Green Hybrid Energy for Office Building

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Abstract. This contribution presents a comparative study of operating a green energy hybrid system to sustain the power production mix of an office building. For this purpose, two scenarios of a hydrogen storage system (S_1) and battery energy storage (S_2) to sustain solar and wind energy inlets were compared from a technical, environmental and financial perspectives. S_1 - hydrogen technology system was found to be more performing than S_2 - battery technology in terms of energy efficiency, as well as CO_2 emissions and initial costs.

1 Introduction

Nowadays, building development and design are led by global sustainability goals. In order to take advantage of the opportunities offered by the global energy transition process, new directions of development and implementation of building power generation systems should be undertaken [1].

The use of local renewable energy sources (RES), on-site green electricity production, hybrid energy systems and the adoption of Distributed Energy Resources (DER) - source of decentralized, community [2] - generated energy, are current concerns, directions and trends in global energy policies.

The current global energy context has triggered unprecedented action by responsible energy and environmental stakeholders. In line with the principles of sustainable development, climate and environmental experts have almost unanimously said that the main cause of climate change was due to the accumulation of CO2 from the fossil fuel burning with a major negative impact on the ozone layer.

In order to correct the environmental imbalance, environmental and energy policies have been promoted to reduce greenhouse gas emissions by reducing consumption and integrating renewable energy sources into energy generation systems. [3]

The main goal of EU energy policies is to develop the process of energy regeneration, especially energy produced through the use of wind, solar, hydropower, geothermal or biomass energy potential.

The new framework agreed by the European Council sets the European Union's target of at least 27% in terms of the share of energy from renewable sources consumed in the EU in 2030. For the EU, investment needs are estimated to be around one thousand billion euros between 2015-2030, only for the production of energy from renewable sources. [4]

Dependence on Romania's primary energy imports is 18-20% compared to some EU member states that import an average of 53% of energy demand. Romania's energy independence will remain for the next two decades, even with a consolidation trend (80-85%). Also, from an energetic point of view, Romania is at an atypical situation for the Southeast European region, as the dependence on external energy suppliers is minimal (the 3rd least EU dependent country).

The current geopolitical framework offers Romania the opportunity to develop the energy sector over the next 20 years in the context of regional and global economic paradigm shifts. [4]

Renewable sources (RES) contribute to mitigating climate change by reducing greenhouse emissions, achieving sustainable development, protecting the environment and improving the health of citizens, while also contributing significantly to increasing energy security with a high potential and availability at the level of Romania.

The procedures and processes of production, capture, storage or conversion of all types of alternative energies are undergoing improvement, the costs of investments in the RES infrastructure are decreasing and the technological efficiencies of the conversion processes are constantly improving, making renewable sources the energy to provide a growing share of the needs of the planetary scale. [5]

Optimistic forecasts estimate alternative energy production to account for more than 50% of the total energy market around 2050 [4], but this depends on finding possibilities for massive electricity storage.

Under the above outlined conditions, this work comes to present a green hybrid energy system that is

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supposed to energetically support, an office building located in Ramnicu Valcea, Romania.

In order to ensure 100% green power supply to the office building, two energy storage scenarios on the operation of the hybrid system were created, namely in scenario 1 (S_1) - energy storage is produced through hydrogen (H_2) and harnessed through the fuel cell (FC) to provide energy for the building and the second scenario (S_2) - energy storage is stored in lithium-ion batteries (B).

In this regard, the following situations have been configured, optimized and simulated in operation [6]:

S_1 - PV+WT+H_2: the hybrid system is composed of photovoltaic panels (PV), wind turbine (WT), inverter (I) and hydrogen production, storage and conversion technology - electrolyzer (Ely), hydrogen tank, fuel cell (FC). The hybrid energy system makes use of both solar and wind energies as renewable primary green sources. For power supply of the office building during the peak load period and weather fluctuation conditions, fuel cell works and employes hydrogen conversion into electricity (secondary source of energy). The hydrogen is produced on-site by the electrolyzer by harnessing the renewable available energy sources (solar and wind).

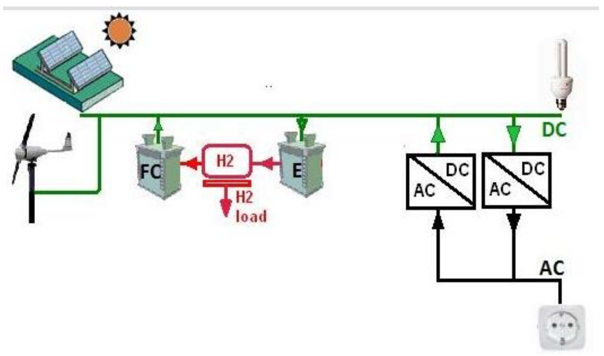

Fig. 1. S_1 - schematic diagram [7]

S_2 - PV+WT+B: in this scenario the hybrid system has the following main equipments: photovoltaic panels and a wind turbine for harnessing solar and wind resources, lithium-ion batteries for renewable energy storage and inverter for DC/AC conversion.

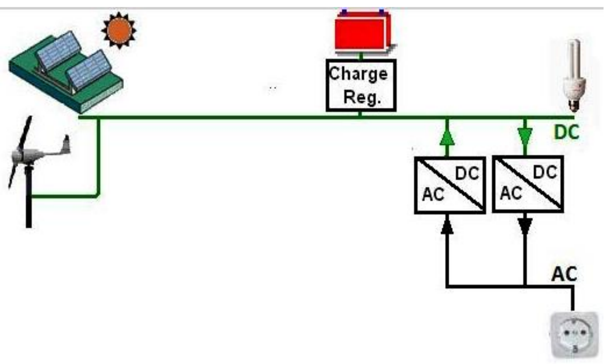

Fig. 2. S_2 - schematic diagram [7]

The purpose of this comparative analysis was to determine the optimal storage solution for the green hybrid system proposed for study, able to supply with electricity an office building.

2 Input data

In order for this comparative analysis to be feasible, it was necessary to define the input data regarding the load of the office building, the regional availability of green energy sources, the characteristics of the green energy hybrid system and the optimal system configuration. Also, it must be identified and specified the technical, environmental and cost characteristics of the main equipment. [5,6,8,9]

2.1 Energy demand of the office building

The average load profile is schematically represented in the figure 3.

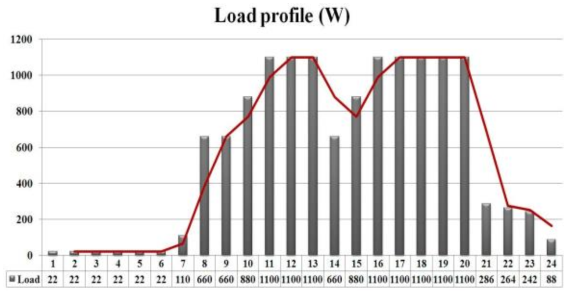

Fig. 3. Average hourly AC power

The energy demand of the office building that was examined for this research, registered an average daily load rate of 13.66 kWh/day, an alternative current maximum hourly active power load of 1100W, an alternative current maximum in half hour intervals of 1268 W and average hourly alternative current power active of 569 W.

2.2 Solar and wind energy

The studied office building where the green energy hybrid system is being implemented is placed in Ramnicu Valcea, Romania.

According to NASA Surface meteorology and Solar Energy: RETScreen Data [10], the location of climate data is as follows:

latitude = 45.10°N,
longitude = 24.36°E,
elevation = 545 m,
frost days at site of 124 days,
cooling design temperature = 24.65°C,
heating design temperature = -10.00°C,
earth temperature amplitude = 20.15°C.

In Ramnicu Valcea, on the ground horizontal surface, the total annual solar irradiation is 1207.68 kWh/m², the daily average solar irradiation is 3.30 kWh/m².

On the PV tilt surface the total annual solar irradiation is 1285.96 kWh/m², and the daily average solar irradiation is 3.52 kWh/m² [10], as illustrated in figure 4.

Fig. 4. Solar irradiation

For the studied site, the ground reflectivity is 0.2, the azimuth of the photovoltaic panels is 0° and the photovoltaic panels are not foreseen with sun tracking systems.

The values that will be taken into account for study represent the monthly average of wind speed registered at a distance of 10 m above the ground. The wind speed for Ramnicu Valcea can be observed in figure 5, which shows the graphic variation of annual average wind speed.

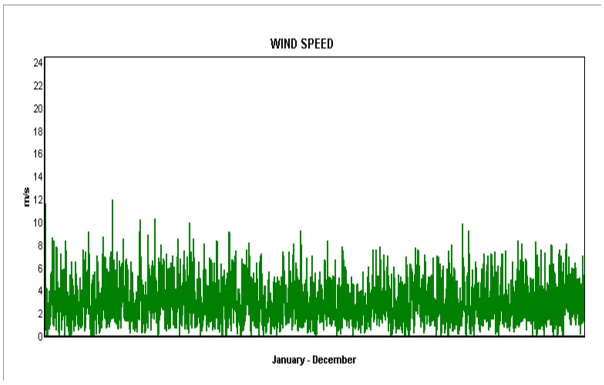

Fig. 5. Wind speed

In Ramnicu Valcea the scaled average wind speed is 3.02 m/s [6], while taking into account for simulation in operation of wind turbines a correlation factor of 0.82.

2.3 Equipment components of hybrid systems

The characteristics of the main equipment components of the green energy hybrid system [7] are as follows:

- PV: rated voltage = 24 V, rated power = 280 Wp, shortcut current = 8.39 A, CO_2 emissions in manufacturing = 800 kg CO_2 equiv./kWp, acquisition cost = 350 euro, Operations and Maintenance (Q&M) cost = 3.5 euro/year, expected lifespan = 25 years;
- WT: output power (W) vs. wind speed (m/s) = 6345 W at 14 m/s, CO_2 emissions in manufacturing = 3500 kg CO_2, acquisition cost = 12056 euro, Q&M cost = 225 euro/year, expected lifespan = 15 years;
- FC: rated power = 1 kW, CO_2 emissions in manufacturing = 330 kg CO_2 equiv./kW rated power, acquisition cost = 7000 euro, Q&M cost = 0.2 euro/ hour of operation, expected lifespan = 40000 hours;
- Ely: rated power = 2 kW, CO_2 emissions in manufacturing = 330 kg CO_2 equiv./kW rated power, acquisition cost = 13500 euro, Q&M cost = 1500 euro/ year, expected lifespan = 20 years;
- H_2 tank: maximum capacity = 10 kg, acquisition cost = 1000 euro/kg, Q&M cost = 10 euro/ year, expected lifespan = 25 years;
- B: rated capacity = 23.5Ah, rated voltage = 410 V, CO_2 emissions in manufacturing = 55 kg CO_2 equiv./kWh capacity, acquisition cost = 15200 euro, Q&M cost = 30 euro/ year, expected lifespan = 45 years;
- Inverter: power = 1600 VA, Imax_ch DC = 20 A, acquisition cost = 1440 euro, expected lifespan = 10 years.

3 Virtual simulation and optimization

The energy, environmental and economic performances were calculated in accordance with the literature [5,11-15].

Computational optimization and simulations are achieved with improved Hybrid Optimization by Genetic Algorithms (iHOGA) software [7] and provide report regarding energetic, environmental and economical performances of the green energy hybrid system during one year of operation.

Multi-objectives optimization approach [7] was used and supplementary conditions were set in order to decrease the excess of energy, the total system cost and the CO_2 emissions.

For the present comparative study the authors have adopted the *Load following* type of *Control Strategy* [7].

Two cases can be analysed when explaining the operating principle of the proposed system. If there is an excess of power generated from the PV and WT sources the electrolyser will produce hydrogen which will be stored for further consumption. In the case the energy generated from RES is not enough to supply the entire building the fuel cell will generate the required power using the already stored hydrogen [12,15,16].

The second proposed scenario entails storing the energy excess in high capacity batteries, so that it can be used on demand if the RES generated power is less than the expected demand [14, 15].

4 Results and discussion

Based on the input data, it has been determined the optimum configuration of the green energy hybrid system in such a way as the overall load energy delivered to feed the office building was supplied 100% from RES in each of the two simulated assumptions.

S_1 is comprised of 2 series *15 parallel photovoltaic panels (PV), 1wind turbine (WT), 1 inverter (I), 1 fuel cell (FC), 1 electrolyzer (Ely) + 1 H_2 tank, and S_2 is comprised of 2 series *15 parallel photovoltaic panels (PV), 1wind turbine (WT), 1 inverter (I), 4 lithium-ion batteries (B).

The results obtained under the provided conditions by the two scenarios are presented comparatively in the following subchapter. The comparative analysis was designed to determine the optimal storage solution for the *Green Hybrid Energy System for Office Building*.

4.1 Energy performance

The results of math calculations and virtual simulations are highlighted in figure 6. For continuous use of the green energy hybrid system for 24 hours /day, during one year of operation, PV will produce an energy of 6473 kWh/year, which represents 54.70% of the total energy generated by the system, while WT has produced an energy of 5359 kWh/year, i.e. 45.30% of the total energy production.

Total green energy supplied by the hybrid system is 11832 kWh / year during one year of operation. From the total generated hybrid energy, 42.14% is used for the office building.

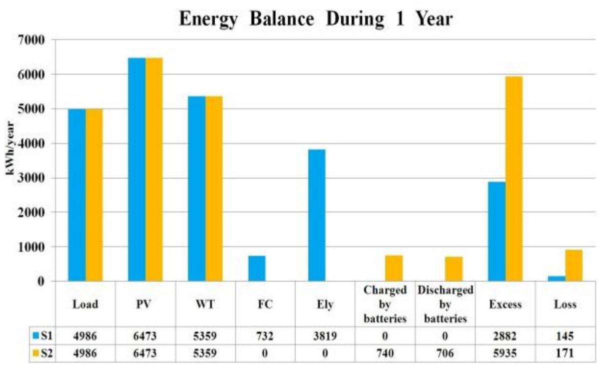

Fig. 6. S_1 - Energy balance for one year of operation

In S_1 scenario, primary energy from renewable energy resources is harnessed through an electrolyzer in proportion of 32.28% (3819 kWh/yr) of the total energy produced by the system, having a hydrogen production of 64.90 (kg/year) and operation time of 3058 (hours/year).

Fuel cell provides backup for the system, 6.20% (732 kWh/year) of the office building's energy demand being covered by it.

From the operation of the hybrid system results an excess of energy of 24.35% (2882 kWh/year) of the total energy production, which can be used in applications, other than the power supply to the office building (i.e. “green-to-green” charging stations for electrical vehicles [17,18]).

Energy balance highlights the annual loss of energy of 1.23%, due to the performance of the system components.

In S_2 scenario, from the energy obtained by the hybrid system, 6.25% was stored into batteries to ensure backup, 50.16% (5935 kWh/year) was an excess of energy which can be used in other applications and the amount of 1.45% was lost due to the performance of the system components.

The monthly and annual average power are generated by the studied component equipment, the results obtained from the simulation of the two systems are illustrated graphically in figure 7 (S_1) and figure 8 (S_2).

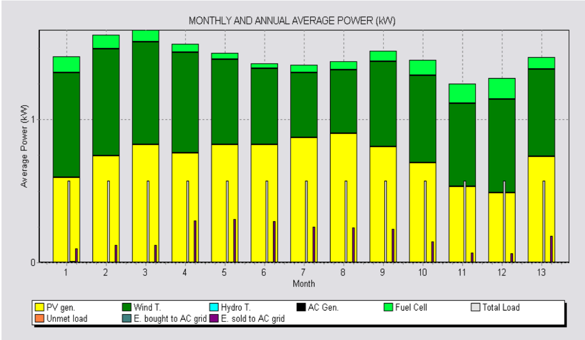

Fig. 7. S_1 - Monthly and annual average power

Hybrid energy is the combined use of two or more forms of energy resulting in a more efficient energy system. Mainly, the advantage of combining the two types of primary energies (sun and wind) removes the deficiencies due to the intermittent availability of wind velocity, but also those of solar irradiation, especially the day/night alternation [19], and still keep the aspect regarding the uneven nature of energy generation.

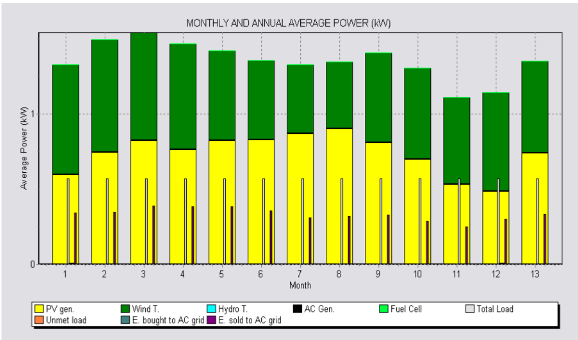

Fig. 8. S_2 - Monthly and annual average power

The worst-case scenario of the studied systems is recorder in December, when the energy demand of the office building is the maximum, and the value of the solar irradiation is minimal. The most favorable situation in which the studied systems work is registered in August, when the energy demand of the office building is minimal and the value of the solar irradiation is maximum. Wind power completes the energy mix so as to ensure the stand-alone building regime.

Exploiting surplus energy from primary sources of sun and wind through hydrogen in the S_1 scenario has the advantage of long-term storage compared to simulated S_2 battery storage which is dimensioned to provide system autonomy for 4 days.

The monthly hydrogen consumption and production, but also the amount of hydrogen stored in the hydrogen tank at the end of each month during a year are shown in figure 9.

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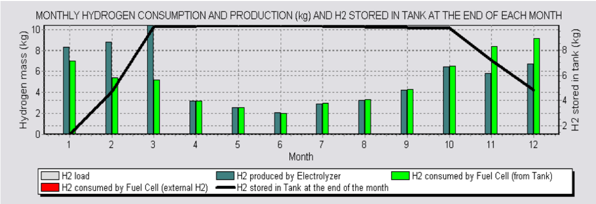

Fig. 9. S_1 - Monthly hydrogen consumption and production

At the beginning of the simulated period (January – March), hydrogen production is higher than hydrogen consumption, reaching the 10 kg capacity of the hydrogen tank by the end of March. Between April and October, hydrogen is produced electrolytically as much as it is needed, and between November and December consumption is higher.

Hydrogen consumption is conditioned by two factors: on one hand, the energy demand to be served by the fuel cell, and on the other hand, the availability of hydrogen fuel. It is important to stress that the hydrogen produced and stored in the hydrogen tanks is consumed according to the energy demand of the consumer, but there is also the case where a surplus of hydrogen can be obtained and further used for other applications. [11,17,18,19].

In terms of energy performance, the hydrogen storage from scenario 1 is more efficient in harnessing renewable energy than the battery storage simulated in scenario 2.

4.2 Environmental performance

The proposed green energy hybrid system generated 11832 kWh/year with a total CO_2 emission embedded in a system of 527 kgCO_2/year in S_1 and 591 kgCO_2/year in S_2. Generating electricity in classical mode (S_C) by the National Energy System is accomplished with the release of 0.3055 kgCO_2/kWh [20]. To generate a quantity of electricity similar to that of the green energy hybrid system, S_C would produce emissions in the amount of 3615 kgCO_2. The values are comparatively illustrated in figure 10.

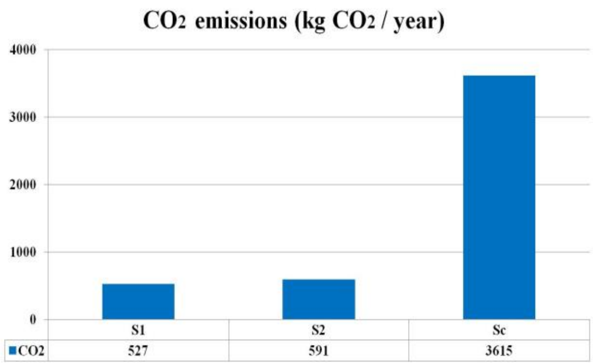

Fig. 10. CO_2 emission

It is found that in S_1 - CO_2 emissions are 85.42% lower than in the case of the classic electricity production system and in S_2 - CO_2 emissions are 83.65% lower than in S_C.

Comparing the two scenarios of the case study, it is found that in case of S_1 the CO_2 emissions are lower by 18.83% compared to scenario S_2. In terms of CO_2 emissions, hydrogen storage from scenario 1 is friendlier with the environment than the battery storage system proposed in scenario 2.

4.4 Financial performance

The initial investment cost comprises the equipment cost of the components included in the system. For the green energy hybrid system with storage based on the hydrogen technologies, the initial investment was calculated of 55886 euros (€), and for the hybrid system with batteries as energy storage, the initial investment cost was of 87993 (€).

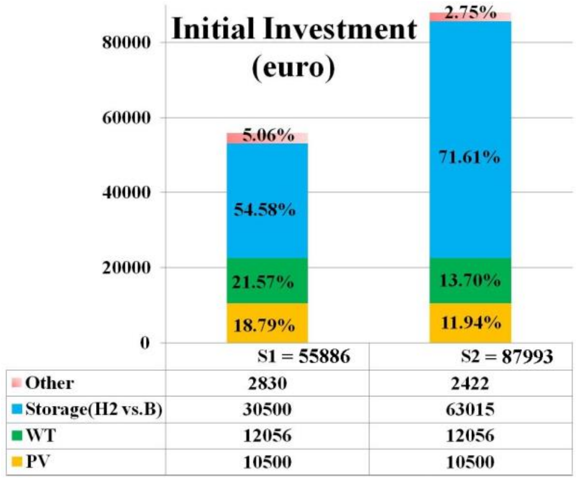

Fig. 11. Initial investment

It is found that the investment cost in S_1 was 36.48% lower than in S_2. As suggestively illustrated in figure 11, the energy storage medium through hydrogen is cheaper than lithium-ion battery storage.

5 Conclusions

Through comparative study the authors have created virtual conditions of operation of two hybrid systems capable to sustain with energy an office building. Then, the performances in operation of these systems have been determined with the purpose to prove the global capabilities of the systems and of the equipments. Next, it has been investigated the performances of the systems by comparing the possibilities and the solutions of RES storage, i.e. hydrogen technology and lithium-ion batteries.

The green energy hybrid system for office building analyzed in this paper can operate in stand-alone mode by using 100% renewable energy sources.

In terms of energy efficiency, hydrogen storage and technologies were more efficient in RES harnessing than lithium-ion batteries storage.

In terms of CO_2 emissions, hydrogen technologies from S_1 is more environment-friendly than lithium-ion battery storage discussed in S_2.

In terms of financial performances, hydrogen technology for storage and conversion into electricity by RES is more economically than lithium-ion battery storage variant, in terms of initial investment spending.

Developing the green building concept with the goal of increasing energy efficiency in the construction sector has brought important contributions to reducing the energy demand for buildings and greenhouse gas emissions, but the success of implementing this concept directly depends on the recovery solution of alternative energies through the various energy generation systems that will be adopted for the energy support of these constructions.

The next generation of green energy systems has significant potential for energy security and efficiency in the buildings sector, having a significant impact on reducing greenhouse gas emissions.

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