Additional Energy Source Identification and Synthesis

Antonio Jaomiary, Myriam Lazard, Yvon Andrianaharison

Abstract—This paper proposes an analysis approach of the energy deficiency problems in the Antsiranana city. The methodology to synthesize the emergency and additional source enabling to satisfy the energy needs is elaborated. The main output of the proposed method is the estimation of optimized relevant energy source corresponding to the needs of this region. Based on the production data from the electricity supplier company JIRAMA and the consumption of Antsiranana city, the analytical models of the households and industrial energy demands are established. Based on these models, the production and the consumption for the next decade are predicted. Furthermore, the optimal balanced produced and consumed energy must be provided by the company JIRAMA is estimated. Knowing the unmet needs, the potential renewable energy sources (fossil, hydro, wind and solar) available in Antsiranana is determined. It was concluded that the wind source is the most optimal technical and economic feasibility for a large scale production. Among the wind turbine variant, the wind farm of turbines VESTAS V80-2.0 MW can be the best candidate for the emergency regional source.

Keywords:—Electricity production; Electric power system; Energy/power consumption; Emergency energy source; Electric Source Synthesis; Modeling method.

I. Introduction

Similar to the most of regions in Madagascar Island, the Antsiranana city is constantly facing to the lack of electricity distribution grid [1]. The electricity shortage causes a serious problem for the residents. Therefore, sustainable technical solution is required to overcome to such awful situation.

Technically, this lack of electricity implies systematically an issue on the unbalanced power distribution [2] between the energy distributed by the electricity supplier company of Madagascar JIRAMA [3] and the power consumption. This unbalanced aspect is costly considerable [4] and drops the economy of the concerned region as Antsiranana. More generally, this situation affects currently the whole regions of Madagascar Island and also those of other developing countries [5-6].

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As engineering remedy, renewable and efficient electric system is necessary to minimize this national tragedy [7]. Nowadays, the ecologic and renewable energy source systems were assumed to be the most promising solutions for terrestrial [8] and spatial system [9]. However, an efficient analysis technique is required for the renewable energy source systems as wind turbine [10]. To evaluate the performance, the International Renewable Energy Agency (IRENA) [11] recommends guidelines on wind resource measurement. Moreover, practical modelling method of energy demands [12-13] is also necessary before the estimation of additional energy. For this reason the present paper is focused on the analysis method of additional energy source applied to the needs of Antsiranana city. The study is basically performed in two aspects. In one hand, the analysis based on the survey illustrating the problems related to the lack of energy in the city of Antsiranana will be explored. The obtained data will serve to reorient the policy of region to identify the best solution with respect to the needs on the energy. In other hand, the tentative solution enabling to propose a relevant policy for the additional energy source synthesis will be elaborated.

For the best comprehension, this paper is organized in three principal sections. Section II is firstly dedicated to the analysis of the energy production from the company JIRAMA during the last decade. The results from this analysis will be used to assess the evolution of the electricity supply and also the difficulties of the company to cover the needs of Antsiranana city. Secondly, based on the knowledge of the needs of households and also those of industry, a comparative study between the production and demand for electricity will be carried out. In Section III, the different sources of usable energy will be investigated, including the possibility of potential renewable energy. Then, the different types of energy source susceptible to compensate the lack of energy will be discussed. The feasibility analysis will be made in order to justify the appropriate sources to the tragic situation related to the needs of Antsiranana city. Finally, the paper conclusion will be drawn in Section IV.

II. Methodology of the Additional Source Identification and Synthesis

The different source of electricity production in the region of Antsiranana will be recalled. Then, the analysis on the realistic data from energy needs survey performed in the Antsiranana city will be proposed in this section. Based on the mathematical modelling approach [13], the energy needs will be compared with the energy production data from the company JIRAMA.

A. Electricity Production Analysis

The demands of the civilian and industrial consumers constitute the main elements to define the parameters of electricity production needs in the Antsiranana city. To meet the needs of the consumers, the energy providers' policy in this city adopt two types of production complementary approaches:

- Energy production from the groups of the company JIRAMA.
- Energy production from other private companies as EDM [14], ENELEC [15] and AGGREKO [16].

The factors influencing the energy produced by JIRAMA is illustrated in Figure 1. To quantify this scenario, we performed a survey on the electricity production in the Antsiranana city during the last decade. Accordingly, the annual values of the average and percentage of energy produced by JIRAMA and the other private companies are addressed in Table I. Indeed, in 2005, JIRAMA could provide 86% of total production and the remaining 14% come from the other private companies. However, in 2014, with the gradual degradation of production equipment JIRAMA society, this trend was dramatically reversed: 98% of total production are performed by hired bands and only remaining 2% are insured by JIRAMA

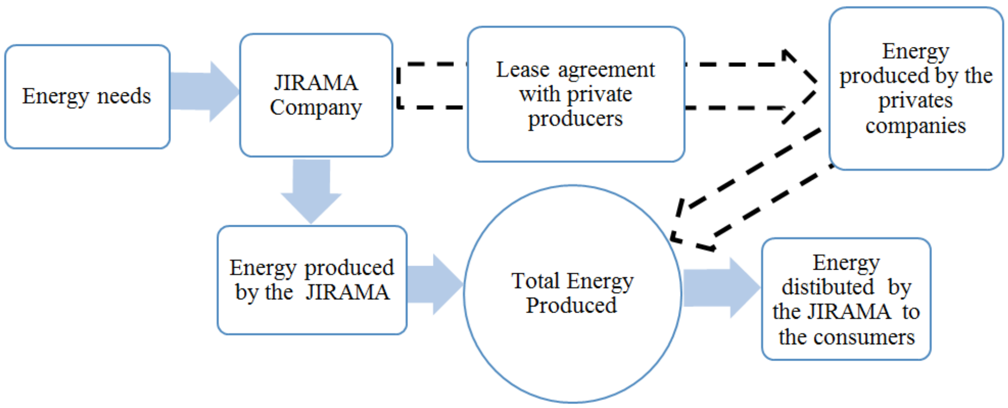

Figure 1. The factors influencing the energy production from the company JIRAMA.

TABLE I. COMPARISON BETWEEN THE ELECTRICITY PRODUCED BY JIRAMA AND OTHER PRIVATE COMPANIES OF ANTSIRANANA SINCE THE LAST DECADE

Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Production of JIRAMA [MWh]	11 633	14 541	17 449	8 725	7 755	5 816	1 604	3 506	6 348	1 236
	86%	86%	86%	36%	21%	15%	4%	7%	14%	2%
Production of Private Companies [MWh]	1 939	2 423	2 908	15 316	28 694	33 929	43 240	43 820	39 241	50 315
	14%	14%	14%	64%	79%	85%	96%	93%	86%	98%
Total [MWh]	13 572	16 964	20 357	24 041	36 449	39 745	44 844	47 327	45 589	51 551

B. Energy Consumption Analysis

Similar to the classical cities, the energy consumers of Antsiranana can be categorized in function of the used energy. Therefore, two types of energy consumption are considered in this paragraph. The first class is the large consumers (industrial, supermarkets, hotels, public, administrative and educational institutions) and the second one is simple those households. Different survey was made for each of these categories. Obviously, the energy consumption needs can be changed and can be significantly different from one consumer to another. Nonetheless, in one side, it was found that the energy needs for large consumers trend to be regularly constant. This aspect can be understood with the annual functionality of the institutions. The probable variation depends on the productions per season. In the other side, the fluctuation of the energy consumption by the other categories is due to the evolution of untimely number of households. As investigated in [13], their electricity needs follow an exponential pace. As a practical illustrative analysis, the energy consumption corresponding and the production of JIRAMA of the big consumers from January to July is summarized in Table II. This data corresponds to the average proportions of the operated energy. It can be pointed out that heavy users extort 35% of the energy produced by the company JIRAMA.

By hypothesis, in this study, the energy production from JIRAMA is assumed as to be fixed. For the analytical modelling, it implies the following relationship:

$$E_{GC} = \beta \cdot E_{PT} \quad (1)$$

with:

- E_{GC}: consumption of the big consumers,
- E_{PT}: total energy produced by JIRAMA Company,
- β: coefficient characterizing the ratio between E_{GC} et E_{PT}. In general case, we have β <1 and for the users purely industrial β = 1.

TABLE II. LARGE CONSUMER POWER CONSUMPTION IN THE FIRST HALF OF 2014

Month	**January**	**February**	**March**	**April**	**May**	**June**	**July**
Large consumers [MWh]	1 355	1 333	1 572	1 706	1 547	1 558	1 397
	31%	32%	33%	40%	36%	39%	33%
JIRAMA [MWh]	4 334	4 216	4 716	4 257	4 278	3 998	4 271

For the case the district of Antsiranana, the coefficient is equal to β = 0.35. Therefore, the previous relation can be rewritten as:

$$E_{GC} = 0.35 \cdot E_{PT} \,. \quad (2)$$

Regarding consumption of the households, we referred to the data from a study concerning the modeling of the energy needs of urban households conducted at the district of Antsiranana [13]. This study suggests that, on the one hand, there are three categories of households; rich, medium and ordinary and secondly, the consumer trend for each category of households is changing exponential manner using the following generalized relationship:

$$y = A \cdot \exp(B \cdot x) \quad (3)$$

where:

- x: represents the time-dependent variable,
- y: the number of people or households at the year x,
- A: intercept or initial value of the function,
- B: the coefficient which is assumed as the model scaling factor.

Table III represents the examples of calculated coefficient A. Calculating one hand, the consumption of each household category using B = 0.0325 and secondly, the sum of consumption in the coming decade, the study proposes the prediction addressed in Table IV.

TABLE III. CALCULATED COEFFICIENT A

Households	**Rich**	**Medium**	**Ordinary**
***A* [GWh]**	4.4	17.2	22.4

TABLE IV. PREDICTED HOUSEHOLDS POWER CONSUMPTION

Year		**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**
Consumption [GWh]	**Rich**	4.4	4.5	4.7	4.8	5	5.1	5.3	5.5	5.7	6	6.1	6.2
	Medium	17.2	17.7	18.3	18.9	19.5	20.2	20.8	21.5	22.2	23	23.7	24.5
	Ordinary	22.4	23.1	23.9	24.7	25.5	26.3	27.2	28	29.1	30	31	32
	Total	**44**	**45.3**	**46.9**	**48.4**	**50**	**51.6**	**53.3**	**55**	**57**	**59**	**60.8**	**62.7**

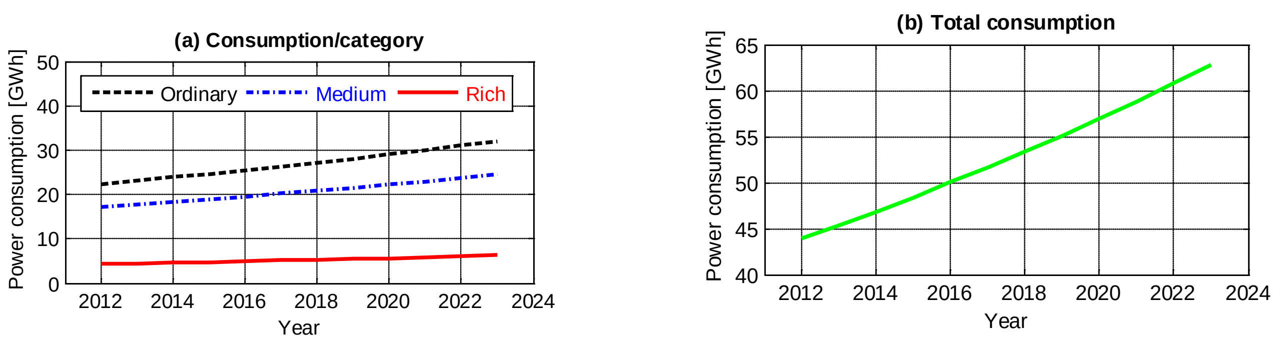

Figure 2. Prediction of households energy consumption in the district of Antsiranana [8].

These analyses lead us to the calculation of the set of consumer needs during the last decade. The empirical investigation was then converts the total power needs to install using the relationship:

$$P_{instal} = \frac{P_u}{0.7}, \quad (4)$$

where :

- P_{instal}: Power to instal in the next time [W],
- P_u: Using Power [W],
- 0.7: real constant representing the power factor.

The power peak *PP* (in W) during the production time Tp (here expressed in hour) is given by:

$$PP = \frac{P_{Production}}{T_P}. \quad (5)$$

C. Additional Energy Source Identification and Synthesis

In the region of Antsiranana, we can find various potential of energy sources as fossil, nuclear, hydro, solar and wind sources. But in terms of efficiency, it was emphasized that the wind sources can be the most suited to the needs of population. For this reason, the present study is subsequently focused on the behavior of the wind source. However, the proposed data plotted in Figure 3 corresponds to the potential wind source provided by the NASA RETScreen database [9].

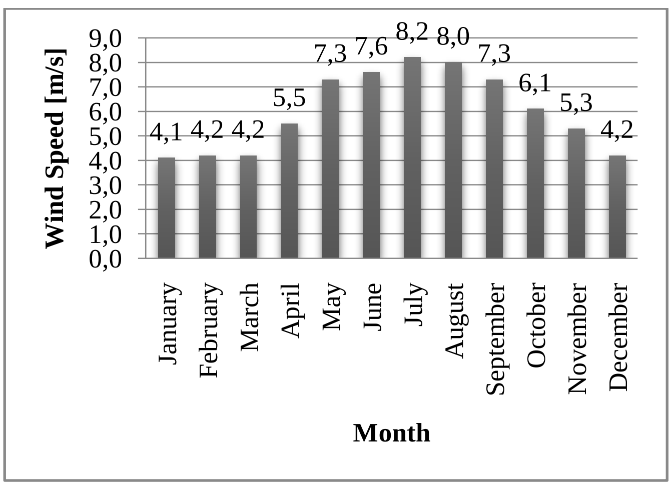

Figure 3. Average values of wind speed of Antsiranana [9].

It is worth noting that the correction relationship between this raw data and the input date corresponding to the input of the analytical calculation can be written as:

$$\frac{V_1}{V_2} = \left(\frac{h_1}{h_2}\right)^{\alpha}, \quad (6)$$

with:

- V_1: reference speed [m/s],
- h_1: reference height [m],
- V_2: wind speed at the height of the mat [m/s],
- h_2: height of the mat [m],
- α: coefficient characterizing the nature of the implantation field.

Knowing the speed V_1, we have the following relationship:

$$V_2 = V_1\left(\frac{h_2}{h_1}\right)^{\alpha}. \quad (7)$$

In function of the parameter h_0 which represents the soil inequality, the exponent α can be determined by:

$$\alpha = 0.096\log(h_0) + 0.016\log(h_0)^2 + 0.24. \quad (8)$$

Consequently, for the different tested site fields of the considered region, the standard values of α are summarized in Table V.

TABLE V. CALCULATED CONSTANT α

Type of field	**h_0 [cm]**	**α**
Flat	0 to 20	0.08 to 0.12
Few rugged	20 to 200	0.13 to 0.16
Rugged	1000 to 1500	0.20 to 0.23
Very rugged (city)	1000 to 4000	0.25 à 0.4

For this study and compared to the implantation site plans, we chose α = 0.14. The calculation performed with formula (7) allows to analyze the variation of the wind speed depending on the height of the mast of the wind turbine chosen. Indeed, it considered three variants wind (GE 3000, N80 and V80) before attaching our proposal on the wind turbine system to be put in place. Then, we calculated the recoverable energy by exploiting the following relationship. The wind power average is equal to:

$$P_{wind} = 0.5\rho SV^3. \quad (9)$$

The maximum energy recoverable is defined by:

$$P_{max} = \frac{16}{25}P_{wind} = \frac{16}{54}\rho SV^3, \quad (10)$$

where:

- P_{wind} average value of the wind power on the upstream of the turbine [W],
- ρ: density of air [kg/m^3],
- S: area swept by the blades [m^2],
- V: wind speed [m/s],
- P_{max}: maximum energy recoverable [W],
- 16/27: the maximum value of the coefficient of power C_p (the Betz limit).

In fact, this limit is not reached. Moreover, in practice, the maximum value of the power factor approaches 0.48 with a three-bladed turbine. For this purpose, in our calculations, the value of the power coefficient C_p is considered that is equal to 0.48.

$$P_{reco} = 0.48 P_{wind} , \quad (11)$$

where P_{reco} is the average value of the wind power recoverable [W]. Illustrative examples of specifications of the wind turbine are shown in Table IV.

TABLE VI. EXAMPLES OF WIND TURBINE TECHNICAL SPECIFICATIONS

MANUFACTURER	GENERAL ELECTRIC	NORDEX	VESTAS
Type	GE 3000	N80	V80
Rated power [MW]	3	2.5	2
Certification class	Class 2	Class 2	Class 2
Height of the mat [m]	95	80	80
Rotor diameter (three-bladed) [m]	104	80	80
Nominal wind speed [m/s]	13	14	15
Starting wind speed [m/s]	4	4	4
Maximum wind speed [m/s]	25	25	25
Power control	Timing variable blade	Timing variable blade	Timing variable blade

III. SYNTHESIS OF ADDITIONAL SOURCE ENERGY AND DISCUSSION

A. *Assessment of Additional Energy for the Antsiranana City*

The electricity shortage [1] remedy consists in the implementation of the emergency source suited to the potential of Anstiranana city. The previous study illustrates the necessity of the additional source as wind source in large scale production to satisfy the demands. However, the balanced distribution between the produced and consumed electrical power must be managed.

TABLE VII. CALCULATED ELECTRICAL POWER FROM THE ADDITIONAL SOURCE FOR THE ANTSIRANANA CITY

Year	Production [GWh]	Consumption [GWh]	Additional Energy [GWh]
2014	84.55	82.41	-2.14
2015	84.55	85.25	0.70
2016	84.55	88.53	3.98
2017	84.55	92.42	7.87
2018	84.55	97.12	12.57
2019	84.55	102.91	18.36
2020	84.55	110.22	25.67
2021	84.55	119.60	35.05
2022	84.55	131.84	47.29
2023	84.55	148.04	63.49

After the consideration of the previous model, Table VII summarizes the quantity of predicted additional energy from 2014-to-2023 deduced from the consumed and produced electrical power.

B. *Predicted Additional Power and Wind Farm Synthesis*

It must be underlined that to provide the additional power, we propose to implement the wind turbine Vestas V80-2MW [17] as the components of the wind park. Indeed, these engines present an optimal performance based on the technical and economical investigation with respect to the situation of Antsiranana. First, the calculated corrected averages of wind speeds of the chosen turbine are displayed in Figure 4. It can be found the wind speed varies from 5.5m/s to 11m/s. The corresponding additional power and the wind turbine of the satisfying wind farm are depicted in Table VII.

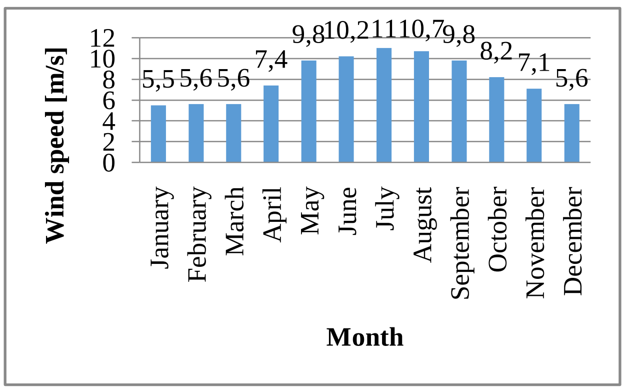

Figure 4. Average values of the wind speed for V80-2MW.

ESTIMATED POWER PRODUCED FROM WIND FARM

Year	Additional Power [MW]	Annual average Power for V80-2 MW [MW]	Number of V80-2 MW	Power of the Wind Farm [MW]
2014	4.66	0.91	5	10
2015	5.76		6	12
2016	7.04		8	16
2017	8.56		9	18
2018	10.39		11	23
2019	12.64		14	28
2020	15.49		17	34
2021	19.15		21	42
2022	23.92		26	52
2023	30.23		33	66

C. Discussion and Comment on the Proposed Energy Compensation Techniques

The above results are due to the fact that a 20% power increase has been used. Indeed, to ensure sustainability of production equipment, and also better manage the production of the park JIRAMA even during peak demands, the reserves of primary, secondary and tertiary powers have proposed.

Between January and December, the V80-2MW's performance varies from 12% to 96%. It means that the wind cannot produce 100% of its listed power. Therefore, when conducting an extensive study of a wind project, we must constantly take into account of this situation. Otherwise, the installation may be undersized.

By considering this situation, the average power of a V80-2MW is 0.91MW. This average power allows us to determine the number of V80-2MW installed in the Wind farm onshore. Depending on the number of proposed V80-2MW, JIRAMA can ensure a smooth installation of the park: by setting up five wind turbines at first, and so on, while maintaining, efficiently thermal equipment for producing electrical energy.

This study is a serious track JIRAMA must analyze thrust a view to finding a lasting solution in terms of solving energy problems of the city of Antsiranana.

IV. CONCLUSION AND FUTURE WORK

After survey on the energy needs in the Antsiranana city, the predictive model on the electrical power consumption is established. The study confirms that the JIRAMA company must expand its grid by installing an onshore wind farm that uses exclusively the turbines VESATS V80-2.0MW. However, it was demonstrated that there are difficulties in the production management.

The present work will be helpful for the JIRAMA company to review its power plant management strategy. This work will also lead to the study and the simulation of the interconnection of the wind farm to the JIRAMA grid. This step will enable the institutions and actors involved in the energy sector to define a relevant policy on the choice of wind source option as a potential future energy source for the Antsiranana city and also for the other regions of Madagascar as well.

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