Feasibility studies for the instalation of wind microgeneration in urban areas in Montevideo

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***Abstract*— In this paper, the feasibility of installing wind power microgeneration in Montevideo urban environments in a self-producing regime is studied. To do this, a characterization of the demand curves of different areas is carried out, data from several wind turbines is collected and the energy produced, the energy replaced and the corresponding savings in electricity bills are simulated. The proposed methodology allows for the identification of cases of location, type of consumer, tariff and the type of wind turbines for which it is feasible to consider installing wind power microgeneration.**

Keywords—wind power, microgeneration, self-production, feasibility of installation.

I. INTRODUCTION

In the traditional structure of the existing electrical systems, in force since its consolidation 100 years ago, the electricity production was carried out, in general, away from consumption and the power flows were one-way, from generation to demand through transmission and distribution networks. In recent years there has been a paradigm shift. Now, Distributed Generation (DG) has been gradually incorporated, where electricity production is done in the same place where the energy is consumed. Flows cease to be one-way, and it may be reversed, turning that particular distribution system into an energy exporter. Under this conception, distribution networks cease being passive (i.e. connecting only loads), becoming active (i.e. connecting loads and generating) just as transmission networks.

Much has been written in literature regarding the impacts of DG in networks, its costs and benefits, and on how to remunerate them in tariffs [1], [2], [3], [4], [5], [6]. In several countries, particularly in Uruguay, regulations that promote this type of generation [7], [8] have been developed. However, the development of DG will depend on the technology and the particular conditions that are presented for its installation and operation, needing to meet the cost-benefit equation and the technical conditions for reliable and safe operation. In [9] an analysis of the usage of wind power in Europe is presented in the DG scheme.

In this paper, the feasibility of installing small-sized wind turbines in urban environments in Montevideo is studied. This study will cover the installation in a self-production regime, in which part of the consumption of a Residential subscriber is supplied by the wind turbine. To do this, a characterization of the demand curves in different areas of Montevideo is performed, several generators available in the market are used and the energy produced (according to measured wind data) the energy replaced (energy that is not taken from the network), and the corresponding savings in electricity bills for two different tariff regimes are simulated.

The proposed methodology, which includes the development of a program for the simulation and calculation of energy savings, can identify cases of location, type of consumer, tariff and type of wind turbines for which it is feasible to consider installing wind power microgeneration. in a self-producing regime.

II. DEMAND AND GENERATION MODELING

A. Determination of wind speed

Determining the speed of the wind is fundamental in the analysis of the viability of residential wind power microgeneration. Figure 1 shows the wind map of Montevideo for winds 90 m high above the ground. The wind shows a substantially uniform behavior, demonstrating a slight increase towards the coastal zone. For the development of the wind map a mass conservation model presented in [13] was used as well as the method of main patterns. This numerical model solves the flow at meteorological meso-scale using surface wind data, and establishes a hourly mean wind speed time history in each node of a grid.

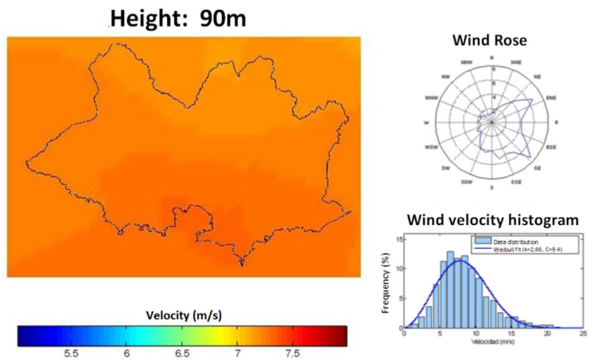

Figure 1. Wind map of Montevideo.

To relate this time history with the wind speed in urban environments where the wind turbine will be installed, physical models of the areas of interest are ran in the wind tunnel. Form the tests speed up factors linking the wind speed at 90m above the ground with the wind speed at the point of interest, for each of the wind directions were obtained. Figures 2 and 3 show two physical models during their test in the tunnel

Figure 2. "Facultad de Ingenieria" model.

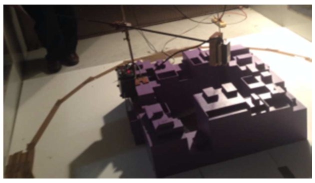

Figure 3. High density residential area model.

B. Selection of the wind turbines

The operation of various wind turbines (mostly from the European market) were analyzed, in order to determine their performance in urban environments. This performance was evaluated by determining the capacity factor (CF) obtained for each wind turbine in each of the sites analyzed. The CF is defined as the ratio between the average power generated and the rated power. This result was obtained for all wind turbines presented in Table 1. In this paper the interest is to analyze vertical axis wind turbines, meaning the right ones to operate in urban areas with high intensities of turbulence.

	Brand	Type	CF (%)	
			Sch. Eng.	High dens.
4	Ecofis	VAWT	11,0	14,5
9	Oy Windside	VAWT	12,2	15,6
12	Ropatec	VAWT	11,6	15,1
13	Ropatec	VAWT	9,3	12,1
14	Ropatec	VAWT	13,1	16,8
21	Turby	VAWT	10,8	14,5
22	Venturi	VAWT	6,2	8,2
25	Windman	VAWT	14,0	18,6

Table 1. Vertical axis wind turbines.

Other factors such as the available equipment information, the cost of this and its installation were considered as well.

C. Determination of residential load curve

Information provided directly by the National Utility (UTE) was used for the determination of the residential load curve. The necessary information was generated from two average load curves for the Montevideo city, one estimated for the summer months (January, February and March) and other for the winter months (June, July and August). The available curves are hourly consumption along one day related to the daily mean value of an average household.

We assume as working hypothesis that the months of November, December and April have the load curve as the summer months, and the months of May, September and October as the three winter months.

As additional hypothesis the consumption of each day of any month is supposed the same and equal to the total monthly household consumption provided by UTE for each month in different areas of Montevideo.

Using the above methodology daily load curves are obtained. Figure 4, shows such curve dimensionless.

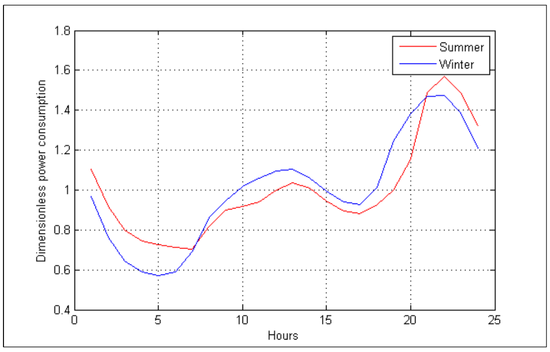

Figure 4. Example of load curves for a tipical July day (blue) and February (orange)

Table 2 shows the monthly residential consumption in kWh/month disaggregated by commercial office and for all Montevideo, per month of the year for an average household. This information was also provided directly by UTE.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DIC	TOT
OC. CENTRO	190	188	202	201	226	250	282	260	229	216	200	200	220
OC. BUCEO	334	331	345	356	423	497	563	510	437	390	337	343	406
OC. UNIÓN	228	219	230	228	253	275	307	285	251	242	224	234	248
OC. GOES	216	207	221	213	236	255	282	263	236	225	214	222	233
OC. PASO MOLINO	226	216	226	217	237	250	274	259	232	228	218	231	235
OC. POCITOS	240	239	259	263	301	340	381	351	310	285	255	253	290
Montevideo	229	222	236	233	261	287	320	297	263	248	230	236	255

Table 2. Average monthly consumption (kWh / month) - Residential Sector - Montevideo

Therefore using the data presented in Table 2, curves from Figure 4 may be scaled generating as many annual load curves as rows presented in Table 2. In this article four categories (summarized in Table 3) were conducted.

Category	Monthly level of consumption (kWh)
Low income	123
Mid income	255
High income	589
Extra high income	937

Table 3. Characteristics of consumption curves

The type of consumers analyzed (residential) have access to two tariff schemes, called Simple Residential and Double Schedule. While the first sets energy prices according to consumption, the second one establishes them depending on the day time. It is noteworthy that the residential user must pay an extra fixed amount which depends on the contracted power. Finally, the user must pay Value Added Tax (VAT) over the consume. The various tariff schemes based on what is established in [2] are presented on table 4.

SIMPLE SCHEDULE	
Energy consumption charge	
1kWh to 100kWh	4,004 $/kWh
101kWh to 600kWh	5,022 $/kWh
601kW and more	6,253 $/kWh
Power charge	47,9 $/kW
Monthly fixed charge	154,5 $

DPUBLE SCHEDULE	
Energy consumption charge	
Peak hour*	6,694 $/kWh
Not in peak hour	2,679 $/kWh
Power charge	47,9 $/kW
Monthly fixed charge	279,0 $

*Energy charges are distributed in two time periods , during all days that make up the monthly bill, acording to:

-Peak hours: de 17:00 to 23:00 hrs.
-Not peak hours: de 00:00 to 17:00 and 23:00 to 24:00 hrs.

Table 4. Residential tariff schemes

[7] states that a residential user can install a generation system with a current consume up to 16 A. [7] states that the remuneration of the energy generated is made based on the net energy consumption applying the same user tariff schedule. In case of the Simple Residential tariff the energy generated is paid using the second tier price. It should be noted by the user that if the monthly net energy flows into the network, VAT will not be applied on its sale and it will also have to pay tax over income at a rate of 12%.

D. Determination of energy production

The annual energy production it is calculated using the wind speed at the height of the wind turbine and the power curve of the equipment, which is usually provided by the manufacturer. An example of power curve is shown in Figure 5 for a 2.5 kW rated vertical axis wind turbine.

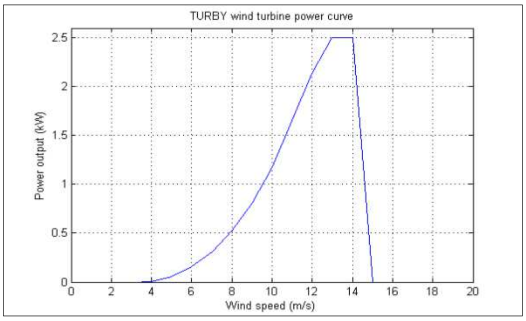

Figure 5. Power curve of a wind turbine

Using the methodology presented in section II the annual wind representative series is obtained to evaluate the energy performance of the wind turbine. As an example of calculation, the speed up factors were determine on the roof of the School of Engineering (site where a wind turbine test bench will be installed) and also in an area of high population density were considered. In [10] and [11] information on a variety of wind turbines available on the European market is presented.

III. Simulation and Case Studies

For the analysis of the wind turbine installation feasibility in an urban environment, a software was developed in MatLab®, which calculates the wind turbine energy production and compares it to the residential load curve. Then, the user cost savings would be obtained.

Finally, depending of the tariff regime the consumer savings in one year are calculated for each residential load curve and for each wind turbine.

With this model is possible identify the wind turbine that converts, in a more efficient way, wind energy into electricity at the site under study and it would also be possible to characterize environmental indicators related to avoided emissions of greenhouse gases.

A. Comparing the curves of consumption

The results obtained for wind turbines considering the different consumption curves corresponding to low, medium, high and extra high income (consumption curves named 1, 2, 3 and 4 respectively), as well as two tariff schemes were analyzed.

Economic savings that a user could have on electricity was determined as the difference between expenses with and expenses without the wind turbine. In Figures 6 and 7 such savings for the two tariff schemes are presented. The power value on the abscissa corresponds to the rated power of different wind turbines analyzed. From comparisons of various wind equipment, it turns out that savings are favored for consumption curves corresponding to higher incomes. Except for one case, this occurs for both, the double schedule tariff and the single tariff schedule.

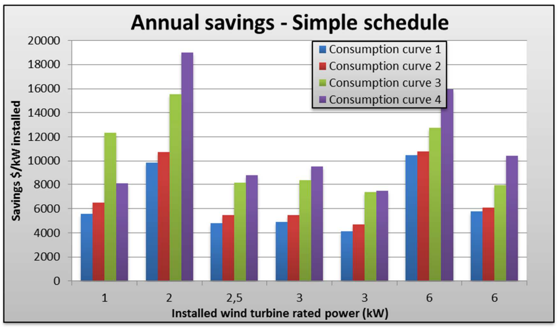

Figure 6. Savings for different consumption curves: Single tariff schedule

From these results the following aspects are highlighted:

- The savings are generally more significant for users of higher level of monthly consumption.
- The savings grow with the installed capacity of generation to a value of 2 kW for both tariff schemes, and then decreases.

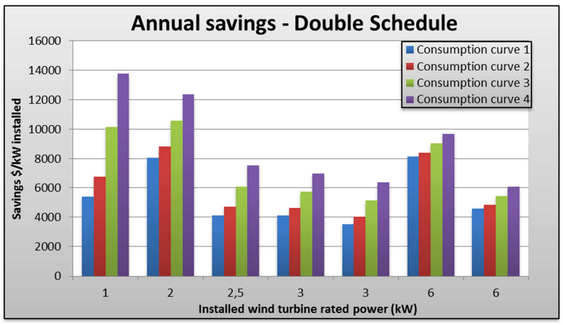

Figure 7. : Savings for different consumption curves: Double tariff schedule

Increased saving along with the increase in consumption can be explained, in the case of the Simple residential tariff, considering that the electricity tariff schedules the energy bill by steps, which increases the price by increasing the amount of energy consumed. Household net energy is the difference between demand and the associated energy production of the wind turbine, and it is this to which the tariff is applied to determine the costs. While net energy remains on the top step of consumption, savings associated with energy production will peak, as the price of energy is highest.

As the net consumption is lower, the net energy demanded by the home will be located on the steps of lower cost energy, and the savings generated from the production will also lower.

B. Generation in double hour

In most of the cases analyzed savings of the double schedule tariff are below the single tariff savings. Figure 8 shows some of the cases modeled for some wind turbines of different rated power.

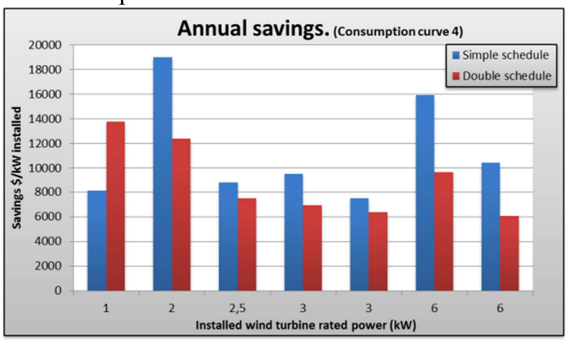

Figure 8. Comparison between single and double schedule savings for consumption curve 4

To understand this difference and consider possible scenarios where this situation changes, the proportion of energy produced for each hour of the day was obtained from the analytical model. For this, the energy ratio for each time along each day was calculated and averaged to obtain a representative daily energy distribution for this time. Consumption along this representative day is presented in Figure 9.

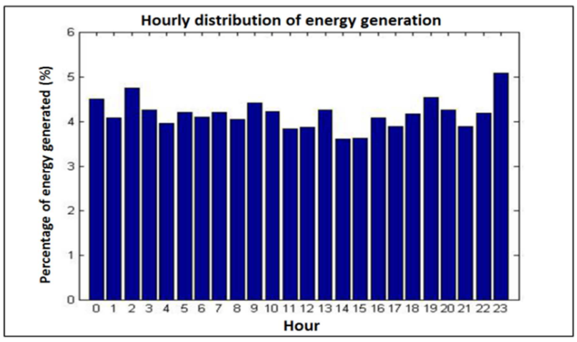

Figure 9. Time distribution of energy generation

The figure shows that, although there are some times where energy production of the wind turbine is higher in relative terms, a period of 4 hours (corresponding to the number of hours of peak hour) where the generation of energy is focused is not identified.

This concludes that it seems to be a nonexistent preferential time for wind power generation, which can be associated with a new tariff schedule for improving the investment project.

C. Base Case

In order to establish a baseline for comparing the results, a particular base case is defined in which the production generated by wind equipment is sold without any energy consumption. The values listed below were obtained for one of the vertical axis wind turbines analyzed, which has the best performance. The wind turbine used to form this case is a vertical axis one, which are generally more expensive but understood to be suitable for urban environments.

The economic evaluation of the different cases is done by determining the economic parameters Net present value, internal rate of return and pay back or return period.

Simple schedule						
Place	Inv. (U$S)	FC	Annual savings ($)	PB (years)	TIR	VNA ($)
School of Engineering	26392	10,8%	11879	61	-8,8%	-6,1E+05
High population density	26392	14,5%	15963	46	-6,7%	-5,8E+05

Double schedule						
Place	Inv. (U$S)	FC	Annual savings ($)	PB (years)	TIR	VNA ($)
School of Engineering	26392	10,8%	8972	81	-10,6%	-6,4E+05
High population density	26392	14,5%	12224	60	-8,6%	-6,1E+05

Table 5. Base case for simple and double tariff schedules

D. Sensibility of the investment

To study how the investment affects a wind project at residential levels, the two wind turbines which have better results were considered (Ropatec 3kW and TURBY 2.5kW wind turbine), and the results by reducing the investment are analyzed. Economic indicators considering real investment are calculated, and then 75% and 50% of real investment, observing the behavior of the project against such declines in the level of investment.

In addition, a payback of 10 years is sought. The results are presented in the following tables for the two areas of study and for the extra high income consumption curve, of which the best results are obtained.

N° 13	Ropatec		Place: School of Engineering				Consumption curve: 4			
Pot. (kW)	3,0									
FC	14,5%	Unitary price (U$S/kW)	Simple schedule				Double schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (ys)	IRR (%)	NPV ($)	Annual savings ($)	PB (ys)	IRR (%)	NPV ($)
100%	23621	7874	22523	28	-2,6	-4,1E+05	19110	33	-4,0	-4,4E+05
75%	17716	5905	22523	23	-0,6	-2,9E+05	19110	27	-2,1	-3,2E+05
50%	11811	3937	22523	15	4,2	-1,1E+05	19110	17	2,4	-1,4E+05
29%	6850	2283	22523	10	9,4	-7,4E+03	19110	12	7,3	-3,4E+04

N° 21	TRUBY									
Pot. (kW)	2,5									
FC	14,5%	Unitary price (U$S/kW)	Simple schedule				Double schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (ys)	IRR (%)	NPV ($)	Annual savings ($)	PB (ys)	IRR (%)	NPV ($)
100%	26392	10557	21961	32	-3,7	-4,8E+05	18792	37	-5,0	-5,1E+05
75%	19794	7918	21961	26	-1,8	-3,5E+05	18792	30	-3,1	-3,7E+05
50%	13196	5278	21961	17	2,7	-1,5E+05	18792	19	1,1	-1,8E+05
29%	7654	3061	21961	10	9,4	-7,4E+03	18792	12	7,3	-3,4E+04

Table 6. Data for change in investment. “Facultad de Ingenieria”

N° 13	Ropatec	Place: High population density zone				Consumption curve: 4					
Pot. (kW)	3,0										
FC	12,1%	Unitary price (U$S/kW)	Simple schedule				Double schedule				
% Inv.	Inv. (U$S)		Annual savings ($)	PB (ys)	IRR (%)	NPV ($)	Annual savings ($)	PB (ys)	IRR (%)	NPV ($)
100%	23621	7874	30433	22	-0,4	-3,8E+05	22070	30	-3,3	-4,5E+05
75%	17716	5905	30433	17	2,4	-2,2E+05	22070	23	-0,8	-2,9E+05
50%	11811	3937	30433	12	7,1	-6,0E+04	22070	16	3,3	-1,3E+05
42%	9921	3307	30433	10	9,5	-8,8E+03	22070	14	5,3	-8,0E+04

N° 21	TRUBY									
Pot. (kW)	2,5									
FC	14,5%	Unitary price (U$S/kW)	Simple schedule				Double schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (ys)	IRR (%)	NPV ($)	Annual savings ($)	PB (ys)	IRR (%)	NPV ($)
100%	26392	10557	30454	25	-1,4	-4,5E+05	22129	34	-4,2	-5,2E+05
75%	19794	7918	30454	19	1,3	-2,8E+05	22129	26	-1,7	-3,5E+05
50%	13196	5278	30454	13	5,8	-9,7E+04	22129	18	2,2	-1,7E+05
38%	10029	4012	30454	10	9,4	-1,2E+04	22129	14	5,2	-8,2E+04

Table 7. Data for changes in investment. High density zone

It is emphasized that the unit price of wind turbines considered results on the order of five to six times the unit price of wind turbines for industrial use of today. Also, the capacity factor that would present the operation of the turbines considered in the study sites is the order of a third of which would present an industrial project in Uruguay.

If a repayment period of 10 years of the investment is considered acceptable, the unit price of wind turbines should be between 30% and 40% of the current value.

E. . Tariff Modification

Considering that the best results were obtained with the simple tariff, the form in which it could be modified for economically profitable results were analyzed. Therefore, a routine in MatLab was developed, which begins with the actual price and will increase the price paid for the energy generated up to a return period of 10 years. The results obtained are presented in Table 8 and 9.

It can be observed that these results match with those obtained in the previous section as for a return period of 10 years, the price at which the electricity generated is paid should increase by 300%, while reducing the investment to the third part has the same result.

Place: School of Engineering — Consumption curve: 4

N° 13	Ropatec					
Pot. (kW)	3,0					
FC	9,3%	Tariff increase (%)	Simple schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (years)	TIR	VNA ($)
100%	23621	0	22523	28	-2,6%	-4,1E+05
100%	23621	306	91443	10	7.7%	-1,4E+05

N° 21	TRUBY					
Pot. (kW)	2,5					
FC	10,8%	Tariff increase (%)	Simple schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (years)	TIR	VNA ($)
100%	26392	0	21961	32	-3,7%	-4,8E+05
100%	26392	366	102340	10	7.8%	-1,5E+05

Table 8. Data for tariff modification. “Facultad de Ingenieria”.

Place: High population density zone — Consumption curve: 4

N° 13	Ropatec					
Pot. (kW)	3,0					
FC	12,1%	Tariff increase (%)	Simple schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (years)	TIR	VNA ($)
100%	23621	0	30433	22	-0,4%	-3,8E+05
100%	23621	201	91604	10	7.7%	-1,3E+05

N° 21	TRUBY					
Pot. (kW)	2,5					
FC	14,5%	Tariff increase (%)	Simple schedule			
% Inv.	Inv. (U$S)		Annual savings ($)	PB (years)	TIR	VNA ($)
100%	26392	0	30454	25	-1,5%	-4,5E+05
100%	26392	206	102320	10	7.8%	-1,5E+05

Table 9. Data for tariff modification. High density zone.

F. Variation of the wind turbine power

We analyze the existence of an optimal case of savings in terms of installed capacity. A family of wind turbines with the curve shown in Figure 5 and with a rated power varies from 50% to 1000% of the showed one. It is assumed that each of these wind turbines was installed in a house located in a zone of high density and the user had a consumption level that falls into the category of extra high incomes.

To find this optimal, savings are expressed in terms of nominal power and the savings per unit of nominal power in terms of the nominal power of the wind turbine. These results are presented in Figures 9 and 10 respectively.

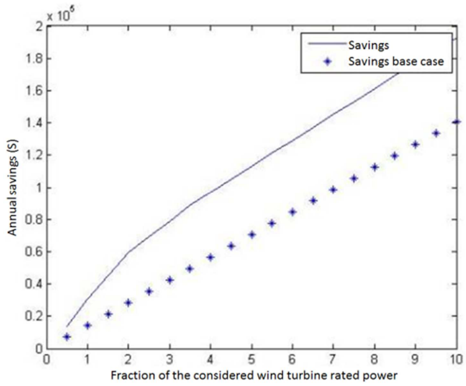

Figure 9. Savings as a function of the wind turbine nominal power. Turby wind turbine. High density population area.

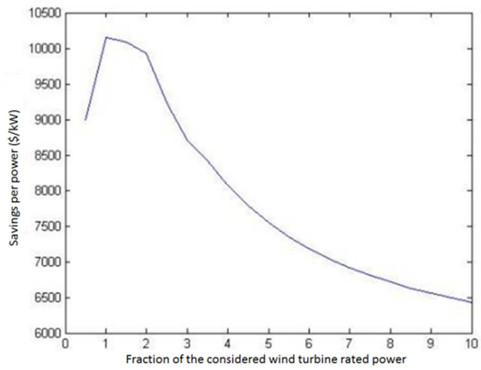

Figure 10. Savings per unit of rated power as a function of the wind turbine´s rated power. Turby wind turbine. High density population.

In Figure 9, the savings that would be achieved for the base case were added, which shows a linear behavior with the rated power. Saving curve of the considered case also presents a linear behavior but split in sections, showing breaks. These breaks will be given when the savings are changed by switching the step of energy consumption in the tariff scheme.

In Figure 11 the net energy exchanged with the network (consumed-generated) is presented. In this figure a reference of 600 kWh is indicated, consumption in which above begins to engage the third step of the Residential Simple tariff.

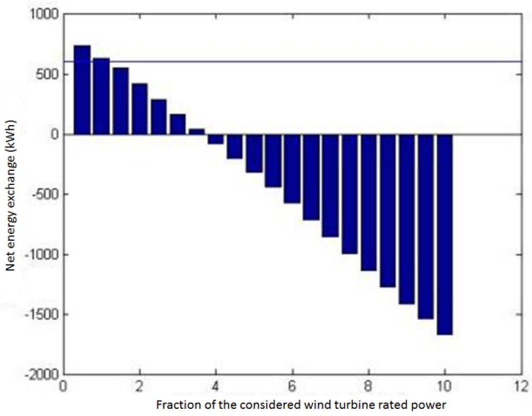

Figure 11: Net energy exchanged as a function of the nominal power of the wind turbine. Turby wind turbine. High density population area.

Figure 10 shows that the function "saving per unit of nominal power as a function of the nominal power of the wind turbine" has a maximum. This maximum occurs approximately where the net energy exchanged is 600kWh, consumption in which above begins to have participation the third step tariff. Then it is noted that the function tends to an asymptotic value as the energy exchanged is negative (more generation than consumption) so we can conclude that the over dimensioning of the wind turbine relative to the dimensions of the user is not favorable.

G. CO2 emission benefit

One way to encourage wind microgeneration is to remunerate the user of this technology a benefit for reducing CO2 emissions to the environment provided by the network.

Uruguayan network currently has an emission factor of 0.528 tons of CO2 / MWh, and the price of a ton of carbon is around USS 5.74. Therefore if you consider the amount of energy generated in a year you can calculate the benefit that can be paid to the user for avoiding carbon emissions. This benefit, which depends on the wind turbine, has a value that never comes to a dollar and, considering that the emission factor of the Uruguayan network is in decline due to the amount of wind power being installed, this benefit would tend to reduce. Therefore it does not seem to be a solution applicable to enhance the remuneration received by the user who installs a micro-scale wind turbine generation.

IV. CONCLUSIONS

In this paper, a program for the simulation and calculation of energy savings was developed, which allows identifying location cases, type of consumer, tariff and type of wind turbines for which it is feasible to consider installing micro wind generators in self-production regime at residential levels.

Performing different simulations for different wind turbine models on the market, it was possible to determine the cases with higher capacity factors, and then use them to determine the locations and types of consumers in which is more feasible to install micro-scale wind generation.

As a first result to note is that at higher consumption curves, investment for the installation of a wind turbine becomes more profitable. It was noted that in the case of the Uruguayan energy tariff, the best results were obtained for Simple tariff schedule. With the results achieved we can conclude that the wind turbine technology is currently very costly but may become profitable if it lowers its cost to a third. Meanwhile, it seems unviable as it is unthinkable to increase 300% the compensation of the energy generated by the distribution company. On the other hand, earnings per carbon proved to be completely negligible, at least in the Uruguayan case, which has a very low emission factor and continues to decline with the passing of the years.

As a most interesting result, it was possible to identify an optimal generation case; that is when the power of the wind turbine is such that it does not consume energy in the third step. This seems to make sense since after 600kWh the energy price rises, therefore, as expected; a good result is obtained when the generator prevents the user from having to pay the price of the most expensive energy.

Finally it is noted that it is not profitable to install a wind turbine with nominal power much higher as we saw that the graph of "savings per unit of nominal power as a function of the wind turbine nominal power" decreases to an asymptotic value for major powers.

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