cost of the system components is supposed to decrease and in order to simulate those conditions for the long term analysis; a 50% decrease in component costs has been included to calculation. When only the PV cost decreases by 50%, the $H_2$ tank capacity and ELC decreases in the OS. In other words, FC works less than previous configuration and storage of energy in $H_2$ form decreases. The system cost and cost of energy falls by 7,3% in this condition.

In the case of 50% decrease in WT cost, the number of WT increases to 13 while PV capacity decreases to 200 kW. The system cost and energy cost also decreases about 5,5%.

Both the number of WT and the size of PV is observed to be decreasing when FC cost decrease is evaluated. The cost of the system and energy also falls about 25,3%.

When the costs of all components decrease by 50%, then the EC of the whole system decreases by 35,4%. The whole cost and system variations are presented in Table 10.

**Table 10.** Effects of component costs to the SA system

| | PV (kW) | WT (kW) | FC (kW) | ELC (kW) | HT (kg) | SC ($) | EC ($/kWh) | % Change |
|---|---|---|---|---|---|---|---|---|
| All components current costs | 250 | 10 | 250 | 100 | 2250 | 8.724.232 | 3,391 | 0 |
| PV Cost 1/2 Decrease | 450 | 10 | 250 | 80 | 2000 | 8.080.265 | 3,140 | 7,38 |
| WT Cost 1/2 Decerease | 200 | 13 | 250 | 100 | 2250 | 8.241.330 | 3,203 | 5,53 |
| FC Cost 1/2 Decease | 200 | 8 | 250 | 120 | 2500 | 6.515.505 | 2,532 | 25,3 |
| All components 1/2 Decrease | 250 | 10 | 250 | 100 | 2250 | 5.627.186 | 2,187 | 35,5 |

### 4.1.2. Effects of capacity shortage fraction to the system.

Givler and Lilienthal has specified that, allowing some of the load to go unserved throughout the year means that the system components do not need to be sized for extreme cases; and economic performance of the system would increase.[11]

When the capacity shortage (CS) to some extend was perceived reasonable in the system, the OS configuration or the operation/size of some components has been observed to be changing.

The CS has been selected to vary between 0% and 4% of the load in this study. The changes of EC and total electrical production (TEC) in this range have been emphasized in Figure 9. It is seen that with the increase in CS, the SC conversely decreases about 26,2% and the EC values fall 2,604 from 3,391$/kWh. Electrical production decreases by 7,2% as also can be seen in Figure 9. The graph illustrates that allowing just a small amount of unserved load can significantly reduce the cost of the system.

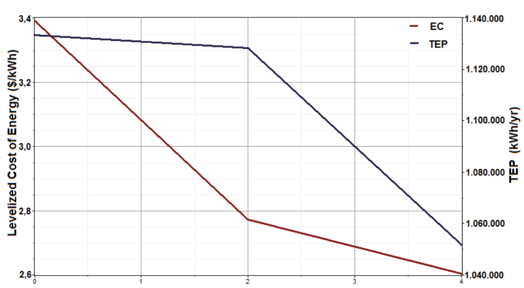


**Fig. 9.** The effects of CS to the TEC and EC

## 4.2 Grid Connected System

When the system is connected to a grid, optimum system has been calculated as 40 kW PV, 20 kW FC and ELC, 30 kW converter and 100 kg HT and grid connection. SC of this configuration is 789.300 $ and EC is 0,307$/kWh. Penetration of RE sources for this system is 25% (24% PV and 1% FC) and grid meets as much as 75% rate of the load.

### 4.2.1 Effects of Electricity Rate to the System.

When an analysis is realized for the case of electricity rate (ER) rising to 2$/kWh, it is found that OS includes 100 kW PV, 5 WT, 20 kW FC, 30 kW ELC with 200 kg HT and grid connection. Total SC for this configuration is calculated as 3.320.820$ and EC is found as 1,292$/kWh. Renewable energy fraction-ratio increases three times and reaches 88% in this optimum configuration. 57% of the energy demand is met from WT, whereas 26%, 6%, 12% is met from PV, FC and grid, respectively.

In Figure 10, with rising electricity rate, the decline of energy purchased from the grid and the increase of PV energy production have been specified.

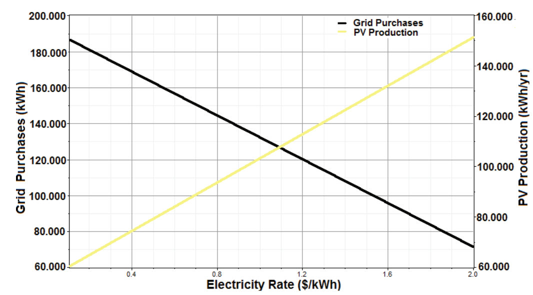


**Fig. 10.** The effect of electricity rate to the grid purchase and PV energy production

According to Figure 10, Purchased energy from the grid decreases about 57% while 2,5 times increase in PV energy production.

The effect of electricity rate to the clean energy production is summarized in Figure 11.

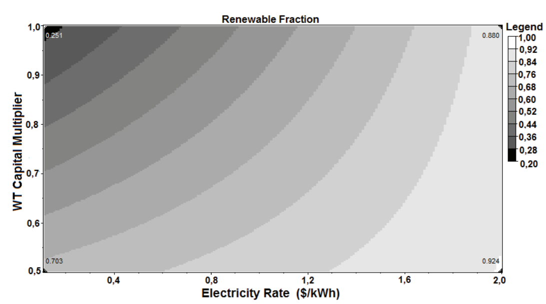


**Fig. 11.** The effect of ER to the renewable energy fraction

According to the Figure 11, in the variation interval of WT capital cost and electricity rate, the renewable energy fraction in the system changes between 0,25 and 0,92.

### 4.2.2 Effects of component costs to the system

The cost of the system components is supposed to decrease and in order to simulate those conditions for the long term analysis; a 50% decrease in component costs has been included to calculation in grid connected system. Such effects are emphasized in Table 11.

**Table 11.** Effects of component costs to the grid connected system

| | Grid (kW) | PV (kW) | WT (kW) | FC (kW) | ELC (kW) | HT (kg) | Project Cost ($) | Energy Cost ($/kWh) | % Change |
|---|---|---|---|---|---|---|---|---|---|
| All components todays costs | 200 | 40 | 0 | 20 | 20 | 100 | 789.300 | 0,307 | 0 |
| PV Cost 1/2 Decrease | 200 | 40 | 0 | 20 | 20 | 100 | 689.300 | 0,268 | 12,6 |
| WT Cost 1/2 Decerease | 200 | 0 | 5 | 20 | 20 | 50 | 769.170 | 0,299 | 2,5 |
| FC Cost 1/2 Decease | 200 | 40 | 0 | 20 | 20 | 100 | 683.687 | 0,266 | 13,3 |
| All components 1/2 Decrease | 200 | 40 | 0 | 20 | 20 | 100 | 583.687 | 0,227 | 26 |

In Figure 12 the effects of electricity rate and RT component cost to the system have been summarized.

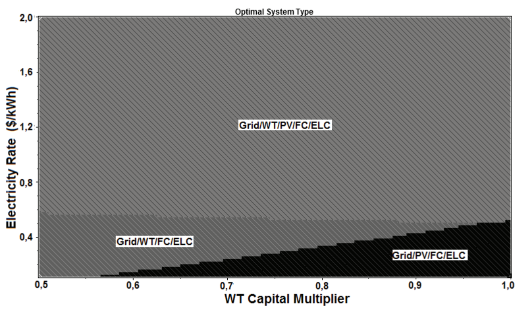


**Fig. 12.** System types over changing ER and WT cost

Since the solar potential of the region is more than the wind capacity, energy production is provided at a lower cost with PV system. Accordingly it is obviously seen in Figure 12 that, when the value of WT capital multiplier is higher than 0,55, the use of PV is a more cost-effective solution. Furthermore in the case of an increase in grid electricity price, hydrogen energy system is set together with solar and wind energy systems in the optimum configuration.

In Figure 13, the effects of the change in electricity rate and the allowed CS on the structure of OS are introduced. The simulation-based OS structure does not change until the unit price of grid electricity reaches 0,5 $ / kWh. After this value, while the grid electricity price is increasing, it is seen that the wind energy system is added to OS.

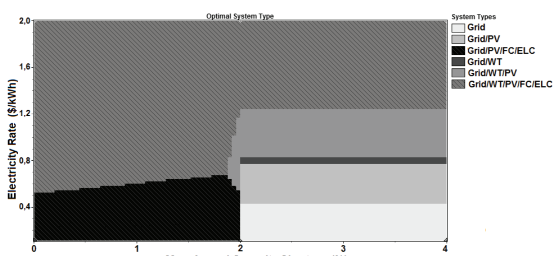


**Fig.13.** System types over changing ER and CS

Nonetheless, when allowed capacity shortage gets higher and is equalized to 1,86%, the optimized system OS consists of PV, WT, grid connection and is not supported with hydrogen energy system. As things stand, increase in the capacity shortage fraction has reduced the need for energy storage which refers to hydrogen energy system in this analyzed system. Consequently the optimized system is not designed with hydrogen, so as not to constitute an increase in the system cost. However while the allowed CS is changing between 2% to 4%, depending on the change in electricity rate, OS is calculated respectively as grid, grid-PV, grid-WT, grid-WT-PV and grid-WT-PV-FC. By the context three values of the electricity rate should get attention. These values are 0,4 $/kWh, 0,8 $/kWh, and 1,2 $/kWh.

Firstly, it can be said that the use of renewable energy is reasonable after the grid electricity rate is higher than 0,4 $/kWh. Secondly, wind and solar energy systems are used together after the unit electricity price is greater than 0,8 $/kWh. Lastly, when the electricity price reaches to 1,2 $/kWh, hydrogen energy system is implicated to the optimum system together with wind and PV systems. All in all, it can be said that the renewables have become cost effective with the increase of the electricity rate. Furthermore the exceed energy that is produced by wind and solar systems is stored in hydrogen system to be converted to electricity when solar and wind energy is unavailable because of the unsuitable weather conditions.

## 5. Simulation Results

The renewable energy potential of Istanbul Ayazaga region and economic analysis of energy production with RE equipments have been assessed in this study. The techno-economic analysis of meeting the pilot region's energy demand with non-emission generating technology has been implemented and its borders of feasibility have been defined.

Several simulations for various scenarios, on the other hand, have been realized by considering different cases. The minimum costs for different system variations have been listed in Table 12 and Table 13. The top rows in the tables include the OS structures; of which details had been given throughout the article.

**Table 12.** System types and costs for CS=0

| System for CS=0 | ICC ($) | SC ($) | EC($/kWh) | CO2 Emissions |
|---|---|---|---|---|
| Grid-PV-FC | 464.073 | 789.300 | 0,307 | 117.755 |
| Grid-WT-FC | 589.323 | 964.170 | 0,375 | 90.197 |
| Grid-WT-PV-FC | 769.723 | 1.114.525 | 0,433 | 80.482 |
| Grid-WT-PV | 2.420.000 | 2.706.431 | 1,053 | 59.945 |
| PV-WT-FC | 5.451.617 | 8.724.232 | 3,391 | 0 |
| WT-FC | 5.083.234 | 9.900.033 | 3,847 | 0 |

**Table 13.** System types and costs for CS=4%

| System for CS=%4 | ICC ($) | SC ($) | EC($/kWh) | CO2 Emissions |
|---|---|---|---|---|
| Grid-PV | 210.000 | 473.631 | 0,185 | 127.389 |
| Grid-PV-FC | 372.573 | 681.769 | 0,266 | 127.389 |
| Grid-WT | 390.000 | 692.265 | 0,270 | 90.330 |
| Grid-WT-PV | 600.000 | 897.632 | 0,350 | 80.539 |
| Grid-WT-FC | 562.573 | 924.516 | 0,360 | 90.330 |
| Grid-WT-PV-FC | 762.573 | 1.105.770 | 0,431 | 80.539 |
| PV-WT-FC | 4.244.117 | 6.430.587 | 2,604 | 0 |
| WT-FC | 4.019.734 | 7.351.721 | 2,967 | 0 |
| PV-FC | 7.226.101 | 10.777.122 | 4,366 | 0 |

The system types for the ER of 2$/kWh has summarized in Table 14.

RE components were to be oversized to make them completely reliable when stand alone system is used; thus, resulting in an even higher total (system) cost in the study.

**Table 14.** System types and costs for ER=2 $/kWh

| System for ER=2$/kWh | ICC | SC | EC | CO2 Emissions(kg/yr) |
|---|---|---|---|---|
| Grid-PV-WT-FC | 1.276.860 | 3.320.820 | 1,292 | 45.097 |
| Grid-WT-FC | 1.370.507 | 3.897.080 | 1,515 | 49.158 |
| Grid-WT-PV | 2.460.000 | 4.464.068 | 1,736 | 49.905 |
| Grid-PV-FC | 1.777.794 | 4.500.342 | 1,750 | 60.479 |

A mixture of RE sources and grid into a hybrid generation system, however, has attenuated the individual fluctuations, increased overall energy output, and reduced energy storage requirements significantly.

A simulation has been performed with decreased component prices and increased electricity rate in order to foresee long term results. The high initial investment cost and source dependence of RE systems have been observed to be posing as the main barrier/pressing-factor/road-block that hampers promotion of these technologies in large scale. On the other hand, low maintenance costs and adjustability in such a case of demand increase were observed as the advantages of these systems.

The decline in the cost of RE resources and the chance of using of hydrogen as the stored energy in order to meet 24 hours load profile, as the results of this study, has increased the feasibility of the system and decreased dependency to the grid. Some performance and cost values of the components used in hybrid system, obtained as a result of the simulation, can be seen in Table 15.

**Table 15.** System equipments performance results

| Optimization Results | | | |
|---|---|---|---|
| WT Enegy Production Cost | 0,136 $/kWh | PV Capacity Factor | 0,173 |
| WT Capacity Factor | 0,233 | PV Enegy Production Cost | 0,293 $/kWh |
| Fuel Cell Efficiency | 47,5% | | |

The turbine capacity factor (CF) is the percentage obtained by division of the electric energy in average wind speed to the maximum turbine capacity mentioned in Table 12. CF generally varies between 20%-45% in wind farms [17]. In another modeling which has been performed using the same WT model, the CF has been calculated as 0,3 and it is close to values in this study.[2] Thus, the calculations above are compatible with values in the literature.

## 6. Conclusions

The evaluation shows that grid connected hybrid RE systems have a higher probability of adaptation than SA (100% renewable system) configurations.

The study indicates that grid connected hybrid systems including grid, PV and hydrogen system have been the most feasible solution in view of the monthly average solar radiation intensity, wind energy capacity of the region and today's equipment costs. The cost of generating energy from this hybrid configuration has been found to be 0,307 $/kWh.

According to those results, the use of RE sources with traditional systems in energy supply and sharing the load by adapting the current system seems to be the most applicable solution for today's conditions. Regarding the similar hybrid system applications in the world, the renewable energy penetration rate varies between 11%-25% [18].

It has been observed that electricity price and cost factor of renewable energy system equipments and changes in CS fraction lead to remarkable differences in the optimum configuration model and energy generation cost.

## 7. References


[1] Lambert,T.,Gilman, P., Lilienthal, P., Micropower system Modelling with HOMER, John Wiley& Sons,Inc. Available:http://www.mistaya.ca/software/docs/MicropowerSystemModelingWithHOMER.pdf

[2] Elkinton, M. R., McGowan, J. G., Manwell, J. F., "Wind Power Systems for zero net energy housing in the United States",*Renewable Ener,*vol. *34*, pp.*1270-78,*May 2009

[3] Alphen, K., Sark, G.J.H.., Hekkert, M., "Renewable Energy Technologies in Maldives-determining the potential"*Rene&Sust E.Rev*,vol.*11*,pp.*1650-74,*Oct 2007.

[4] Beccali, M., Brunone, S., Cellura, M., Franzitta, V.,"Energy, economic and environmental analysis on RET-hydrogen systems in residential buildings", *Renewable Energy* vol 33, pp 366-382, March 2008.

[5] Rehman, S., El-Amin. I.M., Ahmad, F., Shaahid, S.M., AlShehri,A.M.,Bakkashwain,J.M.,Shash,A.,2005.,"Feasibility study of hybrid retrofits to an isolated off-grid diesel power plant", *Renewable& Sustainable Energy Reviews*, vol 11,pp 635-653, May 2007

[6] Khan MJ, Iqbal MT. "Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland", *Renew E,,*vol 30, pp835–54, May 2005.

[7] Dalton, G.J., Lockington, D.A., Baldock, T.E., "Feasibility analysis of stand-alone renewable energy supply options for a large hotel", *Renewable Energy,* vol 33, pp 1475-1490, July 2008.

[8] Garde, R., Aguado, M., Ayerbe, E., Azcarate, C.,Blanco, R., Mallor, F., Rivas, D.,"Economical assessment of a wind–hydrogen energy system using WindHyGen software", *Int Journ of Hydrogen Ener,* vol 34, pp 2845-2854, Apr 2009.

[9] Zoulias EI, Glockner R, Lymberopoulos N, Tsoutsos T, Vosseler I, Gavalda O, Mydske HJ, Taylor P., "Integration of hydrogen energy technologies in stand-alone power systems analysis of the current potential for applications" *Ren and Sust Energy Rev*, vol 10, pp 432–462, Oct 2006.

[10] Zoulias E.I., Lymberopoulos, N.,"Techno–economic analysis of the integration of hydrogen energy technologies in renewable energy-based stand-alone power systems", *Renew E*, vol 32, pp 680-96, April 2007

[11] Lilienthal,P.,Givler,T.,"Using HOMER Software, NREL's Micropower Optimization Model, to Explore the Role of Gen-sets in Small Solar Power Systems", *NREL Technical Report*, Case Study:Sri Lanka,Power-Gen Conf. 2006.

[12] Leva, S., Zaninelli, D., "Hybrid renewable energy-fuel cell system: Design and performance evaluation", *Electric Power System Research* , vol 79, pp 316-324, Feb 2009.

[13] Lagorse, J., Paire, D., Miraoui, A., "Sizing stand -alone street lighting system powered by a hybrid system using fuel cell, PV and battery", *Renewable En.* vol 34, (2009).

[14] Levene, J., Kropski, B., Sverdrup, G.,"Wind Energy Production of Hydrogen and Electricity-Opportunities for Renewable Hydrogen", in *POWER-GEN Conference* , Nevada, April 2006.

[15] Wen, C., Lin,Y., Lu, C., "Performance of a proton exchange membrane fuel cell stack with thermally conductive pyrolytic graphite sheets for thermal management", *Journal of Power Sources,* vol 189, pp 1100-1105, April 2009.

[16] Dufo, R., Bernal, J.L.,HOGA [software program] Available: http://www.unizar.es/rdufo/hoga-eng.htm

[17]Gökçınar, R.E; Uyumaz, A., "Rüzgar Enerjisi Maliyetleri ve Teşvikleri", *VII. Ulusal Temiz Enerji Sempozyumu, UTES'08*, Dec 2008.

[18] Shaahid, S.M., Elhadidy, M.A., 2006. "Technical and economic assessment of grid independent hybrid photovoltaic–diesel–battery power systems for commercial loads in desert environments", *Renewable and Sustainable Energy Reviews,* vol 11, pp 1794-1810, Oct 2007.