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Analysis on the Economic Feasibility of Power Generation from Renewable Energy Systems in Non-Interconnected Zones of Colombia, Study of Cases

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The aim of this study is to give potential solutions to supply the electricity deficit in three Colombian towns (Riosucio, Puerto Concordia, and Valle del Guamuez) with the highest residential energy demand in Non Interconnected Zones (ZNI, by its initials in Spanish). This was done by analysing the economic feasibility of technologies for generating electricity from solar, wind and hydro energy sources using the HOMER simulator. It was assessed by different scenarios in order to analyse how energetic demand and government subsidies can contribute to properly integrate the variability of renewable energy sources (RES) from an economic point of view. The results show for each scenario, the minimum investment recovery time between 6 and 7 years. Viable technologies in unsubsidized scenarios are the wind power with a small wind turbine and small hydro. This change in the subsidized energy scenarios, in which only become viable the photovoltaic (PV).

1. Introduction

Nowadays, energy dependence on fossil fuels (in terms of primary energy consumption representing an average of 35% oil, 27% coal, 23% natural gas, and the rest from alternative energies(Jacobson and Delucchi, 2011)) triggers significant concerns as they are not RES (Eder, et al, 2009).
Furthermore, energy generation is necessary for a country development since it is essential for everyday activities such as lighting, using electrical appliances, transport, livelihoods, and education by increasing employment opportunities that lead to economic and social benefits (Assefa and Frostell, 2007).
In the Colombian case, ZNI are located in isolated places, cover almost 66% of the national territory including about 1,200 settlements, 16 departments, 91 tows and 2 million people. In addition, these zones do not have appropriate access routes (roads and rails), lack industrial and commercial development, public services are limited and undeveloped, and people's basic needs are unsatisfied (Narváez Rincón, 2010). Paradoxically, they have great environmental importance, which are characterized by the wealth of natural resources and biodiversity. In this regard, Colombia has an average wind energy potential of about 6 m/s, except in the Caribbean Coast (UPME and IDEAM, 2005), where it is higher; a daily average solar potential close to 4.5 kWh /m2 year (Marín Ramírez, 2014); water supply in terms of performance of 58 l/s per km^2 (TWENERGY, 2010); and the biomass source has a potential of 16 GWh/year (CORPOEMA, 2010). On the other hand, geothermal and ocean resources have only been preliminarily studied (UPME, 2010).
With the aim of supplying the lack of electricity in ZNI have been established solutions such as generation from RES (solar, wind, small hydro, and biomass) with 2%, and the rest from diesel generation (MME, 2014), which is not sustainable in the long term. In addition several initiatives to implementation of renewable energy in ZNI are in the initial state, which means the formulation of projects for development plans. These projects for the implementation of renewable energy systems have been formulated by the Ministry of Mines and Energy (MME) and other entities attached, such as: the Mining and Energy Planning Unit (UPME), the Regulatory Commission for Energy and Gas (CREG), public facilities such as Planning Institute of Energy Solutions for ZNI (IPSE), among other.

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In addition, energy solution commonly used in ZNI (diesel oil generation) is not the most feasible economically, since the costs necessary to supply the minimum energy demand is very high due to the rising costs of fuels used and the lack of technological development and skills in renewable energy systems.
Nevertheless, RES that are available locally in decentralized systems are an option that should be considered for assisting such isolated consumers, taking into account the availability of natural resources in the region and the advantages inherent to these sources, such as a reduction in diesel oil consumption and the possibility of developing local productive activities in these isolated communities (Zerriff, 2010).
Therefore, the aim of this study is to give potential solutions to supply the electricity deficit in ZNI. This was done by analyzing the economic feasibility of technologies for generating electricity from renewable RES (solar, wind and hydro, since have the most studied potential), using the software HOMER Energy, which take into account available resources, electricity demand, costs associated equipment, transportation, operation and maintenance, etc.
Energy demand and resource potential in ZNI were estimated from previous studies on this topic. As a result, three towns with the highest demand were selected as cases of studies (Riosucio, Puerto Concordia, and Valle del Guamuez in the departments of Chocó, Meta and Putumayo, respectively).
Finally, it was assessed different scenarios in order to analyse about how energetic demand and subsidies from the government can contribute to properly integrate the variability of RES, from an economic point of view.

2. Case of studies

The case of studies were chosen from departments and towns with the highest residential energy demand, which was estimated from information about the number of households without power per town from UPME, (2011) and the average energy consumption per household (kWh/month) (UNAL, 2006) that will allow a 24-h supply in areas connected to the grid, since there are no exact data on energy consumption in ZNI (GREC, 2003).This demand was calculated for two scenarios, see Table 1:
-First scenario: the minimum demand required to supply basic appliances per household as provided by CREG: lights (bulbs), refrigerator, blender and television/radio.
-Second scenario: the maximum demand required to provide electric service in ZNI, equivalent to that provided in areas connected to the grid. With the aim of estimate the maximum demand was included the following appliances: an iron, a fan, a water heater and a washing machine.

Table 1. Minimum and maximum demand per household

Appliances	**Minimum demand [kWh/month]**	**Maximum demand [kWh/month]**
Lighting	30.08	30.08
TV / radio	8.65	8.65
Refrigerator	47.03	47.03
Iron	_	9.20
Blender	1.45	1.45
Washing machine	_	8.60
Water heater	_	31.48
Fan	_	10.68
Total	87.20	147.15

The departments with the largest energy consumption in descendent order are: Choco, Caquetá, Putumayo, Meta, Vichada, Guainía, Amazonas, Vaupés, Guaviare, and Casanare. Caquetá department was excluded due to the armed conflict in this area and the existence of natural reserves, which could be a barrier when installing renewable energy systems.
In addition to the selection of the case of studies, the following conditions are also taken into account:
-That is not part of an indigenous reservation or forest reserve
-That there are no problems of armed conflict
- Large population benefited
- High residential energy demand
By analysing the conditions in each department were chosen the following cases, see Table 2:

Table 2. Description of selected case studies

Town	Description
Riosucio	-It is located in the north of Chocó. Here is no development of industry and commerce -The center of the main town is situated on the right bank of the Atrato River. -The average ambient temperature: 28 ° C -Lack of coverage of electric power in rural areas: 47.30% -Number of households without power: 2,591
Puerto Concordia	-It is located in the south of Meta. Here is no development of industry and commerce -The average temperature, varying between 24 ° C and 27 ° C -Lack of coverage of electric power in rural areas: 67.11%. -Number of households without power: 1,878
Valle del Guamuez	-It is located to the southwest of Putumayo. Here is no development of industry and commerce -The main River is : "La Hormiga" -The average temperature, varying between 27 ° C and 40 ° C -Lack of coverage of electric power in rural areas: 35.60% -Number of households without power: 3,325

3. Methodology for the economic analysis

The economic analysis presented in this paper was done using the software HOMER Energy (Hybrid Optimization Model for Electric Renewables). This modelling tool, developed by the National Renewable Energy Laboratory (NREL) of the United States, facilitates design of stand-alone electric power systems. Once electrical and thermal loads are specified, the model searches for a combination of generation resources, including RES, in order to supply such loads at a minimum cost (Connolly,2010). The methodology with HOMER requires information on resources, time project life, inputs on component types, their costs, efficiency, etc., (Montuori, et al, 2014) and considers the following steps:

3.1 Definition of the primary load

Figure 1 shows the likely status of the hourly behaviour of the load throughout a typical day, for the minimum and maximum consumption (demand), which are obtained by means of the estimated load curves.

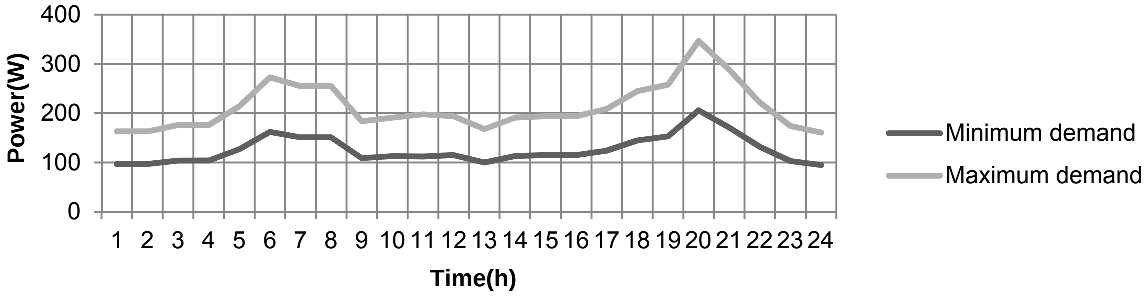

Figure 1. Daily load curve for minimum and maximum demand per household

3.2 Characterization of energy potential of the study areas

In order to make this simulation as realistic as possible, the wind and solar potentials were estimated from monthly data of solar radiation and wind speed (measured approximately 10m high) of Colombian solar radiation atlas, and wind atlas conducted by UPME and IDEAM, (2005, 2006). The water resource potential was estimated from National Water Study conducted by the MME and UPME, (2001).

According to the potential of RES, the resources assessed for each case are:

-Riosucio and Valle del Guamuez: solar and water

-Puerto Concordia: solar and wind

3.3 Selection of the equipment to consider

In this stage, the selection of equipment necessary for the operation of each systems was based on information about developed projects by governmental institutions and according to efficiency and used in the market. See Table 3.

Table 3. Characteristics of the power generation system

PV system		**Wind system**		**Small hydro system**	
Equipment	Amount	Equipment	Amount	Equipment	Amount
Solar modules	150WP	Turbine Bornay Inclin 6000	6000W	Michell	60 kW
Charge Controller	15A	Charge controller	48V	Banki	
Batteries bank	360A	Batteries bank	360A	turbine	
Investor- sine wave	360W	Investor-sine wave	500W	Model R313	

3.4 Costs of technologies

The costs considered for the technologies are distributed as follow:
-PV: 13.3% pre-investment, 74.5% investment, 9.5% replacement, 2.7 % operation and maintenance
-Wind: 9.3% pre-investment, 79.5% investment, 9.3% replacement, and 1.8 % operation and maintenance
-Small hydro: 66.4% pre-investment/investment, 9.6% management, and 24% operation and maintenance

3.5 Simulations and scenarios

In this study, different scenarios have been considered and different simulations have been carried out to evaluate. The four scenarios can be seen below:
-Maximum demand-unsubsidized: the maximum power demand and energy cost calculated by HOMER.
-Minimum demand- unsubsidized: the minimum power demand and energy cost calculated by HOMER.
-Maximum demand-subsidized: the maximum power demand and a subsidy from the government in ZNI.
-Minimum demand- subsidized: the minimum power demand and a subsidy from the government in ZNI.

3.6 Assessment of results and economic evaluation

The last step of the methodology includes the analysis of simulation results and the economic evaluation.
The project lifetime of the simulations was fixed in 10 years, which is used to calculate the annualized replacement cost and the annualized capital cost of each equipment, as well as the value today of future cash flow, called net present value (NPV) of the system. The total NPV is the main economic output obtained with HOMER and it is calculated by using the following expression:

$$\mathrm{NPV} = -\mathrm{INV} + \sum_{t=1}^{n} \frac{V_t}{(1+r)^t} \tag{1}$$

Where INV is the value of the initial investment, t is the time between present and future, r is the discount rate and V_t: are the cash flows in each period t.
Furthermore, the IRR is mathematically the discount rate that makes the NPV equal to 0, see equation 2. This means that the average annual rate of return that project pays to investors for investing their funds. That rate of return should be compared against what is wanted to win at least [24].

$$\mathrm{NPV} = -\mathrm{INV} + \sum_{t=1}^{n} \frac{V_t}{(1+\mathrm{IRR})^t} = 0 \tag{2}$$

NPV and IRR are used to rank all the configurations of the different scenarios here analysed.

4. Result and analysis

4.1 Maximum and minimum demand-unsubsidized scenarios

As shown in Table 4, in the maximum demand-unsubsidized scenario the IRR are very similar in all cases, except for Valle del Guamuez, where the best option is small hydro, with an IRR of 16%. In the other cases the way to decide which option is more attractive to investors is the VPN. In Riosucio and Puerto Concordia, NPV indicates that the best options are small hydro systems, with a recovery time of 6 years, and wind system, with a recovery time of 7 years, respectively.
In the minimum demand-unsubsidized scenario, the implementation of PV system would be more attractive to consumers because the energy cost is the lowest of all. However, for investors it is not economically attractive because its NPV and IRR are lower compared to the other technologies.
In Puerto Concordia, the values of IRR and NPV indicate that wind system is most profitable than PV, because NPV is approximately 10 times higher that PV and shows a recovery time of 6 years.
On the other hand, in the Table 4 NPV show that in Riosucio and Valle del Guamuez the best alternative is small hydro, even though the recovery time in Riosucio exceeds 10 years, NPV is 1.6 times greater than PV.

Table 4. Economic results of maximum and minimum demand-unsubsidized scenarios

Town	Parameters	PV system		Wind system		Small hydro system	
		Minimum demand	Maximum demand	Minimum demand	Maximum demand	Minimum demand	Maximum demand
Puerto Concordia	IRR(%)	9.00	11.60	16.40	14.10	_	_
	NPV(US$)	83,537	156,690	915,508	652,292	_	_
	EC(US$/kWh)	0.695	0.563	2.332	1.891	_	_
	RT(years)	8	8	6	7	_	_
Riosucio	IRR(%)	10.30	10.80	_	_	16.50	16
	NPV(US$)	152,537	146,316	_	_	333,207	317,711
	EC(US$/kWh)	0.695	0.595	_	_	0.827	0.819
	RT(years)	7	7	_	_	6	6
Valle del Guamuez	IRR(%)	10.20	3.34	_	_	16.50	16.00
	NPV(US$)	156,811	-164,200	_	_	333,207	317,712
	EC(US$/kWh)	0.733	0.510	_	_	0.827	0.819
	RT(years)	10	10	_	_	NR	6

EC: Energy Cost RT: Recovery Time NR: Not recovery

4.2 Maximum and minimum demand-subsidized scenarios

As shown in Table 5, the situation with a maximum demand subsidized scenario for PV in Puerto Concordia and Riosucio changes relative to the previous scenarios, as their VPN increases, becoming attractive to investors.

In Puerto Concordia wind system exhibits constant loss in the10 years of study, while PV shows a gain of US$ 621,349,535.

In Riosucio the best option is PV, with a VPN of US$ 3,618,837.0; otherwise the small hydro shows negative VPN and only recover their investment until the last year; this since energy cost from water resources is more expensive because the costs of operation and maintenance are higher.

However for the town of Valle del Guamuez there is not economically viable systems, since they present a negative NPV in all cases.

In the scenario of the minimum demand subsidized scenario, NPV indicates that the only case with a viable project is Riosucio, where the best option is PV, since has a positive NPV, recovery time of 7 year, and an IRR of 11%

In the case of Puerto Concordia wind system generates losses each year, since energy cost subsidy for small wind turbines shows a value below to the actual value. In addition, PV recovers its investment in the 8 year, but their incomes do not pay the initial investment

Finally in the case of Valle del Guamuez, the results are not favourable because the small hydro fails to pay the initial investment in 10 years. Furthermore PV only earns the thirty-third part of the initial investment, since the price is affordable to the consumer but does not generate large profits to recover investment.

Table 5. Economic results of maximum and minimum demand-subsidized scenarios

Town	Parameters	PV system		Wind system		Small hydro system	
		Minimum demand	Maximum demand	Minimum demand	Maximum demand	Minimum demand	Maximum demand
Puerto Concordia	IRR(%)	4.74	14.30	-38.20	-29.00	_	_
	NPV(US$)	-105,630	229,168	-2,391,248	-1,813,492	_	_
	EC(US$/kWh)	0.565	0.565	0.565	0.565	_	_
	RT(years)	9	6	NR	NR		
Riosucio	IRR(%)	11.00	16.80	_	_	2.00	1.95
	NPV(US$)	166,031	3,618,837	_	_	-157,509	-157,509
	EC(US$/kWh)	0.670	0.670	_	_	0.471	0.471
	RT(years)	7	6	_	_	NR	10
Valle del Guamuez	IRR(%)	0.00	2.85	_		2.00	1.95
	NPV(US$)	-286,502	-171,704	_	_	-157,509	-157,509
	EC(US$/kWh)	0.471	0.471			0.471	0.471
	RT(years)	10	10			NR	10

5. Conclusion

In all four scenarios the minimum time to payback is between 6 and 7 years. Unsubsidized energy scenarios are feasible small wind turbine and small hydro systems. This situation changed radically in maximum demand

unsubsidized scenarios in which only become feasible PV system; however, in the case of the minimum demand there is not feasible system, because in any case income is obtained.
Economically, small hydro power plants are the most feasible alternative to ZNI that have high water resources and large population, otherwise the operation and maintenance costs are very high and hinder the viability of these projects.
In attempting to invest in projects for power generation from renewable resources is a good option to have the support of government agencies that are responsible for resolving problems of energy shortages; since the government has a number of incentives and regulations that give benefits to funding agencies for these types of projects in ZNI.
Finally, it is important bear in mind that the sales prices of power generation significantly influence the profitability of projects as these represent the gains of these.

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