CHEMICAL ENGINEERING TRANSACTIONS
VOL. 105, 2023
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: David Bogle, Flavio Manenti, Piero Salatino

ISBN 979-12-81206-04-5; ISSN 2283-9216
DOI: 10.3303/CET23105083

Technical, Environmental, and Economic Evaluation of Alternatives for Hybrid Energy Generation for Rational Energy Use Scenarios at the Santander Technological Units Using HOMER Pro Software

Diego de J. León Nova [a], Diana V. Gallo Ardila [b], Javier Ascanio Villabona [a], Ana M. Rosso Cerón[b,*]

[a] Electromechanical Engineering Program, Unidades Tecnológicas de Santander, Av. Los Estudiantes #9-82, Bucaramanga-Santander, Colombia
[b] Environmental Engineering Program, Unidades Tecnológicas de Santander, Av. Los Estudiantes #9-82, Bucaramanga-Santander, Colombia
arosso@correo.uts.edu.co

The Technological Units of Santander (UTS), a prominent higher education institution in eastern Colombia, consumes an average of 28,490 kWh per month, resulting in monthly costs exceeding USD $5000. To address this, an analysis is underway to reduce expenses and explore viable clean energy solutions for the university buildings. This study aims to assess the technical, economic, and environmental feasibility of hybrid energy generation options, promoting rational energy use. The evaluation utilizes Hybrid Optimization of Multiple Energy Resources (HOMER Pro) software. The analysis of three scenarios indicates that photovoltaic systems can fulfil 24 % to 43.4 % of the energy demand, potentially reducing energy consumption by 30 % through hybrid system implementation. Each scenario offers alternatives with a return on investment (ROI) of over 5.8 % and a feasible internal rate of return (IRR) exceeding 8.9 %. Currently, UTS emits approximately 229.47 t of CO_2 annually. However, implementing rational energy use scenarios could reduce CO_2 emissions by up to 49.3 %.

1. Introduction

Colombia is adopting a new energy generation model with the aim of positioning itself as a country that contributes to mitigating climate change. The national goal is to reduce greenhouse gas (GHG) emissions by 51 % by 2030. Colombia heavily relies on hydroelectric power, which constitutes approximately 65-70 % of the total energy grid. However, there is a growing recognition of the need to diversify the energy sources in the country. Although non-conventional renewable energy sources, excluding large hydroelectric power, represented only 1 % of total electricity production in 2018, there has been substantial progress. Currently, renewables contribute 12 % to the energy mix (Ministry of Environment, 2021).

To further incentivize renewable energy, the Ministry of Mines and Energy in Colombia has implemented several measures; for example: Law 1715 of 2014, which promotes the integration of clean energy systems into the national grid, thereby facilitating the development of hybrid energy systems. Additionally, Resolutions 40590 and 40591 of 2019 provide support for the implementation of clean energy systems by exempting tariff duties and considering operation and maintenance (O&M) expenses, as well as providing the necessary resources for system development (Castaño & García, 2020).To advance Colombia's shift to a sustainable energy generation model, it is vital to investigate the potential of renewable energy sources and their integration into the national grid. This requires evaluating various scenarios and assessing their feasibility using dependable tools and methods.HOMER Pro is a widely commercial used software tool for analysing hybrid renewable energy systems. It simulates, optimizes, and analyses these systems, incorporating modules for modelling solar panels, wind turbines, batteries, and the electric grid. Its main advantage is the ability to generate and evaluate multiple alternatives, exploring different configurations, system sizes, and renewable energy technologies.

Paper Received: 14 March 2023; Revised: 11 July 2023; Accepted: 22 September 2023
Please cite this article as: Nova D.D.J.L., Gallo Ardila D.V., Ascanio Villabona J., Rosso Ceron A.M., 2023, Technical, Environmental, and Economic Evaluation of Alternatives for Hybrid Energy Generation for Rational Energy Use Scenarios at the Santander Technological Units Using HOMER Pro Software, Chemical Engineering Transactions, 105, 493-498 DOI:10.3303/CET23105083

This helps decision-makers identify the most suitable options for achieving energy sustainability and reducing CO_2 emissions.Various studies have utilized HOMER Pro for analysis and optimization purposes. For instance, Palau (2019) employed HOMER to compare renewable hybrid installations in municipal buildings in Betxí, Spain, considering factors like location, climate, and costs. Gómez (2019) explored battery selection for microgrid connection based on storage capacity using HOMER Pro. In Malaysia, Afham et al. (2021) evaluated investments in renewable energy systems using HOMER Pro and demonstrated the cost-effectiveness and CO2 reduction potential of hybrid photovoltaic-electricity systems. In Colombia, Rosso Cerón and Kafarov (2015) conducted financial feasibility studies for isolated populations, evaluating different scenarios for integrating variable renewable energy systems. International experiences, such as Galdamez et al. (2020), highlighted HOMER Pro's role in designing renewable energy systems for educational institutions, emphasizing optimization, economic feasibility, and environmental impact assessment. In Colombia, Osorio (2022) evaluated electricity demand, photovoltaic system sizing, and energy performance monitoring at the National University of Colombia using HOMER software. It proved indispensable in finding sustainable energy solutions and optimizing renewable energy systems. At UTS, monthly electricity consumption averages 28,490 kWh, with a significant cost increase attributed to a growing student population and new building construction (Mora, 2022). Then this research aims to study hybrid energy generation systems and implement energy efficiency scenarios at UTS using HOMER Pro software. Challenges include data availability, accuracy, and the complexity of modelling hybrid energy systems.

2. Methodology

2.1 Estimation of renewable energy resource

Required inputs for HOMER Energy Pro include meteorological data of renewable sources. Wind and solar resource potential were compiled from NASA's Prediction of Worldwide Energy Resource (POWER) portal, utilizing the georeferencing coordinates of the buildings under study. The selection of these specific renewable resources as alternatives for the case study was based on their feasibility, considering the absence of options such as geothermal or nuclear energy sources.

2.2 Estimation of the demand of electric

As a required inputs for HOMER Energy Pro, energy demand in the buildings under investigation was estimated using primary data obtained from the commercial distributor's electrical consumption records. In addition, the load curve was obtained because it plays a crucial role in analysing and optimizing hybrid energy systems. The average daily demand curve currently stands at 949.67 kWh/d. The demand exhibits a distinct pattern characterized by an initial surge in loads at 6:00 am, corresponding to the commencement of daily classes, which then remains relatively stable until approximately 10:00 am. Subsequently, there is a gradual decline in demand throughout the afternoon hours. However, at 5:00 pm, there is a notable increase in demand attributed to the influx of students attending evening classes, resulting in a peak power consumption of 85.47 kWh between 6:00 and 7:00 pm.

2.3 Formulation of three scenarios for rational end use of energy

To promote the rational use of energy at UTS, three scenarios were employed for the simulation of the energy system in HOMER Energy Pro. These scenarios focus on implementing technical improvements in end energy consumption and aim to achieve efficiency levels of 25 %, 30 %, and 35 %, respectively. The scenarios were developed for the analysis and simulations performed using the HOMER Energy Pro. They involve various measures to enhance energy efficiency, such as the use of energy-efficient devices like LED light bulbs and the implementation of corrective energy-saving measures. These measures include optimizing equipment settings, improving insulation, and adopting efficient control systems.

2.4 Assessment of technical, environmental, and financial feasibility

The feasibility of the alternatives provided by HOMER Energy Pro was analysed in each scenario, comparing results in the different systems provided by the tool, considering parameters such as Net Present Cost (NPC), IRR, Levelized Cost of Energy (LCOE), and ROI represented in equations (1) to (4) respectively.
I_t is the Initial Investment, E_{ls} is the electrical load served, p is the profitability, O&M is the cost of operation and maintenance, R_c is the replacement cost, F_c is the cost of fuel, E_{pg} is the energy purchased from the grid, E_{sg} is the energy sold to the grid, C_{salv} is the salvage cost, A_{cf} is the annual monetary flow, $C_{bs(ref)}$ is the cost of the base system (referenced), P_d is the duration of the project, $A_{mf(ref)}$ is the annual monetary flow of the system (referenced) and Cc is the cost of the current system.

The quantification of CO_2 equivalent emissions avoided as a measure of GHG was determined using the equation (5), endorsed by the Colombian Energy Mining Planning Unit (UPME) attached to the Ministry of Energy and Energy of Colombia, with the adaptation of the GHG Protocol document and the ISO 14067 standard, which are fundamental for projects and specific measurements of CO_2 emissions produced by generation and consumption of electrical energy (UPME, 2017). A_{ec} is annual energy consumption and Ef is the emission factors (by national Ministry of Mines and Energy).

$$\boldsymbol{NPC} = \sum\nolimits_{t=0}^{t=n} \frac{(It + Rc + O\&M + Fc + Epg) - (Esg + O\&M + Csalv.)}{(1+p)^t} \quad (1)$$

$$\boldsymbol{IRR} = \sum\nolimits_{t=0}^{n} \frac{Acf}{(1+r)^n} = 0 \quad (2)$$

$$\boldsymbol{LCOE} = \frac{It + \sum_0^n O\&M * (1+p)^n}{Els(1+p)^n} \quad (3)$$

$$\boldsymbol{ROI} = \frac{\sum_{i=0}^{Pd} Amf_{(ref.)} - Acf}{p_d(C_C - C_{bs(ref.)})} \quad (4)$$

$$\boldsymbol{Eco_2} = \mathrm{Aec} * Ef \quad (5)$$

3. Results

In this session, the results of the HOMER simulation for each scenario are presented. The generated energy from each conversion technology, capital cost, operating cost, and financial indicators are provided as alternatives (combination of energy conversion technologies with the electrical grid).

3.1 Analysis and simulation of the first scenario (saving of 25 %)

Figure 1 shows the energy contributions of different technologies (photovoltaic, wind turbines, batteries, and grid connection) in five hybrid generation alternatives simulated using HOMER Pro. Each alternative is associated with its corresponding NPC, LCOE, and annual O&M costs. Alternative A1 has a total capacity of 136,808 kWh/y, with 123,163 kWh/y from the photovoltaic system. It has an NPC of USD $415,957, an IRR of 10 %, and a payback time of 13.43 y. Alternative A2 generates a total of 176,617 kWh/y, with 120,179 kWh/y from the photovoltaic system with battery usage and the rest from the grid. It has an NPC of USD $416,275, an IRR of 10 %, and a payback time of 13.32 y. Alternatives A3 and A4 rely on grid supply for 126,710 kWh/y and 153,809 kWh/y, respectively. They also incorporate energy generation from the photovoltaic system, with A3 producing 133,256 kWh/y and A4 producing 106,222 kWh/y. Wind turbines contribute an additional 5.57 kWh/y, but due to limited wind resources, this option is deemed impractical. Lastly, alternative A5 solely relies on the existing grid for 100 % of the electricity supply, with costs provided by the energy distributor remaining unchanged.

Table 1 presents the CO_2 emissions associated with each alternative in the first scenario and the percentage reduction in equivalent CO_2 emissions with respect to A5. Alternative A1 emits 93.65 t of CO_2eq/y, alternative A2 generates 95.57 t of CO_2eq/y, alternative A3 produces 87.21 t of CO_2eq/y, and alternative A4 results in 104.48 t of CO_2eq/y. In comparison, alternative A5 represents the current system with a 25 % energy savings and serves as a benchmark for the other alternatives, resulting in 172.101 t of CO_2eq/y. These findings highlight the effectiveness of implementing hybrid systems in reducing GHG emissions.

Alternatives	Grid (kWh/y)	Solar (kWh/y)	Wind (kWh/y)	Initial Capital ($)	LCOE ($)	O & M Cost ($/y)	NPC ($)
A1	136,808	123,163	-	117,384	0.108	23,096	415,957
A2	176,617	120,179	-	114,877	0.109	23,314	416,275
A3	126,710	133,256	5.57	132,017	0.108	22,861	427,555
A4	153,809	106,222	5.57	106,764	0.115	24,915	428,857
A5	259,971	-	-	-	0.138	35,988	465,238

Figure 1: Technical and financial parameters in the first scenario (25 % energy savings)

Table 1: CO_2 emissions and percentage savings in the first scenario's alternatives.

Alternatives	tCO_2eq/y	%
A1	93.65	45.58
A2	95.57	44.47
A3	87.21	49.33
A4	104.48	39.29
A5	172.101	-

Alternative A1 exhibits the lowest LCOE and NPC among all the alternatives in the first scenario, with an NPC of USD $415,956. The cost breakdown is as follows: 30 % corresponds to the initial capital investment of USD $117,384 required for the installation of the photovoltaic system, while the remaining 70 % covers the grid supply costs and annual O&M expenses of the renewable system. This alternative achieves a generation capacity where 58.8 % comes from the grid supply and 41.2 % is generated by the photovoltaic system. Additionally, it results in a reduction of 93.65 t of CO_2eq/y in GHG emissions.

3.2 Analysis and simulation of the second scenario (saving of 30 %)

Figure 2 presents the energy contributions of different conversion technologies in five hybrid generation alternatives simulated using HOMER Pro. Each alternative is accompanied by its respective NPC, LCOE, and annual O&M costs. Alternative A1 generates 144,650 kWh/y from the grid and 97,998 kWh/y from the photovoltaic system, with an NPC of USD $382,159, an IRR of 9.2 %, and a payback time of 14.73 y. Alternative A2 produces 136,462 kWh/y from the grid and 106,222 kWh/y from the photovoltaic system with battery integration, with an NPC of USD $382,670, an IRR of 8.9 %, and a payback time of 15.32 y. Furthermore, alternatives A3 and A4 involve the combination of solar photovoltaic and wind systems, resulting in NPCs ranging from USD $393,787 to $400,639, IRRs from 7.8 % to 8.2 %, and payback times from 17.82 to 16.84 y. However, these alternatives are considered technically unfeasible due to limited wind resource capacity, resulting in a minimal supply of only 5.57 kWh/y. Finally, alternative A5 represents the current system, with costs provided by the energy distributor remaining unchanged.
Table 2 shows the annual reduction in CO_2 equivalent emissions for the second scenario and the percentage reduction in equivalent CO_2 emissions with respect to A5. Alternative A1 emits 98.21 t of CO_2eq/y, alternative A2 generates 92.99 t of CO_2eq/y, alternative A3 emits 94.14 t of CO_2eq/y, and alternative A4 produces 126.81 t of CO_2eq/y. In comparison, alternative A5 serves as a reference point for the others, as it produces 160.63 t of CO_2eq/y under a savings scenario of 30 %.

Alternatives	Grid (kWh/y)	Solar (kWh/y)	Wind (kWh/y)	Initial Capital ($)	LCOE ($)	O & M Cost ($/y)	NPC ($)
A1	144,650	97,998	-	93,400	0.110	22,339	382,189
A2	136,462	106,222	-	101,572	0.108	21,744	382,670
A3	138,260	104,383	5.57	104,495	0.112	22,378	393,787
A4	189,549	53,111	5.57	55,954	0.125	26,663	400,639
A5	242,648	-	-	-	0.132	31,993	413,593

Figure 2: Technical and financial parameters in the second scenario (30% energy savings).

Table 2: CO_2 emissions and percentage savings in the second scenario's alternatives

Alternatives	tCO_2eq/y	%
A1	98.21	38.86
A2	92.99	42.11
A3	94.14	41.39
A4	126.81	21.05
A5	160.63	-

Among all the alternatives, Alternative A1 exhibits the LCOE and NPC in the hybrid system, totalling USD $382,189. This distribution allocates 23 % to the initial capital investment of USD $93,400, which is required for the installation of the grid-connected photovoltaic system, while the remaining 77 % covers grid supply costs and annual O&M expenses of the renewable system. This alternative achieves a generation capacity of 63.5 %

from the grid and 36.5 % from the photovoltaic system, resulting in a reduction of GHG emissions to 98.21 t of CO_2eq/y.

3.3 Analysis and simulation of the third scenario (saving of 35 %)

Figure 3 illustrates the energy contribution of each conversion technology in five hybrid generation alternatives result of the HOMER Pro simulation, along with their corresponding NPC, LCOE, and annual O&M costs. Alternative A1 sets a substantial generation capacity of 169,388 kWh/y from the grid and 55,923 kWh/y from the photovoltaic system. It presents an NPC of USD $390,410 with an impressive IRR of 8.9 %. Furthermore, it exhibits a remarkable capital recovery time of 11.13 y, making it an attractive option for sustainable energy investment.

Moving on to alternative A2, it features a considerable contribution of 157,247 kWh/y from the grid and 68,104 kWh/y from the photovoltaic system with battery implementation. With an NPC of USD $390,864 and an IRR of 8.3%, it presents a promising payback time of 11.71 y. This alternative demonstrates the feasibility and effectiveness of incorporating battery storage into the hybrid generation system.

In contrast, alternative A3 and A4 present an NPC of USD $401,975 and USD $405,024, respectively, along with an IRR of 6.5 % and 5.8 %. These alternatives have a longer capital recovery time of 24.47 y. While they incorporate both solar photovoltaic and wind systems, the limited wind potential allows for a mere generation of 17 kWh/y, rendering them technically unviable options.

Lastly, alternative A5 represents the current system, relying solely on the supply from the network. The costs provided by the energy distributor remain consistent, providing stability and continuity to the energy supply.

Table 3 shows the annual reduction in CO_2 equivalent emissions for the third scenario and the percentage reduction in equivalent CO_2. Alternative A1 achieves an impressive reduction to 113.53 t of CO_2eq/y. Similarly, A2 demonstrates a noteworthy reduction, generating only 105.8 t of CO_2eq/y. A3 further minimizes emissions to 115.31 t of CO_2eq/y, meanwhile A4 presents a reduction of 128.87 t of CO_2eq/y. In comparison, A5, representing the current system, produces 149.16 t of CO_2eq/y, serving as a vital benchmark. The significant reduction achieved in A1, A2, A3, and A4 highlights the effectiveness of hybrid systems in reducing GHG emissions. Particularly, A2 surpasses the current system by generating 43.36 t of CO_2eq/y less, emphasizing the advantages of embracing hybrid energy solutions in curbing environmental impact and promoting sustainability.

Alternatives	Grid (kWh/y)	Solar (kWh/y)	Wind (kWh/y)	Initial Capital ($)	LCOE ($)	O & M Cost ($/y)	NPC ($)
A1	169,388	55,923	-	53,299	0.130	26,077	390,410
A2	157,247	68,104	-	65,270	0.127	25,186	390,864
A3	172,185	53,111	17	55,638	0.134	26,791	401,975
A4	193,470	31,851	17	35,910	0.138	28,553	405,024
A5	225,310	-	-	-	0.139	31,318	404,867

Figure 3: Technical and financial parameters in the third scenario (35 % energy savings).

Table 3: CO_2 emissions and percentage savings in the third scenario's alternatives.

Alternatives	tCO_2eq/y	%
A1	113.53	23.89
A2	105.8	29.07
A3	115.31	22.7
A4	128.87	13.6
A5	149.16	-

Alternative A1 stands out as the most cost-effective option among the alternatives in the scenario, with an NPC of USD $390,410. This allocation can be further specified: 14 % represents the initial capital investment of USD $53,299, required for installing the grid-connected photovoltaic system, while the remaining 86 % covers grid supply costs and annual operation and maintenance expenses of the renewable system.

With a generation capacity of 76 % from the grid and 24 % from the photovoltaic system, Alternative A1 achieves a substantial reduction in GHG emissions, amounting to 113.53 t of CO_2eq/y. Its superior economic performance and notable potential for emission reduction establish Alternative A1 as the most favourable choice among the project's alternatives.By effectively integrating the grid and photovoltaic system, this alternative demonstrates its ability to minimize environmental impact and contribute to a sustainable future.

4. Conclusions

The UTS in Colombia exhibits a monthly average energy consumption of 28,490 kWh, resulting in a considerable financial burden exceeding USD $5000 per month. This underscores the imperative for implementing measures aimed at reducing energy costs.

This study focus on assessing the technical, economic, and environmental viability of hybrid energy generation alternatives employing the HOMER Pro software. The analysis reveals that the integration of photovoltaic systems can satisfy a portion ranging from 24 % to 43.4 % of the energy demand, leading to potential energy savings of approximately 30 %.

Each proposed scenario demonstrates a return-on-investment surpassing 5.8 % and an achievable internal rate of return greater than 8.9 %. These metrics indicate the financial feasibility of implementing hybrid energy systems at the UTS, yielding long-term cost reductions.

The current energy supply system employed in UTS buildings contributes to an estimated 229.47 t of CO_2eq/y emissions. However, the analysis demonstrates that the implementation of energy-efficient scenarios incorporating hybrid energy systems can mitigate CO_2 emissions by up to 49.3 %, yielding substantial environmental benefits.

The efficacy of the HOMER Pro software as a vital tool for optimizing renewable energy systems and evaluating their economic and environmental viability has been confirmed. Drawing upon international experiences, its utilization in designing hybrid renewable energy systems for educational institutions can facilitate the transition towards sustainable energy provision.

In conclusion, this study underscores the potential for the UTS to embrace clean energy adoption, achieve cost reductions, and realize environmental advantages through the integration of hybrid energy generation alternatives. The findings align with Colombia's objectives of diversifying its energy sources.

Future research endeavours should concentrate on conducting socio-economic analyses to assess the broader implications of transitioning to a hybrid energy system for the university and its surrounding community. Factors such as energy affordability and social acceptance ought to be taken into consideration. Additionally, future investigations are anticipated to evaluate the socio-political barriers associated with establishing energy communities in partnership with universities, enabling energy trading within the grid and overcoming prevailing monopolistic practices in the country.

Acknowledgments

The authors acknowledge the financial support of the Technological Units of Santander.

References

Afham, N. A., Harun, N. S., Abdullah, A. R., Abd. Wahab, M. I., 2021. Techno-economic analysis of hybrid photovoltaic and electricity storage system using HOMER. Energy Reports, 7, 1775-1784.

Castaño, C., García, E., 2020. Energy transition in Colombia: a commitment to a sustainable future. Aglala: Journal of Cultural Studies, 11(22), 53-67.

Galdamez, E. L., Bursztyn, M., Barrios, A., 2020. Planning renewable hybrid energy systems for universities: The HOMER software as a planning tool. Case study: Honduras. Energy Reports, 6, 671-679.

Gómez, F., 2019. Analysis and selection of an energy storage system for a hybrid renewable generation microgrid. Energy Reports, 5, 799-805.

Ministry of Environment and Sustainable Development, 2021. Sixth Biennial Update Report of Colombia to the United Nations Framework Convention on Climate Change.

Mora, N.B., 2022. Requirement of electric consumption data (Electric consumption invoices, 2022).

Osorio, G. A., 2022. Implementation and evaluation of scenarios for monitoring and control of energy performance at the Campus of the National University of Colombia, Medellín Campus. Bachelor's thesis, National University of Colombia (in Spanish).

Palau, J. M., 2019. Technical-economic study of the integration of renewable hybrid installations in municipal buildings. Bachelor's thesis, Jaume I University.

Rosso Cerón, A. M., Kafarov, V. 2015. Analysis on the Economic Feasibility of Power Generation from Renewable Energy Systems in Non-Interconnected Zones of Colombia, Study of Cases. Chemical Engineering Transaction, 43, 1447-1452.

UPME, 2017. Emission Factors of the National Interconnected System Colombia-SIN. Retrieved on 30th January 2023 from Emission Factors of the National Interconnected System Colombia-SIN <1.upme.gov.co> accessed 15.6.2023 (in Spanish).