Methodology and tools to optimise universalising electrical energy services in Bahia: from geo-referenced data, including a decentralised generation option for alternative service.

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Summary - **This P & D project developed for COELBA has the principal aim of developing a tool (software) that allows this concessionaire to carry out field rural electricity supply projects at low cost, comparing the alternative of extending distribution grids with reception via photo-voltaic systems as foreseen in its Universalising Reception Plan. In this sense it fills a gap in electricity distribution planning in Brazil, seeing as few studies have been dedicated to the subject and there is no known effort from the distribution concessionaire to institutionalise this procedure in its planning processes.**

***Key words*— Computing Tool, Decentralised Generation, Universalising.**

I. Introduction

This article is made up of three sections, as well as the conclusions. The first section analyses the non-electrified market of the State of Bahia, COELBA's concession area, which constitutes in absolute terms, the most deficient in terms of service in the ranking of Brazilian states. This market presents growing service costs if the option of extension of electrical grids is considered alone. To get to know better and characterise this market, mainly its consumption profile, information has been raised and compared from two sources: that available in the COELBA database and that obtained in sample field research in non-electrified homes and those already served with photo-voltaic systems.

In the second section, the cost items considered in the elaboration of electrification projects – investment and maintenance – are raised by COELBA, as much in grid extension as in photo-voltaic systems, used in the proposal that the company presented to the Ministry of Mines and Energy for the inclusion of these systems to reach part of its goals in the universalising programme. Taking the costs of the company as reference quantified the potential market for solar systems in the company's concession area.

The third section presents in detail the software development, including the tool utilisation manual elaborated from the existing databases – grid and residences – in COELBA. It allows the field achievement of this rural electrification project via grids, at low cost, observing the quality service criteria and possible physical obstacles that alter/weigh on the costs. With this software the company can intricately compare the attendance costs of grids X photo-voltaic systems, considering that the company has reference costs for the implementation of these systems, identifying in a more agile and precise way the residences where the costs of interconnection are more expensive and so, are presented as a potential market for decentralised systems, considering that the company proposes to implant 18,000 of these systems.

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II. COELBA's Non-Electrified Market

With a concession area of 563.6 km2, COELBA serves 415 of 417 municipalities, and almost 3,300,000 consumers, of which 52% are classified as low income. In 2003, when the universalising programme was launched in the State of Bahia, in the uncomfortable position of having the largest number of rural residences without electricity, summing up more than 400,000 units from a total of 2 million residences not served in the whole country.

Such a high level of electrical exclusion is owed, amongst other factors, not just to the territorial extension of land, that implies on the need to build an ample distribution grid to attend to disperse needs, with marginal service costs that grow in potential scale, but also by the socio-economic characteristics of the population to be attended, who in their majority, according to COELBA, can be classified as low income, as much in periphery urban zones as in rural areas where productive small farmers prevail..

The great effort being developed to increase the electricity service rate in the State deserves to be highlighted, with the participation of COELBA in the "Light in the Country Programme", through which almost 142,000 consumer units were electrified between 2002 and 2004, when the works of this programme were completed, allowing the reduction of indices of electrical exclusion in Bahia, as can be seen as follows.

It is important to mention that, on the occasion of the referred to programme, COELBA proposed to implant 9,000 individual photo-voltaic systems as part of the service goals, of which only 1,350 were effectively installed, but, before the usage of these systems was regulated for residences without electricity.

A. *Quantification and regional distribution*

In accordance with adjusted data from the COELBA Electricity Universalising Plan, the stock of non-electrified residences in October 2005 totalled 373,538 consumers, for whom the proposed works programme involved investments in the order of R$2.8 billion Brazilian real, representing an average investment of R$7,571.08 per consumer, with the implantation of 115,000km of distribution lines and 1,211,000 poles (Table 1).

TABLE I
STATE OF BAHIA: COELBA UNIVSERSALISING PROGRAMME – RANKING OF GEOGRAPHICAL REGIONS IN RELATION TO NUMBER OF CONSUMERS TO BE SERVED, TOTAL COST OF WORKS AND AVERAGE COST PER CONSUMER.

Geographical Region	Number of consumers			Geographical Region	Total Cost			Geographical Region	Cost per consumer	
	absolute	%	% accumulated		R$	%	% accumulated		R$	variation % average
North East	59,323	15.9	15.9	North East	423,544,975.31	15.0	15.0	Baixo Médio São Francisco	9,582.17	26.2
Chapada Diamantina	38,555	10.3	26.2	Paraguaçu	311,119,050.00	11.0	26.0	Extreme South	8,653.38	13.9
Paraguaçu	37,805	10.1	36.3	Chapada Diamantina	285,198,681.87	10.1	36.1	West	8,527.25	12.3
South West	35,932	9.6	45.9	South West	269,600,665.46	9.5	45.6	Paraguaçu	8,229.57	8.3
Serra Geral	31,815	8.5	54.5	Serra Geral	260,168,043.87	9.2	54.8	Serra Geral	8,177.53	7.7
West	28,945	7.7	62.2	West	246,821,158.54	8.7	63.5	South West	7,503.08	-1.2
South Coast	28,475	7.6	69.8	South Coast	179,916,364.39	6.4	69.9	Chapada Diamantina	7,397.19	-2.6
Médio São Francisco	23,163	6.2	76.0	Baixo Médio São Francisco	168,540,789.43	6.0	75.9	North Coast	7,298.99	-3.9
Piemonte da Diamantina	22,215	5.9	82.0	Médio São Francisco	163,664,595,31	5.8	81.7	Irecê	7,117.62	-5.5
Baixo Médio São Francisco	17,589	4.7	86.7	Piemonte da Diamantina	157,905,319.24	5.6	87.2	North East	7,139.64	-6.0
Recôncavo Sul	17,280	4.6	91.3	Recôncavo Sul	115,031,358.18	4.1	91.3	Piemonte da Diamantina	7,108.05	-6.4
North Coast	10,982	2.9	94.3	Extreme South	90,462,385.39	3.2	94.5	Médio São Francisco	7,065.78	-7.0
Extreme South	10,454	2.8	97.1	North Coast	80,157,498.87	2.8	97.3	Recôncavo Sul	6,656.91	-12.4
Irecê	9,775	2.6	99.7	Irecê	70,161,232.91	2.5	99.8	South Coast	6,318.40	-16.8
Salvador Metropolis	1,230	0.3	100.0	Salvador Metropolis	5,795,417.09	0.2	100.0	Salvador Metropolis	4,711.72	-38.0
TOTAL	**373,538**	**100.0**	-	**TOTAL**	**2,828,087,535.96**	**100.0**	-	**TOTAL**	**7,571.08**	-

Source: COELBA

It can be observed that of a total of 15 regions in the State, five concentrate more than half of the non-served consumers (54.5%) and, as a consequence also 54.8% of the total cost of the works. They are: North East, Chapada Diamantina, Paraguaçu, South West and Serra Geral. However when the variable cost per consumer is considered this situation changes, since the highest unit costs are in the border regions: Lower Mid São Francisco, Extreme South and West, respectively 26.2%, 13.9% and 12.3% above average, followed by the regions of Paraguaçu and Serra Geral. Just these regions have higher average costs than the State average. An expressive variation in cost is registered between regions, with values between 26.2% higher and 38.0% lower than the average of the total collection of works.

The information from this database was organised according to the methodology proposed in a previous study carried out with the database of the "Light for All Programme" that will be used as a comparison. According to this methodology, the works were grouped for the constitution of matrices according to two criteria / variables: distance of residence in relation to grid (in km), for which were used data referring to the extension of the distribution lines and the dispersion of these residences measured by the number of poles per consumer served. Each one of these variables was organised in class intervals that show the Matrices of Average Unit Cost of the Grid and of the Number of Residences served by the Programme. To obtain global data, initially the works were aggregated by municipality and, in sequence, by geographical region so as to obtain the State totals. In the geographical aggregation the classification was used of Economic Regions of the Bureau of Studies and Information – SEI (BA), having in sight the need to relate other variables per municipality, like the Municipal GDP and the HDI (human development index), that were extracted from the statistical data of the body referred to, for the phase of field research foreseen for this project.

As observed in the study referred to, the criteria number of poles per consumer served came about from the need to incorporate in the analysis the great dispersion of rural residences, an indicator that reflects well its level of dispersion: the more disperse, the more poles need to be used to carry out the service.

The correlation between the two criteria – distance from grid and poles/consumer – generated a collection of three matrices, presented in Table II. The Matrix of the Number of Consumers shows that the majority of residences to be served are found in the fourth and fifth class interval of the level of dispersion, which added up is the equivalent of 76.6% of the total, in other words, works to serve the majority of the market, demand

TABLE II
COELBA UNIVERSALISING PROGRAMME: MATRIX OF NUMBER OF CONSUMERS TO BE SERVED, TOTAL INVESTEMENTS AND AVERAGE COST OF SERVICE

Level of dispersion (posts per consumer)	**Distance from grid in km**						**Total**
	0 - 1	**> 1 – 5**	**> 5 – 10**	**> 10 - 20**	**> 20 - 50**	**> 50**	
			Number of Consumers				
<= 0,5	8.199	1.792	316	157	269	-	10.733
> 0,5 - 1	6.768	6.037	1.903	266	515	69	15.558
> 1,1 - 2	7.168	17.190	14.622	12.100	7.755	2.370	61.205
> 2,1 - 4	4.947	26.725	45.708	64.529	46.595	11.780	200.284
> 4	1.624	8.453	14.209	25.501	26.689	9.282	85.758
Total	28.706	60.197	76.758	102.553	81.823	23.501	373.538
			Total Value of Investments (in R$1,000.00 Brazilian Real)				
<= 0,5	23.531,27	4.764,84	1.398,86	772,56	417,61	-	30.885,14
> 0,5 - 1	18.493,08	15.327,99	5.094,08	1.014,86	3.350,10	1.085,87	44.365,97
> 1,1 - 2	29.695,48	75.969,16	57.663,87	52.532,57	34.677,30	9.389,95	259.928,32
> 2,1 - 4	34.769,29	171.373,43	298.422,65	467.538,11	329.458,26	92.190,62	1.393.752,37
> 4	24.729,37	113.246,79	164.921,89	304.357,54	352.977,85	138.922,30	1.099.155,74
Total	131.218,49	380.682,21	527.501,34	826.215,64	720.881,12	241.588,74	2.828.087,54
			Average Cost per Consumer (in R$ Brazilian Real)				
<= 0,5	3.822,64	6.125,10	14.109,68	9.976,11	1.552,46	-	2,9
> 0,5 - 1	4.719,41	3.243,07	2.747,02	4.413,07	5.986,65	15.737,20	2,9
> 1,1 - 2	5.559,18	5.079,06	4.173,66	4.546,03	4.680,36	4.061,45	4,2
> 2,1 - 4	8.346,87	6.780,95	6.827,49	7.490,34	7.397,33	7.800,06	7,0
> 4	17.700,53	17.841,05	14.677,97	15.908,73	17.482,79	23.313,55	12,8
Total	4,6	6,3	6,9	8,1	8,8	10,3	7,6

Source: UNIFACS and COELBA

the installation of more than two posts per consumer. In relation to the distance of the residence from the grid, then the distribution is more uniform, it is relevant to note that more than half of the residences are at more than 10 km from the grid, mostly between 10 and 50 km.

The Investment Matrix, reflecting the distribution of consumers not served, reveals that the greater values of investments were destined to the third or fourth class interval of the level of dispersion – 88.3% of the total allocated, in other words, the market to be served has as characteristic a raised dispersion of consumer units. This information is even more important when it is observed that the allocation of investment from the point of view of the distance from the residence to the grid has a more uniform distribution. Then, the rising of costs is more correlated to the dispersion

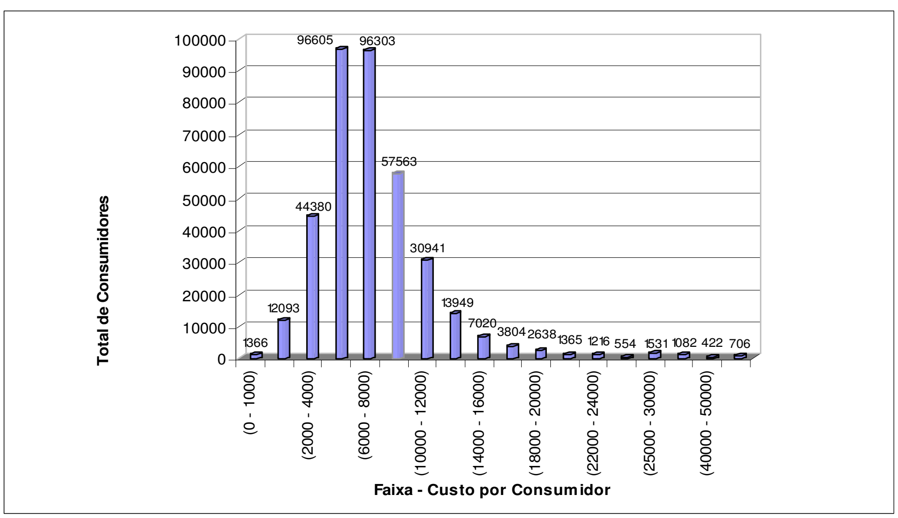


Figure 1: Distribution of Frequency of Average Unit Costs per Consumer of the COELBA Universalising Plan.

and less to the distance from the grid. In any way, 63.3% of investments are destined to attend localised consumers more than 10 km from the grid.

The third Matrix, of Average Cost per Consumer, shows that according to the level of dispersion the values present a growing tendency, but the same does not happen in relation to distance from the grid, where the costs present erratic values for this criteria, a phenomenon that was observed during the study of the works for the "Light for All Programme", and this apparent contradiction was explained by the quantity of works and by the number of clients served in each class interval, seeing as a small number of works that present costs outside the average can alter the average of the class interval. This behaviour was also explained by the fact that the rising of costs suffered more influence from the level of dispersion (number of poles per consumer).

The comparison between the data of unit costs per consumer between the two programmes reveals an expressive increase in costs in all classes, according to the two criteria of the matrix composition, which was already expected, seeing as in universalising it is obligatory to attend to all consumers, whereas in the previous Programme the criteria was to interconnect the greatest number of consumers closest to the grid in the sense of optimising projects and costs.

To reduce the weight of extreme values the data was grouped in distribution of frequency, as represented graphically in the Histogram of Figure 1. In this way the costs situated in distribution extremes are not very representative. On the other hand, there is a band (that goes from R$ 4,000.00 to R$ 8,000.00 Brazilian Real) that registers the classes with greater frequency and answers for R$51.7% of observations.

B. Consumer Profile on the basis of Electrified Residences

Once quantified the market to be served in terms of its geographical location and of the necessary investments for service, it is possible to estimate the average connection costs, in terms of dispersion and distance from distribution grids. This makes it necessary to aggregate a third dimension in the characterisation of the non-served market that is the energy consumption profile, seeking to infer the potential energy demand of the market to be electrified. This variable is of utmost importance when service alternatives are evaluated, such as photo-voltaic systems.

A first dimension of this variable was obtained from historical data of energy consumption by rural COELBA consumers served with electricity via the “Light for All” and “Light in the Country” Programmes, illustrated in Figures 2 and 3.

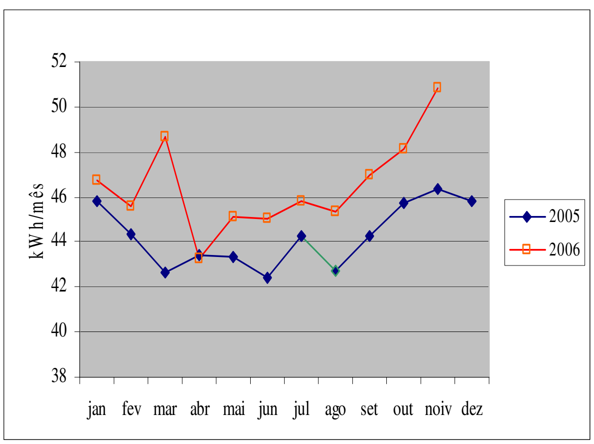


Figure 2. “Light in the Country Programme”: Average Read Consumption (COELBA).

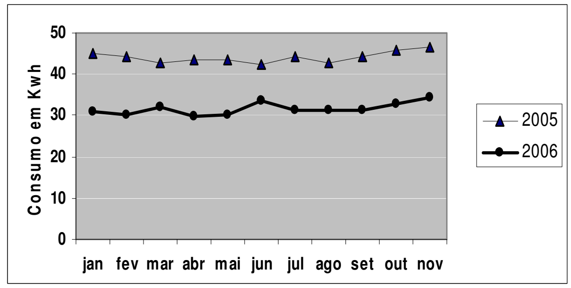


Figure 3. “Light for All Programme”: Average Read Consumption.

The tendency to reduce the levels of average energy consumption for new rural consumers is corroborated when Table III data is analysed, therein quantified for the year 2005, in the two quoted rural electrification programmes, the number of consumers with average monthly consumption of up to 13 kWh. Whilst for the “Light in the Country” Programme the number of consumers in this band was the equivalent of 23.4% of the total served, in the “Light for All” Programme this percentage rose to 37.1%.

TABLE III
CONSUMERS WITH AVERAGE MONTHLY CONSUMPTION LESS THAN 13 KWH

Programme	Number of Consumers			Consumption	%
	Solar	Grid	Total	up to 13 kWh	
Light in the Country	0	113,753	113,753	26,645	23,4
Light for All	2,358	48,698	51,056	18,043	37,1
Total	2,358	162,451	164,809	44,688	27,5

Source: COELBA

In addition to this approach, using historical data of average consumption, sought in the same databases to obtain a sample of consumers, aiming to label these consumers by bands of average monthly consumption and accompany the evolution of their consumption over the course of time. The treatment of this information allows us to infer the demand behaviour of consumers of the same profile over the course of time, in other words, if the level of energy consumption grows and at what rhythm. This variable is fundamental when service alternatives are evaluated such as photo-voltaic systems.

It is worth observing, initially, that there is a significant variation of the number of consumers between the years of the series, varying from 30 in 2000, to 51,502 in 2005. Leaving aside the first three years, in which few consumer registrations were supplied, in the other years, almost 60% of consumers interconnected had a consumption of up to 30 kWh. (see Table IV) and more than a third up to 13kWh.

TABLE IV
RURAL ELECTRIFICATION PROGRAMMES * – NUMBER OF CONSUMERS PER BAND OF ELECTRICAL ENERGY CONSUMPTION.

Consumption Read (in KWh/month)	Number of consumers			%		
	2003	2004	2005	2003	2004	2005
up to 13	119	1,828	18,623	43.6	45.2	36.2
13 -30	41	882	14,055	15.0	21.8	27.3
30 - 45	23	418	6,977	8.4	10.3	13.5
45 - 60	28	274	4,308	10.3	6.8	8.4
60 - 80	23	267	3,672	8.4	6.6	7.1
80 - 200	31	315	3,570	11.4	7.8	6.9
200 ->	8	58	297	2.9	1.4	0.6
TOTAL	273	4,042	51,502	100.0	100.0	100.0

Source: COELBA *Light in the Country and Light for All

From this database 4,042 consumers were selected (interconnected by the Light in the Country and Light for All

Programmes) from 2004 (year in which the sample is most representative) to accompany the evolution of their consumption in the following year (2005). This information is shown in Table V and Figure 4 where one can observe the significance of the number of consumers that migrated from the initial band of least consumption (13 kWh / month) to subsequent bands, with greater concentration in that of 30 kWh / month. Although the period analysed was very small, just two years, it can be affirmed that there is a tendency that a section of rural consumers, once they have electricity, migrate to higher levels of consumption.

TABLE V
EVOLUTION OF THE AVERAGE MONTHLY CONSUMPTION OF A SAMPLE OF CONSUMERS SERVED BY RURAL ELECTRIFICATION PROGRAMMES

Year		up to 13	13 - 30	30 - 45	45 - 60	60 - 80	80 - 200	200>	Total
2004	ABS	1828	882	418	274	267	315	58	4042
	%	45.23	21.82	10.34	6.78	6.61	7.79	1.43	100.00
2005	ABS	9.55	1044	591	493	460	414	60	4017
	%	23.77	25.99	14.71	12.27	11.45	10.31	1.49	100.00

Source: COELBA

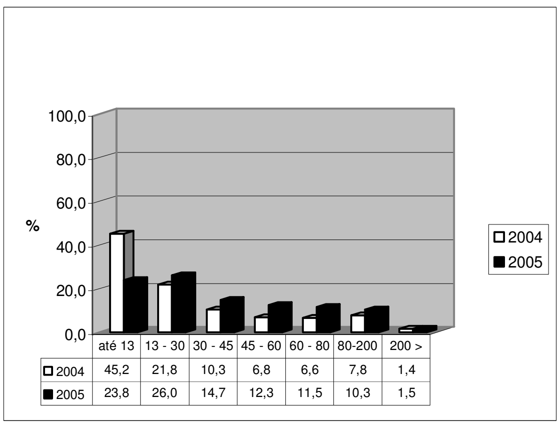


Figure 4. Distribution of the consumers by consumption bands in kWh / month.

III. SERVICE COSTS WITH GRID X IGSIS.

(**I**ndividual **G**eneration **S**ystems with **I**ntermittent **S**ources).

In January 2006, with the Light for All Programme in progress, COELBA reviewed the calculations of average costs per consumer of the works programme, grouping the projects in terms of the distance in kilometres from the interconnections, arriving at the constant results in Table VI. With this revision, the average cost was R$ 8,702.79, a growth of 15.0% in relation to the value of R$ 7,571.08 estimated in the Universalising Plan presented in 2005.

In face of the dimension of the market to be attended, nearly 373,500 residences, of the characteristics of this market, the company began to consider in its universalising programme planning the possibility of serving part of this market with photo-voltaic systems. In this way, with the aim of minimising the costs of the universalising programme, they selected from the database for the works programme the 18,000 consumers with the highest interconnection unit costs, comparing this result with the costs of serving with photo-voltaic systems. The results of the referred analysis are presented in Table VII, where it is observed that the cost of interconnection is 4.7 times higher to the service cost with IGSIS. So, if service were activated for these 18,000 residences by the alternative at a lower cost, there would be an economy of R$ 347 million for the COELBA Universalising Plan, with less tariff impact on its consumers, seeing as the company's participation is 20% of the investment total.

TABLE VI
COELBA UNIVERSALISING PROGRAMME – AVERAGE COSTS OF INTERCONNECTION OF RURAL CONSUMERS (JAN/2006)

Distance from the Grid	Number of Projects	Number of Consumers	Investment Value (R$ 1.00)	Average Cost
0 a 0.5 Km	1,596	3,799	22,321,282	5,875.57
0.5 a 1 Km	915	4,086	27,126,557	6,638.90
1 a 2 Km	1,292	8,721	57,067,764	6,543.72
2 a 3 Km	1,000	9,220	67,999,634	7,375.23
3 a 5 Km	1,562	20,367	243,690,329	11,964.96
5 a 7 Km	1,230	23,137	171,813,524	7,425.92
7 a 9 Km	995	23,621	181,249,528	7,673.24
9 a 13 Km	1,371	42,779	327,544,387	7,656.66
13 a 18 Km	1,032	42,173	345,821,286	8,200.06
> 18 Km	1,453	101,387	985,967,070	9,724.79
Total	**12,466**	**279,290**	**2,430,601,361**	**8,702.79**

Source: COELBA

TABLE VII
COELBA UNIVERSALISING PROGRAMME – COMPARISON BETWEEN SERVICE COSTS OF CONSUMERS (JAN/2006)

Form of Reception	Number of Consumers	Average Cost (R$)	Total Cost (R$)
With grid	18,000	24,484	440,706,773
With IGSIS	18,000	5,213	93,835,800

Source: COELBA

In 2006, a COELBA proposal was taken into consideration by the Ministry for Mines and Energy for the Light for All Programme, for the connection of these 18,000 residences with photo-voltaic systems, at an estimated cost of R$ 94 million, contemplating systems of three types, as discriminated in Table VIII. The average cost of these connections were budgeted at R$ 5,213.10 per residence, within the contracted limit with ELETROBRÁS for the execution of the referred to programme. Compared with the cost of interconnection to the grid, estimated at R$ 396 million, this initiative would represent an economy of R$ 302 million.

In this proposal the selection criteria of residences to be served was to prioritise those most distant from the electrical grid, the opposite of the criteria used for interconnection, which can bring forward the connection of consumers who, by their location, would only be attended to last. Concomitantly, as agreed with the Ministry for Mines and Energy, the company established as criteria[1] for the use of photo-voltaic systems, identification of consumers with a profile compatible with that specified in the regulation of IGSIS 13, in other words, monthly consumption of 13 kWh and inter-

[1] Internal document elaborated by the Bureau of Engineering / Department of Investment Planning / Distribution Planning Unit, entitled Criteria for use of Photo-voltaic Energy in Light for All Programme.

connection cost to the grid per consumer above R$ 13,872.00. This value was found from the parameters related in Table IX.

TABLE VIII
COELBA – LIGHT FOR ALL PROGRAMME
PROPOSAL FOR CONNECTION WITH PHOTO-VOLTAIC SYSTEMS

Types of System	Unit Value (R$)	Quantity of Systems	Total Value (R$)
IGSIS 13 kWh/150Wp	4,841.59	16,85	81,580,791.50
IGSIS 13 kWh/150Wp	10,033.32	1,100	11,036.652.00
IGSIS 13 kWh/150Wp	24,365.33	50	1,218,266.50
Total	**5,213.10**	**18,000**	**93,835,800.00**

Source: COELBA

TABLE IX
COELBA – COSTS OF INDIVIDUAL GENERATION SYSTEMS WITH INTERMITTENT SOURCES (IGSIS) (1)

Parameters	Values
Basic Investment Kit including installation	R$ 4,664.35
Operation and Maintenance	R$ 26.03
Life Expectancy	25 years
Capital Incentive Rate	15 % year
Reference Value Obtained	R$ 9,247.81/consumer
Reference Value increased by 50%	R$ 13,872.00

Source: COELBA
(1) IGSIS of 13 kW

A. *Dimensioning the Potential Market for IGSIS*

Table X presents the results of a potential market estimate for applying the use of IGSIS by COELBA in its universalising programme, based on the criteria of the average service cost per consumer. In this way the average interconnection costs will be compared with the average service costs with IGSIS 13, using two values quantified by the same company. Thus, with the adoption of the value of R$ 13.872,00 (see Table 3.4) as the limit cost from which residences without electricity should be served with photo-voltaic systems, a value used in the proposal negotiated with the MME, the potential market of IGSIS 13 is of 21,018 residences, the equivalent of 5.6% of the total of residences without electricity in Bahia. In other words, only this total of consumers of the COELBA market would have an interconnection cost above this value. As the proposal of the company is to install 18,000 systems, with this measure it would be contemplating 85.6% of the potential market for the use of these systems.

Considering that this IGSIS cost was over-estimated by COELBA, seeing as in this value an over price of 50% is built-in above the reference cost found that is R$ 9.247,81 (Table 3.4), the potential market for photo-voltaic systems was also estimated based on the reference cost. Based on this value the potential IGSIS market would go up to 84,200 residences, which represent 22.6% of the total of units without electricity.

As the COELBA proposal aims to install 1,100 IGSIS– 30 systems and 50 IGSIS - 80 systems, it is important that the consumer criteria be associated to the cost criteria or the potential demand for energy in the residences to be energised. It is important for the company to get to know the energy consumption and demand profile of this market, aiming to not just measure the percentage of consumers with repressed demand, seeing as they are or will be served with IGSIS – 13 systems; as also identify a "standard distribution" of rural location markets, looking towards serving a section of consumers with larger IGSIS, which is the aim of the proposal submitted to the Ministry for Mines and Energy.

To try to measure this "standard distribution", two sources of information were used: the consumption data from residences already electrified by COELBA and the research field data carried out in the sphere of this project in residences without energy and electrified with IGSIS – 13 systems. The compared data are presented in Table XI.

Various scenarios to establish a "consumption standard" can be extracted from the analysis of numbers in this table. For residences without electricity, as was to be expected, the energy consumption of the predominant part of residences (87.2% on average) are found in the band of up to 13kWh/month, behaviour which can be checked in all regions. In the higher band, with consumption between 13 and 30 kWh/month, are just 12.8% of residences and there is no registration of consumption higher than this band. However, taking into account the consumption potential, the predominant band is the second, between 13 and 30 kWh /month, where 71% of residences are located, with consumption registrations higher than 30 kWh /month in all bands, although the percentages are small.

If we consider the residences already electrified with IGSIS, then 59.2% have a consumption level that is satisfied by the quantity of energy supplied, a significant section of (40.8%) have a consumption level located in the higher band, between 13 and 30 kWh / month, varying between 25.5% in extract 4 and 61.4% in extract 2. Considering the demand potential for these same residences electrified with IGSIS – 13, we can observe that 40.2% of residences have repressed energy consumption, seeing as it cannot be met by the installed systems, but which could mostly be served if the systems were larger (IGSIS – 30). We can also observe here a significant variation between the regions, behaviour that must be observed when selecting the locations that will be supplied with larger systems (IGSIS – 30).

TABLE X

COELBA UNIVERSALISING PLAN – POTENTIAL MARKET FOR IGSIS – 13 SYSTEMS ACCORDING TO AVERAGE SERVICE/CONSUMER COST

Strata	Geographical Region	Number of Residences				
		Total	IGSIS (1)	% IGSIS/ TOTAL	IGSIS (2)	% IGSIS/ TOTAL
1	Baixo Médio São Francisco	17,589	3,477	19.8	6,816	38.8
	West	28,945	1,963	6.8	7,214	24.9
	Sub-total	**46,534**	**5,440**	**11.7**	**14,030**	**30.1**
2	North East	59,323	3,475	5.9	11,519	19.4
	Sub-total	**59,323**	**3,475**	**5.9**	**11,519**	**19.4**
3	Extreme South	10,454	1,411	13.5	4,812	46.0
	North Coast	10,982	561	5.1	2,197	20.0
	South Coast	28,475	484	1.7	3,193	11.2
	Paraguaçu	37,805	1,825	4.8	9,796	25.9
	Recôncavo Sul	17,280	212	1.2	2,633	15.2
	South West	35,932	1,784	5.0	7,583	21.1
	Sub-total	**140,928**	**6,277**	**4.5**	**30,214**	**21.4**
4	Chapada Diamantina	38,555	1,579	4.1	8,968	23.3
	Irecê	9,775	854	8.7	1,792	18.3
	Médio São Francisco	23,163	1,140	4.9	4,219	18.2
	Piemonte da Diamantina	22,215	947	4.3	4,450	20.0
	Serra Geral	31,815	1,306	4.1	8,989	28.3
	Sub-total	**125,523**	**5,826**	**4.6**	**28,418**	**22.6**
Total		**372,308**	**21,018**	**5.6**	**84,181**	**22.6**

Source: COELBA

(1) interconnection to grid cost per consumer higher than R$ 13.872,00

(2) interconnection to grid cost per consumer higher than R$ 9.247,81

Finally, considering the data of COELBA consumers already inter-connected, the percentage of those who consume up to 13 kWh / month is significant, but is minor, bearing in mind that 63.7% of residences consume above this level. In this case, the consumption variations between the bands and regions are not very significant in relation to the average.

Taking as a reference these data to define the "standard distribution", three scenarios can be drawn, being that the consumption band between 13 and 30 kWh, of most interest for COELBA seeking to install 1,100 IGSIS- 30 systems foreseen in its universalising plan, can vary between 12.8% and 27.4% of the number of residences of each location to be electrified with these systems, depending on the scenario that is considered.

Conservative scenario – using the annual distribution of consumption by residences without electricity, the residences would be grouped in just two consumption bands, with just 12.8% in the band between 13 and 30 kWh / month and the majority 87.2% in the band up to 13 kWh / month;

Reference scenario – using the potential consumption distribution of consumers electrified with IGSIS, it can be checked that consumers exist for all consumption bands considered, being that the lowest consumption band is in the order of 59.2% of residences and the percentage between 13 and 30 kWh/month grows to 18.3%;

Optimistic scenario – using the consumption distribution of the residences interconnected to the COELBA distribution system the number of those located in the first band of up to13 kWh/month is reduced to 36.3%, and those of the higher band between 13 and 30 kWh/month increases to 27.4%.

The distributions of these scenarios are represented graphically in Figure 5, which can be used by the company to estimate the potential for implantation of the larger IGSIS in each location.

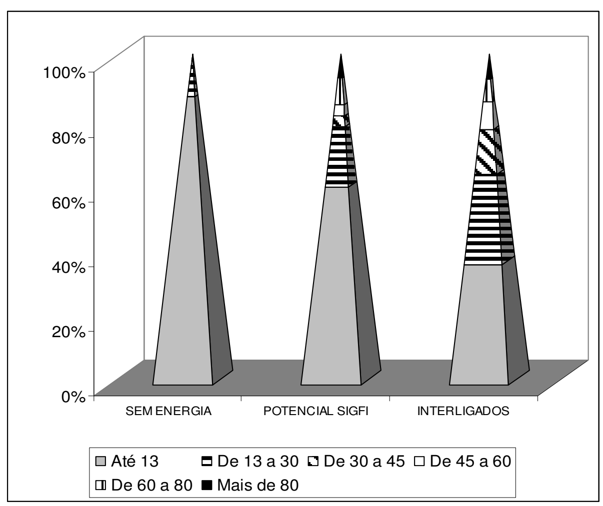


Figure 5: Standard Distribution of the Market by Consumption Bands in kWh/month (Source: COELBA and UNIFACS/COELBA Field Research)

TABLE XI
ESTIMATE OF ENERGY CONSUMPTION AND DEMAND ACCORDING TO BANDS (IN %)

Consumption Bands (in kWh / month)	Strata				
	1	2	3	4	Total
Field Research in non-Electrified Residences					
Actual Consumption (electro-domestics / equipment used)					
Up to 13	79.1	78.2	90.2	91.5	87.2
13 - 30	20.9	21.8	9.8	8.5	12.8
30 - 45	0.0	0.0	0.0	0.0	0.0
45 - 60	0.0	0.0	0.0	0.0	0.0
60 - 80	0.0	0.0	0.0	0.0	0.0
more than 80	0.0	0.0	0.0	0.0	0.0
Potential Demand (electro-domestics / equipment to be acquired)					
Up to 13	55.8	41.8	18.9	4.3	22.3
13 - 30	34.9	54.5	79.5	82.9	70.9
30 - 45	0.0	1.8	0.0	1.7	0.9
45 - 60	2.3	0.0	0.0	2.6	1.2
60 - 80	7.0	0.0	0.0	5.1	2.7
more than 80	0.0	1.8	1.6	3.4	2.1
Field Research in Residences Electrified with IGSIS					
Actual Consumption (electro-domestics / equipment used)					
Up to 13	60.4	36.8	37.2	74.5	59.2
13 - 30	37.6	61.4	53.5	25.5	38.8
30 - 45	2.0	1.8	9.3	0.0	2.0
45 - 60	0	0	0	0	0
60 - 80	0	0	0	0	0
more than 80	0	0	0	0	0
Potential Demand (electro-domestics / equipment to be acquired)					
Up to 13	76.2	45.6	51.2	56.2	59.8
13 - 30	18.8	5.3	16.3	24.1	18.3
30 - 45	1.0	8.8	2.3	2.9	3.3
45 - 60	0.0	3.5	4.7	5.1	3.3
60 - 80	2.0	21.1	18.6	4.4	8.3
more than 80	2.0	15.8	7.0	7.3	7.1
COELBA Database (rural consumers in 2005)					
Up to 13	41.5	36.8	30.8	41.3	36.3
13 - 30	22.6	31.4	25.8	28.1	27.4
30 - 45	11.8	13.7	14,0	13.3	13.6
45 - 60	7.7	7.3	9.7	7.5	8.3
60 - 80	7.6	5.9	9,0	5.2	7,0
more than 80	8.8	4.9	10.7	4.6	7.4

Source: COELBA and COELBA/UNIFACS Field Research

IV. Development of Software to Optimise the Universalising Planning

A. Background

The initial prototype executed the elaboration of project drafts for supplying energy from manually informed scenarios. Such scenarios reproduced hypothetical situations that possessed the following data: groups of residences that made up a non-served community; positioning of poles of the primary grid and recognition of the regions of difficult or impossible access, or containing environmental preservation zones, lakes and private properties.

In the original prototype, as the scenario data were supplied, the tool carried out calculations with the aim of determining the best form of energy grid expansion: the location of primary and secondary grid poles and the location of the transformer (s) in a configuration that represented the project with the lowest cost.

It can be understood as the "best form of energy grid expansion" the project most economically viable to the concessionaire, considering the concepts that orientate the calculation methodology to find the solution that represents the minimum cost and still attends to all in a satisfactory way, respecting supply quality standards.

To contemplate all of these aspects the tool used its own algorithm that initially calculates the minimum coverage tree on the graph totally connected, made up of non-served residences and at a short distance from the group of residences to existing grids. This allows computing of an initial proposal of a grid sketch. When the grid sketch intersects geographical obstacles, the grid is automatically recomputed using the cost X benefit calculation, using operations of convex contour determination of these geographical obstacles. The calculation of the final proposal thus considers the possible primary and secondary grid sketches from the interactive positioning of transformers on this grid. A total estimate of the pre-project is calculated from the totalling of the necessary materials and structures to carry out the projected grid. This totalling considers the rules of primary and secondary grid projects for the type of region served, amongst them the type of grid, distancing between poles, types of poles and maximum distance between the transformer and the residence.

B. The tool developed

The tool was completely re-structured to permit the entry of real data instead of hypothetical data used during the academic project. The data of grid-type projects, distancing between poles, types of poles, the maximum distance between the transformer and the residence were revised to adapt them to COELBA's reality.

Consequently the tool was adapted to use the Geographic Information Systems (GIS). Its internal structure was adapted to navigation and analysis of maps, proportioning to the user navigation facility between regions and the points that represent residences and the grids.

The new version allows the selection of a region for the grid sketch. Once the scenario is defined (selection of a group of non-served residences), the calculation process of the grid expansion project is automatically initiated. The interactive process of taking the decision can be carried out from the grid option supplied with the addition or removal of transformers, poles and residences.

The tool produced facilitates the pre-project procedure of grids, as it proportions more agility to the analysis of project scenarios and calculations, suggesting a sketch to the technician who goes on field to raise and determine the positioning of equipment and the necessary structures to supply the service of electricity to residences in small communities.

C. Limitations and Future Projects

The data available to the work are sufficient for representing scenario. However, for an approach closer to reality and more exact, some information not available would be of great value to the tool. The data available on the Geo-Grid (GEOREDE) already allow a project elaboration that is of great use to the company, but information such as relief accidents, alto-metric rising, hydrographs, roads and rural ways are not available in COELBA. As such information directly influences the sketching of the grid and, consequently, on the project to be elaborated, it would be of great value to obtain them and integrate to the tool. Here it should be noted that the tool already has a facility to contour geographical obstacles, but it must eventually be expanded to consider alto-metric aspects in its calculations.

D. Tool Manual

Interface with the user

The tool uses a totally interactive graphic interface. All the tool operations are activated by the mouse. Figure 6 shows the main screen of the tool. It is made up of a Menu Bar with the options, an Access Bar with buttons that facilitate navigation and rapid access to the main functions of the tool: Information Bar and Map Area.

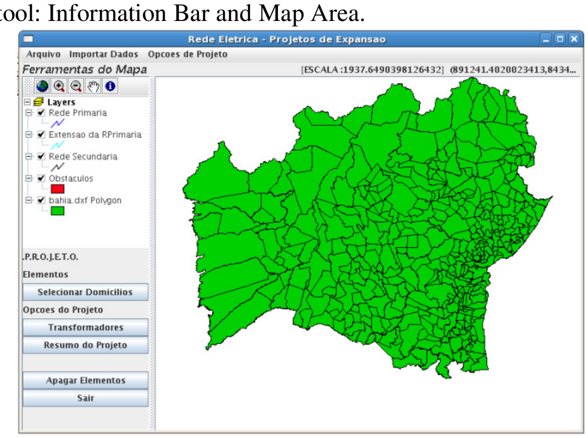


Figure 6: Main screen of the tool.

Importing Data

A pre-project begins with importing to the tool the data from the COELBA grid and from residences still not served by the electrical grid. With these data, the tool will bring up a new screen that shows an example where a group of primary grid structures was loaded in the northern region of the state, together with the non-electrified residences represented by white squares. Finally, just the area where the pre-project is planned to be executed needs to be delimited and the programme automatically calculates the lowest cost grid that interconnects the residences and immediately shows the resulting grid to the user – presented in Figure 8, which represents an approximation (*"zoom"*) of Figure 7.

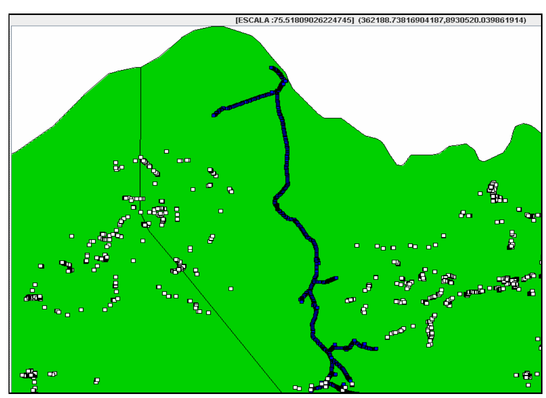


Figure 7: Example of region with residences to be selected.

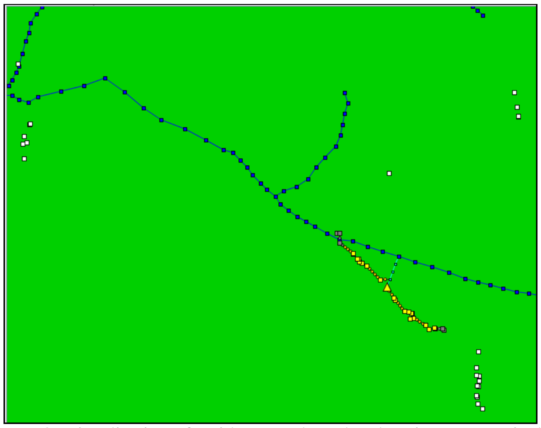
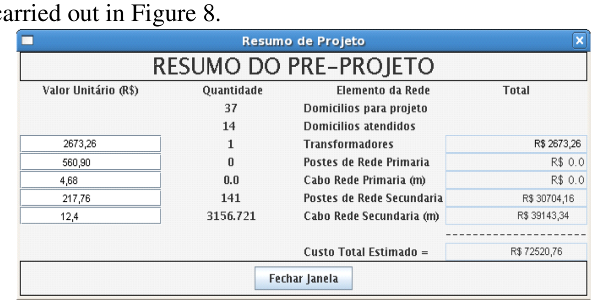


Figure 8: Visualisation of residences selected and project automatically calculated.

As a result of the selection, the grid lines are sketched, the poles to be used are positioned and the location for a transformer is suggested. To facilitate the visualisation and understanding of the project, the elements of the determined scenario, residences (squares) and poles (circles) are coloured in the following way: elements that receive energy within the established standards (standard distance from the grid to the transformer) are coloured *yellow;* whereas the others, even if they are connected to the grid, that do not attend to the standard, are coloured *grey*. Other default values can be defined for the number of transformers, but it was opted to begin the project with one transformer and interactively add new transformers to interactively establish new project scenarios.

Visualisation of Project Totals

Once a pre-project is concluded, the programme presents to the user the project totals, involving materials and structures used and residences served. Figure 9 shows an example of this summary presenting the totals of the pre-project carried out in Figure 8.


Resumo de Projeto

RESUMO DO PRE-PROJETO

Valor Unitário (R$)	Quantidade	Elemento da Rede	Total
	37	Domicilios para projeto	
	14	Domicilios atendidos	
2673,26	1	Transformadores	R$ 2673,26
560,90	0	Postes de Rede Primaria	R$ 0.0
4,68	0.0	Cabo Rede Primaria (m)	R$ 0.0
217,76	141	Postes de Rede Secundaria	R$ 30704,16
12,4	3156.721	Cabo Rede Secundaria (m)	R$ 39143,34
		Custo Total Estimado =	R$ 72520,76

Fechar Janela

Figure 9: Summary of the project in Figure 8.

The tool possesses standard values, pre-defined for the cost of materials used in the project. However, the fields referring to the values can be edited to carry price changes. Once altered, the total values are instantly updated in the totalling presented on the right side of the screen. This is an extremely important resource to study project scenarios and pre-evaluate the viability of diverse solutions, where the initial grid sketch, the totals involving necessary materials and structures are exposed.

V. Conclusions

The final objective was to obtain an interactive pre-project tool for grid expansion of electricity distribution to aid COELBA technicians in the execution of the Light for All Programme. And so the following was done:

- the revision of the project elaboration procedures for distribution grid expansion;
- the creation of an interactive project paradigm so that the computational tool can rapidly propose possible sketches for distribution grid expansion from information on existing grids, the residences as yet not served, and the geographical obstacles to the sketching of a grid in a given region;
- the integration of this tool with Geo-Grid (GEOREDE), COELBA's database system that contains the geo-referenced information on non-served residences, existing electricity grids and geographical obstacles.

The initial tool has been completely restructured to allow the entry of real data instead if hypothetical data used during the academic project. The project data on the type of grid, distancing between poles, types of poles and the maximum distance between the transformer and the residence were revised to adapt to COELBA's reality. For this purpose import modules of necessary data were created for the pre-project of the Geo-Grid (GEOREDE) system grids. Consequently the tool was adapted for the use of Geographic Information Systems (GIS) and its internal structure was adapted for navigation and map analysis, proportioning to the user the facility of navigation between regions and the points that represent residences and grids. The function of "zoom" was added and map navigation (in particular the map of the State of Bahia). In this way the interface now allows a detailed vision of any particularity of the scenario, with the approximation or distancing of a specific point on the map.

The interface of the project tool was adapted to work with GIS, allowing the selection of a region/area/location for the grid sketch. Once the scenario is defined (selection of a group of non-served residences), the calculation process for the grid expansion project is automatically initiated. The interactive process of decision-making can be executed via the option of grid supplied with the addition or removal of transformers, poles and residences.

The tool produced facilitates the pre-project procedure of grids, as it proportions more agility to the analysis of project scenarios and calculations, suggesting a sketch to the technician who is going on field to raise and determine the positioning of the necessary equipment and structures for the supply of electricity service to residences in small communities. The step by step of its application is described in the manual.

A future proposal is the expansion of the tool to be able to carry out comparison between the alternatives of energy supply. That is, implanting functionality to analyse a scenario and determining the most viable option for energy supply, comparing the grid expansion with the use of alternative sources of local generation, considering the consumer horizons, the maintenance costs and other social and economic aspects of the project.

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[14] Decree nº 4.541, of 23rd December 2002.

[15] Resolution nº 223, of 29th April 2003.

GLOSSARY

IGSIS (SIGFI) = Individual Generation Systems with Intermittent Sources