ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

GRADO EN INGENIERÍA ELECTROMECÁNICA

Especialidad Eléctrica

Analysis of prepaid electricity systems in rural areas of developing countries

Autor: Pablo Minayo Ferreruela

Director: Jimmy Ehnberg

Madrid
Junio 2015

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Fdo.: .... Fecha: 2 / Julio / 2015

Autorizada la entrega del proyecto cuya información no es de carácter confidencial

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ANÁLISIS DE SISTEMAS ELÉCTRICOS DE PREPAGO EN ÁREAS RURALES DE PAÍSES EN DESARROLLO

Autor: Minayo Ferreruela, Pablo

Director: Jimmy Ehnberg

Entidad colaboradora: Chalmers University of Technology

RESUMEN DEL PROYECTO

Desde hace ya mucho tiempo, la electricidad viene adquiriendo cada vez una importancia mayor en el día a día de los países desarrollados a través de las diversas aplicaciones para las que se usa; desde el simple alumbrado de casas hasta aparatos electrónicos, electrodomésticos, transporte, industria, etc.

Por desgracia, esta realidad, como se ha mencionado, sólo se da en países desarrollados: el nivel de desarrollo de un país está directamente relacionado con el grado de uso de la electricidad, de modo que los países subdesarrollados se caracterizan por un uso mucho más precario de la electricidad.

Por ello, la obligación de los países desarrollados debe ser luchar en contra de esa situación de desigualdad y subvertir esta situación. A través de diversos proyectos, algunos de estos países subdesarrollados pueden hacer uso de aparatos eléctricos gracias a pequeñas redes independientes instaladas en ciertas áreas.

Este Proyecto se centra en el funcionamiento de una red eléctrica independiente, la cual funciona con un sistema de prepago de electricidad, en un área rural del sur de Tanzania, llamada Mawengi. El sistema de prepago consiste en la adquisición por adelantado de electricidad, con el precio de compra fijado de acuerdo a las distintas tarifas según el grupo de consumidores, para su posterior uso. En Mawengi los grupos de consumidores están divididos atendiendo al nivel de ingresos de cada consumidor, con distintos precios de compra de la electricidad de acuerdo a la Tabla 1.

Tabla 1: Precios de compra para las diferentes tarifas

	Tarifa 1 [TZs/kWh]	Tarifa 2 [TZs/kWh]	Tarifa 3 [TZs/kWh]	Tarifa 4 [TZs/kWh]	Tarifa 5 [TZs/kWh]
Precio de compra	150	170	200	270	330

Los precios de la tabla están en la moneda de Tanzania el Chelín Tanzano (TZs : Tanzanian Shilling), y se observa cómo van en orden ascendente empezando por la tarifa 1 hasta la tarifa 5. La clasificación de estas tarifas es la siguiente:

- Tarifa 1: Casas desde 1 hasta 7 puntos de potencia (enchufe eléctrico/salida eléctrica).
- Tarifa 2: Casas e instituciones de más de 8 puntos de potencia.
- Tarifa 3: Negocios.
- Tarifa 4: Fresadoras.
- Tarifa 5: Otra maquinaria eléctrica.

Atendiendo a la clasificación mostrada de las tarifas, los datos de las compras eléctricas fueron la base para poder elaborar el análisis de este sistema de prepago. Estos datos, en formato de Microsoft Excel, proporcionados por la Oficina Central de Lumama, recogían, entre otros, la fecha de compra de la energía, el código del cliente de la compra, los costes fijos por el servicio de compra, el coste de la energía adquirida y el valor de la energía comprada.

Con esta información fue posible la elaboración de los gráficos necesarios para hacer el análisis más visual y rápido. La metodología para elaborar el análisis se centró en la siguiente pregunta de investigación:

¿Es posible analizar y extraer conclusiones válidas de la compra de energía de diferentes clientes en un sistema de prepago de energía en Mawengi? Si es así, ¿cuáles son las conclusiones válidas extraídas de esos datos?

A modo de desglose de esta pregunta, el Proyecto se centró en tres subsecciones para hacer el análisis más concreto, a saber:

1. Observación de la demanda anual de energía.
2. Comportamiento de cada grupo de clientes.
3. ¿Cuándo compran los clientes energía?

Para la primera sección, con la Figura 1 queda recogida la información de la demanda mes a mes en un año.

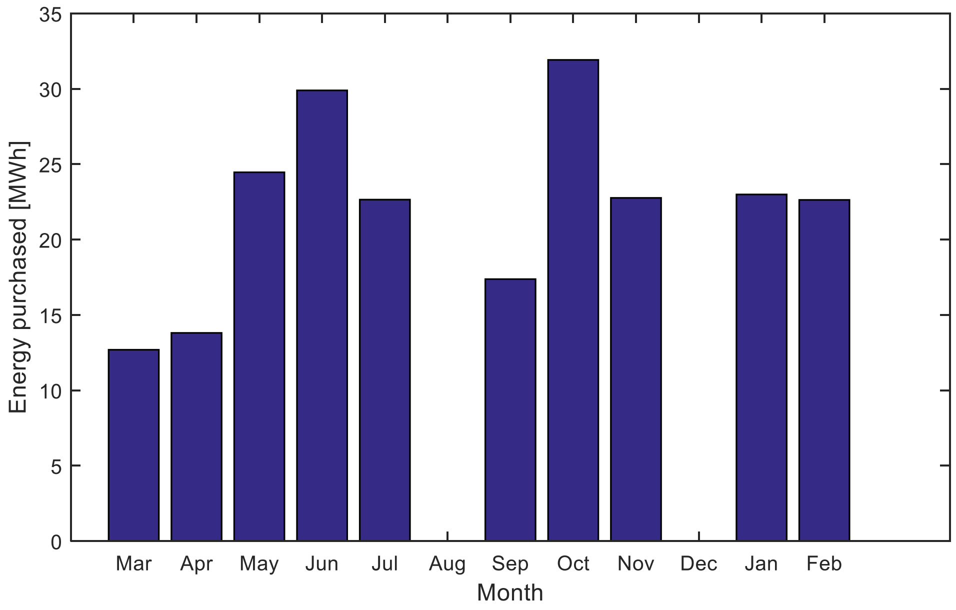

Figura 1: Variación anual de la demanda de energía

En esta imagen se puede observar la ausencia de datos de energía para los meses de Agosto y Diciembre. Ello se debe a que hubo problemas en la transferencia de la recogida de los datos de las compras de energía. En cuanto a los valores, se puede ver una alta variación en la demanda de energía dependiendo del mes que se esté analizando, con una media de consumo mensual de alrededor de 22 MWh. Esta gráfica anterior puede servir para tener una idea del consumo medio del área en un mes, en términos de energía, para poder medir el orden de magnitud de la compra de energía de este área.

Una posible solución a la hora de suministrar esta energía, dada la alta variabilidad, podría ser el tener en continuo funcionamiento una central durante todo el año suministrando cierto valor de energía, y en aquellos meses en los que el consumo observado sea mayor, usar una fuente de energía adicional para cubrir ese extra necesitado. En la Figura 2 se muestra la Radiación solar global en superficie horizontal (GHI) en Tanzania, y haciendo la suposición que en Mawengi estos valores son similares para poder hacer una estimación, se puede calcular el área requerido por los paneles solares, como posible fuente de energía adicional, dadas las características climáticas de la zona.

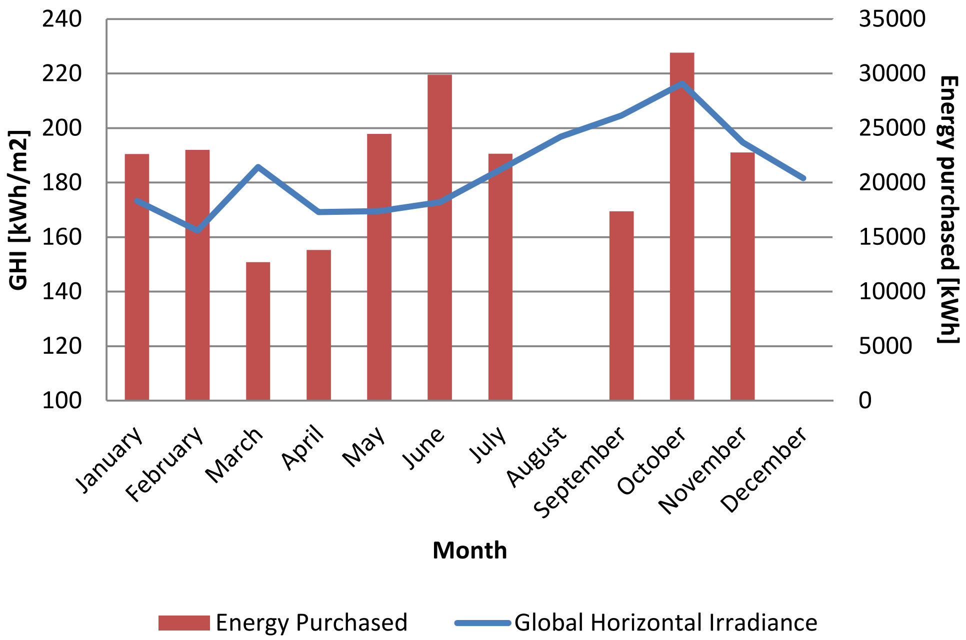

Figura 2: Radiación solar global en superficie horizontal en Tanzania

Se puede observar cómo el pico de energía comprada coincide con el valor más elevado del GHI en Tanzania, por lo que puede ser interesante estudiar más acerca de las posibilidades de tener una fuente adicional de energía para ciertos meses. Pero esta información es relativamente incompleta si no es puesta en relación con el momento en que esta energía fue consumida, para poder tener el otro eje importante a la hora de calibrar un sistema eléctrico, la potencia; por lo que debería instalarse un sistema que recoja también cuándo la energía es consumida, para poder satisfacer las necesidades de este área desde los dos puntos de vista.

En la Figura 3 se muestran las compras de energía de cada grupo de consumidores, para poder dar explicación a lo enunciado en la sección segunda.

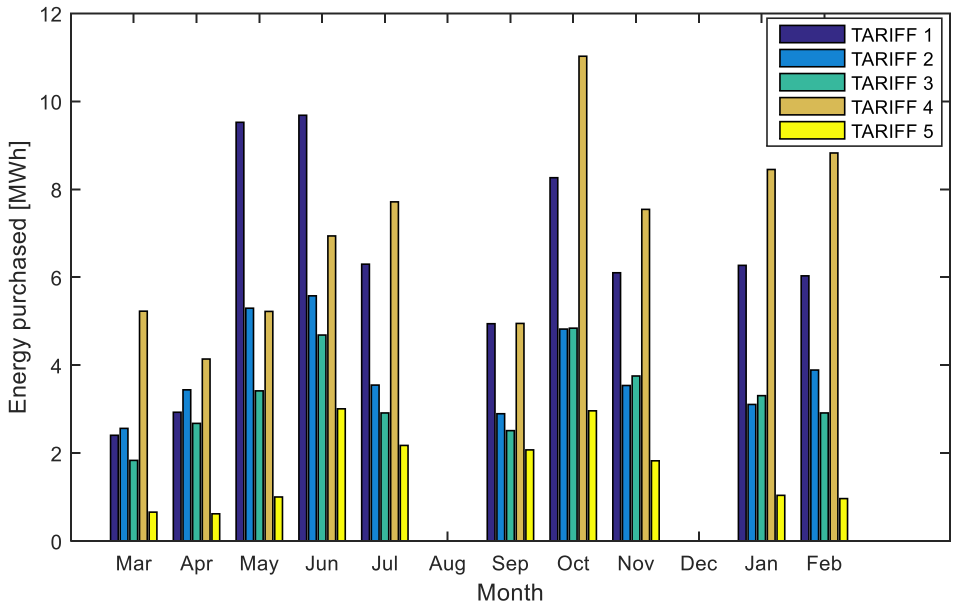

Figura 3: Variación anual de energía comprada por tarifa

En la figura se observa que la Tarifa que más energía compra es la Tarifa 4 (Fresadoras), y la que menos, la Tarifa 5 (Otra maquinaria eléctrica); siendo esta también la que tiene una desviación estándar más alta en valor relativo, es decir, la que más varía respecto a la media en un año. La Tarifa 2 (Casas e instituciones con más de 8 puntos de potencia) es la que presenta un desviación estándar menor en valor relativo, es decir, la más constante durante el año.

Analizando el número de clientes y número de compras por tarifa, cabe destacar que se puede hacer una división en dos grandes grupos según estos números, pues para las Tarifas 1, 2 y 3 ambos números son significativamente más altos que para el resto de tarifas (4 y 5). El número de clientes es importante pues refleja la importancia que puede tener que uno de ellos se dé de baja en el sistema. Para el segundo grupo de consumidores (Tarifas 4 y 5), un sólo consumidor puede ser importante en la energía comprada, mientras que para el primer grupo de consumidores, al ser el número de clientes mucho más grande en comparación, un sólo cliente no influirá de la misma manera en el consumo de esa tarifa.

En relación a la última sección, en el análisis se observó la gran variabilidad de días en el mes en los que se compra la energía, pues adquiere un perfil muy irregular, dependiendo mucho del mes estudiado. Como regla general para todos los meses, se puede observar cómo en todos ellos hay un día o dos (dependiendo del mes) en los que la compra de energía destaca con respecto a los otros días del mes.

De manera adicional, desde el punto de vista económico, señalar que el beneficio real sólo por la energía comprada, sin tener en cuenta costes de inserción en el sistema, es más bajo, en general, de lo esperado; como se muestra en la Tabla 2.

Tabla 2: Comparativa entre el beneficio esperado y real para las diferentes tarifas

	Tarifa 1	**Tarifa 2**	**Tarifa 3**	**Tarifa 4**	**Tarifa 5**
Beneficio esperado [Millones de Tzs]	13.5	8.5	15.5	28.4	5
Beneficio real [Millones de Tzs]	11.2	7.9	7.9	22.7	6.5

ANALYSIS OF PREPAID ELECTRICITY SYSTEMS IN RURAL AREAS OF DEVELOPING COUNTRIES

Abstract

Everyday electricity is becoming more and more important in the daily life of developed countries through the various applications for which it is used; from lighting in houses to electronic devices, electrical appliances, transport, industry, etc.

Unfortunately, this fact, as mentioned, only occurs in developed countries. The level of development of a country is directly related to the level of use of electricity, so that developing countries are characterized by a much more precarious use of electricity.

Thus, the obligation of developed countries must be to fight against this inequality and subvert this situation. Through various projects, some of these developing countries can make use of electrical appliances thanks to small independent grids installed in certain areas.

This project focuses on the analysis of an independent electric network, which works with a system of prepaid electricity in a rural area of southern Tanzania, called Mawengi. This prepaid system consists in the acquisition in advance of electricity, with the purchase price set according to different tariffs depending on the consumer group, for later use. In Mawengi, consumer groups are divided based on the level of income of each customer, with different purchase prices for electricity according to Table 1.

Table 1: Purchase prices for different tariffs

	Tariff 1 [TZs/kWh]	Tariff 2 [TZs/kWh]	Tariff 3 [TZs/kWh]	Tariff 4 [TZs/kWh]	Tariff 5 [TZs/kWh]
Price of purchase	150	170	200	270	330

The prices shown in Table 1 are in the currency of Tanzania, the Tanzanian Shilling (TZs), and it can be observed that for Tariff 1 the purchase price is the lowest, which means that this customer group has the lowest income and for Tariff 5 is the highest, being the difference between both of more than the double. The classification of these tariffs is as follows:

- Tariff 1: Households with 1-7 power points (electrical plug/outlet).
- Tariff 2: Households and institutions with more than 8 power points.
- Tariff 3: Businesses.
- Tariff 4: Milling machines.
- Tariff 5: Other electric machinery.

By the classification shown in tariffs, data from power purchases was the basis to develop the analysis of this prepaid system. This data, in Microsoft Excel format, provided by the Lumama Head Office, collected, among others, the transaction date

time, the customer who purchased the energy, the charges for the service, the cost of this energy and the amount of energy purchased for each month.

With this information, it was possible to develop the graphs needed in order to make the analysis more visual and faster. The methodology for preparing the analysis was focused on the following research question:

Is it possible to analyse and extract valid conclusions of different customers' energy purchases in a prepaid electricity system in Mawengi? If so, what are the valid conclusions from this data?

For a deeper analysis of the main ambition of the report, the main research question was divided into the next topics:

1. Observation of the yearly variation of the demand of energy.
2. Behaviour of each different customer group.
3. When do customers purchase energy?

For the first topic, Figure 1 shows the yearly variation of energy purchased.

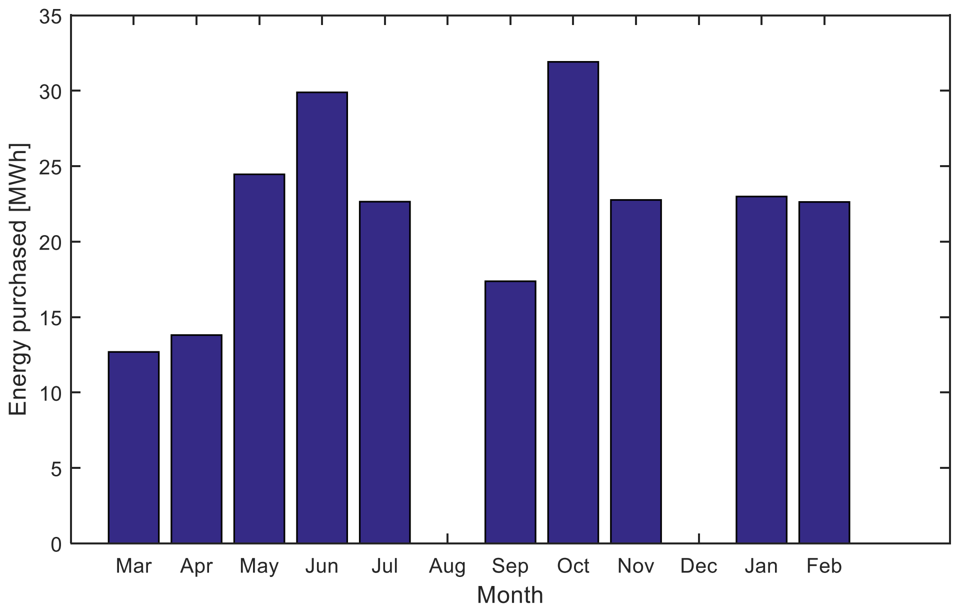

Figure 1: Yearly variation of energy demand

This picture shows that there is not available data for August and December. Solely ten out of twelve months were available to study their data due to problems with the prepaid system and technical problems when transferring the data. Regarding the values of the energy purchased, it can be noticed a high energy variation depending on the month being analyzed, with an average monthly consumption of about 22 MWh. Figure 1 can be used to get an idea of the average consumption of the area in a month, in terms of energy, to size the electrical system of this area.

One possible solution about the supply of energy, because of the high variability, could be a power station in continuous operation throughout the year providing a determined value of energy, and in those months in which the purchased energy is higher, use an additional power station to meet this additional energy needed. In Figure 2, the Global Horizontal Irradiance (GHI) in Tanzania is shown, and, making the assumption that in Mawengi these values are similar, to be able to make an estimation, it can be calculated the required area for solar panels, as a possible additional source, with the climatic conditions of this area.

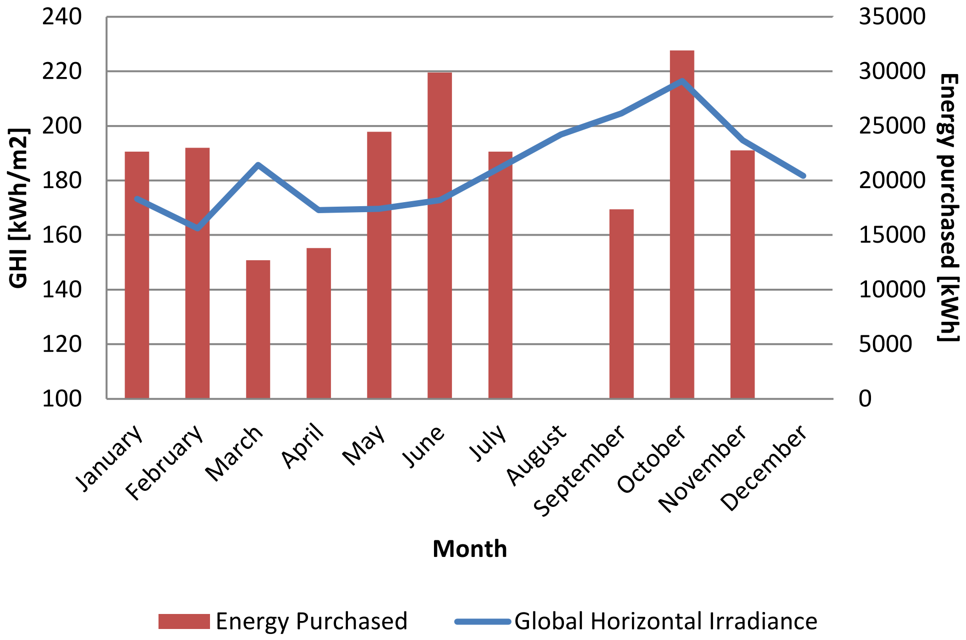

Figure 2: Global Horizontal Irradiance in Tanzania

It is observed that the peak of purchased energy coincides with the highest value of GHI in Tanzania, which can be interesting to investigate more about the possibilities of having an additional source of energy for some months. But this information is relatively incomplete if the time when the energy was consumed is not registered. With this extra information, the system can be sized meeting the other basic need that electrical systems require, the power. For the completion of the sizing of this system, a mechanism for collecting when energy is consumed would be needed.

In Figure 3, energy purchases for each group of customers are presented, in order to give explanation to what is stated in the second topic.

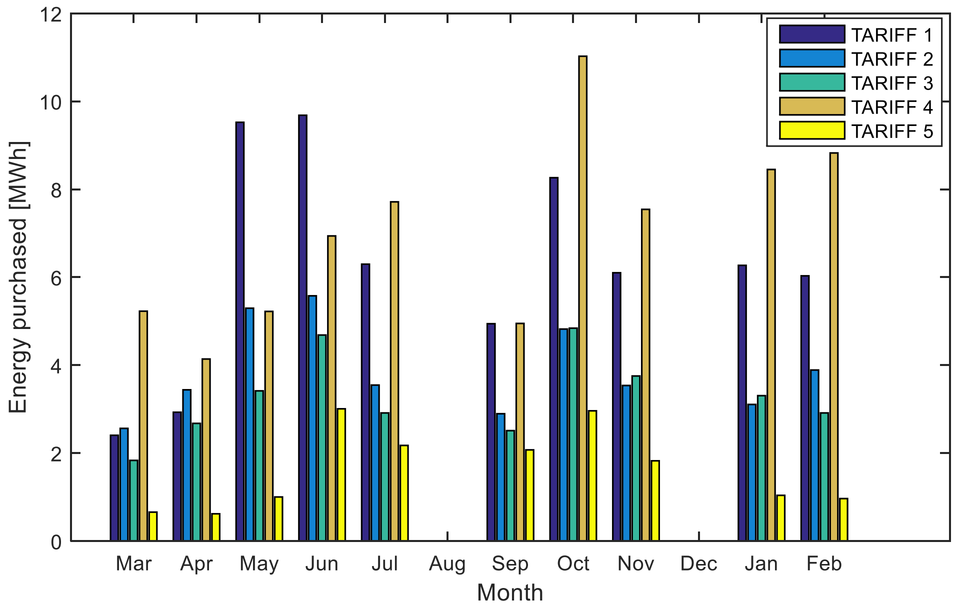

Figure 3: Yearly variation of energy purchased per tariff

This figure shows how Tariff 4 (Milling Machines) is leading the energy purchase during the year, and that Tariff 5 (Other electrical machinery) is the tariff that is purchasing less energy; being also the one with the highest standard deviation in relative value, i.e. the tariff that most varies from the average value during the year. Tariff 2 (Houses and institutions with more than 8 power points) is the one with the lowest standard deviation in relative value, which means that is the most constant throughout the year.

Analyzing the number of customers and the number of purchases per tariff, to highlight that it can be made a distinction into two bigger groups according to these values, because for Tariffs 1, 2 and 3 both numbers are significantly higher than for all other Tariffs (4 and 5). The number of customers is important because it reflects the importance that can have one single customer if decides to leave the system. For the second group of consumers (Tariffs 4 and 5), a single customer can influence in the purchased energy, while for the first group of consumers, as it has a larger number of customers in comparison, a single client will not influence in the same way in the consumption of that tariff.

In relation to the last topic, the analysis of the days in a month when energy is purchased, showed the variability depending on the month studied, with an irregular profile in general for all the months. Looking at the graphs, it can be observed that there is a day or two (depending on the month) when the purchase of energy stands out from the rest of the days of the month.

Additionally, from the economic point of view, it is important to notice that the actual benefit, only taking into account the income from the purchased energy, without looking to the costs for joining the system, is, in general, lower than expected; as it is shown in Table 2.

Table 2: Comparison between expected and actual income for different tariffs

	Tariff 1	Tariff 2	Tariff 3	Tariff 4	Tariff 5
Expected income [Millions of Tzs]	13.5	8.5	15.5	28.4	5
Actual income [Millions of Tzs]	11.2	7.9	7.9	22.7	6.5

ACKNOWLEDGEMENTS

I wish to thank many people for their contribution to this project, without whom this project would not have been accomplished.

Firstly, to my family for their support in the good and bad moments has been crucial all throughout these years during my bachelor.

Secondly, I would like to thank Jimmy Ehnberg, the director of this final year project, for helping me make this possible, for his patient guidance, enthusiastic encouragement and useful critiques of my work.

Thirdly, I wish to thank Elias Hartvigsson for the facilities about the data and for answering all the questions that arise with kindness and quickness.

Besides, I want to thank all my friends, those who I met in school and have been part of my life for so many years, those that I have met in university, that although it seems to have been such a short time, they have become very good friends, and all the rest that I have met along the way.

Additionally, I would like to thank ACRA-CCS and LUMAMA for providing the data, which has made possible the accomplishment of this project.

Last but not least, Iñigo García de Madinabeitia, a person who searched for everything I asked, helping me with this project by giving advices and personal opinion about everything he could help me with.

From the bottom of my heart, thank you.

ABSTRACT

Currently, the possibilities and characteristics about loads in new rural electrified areas are still to know. In this report it is analyzed a recent installed electric prepaid system in order to see if it is possible to extract the suitable conclusions with only the data of the purchases. Besides, it aims to size a system with these attributes, through the available data from this electric system facilitated by the central office of this area, in Mawengi, Tanzania. It is seen how the irregular profile of the purchases of energy of Mawengi through a year makes more difficult to set a power station and it is discussed if this system in particular is oversized. Also, it is analyzed how different customer groups, divided depending on their income, affect to this prepaid system, in terms of energy purchased and number of customers per group among others as well as the revenue that each of these groups is generating compared to the expected values. Finally it is advised some future steps in order to maximize the profit and think about new possibilities for this system or future systems in rural areas in developing countries.

Key words: Energy, Purchase, Consumption, Customer.

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1 Introduction

Energy is nowadays a vital tool for meeting needs of people all around the world in their daily life. As human development has evolved considerably during last centuries, energy consumption has increased also in an appreciable extent, as can be seen in Figure 1.

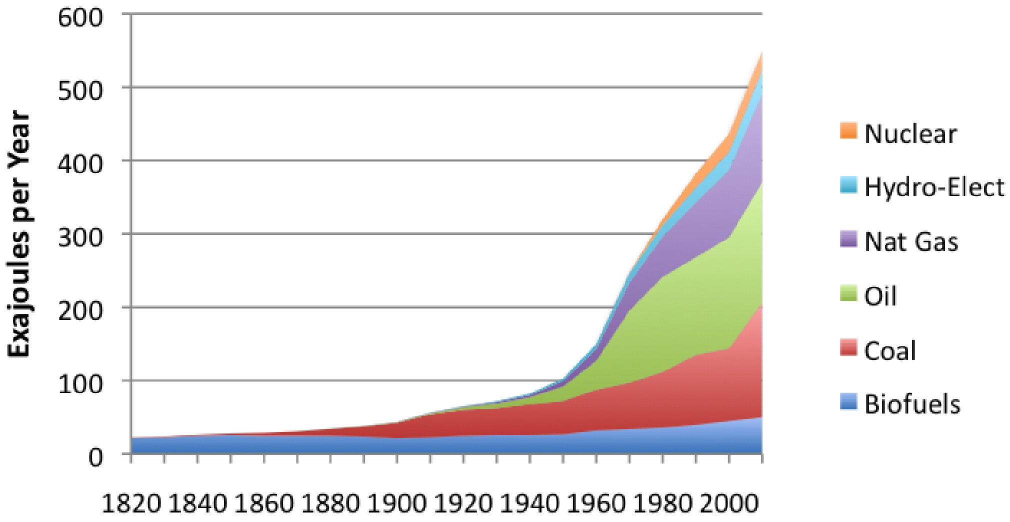

Figure 1: World Energy Uses

Source: Our Finite World [1]. Published with permission of Gail Tverberg

Considering the world energy uses, according to Figure 1, it is possible to see the tendency that every day reaches higher levels. In the future, following the current trend, it is expected to continue growing, playing as now a key role in human life.

As a result of these predictions, the sustainability concept was conceived around the 1970s. It was presented as a solution for giving the chance to the future generations to deal with problems of their own age, not to think about the problems that past generations have transferred to them [2].

As previously stated, energy will be substantial, so the efforts of the humanity must be made in order to guarantee a sustainable source for the production, transportation and use of the energy. Sustainability regarding energy can be understood as the use of resources that will assure availability of renewable energy for future generations [2].

The current situation and future foresights have made the unique solution to develop renewable energies for several reasons as for example the raising of the rate of CO_2 emissions during the last century and how it will continue if no policies are implemented.

When attending to the reasons of how these quantities of CO_2 and other greenhouse gases are produced, as shown in Figure 3, it can be seen that more than the 75 % of emissions are of CO_2, and that more than the half of total greenhouse gas emissions are only in fuel uses.

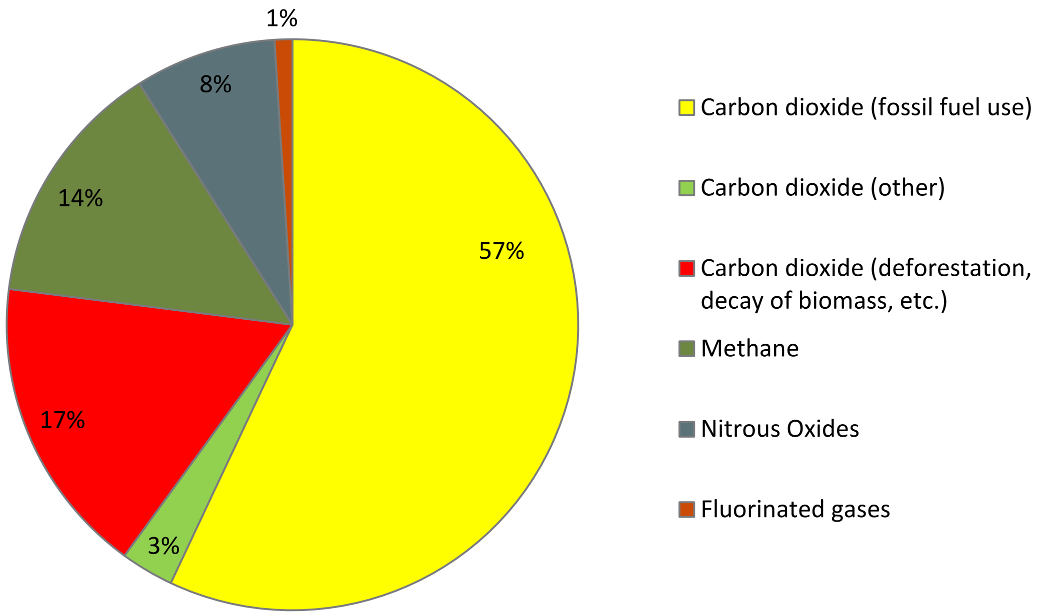

Figure 2: Global Greenhouse Gas Emissions by Gas

Source: IPCC [3] (2007)

In Figure 3 it is observed that one quarter of the total emissions correspond to the production of electricity.

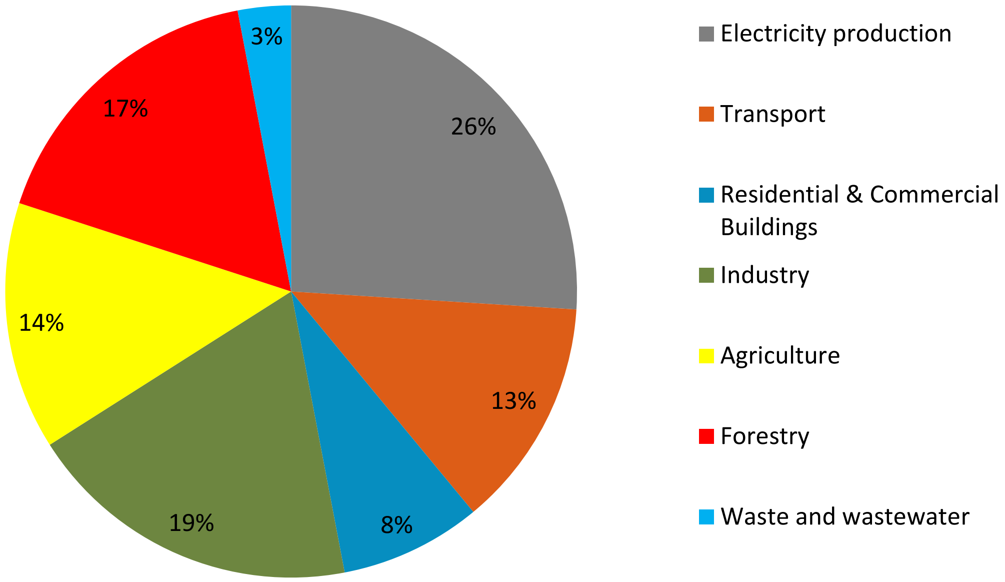

Figure 3: Global Greenhouse Gas Emissions by Source

Source: IPCC [3] (2007)

Thereby it is demonstrated that all these concepts of CO_2 emissions, energy supply and consumption, sustainaiblity, etc. are strongly related to each other.

Regrettably, as it has been shown, the current situation does not start from scratch. Current levels of greenhouse gases emissions are causing an increase of the average temperature of the Earth resulting in the melting of the poles, also a rising of sea level, extreme climate events, etc. [4]

1.1 Situation in Africa

It is known that climate change affects all continents, but not equally. The possibility to deal with climate change is related to the resources that can be allocated to battle against it.

One example of this inequality is the situation in Africa. Africa is by far the poorest continent of the world attending to the classification of the GDP per capita of the countries of the continent. African countries mostly base their economy in agriculture. An extreme climate event as a drought or a flood can be the reason for seen most of the industrial system paralyzed. Also the buildings´ infrastructures of some countries of Africa make them more exposed to suffer damage in case of a severe episode as the mentioned before.

With these scenarios, it is easier to understand that climate change affects more the developing countries rather than the developed ones.

Despite all this negative data about poverty and slow development, Africa is the continent with the highest potential in the world due to its resources. Some examples of these resources are solar power with the Sahara´s desert [5], or wind power with the IRENA project in countries as Egypt or Ethiopia [6], besides the hydropower and geothermal possibilities that this continent has. [7] [8]

For the achievement of success of these projects, a deep understanding and an adequate interpretation of the data of consumption and purchase of energy in the areas to study are of vital importance.

1.2 Mawengi

This project will intend to understand and analyse the data of the purchase of energy in a determined area of Tanzania, specifically Mawengi.

Mawengi is part of the United Republic of Tanzania. Tanzania is located on the east part of Central Africa, with a population of 44,928,923 residents in accordance to the census of 2012.

Mawengi is an area in the Ludewa district inside the Iringa region. There are 9123 inhabitants [9], and it is located close to the Nyasa Lake. Mawengi can be seen in the light green area in the left part of the Figure 4

Figure 4: Mawengi, Tanzania

Source: Global Administrative Areas [10]

In Tanzania, according to the different seasons of the area where it is located, a year can be divided into two main seasons:

- Dry season: June, July, August, September and October.

- Wet season: November, December, January, February, March, April and May.

From the electrical consumption point of view, loads of Mawengi are categorized into five different groups or tariffs depending on the economic level or income of each customer as follows: [11]

- Tariff 1: Households with 1-7 power points (electrical plug/ outlet).
- Tariff 2: Households and institutions with more than 8 power points.
- Tariff 3: Businesses.
- Tariff 4: Milling machines.
- Tariff 5: Other electric machinery.

Each different group has a different purchasing price as shown in Table 1.

Table 1: Purchasing prices for different tariffs

	Tariff 1 [TZs/kWh]	Tariff 2 [TZs/kWh]	Tariff 3 [TZs/kWh]	Tariff 4 [TZs/kWh]	Tariff 5 [TZs/kWh]
Price of purchase	150	170	200	270	330

These prices, in Tanzanian shillings (TZs), the currency in Tanzania, are the cost of purchasing electricity in a prepaid system. In this system the customer decides how much to spend in a single purchase, and starts to consume until the credit purchased expires. It is important to differentiate between the purchase and the consumption of the energy. Despite an amount of energy is purchased, it does not mean that all of it will be consumed in the moment of the purchase; it can be used when the customer requires this energy.

In Table 1 it can be observed that for Tariff 1 the purchase price is the lowest, which means that they have the lowest income and for Tariff 5 is the highest, being the difference between both of more than the double. It is also important to highlight that households in general are the group of customers that are acquiring electricity with the lowest prices, compared to the industry and larger loads.

This research project focuses on the study of electricity purchases in Mawengi, in order to facilitate future researchers the study of forthcoming possibilities about the establishment of a grid or alternative ways of getting electricity to this rural area. It also will aim to gather and classify the data of the energy purchase, identifying the different needs depending on each customer.

Regarding the analysis tools, the data was gathered in Microsoft Excel from the Lumama Head Office. This data had the information about the Transaction date time, the customer who purchased the energy, the charges for the service, the costs of this energy and the amount of energy purchased for each month, as well as some extra information about bureaucracy aspects that were not important for the analysis . With all this information the study had enough material to analyse and to make a deep analysis of different patterns, etc.

1.3 Purpose

Is it possible to analyse and extract valid conclusions of different customers' energy purchases in a prepaid electricity system in Mawengi? If so, what are the valid conclusions from this data?

1.4 Problem statement

For a deeper analysis of the main ambition of the report, the main research question will be divided into the next topics:

1. Observation of the yearly variation of the demand of energy.
2. Behaviour of each different customer group.
3. When do customers purchase energy?

In order to improve the understanding of these topics, here they are explained deeper:

For the first topic, the objective will be to look to the general purchase of the whole area, not distinguishing between the different tariffs, only to see the evolution through a year of the utilization of energy.

The second will study the different purchases of energy depending of which tariff it is. It will be a more specific investigation, seeing whether there is some pattern when the different customers need to buy energy.

Finally, with the third one, it will be proceeded an examination of the time of the month when the customers purchase energy, seeing if it is maintained through several months for the different tariffs.

It also will try to look at what periods the energy consumption is higher in order to recommend to researchers the different possibilities to produce the energy in terms of what kind of power production should be more adequate.

This project is an initial study, its outcomes and conclusions will aim to answer the questions that arisen before mainly, but also will try to elaborate new approaches in the gathering and analysis of the data, creating new questions in order to give to future researchers the possibility to investigate and to develop this project from a different perspective.

1.5 Scope/ limitations

When processing the data, it is important to know the limits of the research, to make the results valid. Hence, research limitations can be standardized in some different ways.

Only data of Mawengi will be studied, so only an analysis for this region can be elaborated. Results for other areas in other countries can vary due to different data, different weather conditions that can influence in the electric consumption, etc. [12]

Solely ten out of twelve months were available to study their data due to problems with the prepaid system and technical problems when transferring the data. This issue limited the possibility of having a complete and wider analysis for an entire year. For handling these data points it was chosen to leave a gap for the months when the data was not available, instead of other possibilities that were also discussed. An option that was rejected was to make the average value between the months adjacent to the month when the data was missing. Choosing the gap between months implied not showing the entire flow of the purchase of energy during a year. It was risky to guess an average value without ensure that it was what actually the energy that was purchased in the previously mentioned months and it did not provide extra information to the figures, that is why it was chosen to leave a gap when there was no data available.

Also in the time issue, exclusively the data of the year 2014 and two months of year 2015 were registered, and as a result of that, the analysis was about this recent time, and it could not be generalized for the last years, as this prepaid system is relatively new.

Moreover, regarding the data, as it was said before, only the time when purchases were done was available, which limited the possible explanations and assumptions about the consumption of the energy. By only having the purchases, it cannot be assumed that the consumption would be done at the same period of time, so with the available data it cannot be guaranteed that a specific month will have more consumed energy than other, because maybe the purchases are done but the energy is not consumed until the month after.

2 Method

The method used in this project is based on the analysis of data, so it can be enhanced that it is closer to an empirical investigation than to a theoretical one. Due to the practical high content, it was difficult to connect all these contents to a theoretical base, but for future work it could be interesting and recommended to perform this study from a theoretic perspective.

Through some literature research, the required knowledge to judge electrical loads was acquired, giving a general overview on the relation between the energy access and the grade of development that an area or a country can have. It also gave ideas for thinking about the relationship between the poverty and the levels and uses of energy consumption. This study is classified as an analytical study [13], because it analyses energy demand of an area of a developing country. In order to make this study complete, it should be complemented with the other two influences that this author mentions, the descriptive (includes policies programs) and the experimental (tests efficiency of devices or appliances in order to improve technologies).

To perform the real analysis and classification of this data, it was used the numerical computer program Matlab, which through several lines of programming, made the necessary graphs for the analysis of the data. When only a partial part of the data was gathered, it was developed a general code in order to make the analysis of the arriving data faster and easier, so the next batches of data, of the year 2015, were instantaneously added to the programming code and analysed.

The programming code can be seen in APPENDIX A - Matlab code, where a script for each of the questions of the problem statement is shown. Basically, it is based on the reading of the data from the Microsoft Excel file, then loops and conditionals for the classification of the data depending on the question, and finally the gathering of this data in order to show it in figures or to extract the required values.

3 Analysis: Observation of the yearly variation of the demand of energy

3.1 Study of the magnitude of energy purchased

In Figure 5, the yearly variation of energy purchased is shown. It can be observed that there are two differentiated periods of energy purchase. The first is characterised for a larger energy purchase, and goes from May to October, considering the constraint of not having the data of August. The second one, with in general lower energy purchased is the period from November to April, not having the data of December.

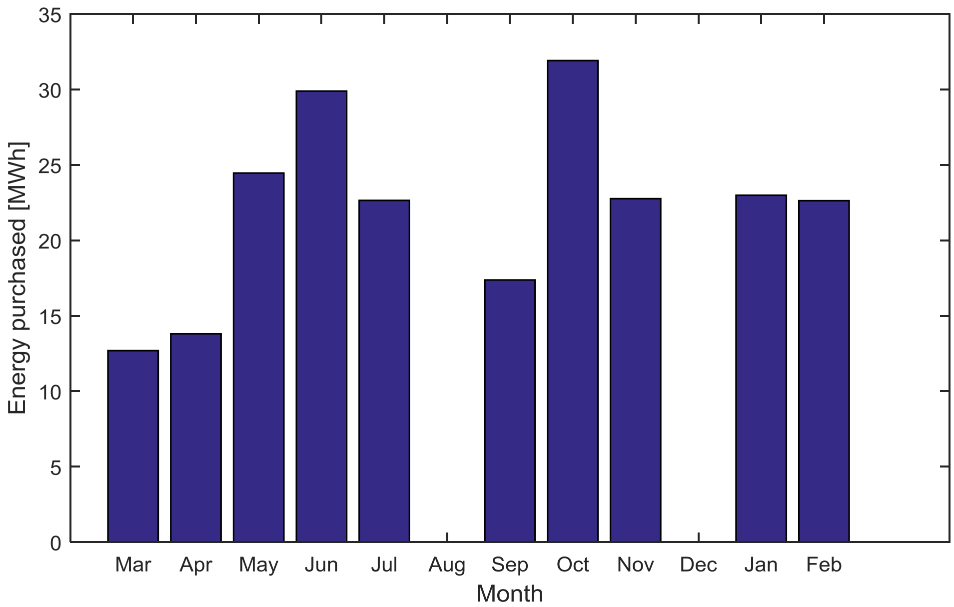

Figure 5: Yearly variation of purchased energy

Observing the different two seasons, described in the description of Mawengi, in Figure 5, it can be seen that there is more energy purchase just in the period that there is a change in the season, which are in April to May and June, and also in October to November.

The maximum consumption of energy is in October, with around 32 MWh. It would be recommended, in case it would be wanted to have possibility to produce this amount of power every month, a power station of 35 MWh, only looking to the energy purchased.

Through the analysis of the data, the standard deviation that resulted for all the months was 5632.1 kWh, which means that about the 70% of the data is gathered around the mean value (around 22000 kWh), giving a range from 16367.9 to 27632.1 kWh.

By only looking to the general energy acquired, it is clear that the power varies through a wide range during the year, around 25% of variation around the average value, which means that it would be difficult to set a general value to estimate the general purchase in order to have an idea about an average purchase for all the months.

3.2 Behaviour of each different customer group

In Figure 6, it is shown the energy purchased for each different tariff during a year. A general observation about this figure is how Tariff 1 (1-7 power points households) and Tariff 4 (milling machines) are leading the purchase of energy during the year.

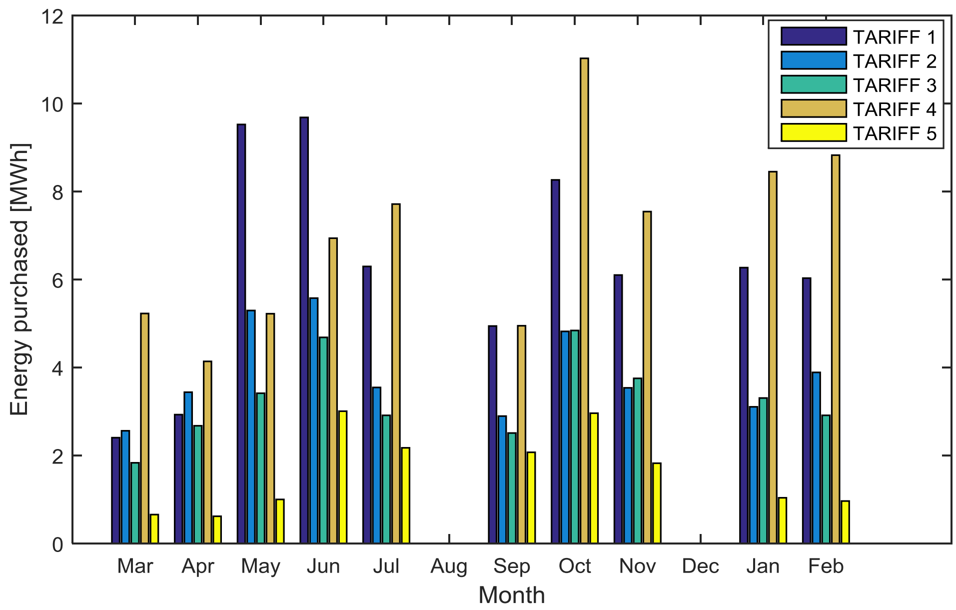

Figure 6: Yearly variation of purchased energy per tariff

In accordance to the standard deviation shown in Table 2, not considering the number of customers, it gives a general idea that Tariff 5 (Other Machines) purchases vary a lot depending on the month that it is being considered. Tariff 1 and Tariff 3 (Businesses) are the following tariffs that vary most.

The group that has the lower deviation is Tariff 2 (more than 8 power points households) close followed by Tariff 4 (milling machines).

Table 2: Characteristic values of energy purchase per tariff

	Tariff 1 [kWh]	Tariff 2 [kWh]	Tariff 3 [kWh]	Tariff 4 [kWh]	Tariff 5 [kWh]
Average value	6244.8	3867.5	3285.5	7003.8	1633.3
Standard deviation	2452.5	1026.9	940.9	2137.7	903.7
Deviation from the average value in %	39.27	26.55	38.63	30.12	55.33

As can be seen in Figure 6, it can be observed that Tariff 4 purchases more energy in general, but not for May and June when Tariff 1 (1-7 power point households) is the one that consumes more.

Also it is important to highlight that Tariff 5 is the one which purchases less energy, which can give an idea that large loads in Mawengi do not influence the system as other groups, only a small percentage of total production of energy is bounded to this group.

Regarding Table 3, it is gathered the data for the purchase of every month for each different tariff as in Figure 6, with the specific values of the purchases, to know exactly the differences of purchased energy between tariffs and between months.

Table 3: Energy purchased for each tariff during a year

	Tariff 1 [kWh]	Tariff 2 [kWh]	Tariff 3 [kWh]	Tariff 4 [kWh]	Tariff 5 [kWh]
March	2406	2562.7	1835.1	5228	658.5
April	2930	3439.8	2676.7	4140	620.5
May	9523	5295.8	3416.2	5222.8	1002.9
June	9683	5577.2	4685.1	6939.2	3007.7
July	6297.2	3547.4	2913.8	7714	2175.3
September	4942.7	2896	2511.6	4949.5	2074
October	8263.2	4821.2	4841.8	11025.2	2962.2
November	6101.8	3538.4	3754	7542.9	1825.6
January	6269.9	3107	3307	8450.2	1040.2
February	6031.7	3889.4	2914	8825.8	966.4

Knowing the total amount of energy that is purchased for all the different tariffs, it can be pointed out the income for only the price of electricity, not considering the taxes or the service charge due to its purchase, as shown in Table 4.

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Table 4: Income for each different tariff in a year

	Tariff 1 [kWh]	Tariff 2 [kWh]	Tariff 3 [kWh]	Tariff 4 [kWh]	Tariff 5 [kWh]
Energy in 10 months	62448.5	38674.9	32855	70038	16333
Energy in 12 months	74938.2	46409.9	39426	84045.6	19599.6
Millions of Tzs	11.2	7.9	7.9	22.7	6.5

To elaborate Table 4, the actual purchased energy it was considered for each tariff in the 10 months when data was available. Then it was made a theoretical average purchase per month and it was extended to one year, in order to have the yearly income for each tariff.

From these simple calculations, it can be observed that tariff 4 produces more than the double of money than any other tariff. Also it can be seen that despite tariff 5 is with difference the tariff that is purchasing the less quantity of energy, it is billing almost the same amount than tariff 2 or 3, so it can be discussed that it is also important to satisfy the amount required by tariff 5, from the economic efficiency point of view.

In Table 5, it can be seen the number of customers depending on the month and on the tariff. It is important to look carefully at this data, because it can show if the consumption of a determined tariff is due to small purchases of a large number of customers, so it can be considered as a stable value, or in the contrary, the number of customers is low, despite the value of the consumption is similar to the consumption of other tariff, so if in next month another customer or small group of customers join or leave their consumption, the total consumption will be significantly affected.

Table 5: Number of customers that purchased energy for each different tariff

	Tariff 1	Tariff 2	Tariff 3	Tariff 4	Tariff 5
March	95	77	63	12	6
April	270	133	136	12	10
May	307	126	135	18	12
June	372	130	174	18	17
July	228	96	111	20	17
September	273	102	120	19	22
October	327	113	139	21	20
November	316	102	146	21	16
January	290	108	158	75	30
February	272	121	145	70	22

In Table 6 it is shown the monthly average purchase per customer looking to each different tariff.

Table 6: Monthly average purchase per customer for each tariff

	Tariff 1 [kWh]	Tariff 2 [kWh]	Tariff 3 [kWh]	Tariff 4 [kWh]	Tariff 5 [kWh]
March	25.33	33.28	29.13	435.67	109.75
April	10.85	25.86	19.68	345	62.05
May	31.02	42.03	25.3	290.16	83.58
June	26.03	42.90	26.93	385.51	176.92
July	27.62	36.95	26.25	385.7	127.96
September	18.11	28.39	20.93	260.5	94.27
October	25.27	42.67	34.83	525	148.11
November	19.31	34.69	25.71	359.19	114.1
January	21.62	28.77	20.93	112.67	34.67
February	22.18	32.14	20.10	126.08	43.93

As can be observed in the results of the Table 6, the differences from the first group of tariffs (Low and High Households and Public Places) and the second one (Small Industry and Large Loads), are obvious. The purchases per customer in general are much higher for the second group of tariffs. Also it can be observed the dominance of energy per customer in Tariff 4, which is always leading the classification for every month, followed by Tariff 5. It shows the importance that a single customer of these tariffs can have in the system; it will be noticed if some customers are missing in one month, meanwhile for the other group of tariffs the system will not realize that a small group of customers are missing due to the larger amount of customers.

In Figures 7-11, it is shown the number of purchases per month for all the five tariffs.

In Tariff 1, it is interesting to observe how the purchases in October are close to the values of May and June, despite the values of the energy purchased are clearly bigger for October, as can be seen in Figure 6. In March, the number of purchases is smaller than in April, despite the values of the energy purchased are again close. The meaning of it is that for these months the energy was purchased in higher quantities, making lower the number of purchases.

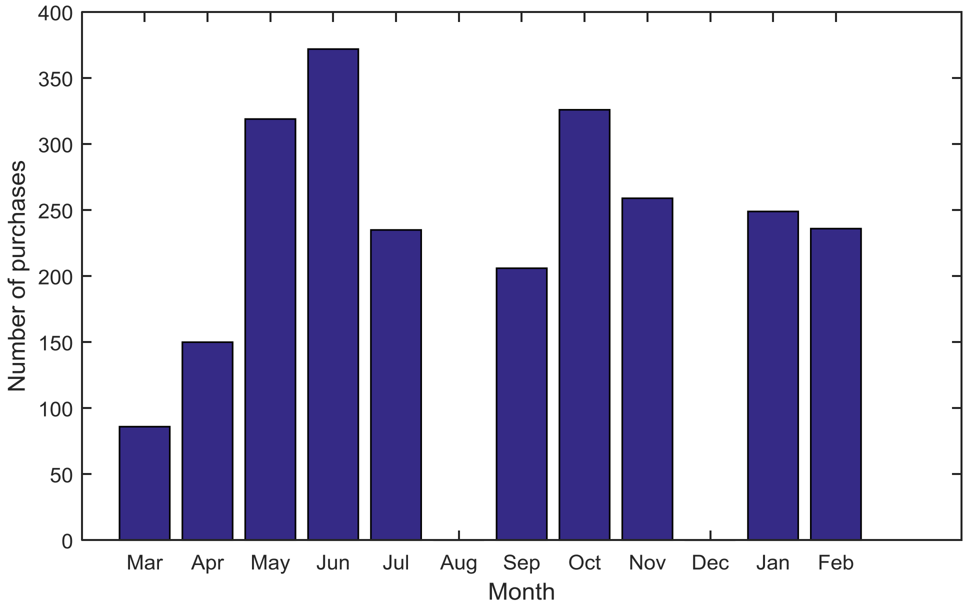

Figure 7: Yearly variation for number of purchases for Tariff 1

For Tariff 2, according to Figure 6 and to Table 2, it can be seen that the energy purchased is more constant during the year, which also happens with the purchases, being the differences between months smaller than for Tariff 1, as can be seen in the comparison between Figure 7 and Figure 8.

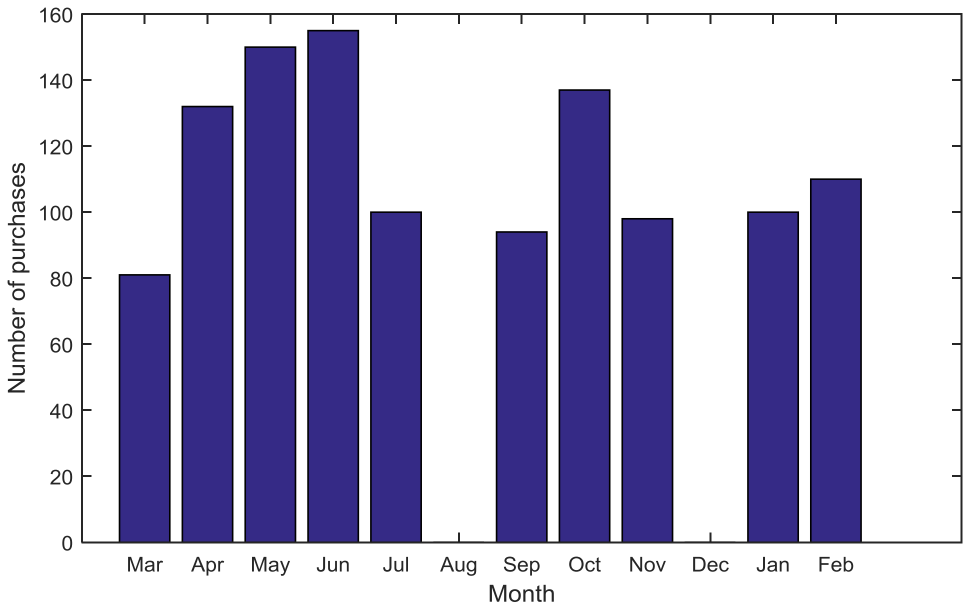

Figure 8: Yearly variation for number of purchases for Tariff 2

In Figure 9 can be detected that there is a variation in the purchases during the year for Tariff 3, which does not coincide with the regular profile of the energy purchased as can be seen in Figure 6. In the purchases, the profile is more irregular, varying when months like March and June are compared, with higher difference of purchases than for energy purchased.

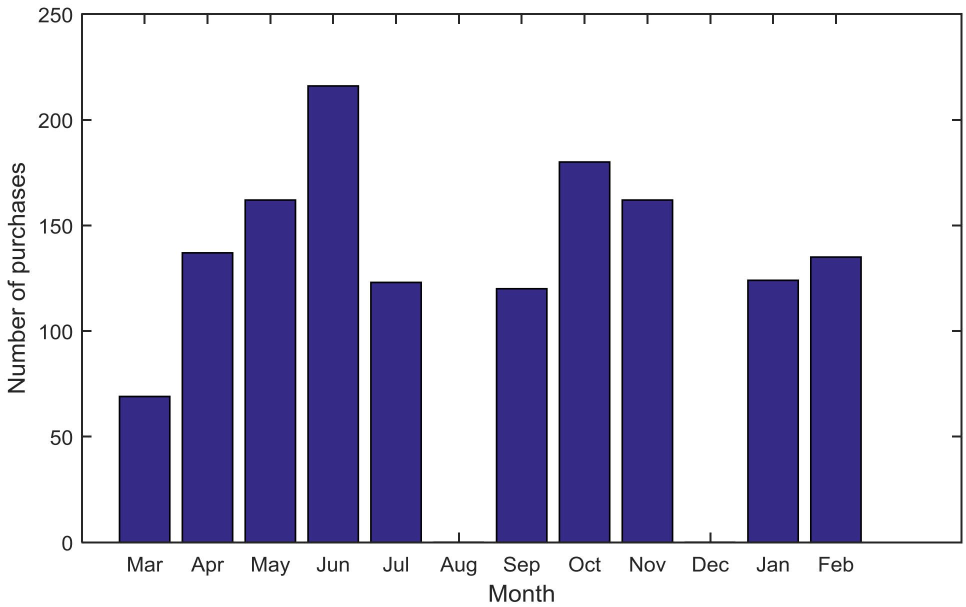

Figure 9: Yearly variation for number of purchases for Tariff 3

As a general conclusion for this first group of tariffs, it can be highlighted that Tariff 1 is varying more than the other, due to the high difference of customers depending on the month. Comparing Tariff 2 and Tariff 3, in general they have similar number of purchases for some months, but almost always that there is a difference; Tariff 3 has more purchases than Tariff 2, which coincides with the amount of customers per tariff as it is seen in Table 5.

Regarding Figure 10, it is very interesting to notice that despite October was the month when energy purchased was bigger, being the highest energy purchased for all the months and for all the tariffs, for the number of purchases October is the third month when there were more. It means that for this month, despite a larger value of energy was purchased, it was done in higher quantities.

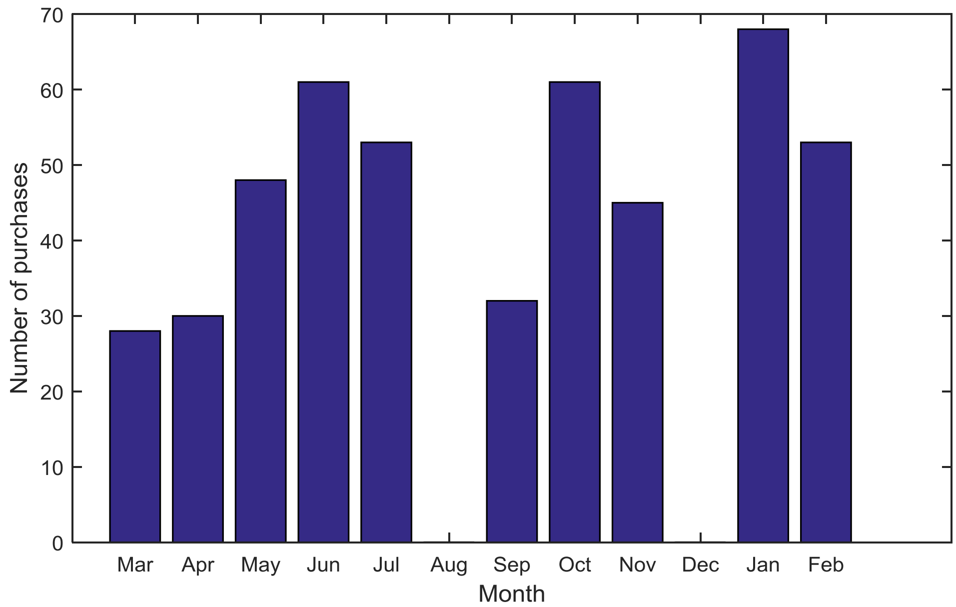

Figure 10: Yearly variation for number of purchases for Tariff 4

Finally, for Tariff 5, which yearly profile of purchases is observed in Figure 11, it can be seen that the number of purchases varies among the smallest range, from 12 to 54, which means that the energy for other electric machinery is purchased in relatively big quantities.

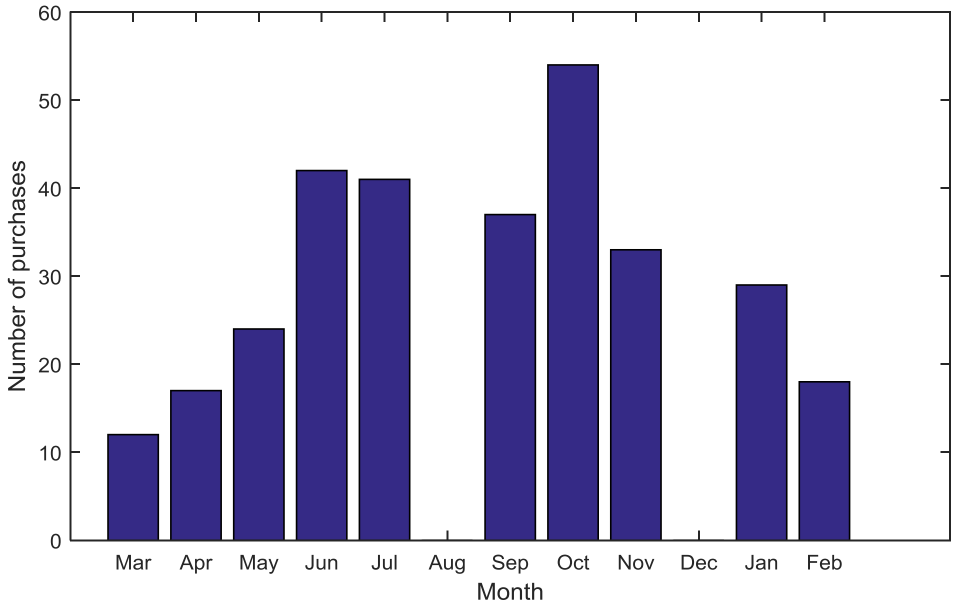

Figure 11: Yearly variation for number of purchases for Tariff 5

3.3 Study of the monthly variation of energy purchases

In Figures 12-21, it is shown the profile of the energy purchased per day in all the months that there was available data. They also include the number of purchases in order to know if the quantity of energy was acquired in one unique purchase or several and different moments. In the Appendix, inside the section 6.4 other figures, it is presented the average purchase including also the number of purchases, which show a fictional mean quantity acquired considering that only one unique purchase is done, in order to see the magnitude of each purchase per day, which is also interesting to evaluate.

Looking into deep to each of the figures, in the first two, Figure 12 and Figure 13 it can be observed that in general the number of purchases and the energy purchased are low compared to the rest of the months, which confirm what was expected, according to Figure 5. In April, Figure 13, it is interesting the comparison between the day 8th and the day 14th. Despite on the 14th there is more energy consumed than in the 8th, there are fewer purchases, less than the half(21 vs. 45). It means that the energy acquired in each purchase was bigger, as it observed in Figure 24.

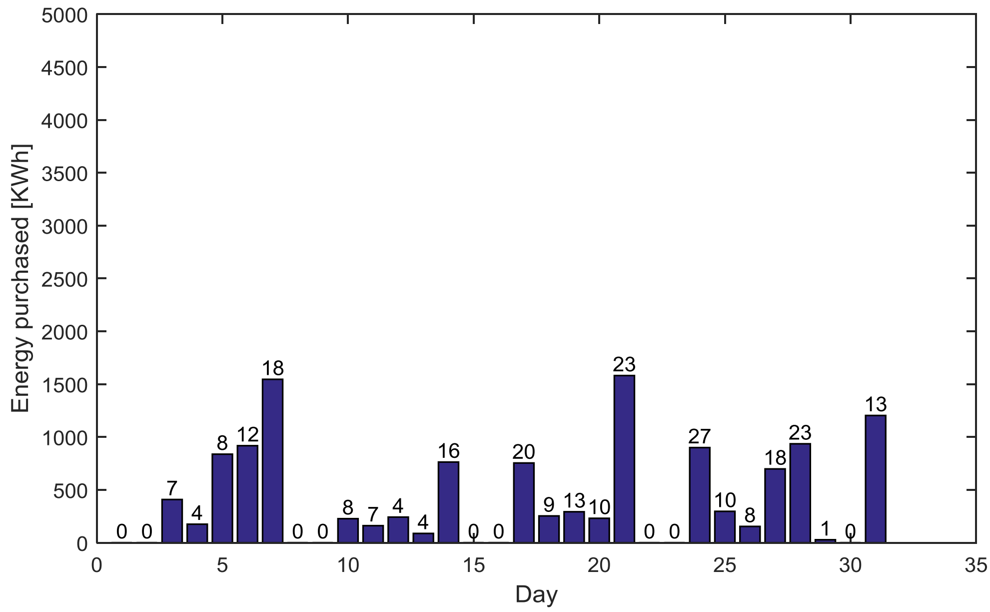

Figure 12: Monthly variation of energy purchased [kWh] – March

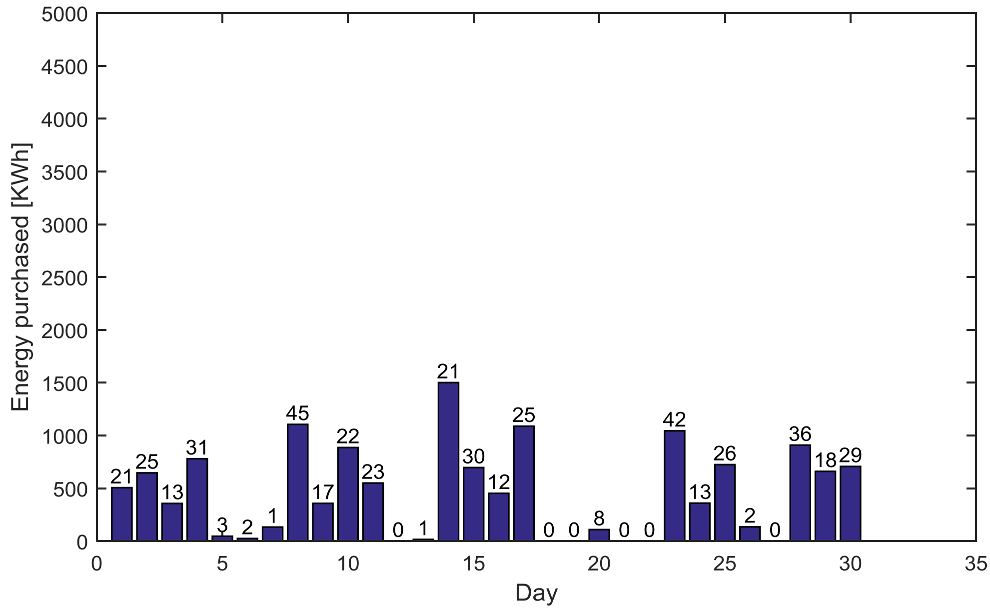

Figure 13: Monthly variation of energy purchased [kWh] – April

Also it is important to see the change that has place in the month of May, as it is seen in Figure 14. There are in general more purchases and energy purchased per day than for the last two months. It is seen also in Figure 5 that in this month the change for having more energy purchased starts.

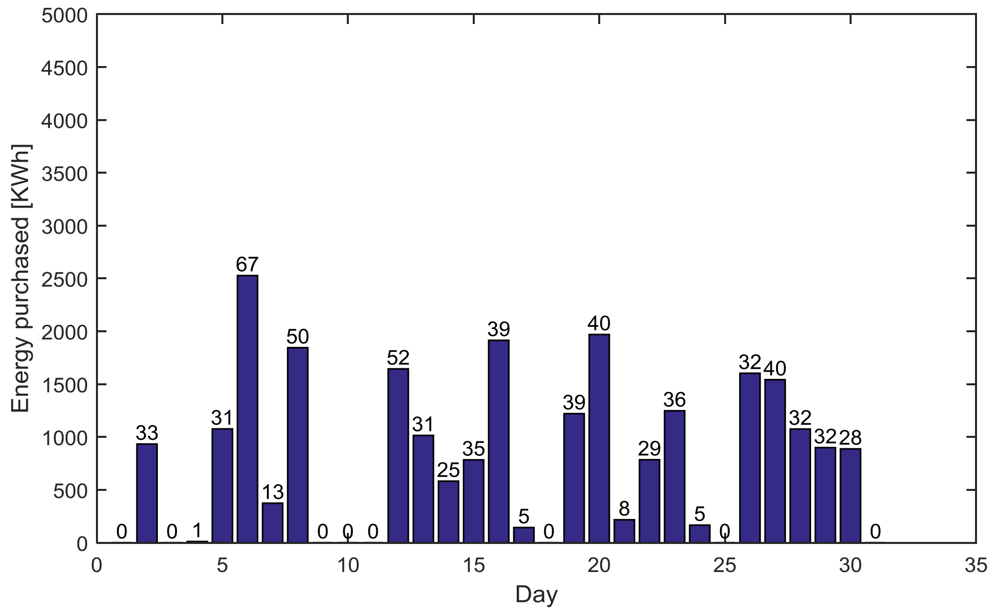

Figure 14: Monthly variation of energy purchased [kWh] – May

Regarding June, it is seen in Figure 15 that here takes place the day with more energy purchased as well as the day with more purchases, the 9th of June. The number of purchases for this day was 131 with a respective energy purchased of 4728.2 KWh; in order to have an idea about how much is the maximum in energy purchased on a single day. It can be observed also that the energy purchased continues increasing, so it is possible to see a trend.

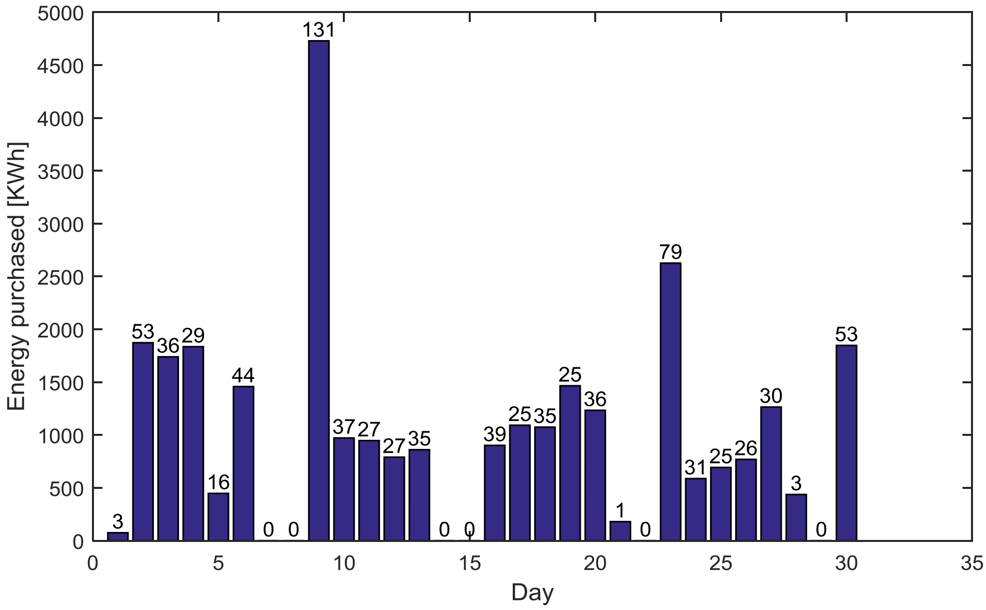

Figure 15: Monthly variation of energy purchased [kWh] – June

In July, according to Figure 16 there is a decrease in the energy purchased and in the number of purchases, but still with higher values than for the first months. It is important to notice that in the last days of the month there were no purchases or energy consumed.

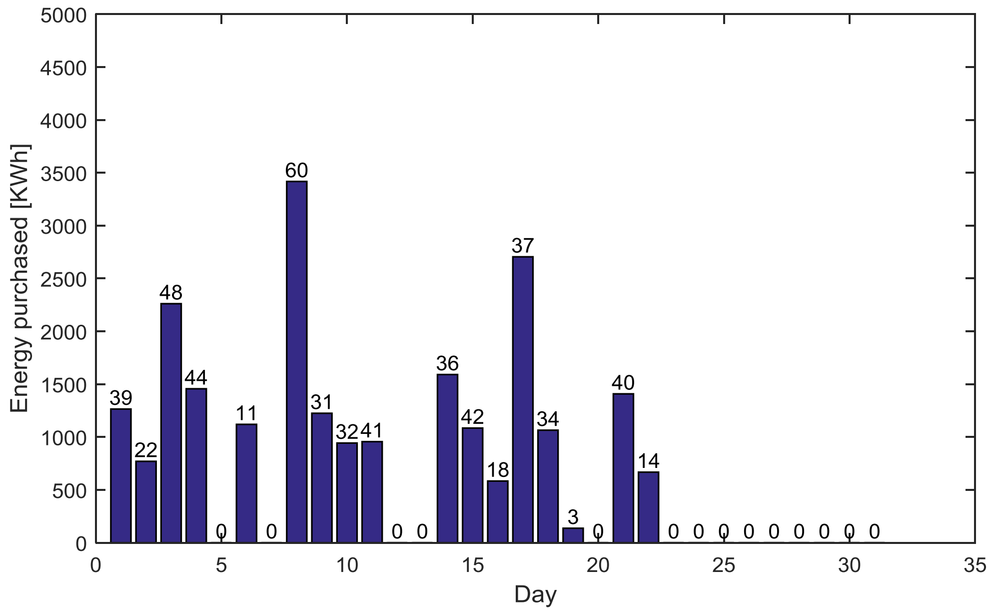

Figure 16: Monthly variation of energy purchased [kWh] – July

For September, Figure 17, there is again an important decrease in the energy purchased and in the number of purchases. Also to comment that in the initial days of the months there were no purchases again, as for the last days of July.

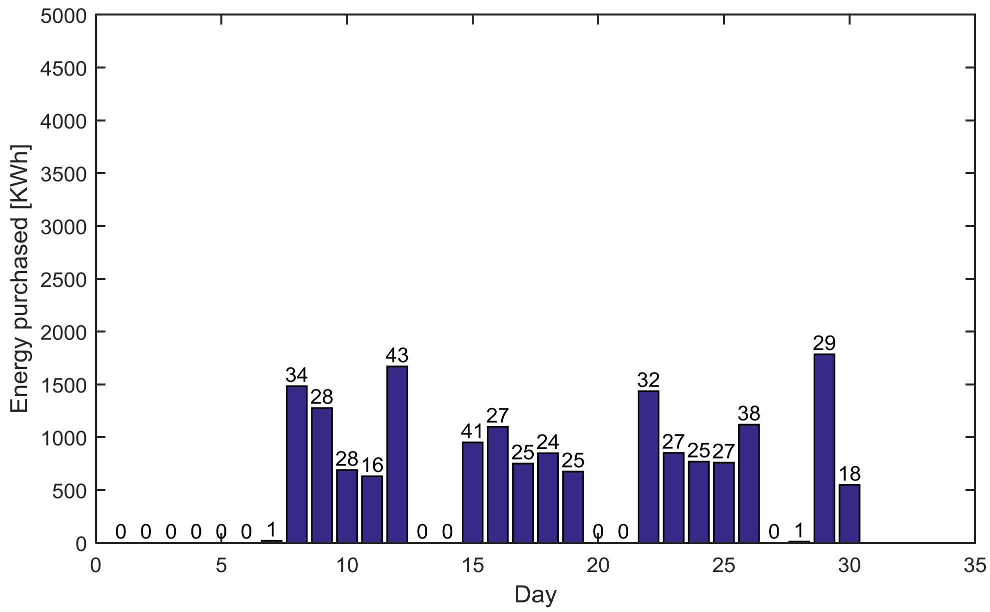

Figure 17: Monthly variation of energy purchased [kWh] – September

Regarding Figure 18, October is the month when more energy is purchased as seen in Figure 5. This month is characterized for the large amount of purchases during the month, being more constant than for other months, with peaks of energy purchased in two days (15th and 27th), despite there are some days with no energy purchased.

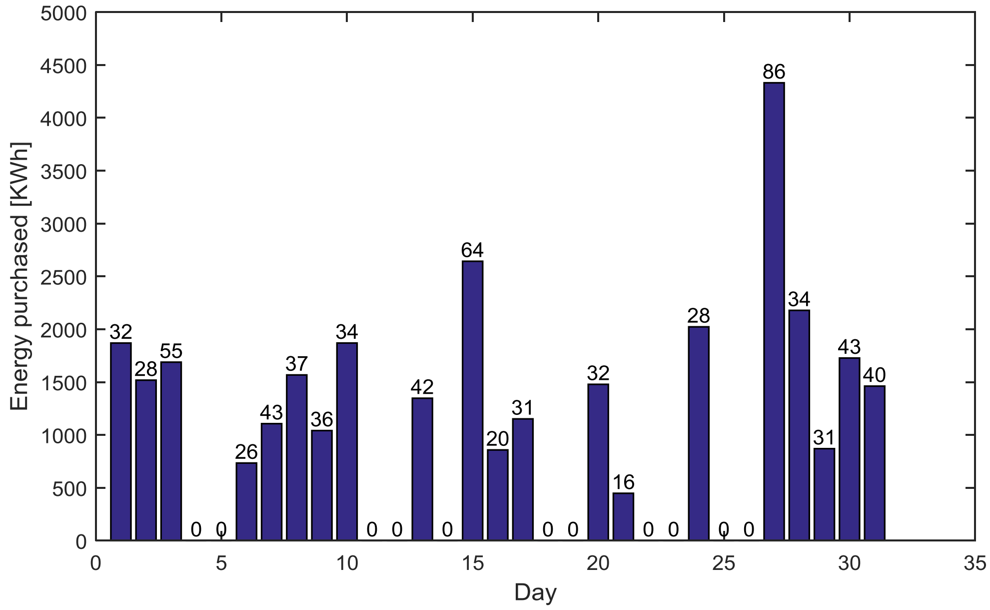

Figure 18: Monthly variation of energy purchased [kWh] – October

In Figure 19 the energy purchased in November it is shown. It stands out for its constant energy purchased through the month, varying also the number of purchases in a narrower range than for other months.

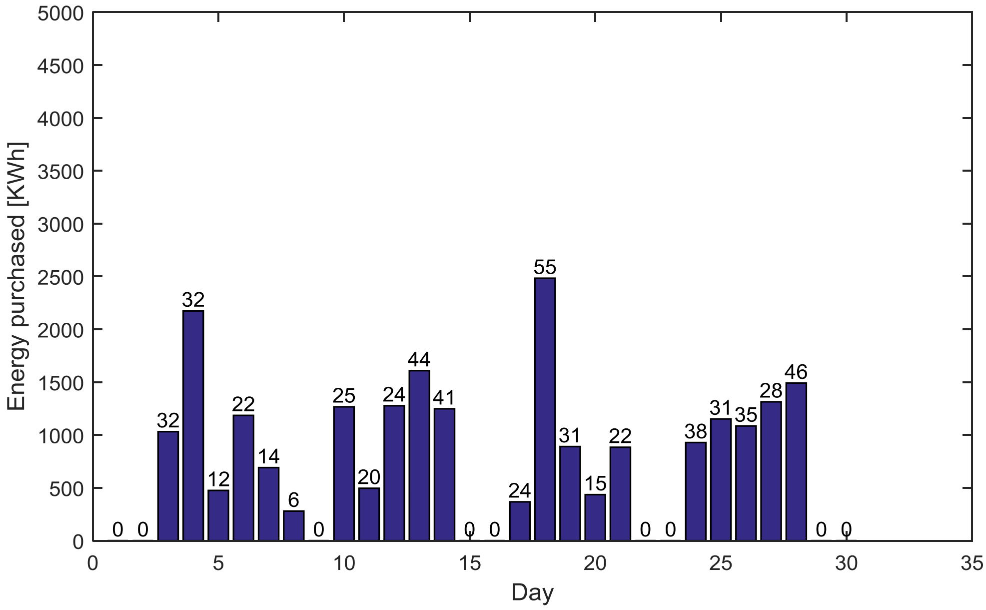

Figure 19: Monthly variation of energy purchased [kWh] – November

The monthly consumption in January and February are shown in Figure 20 and Figure 21. They are similar in the sense that both have some peaks of energy purchased in several days, not having a constant profile of number of purchases.

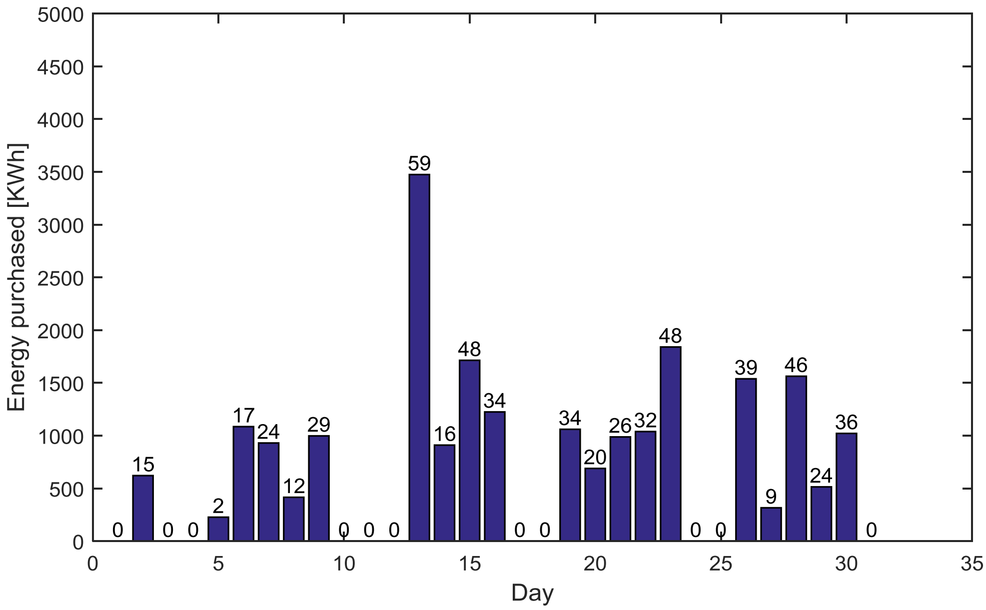

Figure 20: Monthly variation of energy purchased [kWh] – January

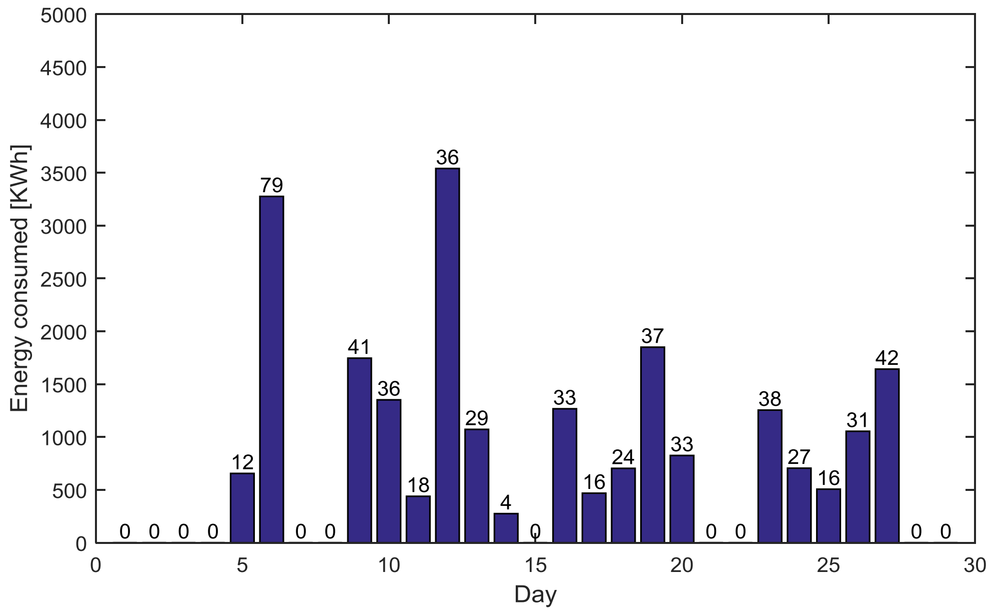

Figure 21: Monthly variation of energy purchased [kWh] – February

As a general observation for all the figures, it is important to highlight the characteristic changeability of the energy purchased depending on the month, due to the non-presence of an interval of days which has always the maximum energy purchased inside.

Although, it can be observed that there is almost for all the months analysed one or two days per month when the energy purchased is much higher than in the rest of the month. If it is examined when these periods use to appear it can be seen that they go from the 5th to the 15th of all the months in general, with some exceptions (September, October and November).

4 Discussion

Based on how the results part was presented, it will be performed an interpretation about the subsections analyzed in that part. Also, some advices and considerations will be made in order to an easier electrification of the area of Mawengi from a generic point of view without looking it deep. Hence, this part of the report will be divided into the same parts as the analysis part.

4.1 Magnitude of energy purchases

4.1.1 General consumption per month and alternative ways of producing energy

Giving a possible solution for sizing a system for their own production of energy, in Figure 22 it is presented the irradiance in Tanzania having in consideration the data of the last 22 years and also the energy purchased with the availabe data from the analysis. It can be highlighted that the maximum of the irradiance coincides with the maximum of the energy purchased, fact that can be used to implement solar panels additionaly to the system in order to cover and help with this energy that it is above the average, what is know as a peak in the purchase.

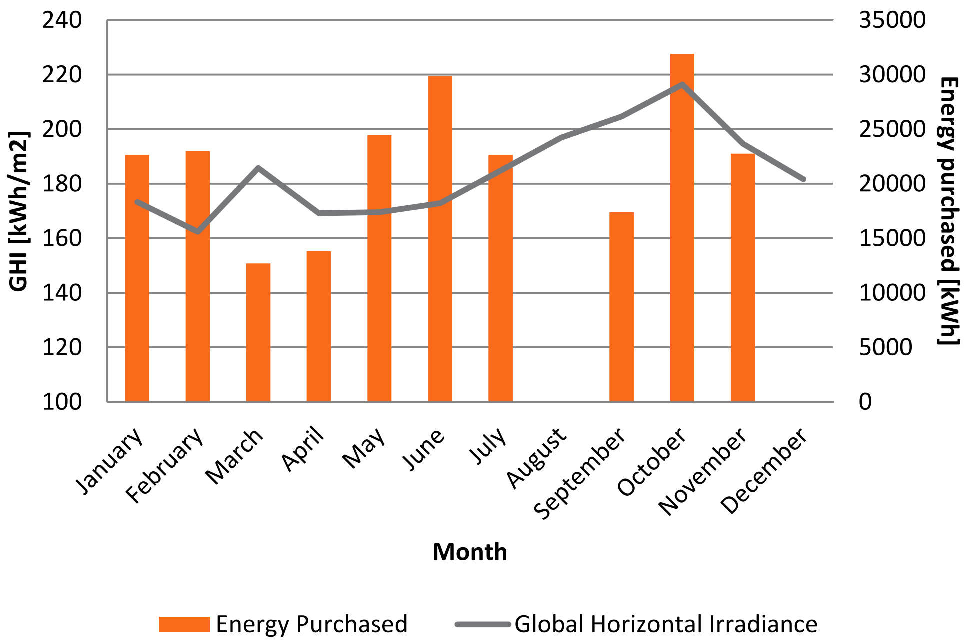

Figure 22: Global Horizontal Irradiance in Tanzania

Source: NASA Langley Research Center Atmospheric Science Data Center [14]

A hydropower system of 300 kW (2 turbines with a capacity of 150 kW each) was implemented in 2010 for supply electricity to the customers in Mawengi [11]. When this system is referred to energy in one month, it gives a theoretical value around 216 MWh. It is true that a system has to look to the peak values of energy consumption in order to cover the energy consumption every moment, but that difference of values can be the reason to discern if the system is efficient enough or if some energy is being wasted.

As Mawengi does not have problems about extra energy, because as it was stated before, the actual capacity installed is much larger than the required, the implementation of solar panels would be for other systems that need this extra energy, as well as for sizing future systems that have been not built yet.

Then, it would be a feasible solution to implement solar panels in the area of Mawengi, so accepting that this area has the same irradiance than Tanzania in general, it can be done a simple calculation of the area of the solar panels that should be implemented as can be seen in eq.1, accepting the simplifications about the fact that in Mawengi the GHI should not be exactly the same than the general for Tanzania.

$$Area\ of\ solar\ panels = \frac{K}{\eta * GHI} \tag{1}$$

Where η is the efficiency of the solar panels, which was assumed a standard value (15% [15]), GHI is the Global Horizontal Irradiance and K is the energy purchased. If the data of October is considered in eq. 1, that is to say, a global horizontal irradiance of 216.4 $\frac{kWh}{m^2}$, the result will be that for each MWh, it will be needed an area of 30.8 m^2. It is not needed a big area for placing the solar panels compared to the energy that they produce, and they would help to cover the peak values of consumption of energy, in the months when the consumption is larger.

It is seen also in Figure 22 that despite for October the GHI is maximum, as the electricity purchased, in other months as June the GHI is considerably lower than for October, so it would be a suitable solution for some months during the year, as July and December, when the energy purchased and the GHI are relatively high, but what it should be looked to implement would be some additional power source that is able to produce these quantities of energy without depending on the month or the season.

Apart from this solution, it can be observed in Figure 5, as it was stated before, the change in the purchase of energy takes place in the change of season. The reason of why in periods of a change of season the energy purchased is higher than in others could be because of the change of climate, due to its effects in agriculture, important sector in Tanzania. Every time there is a change of season, it has to be changed the system that is being used to support water to the crops. As it was written, agriculture is one of the economic activities that African countries base their economy on. Then, it cannot be implemented a photovoltaic station during only the dry season, but it can be done in these periods when solar irradiance is higher, to try to help with the extra energy purchased. [16]

It would make difficult to implement any kind of power plant to cover the needs of the area during the entire year maximizing profit, because there is not a season in which the power consumption is greater than in the other one. A possible solution could be to make a change, during the change of season, in the way energy is produced, changing it from photovoltaic to fuel production in the change from the dry to the wet season or vice versa, as it was calculated before. This kind of system is called hybrid system, and they are characterised for using different ways of producing electricity depending on the circumstances. [17]

But, as some power station has to be implemented, it would be necessary to satisfy the energy consumption of the customers for all the months. According again to Figure 5, only for one month the production overcomes the limit of the $30\ MWh$ and that only for two months the limit of $25\ MWh$ is reached. Looking it from an efficient point of view, it will be more profitable to have power stations of around $25\ MWh$, so ten out of twelve monthly consumptions can be supplied with a smaller power station, and energy and money would not be wasted. For these months which the consumption is bigger, additional power plants should be connected in order to help with the production and meet the needs of the customers as it was discussed before.

All these assumptions and advices in order to produce the required energy have been done only in energy terms. For a complete analysis of the sizing of the system, the information about when the energy is consumed has a vital importance, because it can give the values in terms of power that are needed.

4.1.2 Tariff consumption per month

The standard deviation of Tariff 1, seen in Table 2, could be because the cost that should be invested in energy is limited, so it is spent only the minimum amount of electricity depending on the month. In Table 6 it is observed that for Tariffs 1, 2 and 3, the average purchase per customer is much lower than for the other group of Tariffs, 4 and 5. It means that the first group will not notice a big difference when a customer joins or leaves the systems, due to their large amount of customers as seen in Table 5. It is important to highlight that apart from considering the larger number of customers for these tariffs, what makes the difference is the average consumption, which shows an indicative about how much will a single customer contributes to the system.

For Tariffs 2 and 4, the explanation about their low standard deviation can be understood as these tariffs plan their energy consumption better than other tariffs due to its regular monthly purchase, and have the enough money to purchase all the energy needed in one unique purchase, so it makes their purchases more constant.

Milling machines and other electric machinery, as it is seen in Figure 11 and Table 5, have the lowest number of customers and purchases generally through a year. This means that they purchase the energy in big and planned acquisitions.

The explanation then about why for other electric machinery the standard deviation is high, could be that the energy required for this sector varies a lot depending the month that it is being considered, so despite the purchases are low in number, the quantities required are changing each month.

In Figure 10 and Table 5 it can be seen that despite Tariff 4 has the highest average consumption, its number of purchases and customers are significantly low compared to the tariffs of the first group. In this tariff, due to its number of customers, it would make the difference having a few customers more or less. Each customer is purchasing the highest quantity of energy according to Table 6, being for some months more than four times the quantity purchased for the next tariff. So, in this tariff, the customer should be protected in order to maintain their consumption, because a few customers can make the difference for the income received only for this tariff.

4.1.3 Daily consumption per tariff

Looking to the figures of each month, it can be seen that is clear that there are bigger purchase some certain days in each month depending on which month the data is considered. It can be related to when they receive their salary or the income is received in the case of the industrial loads.

Due to this irregular profile when looking to the purchases the different days in a month, it is not possible to extract some extra conclusions, only that it cannot be seen any distinguished pattern in its profile. The unique valid is to notice that some period of days are distinguished for not having energy purchased. Some examples of this are the last days of July, and the first days of September or February. This could be because there was a failure on the system of registering the data, because in a system of five hundred customers it was expected that at least some of them purchased some energy one of these days. With this interpretation it could be explained why there was not data for August, due to a failure in the measurement system from the 23rd of July until the 6th of September.

Also it is interesting to see how graphs in APPENDIX B - Average energy purchased per day and number of purchases, are showing that for some days the average energy purchased is low despite there is a lot of energy purchased, which means that it was acquired in low quantities or with larger amount of customers.

4.2 Economic point of view

Looking to the economical profit, in Table 7 it is shown the difference in prices for purchasing electricity and also in the average salaries for two representative countries, as Sweden and Tanzania for Europe and Africa respectively.

Table 7: Price per kWh in Mawengi and Sweden

	Tariff 1 [€/kWh]	Tariff 2 [€/kWh]	Tariff 3 [€/kWh]	Tariff 4 [€/kWh]	Tariff 5 [€/kWh]	Average monthly wage [€]
Mawengi	0,0729	0,0826	0,097	0,13	0,16	37´9 [18]
Sweden (2014)	0,197 (Households)		0,071 (Industry)			3283.1[19]

This comparative is to point out the difference of prices of electricity between a developing and a developed country, and knowing the obvious differences, as that Sweden does not work with a prepaid system and Tanzania does, to wonder if the differences are fair or not. This can be seen from the sociological point of view to look to the difference of the average salary in both countries and the prices of electricity shown in Table 7, it can be seen the huge difference between salaries in both countries, and not in the price of electricity, which can be a point to reflect about.

Also about the economic income that each tariff is billing, milling machines is the group of customers that more money in energy is spending, followed by low households. This also gives the idea on where Mawengi electric system is receiving the money from, and that from this point of view are the most important group of customers for maintaining the system. On the other hand, High households and Businesses are, along with other electric machinery, the groups that are billing lower amounts of money. It is interesting to observe how, despite that other electric machinery is the group that is purchasing lower values of energy, because of the price of purchase; it is billing almost the same amount than these other two tariffs. Mawengi electric system sees economically efficient to have loads like large loads, because selling lower quantities of energy receives the same amount of money than other tariffs that purchased higher quantities of energy.

In Table 8 it is compared the actual income that each tariff is billing to the expected income that each tariff should bill.

Table 8: Comparison between expected and actual income for different tariffs

	Tariff 1	Tariff 2	Tariff 3	Tariff 4	Tariff 5
Expected income [Millions of Tzs] [11]	13.5	8.5	15.5	28.4	5
Actual income [Millions of Tzs]	11.2	7.9	7.9	22.7	6.5

It can be observed that for all the tariffs, but Tariff 5, the expected income was higher than the actual income is. For Tariff 3, and also slightly for Tariff 4, the actual income is considerably lower than expected, so for these tariffs it should be looked why there is such a difference as it is. It is interesting to highlight that for Tariff 5 the actual income is higher than the expected, the unique tariff that improved the calculations done before having the real data of the year 2014. For Tariffs 1, 2 and 5, the calculations done beforehand are close to the actual incomes.

4.3 Is purchased energy the same as consumed energy?

One of the most important outcomes of this thesis is to relate if it can be achieved relevant results only looking to the time when energy was purchased and not consumed. It should be differentiated, as was mentioned in the limitations, the purchase and the consumption time. One customer can purchase an amount of energy, but it does not mean that this energy will be consumed during that month or week when it was bought.

Knowing when energy is purchased can be illustrative to when is the electricity consumed, but with evident limitations. Only having the purchased energy data, it can make an idea about how the system is and its behaviour, enabling to do some conclusions and look how the profiles change during one year, but if a deeper or more concrete analysis is needed to be done, it will be vital also to have the data of the consumed energy, which actually allows to know the energy and the power needed and the real behaviours of the different customer groups.

Another important outcome related to this is that when comparing the current capacity installed, two turbines of 150 kW, which means an average production of energy of around 216 MWh if both are being used and giving the maximum power, it is clearly higher than what is actually needed (for the month when more energy was required, it was 32 MWh). But with this data about the purchased energy per month it is not enough to determine if this system is oversized. It would be necessary to have also the time when this energy is consumed, in order to establish the proper power station in terms of power, because despite a system requires low amounts of energy, if it asks for this energy in a relatively low time, the system has to answer to this amount of energy also in terms of power.

One possible solution could be to install a measurement system in order to see if the energy is consumed or not in the same moment that it has been bought, to be able to relate the quantity bought to the quantity consumed. With this measurement, in combination with the data, it will be determined the size of the system, the graphs would be more realistic and useful because they would represent the energy consumed and it would be compared the difference between when the energy is purchased and when is consumed. This maybe will raise new questions about how customers purchase energy, looking also to when they use it, in the hypothetic case that the price of energy varies through the day and the customers try to purchase electricity when the prices are lower, in order to save money.

5 Conclusions

As a summary of this report, here it will be presented the main outcomes and highlighted the most important results.

First of all, it is important to differentiate one more time between energy purchased and energy consumed. In order to make the suitable analysis deeper and with better conclusions, it will be useful to have this data for future researches in order to have a more realistic behaviour of the system.

Due to the irregularity of the results from the data available, it would be very hard to set a power station in order to satisfy customer needs. Also it is important to highlight that it is important for sizing a system to have data about the energy purchased, but it is also necessary to register the data of the time the energy is consumed, in order to be able to size the system in all the ways, including the point of view of the power as was explained before. The issue about power versus energy is one of the most important things when sizing a system, because they are the two main characteristics of all electric systems.

About the role of each group of customers, it is clear that the major part of the energy purchased goes to Low households and milling machines, so the energy produced should be mostly based on the consumption of these two groups as they are purchasing more energy. But as electricity is in the end also a service, the other groups cannot be neglected, in special High households, as they are a particular group. It should be said also that the low variability of High households make this group easier to satisfy their demand of energy, which can be useful if the different groups are divided in terms of handing the desired quantities of energy.

Regarding the economic profitability, it is clear that milling machines are leading the income to the system. This is because, besides they are purchasing greater quantities of energy, their purchasing prices are much higher than for the other tariffs, except other electric machinery. That gives a high importance to this group, because the system income is mostly based on their money for purchasing electricity, so the system has to look after them, being the number of customers for this group not extremely high. If a customer of this group leaves the system, it will have a higher repercussion than for other groups of customers. Also it should be highlighted, as it was stated, that other electric machinery is billing almost the same amount of money than other groups, because their high purchasing price, despite they are not purchasing that high energy. This can be really useful to the system, because with selling low quantities of energy, it can receive large quantities of money for the maintenance of the system or for improving it.

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APPENDIX A - Matlab code

Question 1

```
%Reading of all the months for store the data of the monthly energy
january = xlsread('FIN100 - Total Electricity Sales Revenue january
2015','P:P');

%Read the length of the vector, because not all the months have the
same
%length

ja=length(january);

%The last row of each vector is the total consumption of all the
different
%types of loads for one month

energy_january=january(ja)/1000;
energy_february=february(fe)/1000;
energy_march=march(ma1)/1000;
energy_april=april(ap)/1000;
energy_may=may(ma2)/1000;
energy_june=june(ju1)/1000;
energy_july=july(ju2)/1000;
%energy_august=august(au)/1000;
energy_september=september(se)/1000;
energy_august=0; % Temporary because August month energy is missing
energy_october=october(oc)/1000;
energy_november=november(no)/1000;
%energy_december=december(de)/1000;
energy_december=0; % Temporary because December month energy is
missing

Y=[energy_march,energy_april,energy_may,energy_june,energy_july,energy
_august,energy_september,energy_october,energy_november,energy_decembe
r,energy_january,energy_february];
en_max=max(Y);


figure('name', 'Yearly profile bar graph','position', [0, 0, 700,
400])
bar(Y)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
hold off
ylabel('Energy purchased [MWh]');
xlabel('Month');
M=mean(Y)
S=std(Y)
```

Question 2

```
[ndataJanuary, textJanuary, alldataJanuary] = xlsread('FIN100 - Total
Electricity Sales Revenue january 2015');

tariff_vector_january=alldataJanuary(:,3);
consumption_vector_january=alldataJanuary(:,16);
j_january=length(tariff_vector_january);
totalenergy_tariff_january=[];
for i=1:j_january
   for h=i+1:j_january
       if strcmp(tariff_vector_january(i),'TARIFF 1  TARIFF')
           if strcmp(tariff_vector_january(h),'Sub Total')
               A_january=consumption_vector_january(h);
               totalenergy_tariff_january(1)=cell2mat(A_january)/1000;
               break;

           end

        elseif strcmp(tariff_vector_january(i),'TARIFF 2  TARIFF')
            if strcmp(tariff_vector_january(h),'Sub Total')
               B_january=consumption_vector_january(h);
               totalenergy_tariff_january(2)=cell2mat(B_january)/1000;
                break;

            end

       elseif strcmp(tariff_vector_january(i),'TARIFF 3  TARIFF')
            if strcmp(tariff_vector_january(h),'Sub Total')
               C_january=consumption_vector_january(h);
               totalenergy_tariff_january(3)=cell2mat(C_january)/1000;
                break;

            end
      elseif strcmp(tariff_vector_january(i),'TARIFF 4  TARIFF')
            if strcmp(tariff_vector_january(h),'Sub Total')
                D_january=consumption_vector_january(h);

totalenergy_tariff_january(4)=cell2mat(D_january)/1000;
                break;

            end
       elseif strcmp(tariff_vector_january(i),'TARIFF 5  TARIFF')
            if strcmp(tariff_vector_january(h),'Sub Total')
                E_january=consumption_vector_january(h);

totalenergy_tariff_january(5)=cell2mat(E_january)/1000;
                break;
            end
       end

  end

end
energy_january=sum(totalenergy_tariff_january);
totalenergy_tariff_august=[0,0,0,0,0];
```

```
totalenergy_tariff_december=[0,0,0,0,0];
vector_of_tariffs=[totalenergy_tariff_march;totalenergy_tariff_april;t
otalenergy_tariff_may;totalenergy_tariff_june;totalenergy_tariff_july;
totalenergy_tariff_august;totalenergy_tariff_september;totalenergy_tar
iff_october;totalenergy_tariff_november;totalenergy_tariff_december;to
talenergy_tariff_january;totalenergy_tariff_february];


vector_of_energies=[energy_march;energy_april;energy_may;energy_june;e
nergy_july;energy_august;energy_september;energy_october;energy_novemb
er;energy_december;energy_january;energy_february];

figure('name', 'Tariff yearly profile bar graph 1','position', [0, 0,
700, 400])
bar(vector_of_tariffs)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
legend('TARIFF 1','TARIFF 2','TARIFF 3','TARIFF 4','TARIFF 5')
ylabel('Energy purchased [MWh]');
xlabel('Month');

A_total=[
totalenergy_tariff_january(1),totalenergy_tariff_february(1),totalener
gy_tariff_march(1),totalenergy_tariff_april(1),totalenergy_tariff_may(
1),totalenergy_tariff_june(1),              totalenergy_tariff_july(1),
totalenergy_tariff_september(1),totalenergy_tariff_october(1),totalene
rgy_tariff_november(1)];
B_total=[
totalenergy_tariff_january(2),totalenergy_tariff_february(2),totalener
gy_tariff_march(2),totalenergy_tariff_april(2),totalenergy_tariff_may(
2),totalenergy_tariff_june(2),              totalenergy_tariff_july(2),
totalenergy_tariff_september(2),totalenergy_tariff_october(2),totalene
rgy_tariff_november(2)];
C_total=[
totalenergy_tariff_january(3),totalenergy_tariff_february(3),totalener
gy_tariff_march(3),totalenergy_tariff_april(3),totalenergy_tariff_may(
3),totalenergy_tariff_june(3),              totalenergy_tariff_july(3),
totalenergy_tariff_september(3),totalenergy_tariff_october(3),totalene
rgy_tariff_november(3)];
D_total=[
totalenergy_tariff_january(4),totalenergy_tariff_february(4),totalener
gy_tariff_march(4),totalenergy_tariff_april(4),totalenergy_tariff_may(
4),totalenergy_tariff_june(4),              totalenergy_tariff_july(4),
totalenergy_tariff_september(4),totalenergy_tariff_october(4),totalene
rgy_tariff_november(4)];
E_total=[
totalenergy_tariff_january(5),totalenergy_tariff_february(5),totalener
gy_tariff_march(5),totalenergy_tariff_april(5),totalenergy_tariff_may(
5),totalenergy_tariff_june(5),              totalenergy_tariff_july(5),
totalenergy_tariff_september(5),totalenergy_tariff_october(5),totalene
rgy_tariff_november(5)];

%A_total: Vector that keeps consumptions of Tariff 1 for all the
months
%B_total: Vector that keeps consumptions of Tariff 2 for all the
months
```

```
%C_total: Vector that keeps consumptions of Tariff 3 for all the
months
%D_total: Vector that keeps consumptions of Tariff 4 for all the
months
%E_total: Vector that keeps consumptions of Tariff 5 for all the
months

S1=sum(A_total)
S2=sum(B_total)
S3=sum(C_total)
S4=sum(D_total)
S5=sum(E_total)

A_AVG=mean(A_total) %Average consumption of Tariff 1 [MWh]
B_AVG=mean(B_total)
C_AVG=mean(C_total)
D_AVG=mean(D_total)
E_AVG=mean(E_total)

A_deviation=std(A_total) %Standard deviation of Tariff 1 [MWh]
B_deviation=std(B_total)
C_deviation=std(C_total)
D_deviation=std(D_total)
E_deviation=std(E_total)

figure('name', 'Tariff yearly profile bar graph 1','position', [0, 0,
700, 400])
bar(A_total*1000)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
ylabel('Energy purchased [kWh]');
xlabel('Month');

figure('name', 'Tariff yearly profile bar graph 2','position', [0, 0,
700, 400])
bar(B_total*1000)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
ylabel('Energy purchased [kWh]');
xlabel('Month');

figure('name', 'Tariff yearly profile bar graph 3','position', [0, 0,
700, 400])
bar(C_total*1000)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
ylabel('Energy purchased [kWh]');
xlabel('Month');

figure('name', 'Tariff yearly profile bar graph 4','position', [0, 0,
700, 400])
bar(D_total*1000)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
ylabel('Energy purchased [kWh]');
xlabel('Month');
```

```
figure('name', 'Tariff yearly profile bar graph 5','position', [0, 0, 
700, 400])
bar(E_total*1000)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug', 
'Sep','Oct','Nov','Dec','Jan','Feb'})
ylabel('Energy purchased [kWh]');
xlabel('Month');
```

Question 3

```
[ndataJanuary, textJanuary, alldataJanuary] = xlsread('FIN100 - Total 
Electricity Sales Revenue january 2015');
date_vector_january=alldataJanuary(:,5);
consumption_vector_january=alldataJanuary(:,16);
j_january=length(date_vector_january);
strings_january=[];
tariff_vector_january=alldataJanuary(:,3);
customers_vector_january=alldataJanuary(:,6);
j_january_2=length(customers_vector_january);
c_january_1=0;
c_january_2=0;
c_january_3=0;
c_january_4=0;
c_january_5=0;
purchases_january_1=0;
purchases_january_2=0;
purchases_january_3=0;
purchases_january_4=0;
purchases_january_5=0;


for i=1:j_january
    strings_january = cell2string(date_vector_january(i));
     if(isnan(date_vector_january{i})~=1)  %When the value is 0(NaN), 
it returns a 1
         if(strcmp(strings_january,'Transaction Date Time')==0)
            a_january=strings_january(1:10);%Keeps only the date, 
without the hour
            d_january=datenum(a_january, 'dd/mm/yyyy'); %Converts the 
date into a number
            b_january(i)=d_january; %Keeps the date i
            cons_january(i)=cell2mat(consumption_vector_january(i));
%Keeps the consumption for the date i
         end
     end
end
sum_january=[];
s_january=0;
purchases_january_vector=[];
purchases_january=0;
Date=datetime(b_january,'ConvertFrom','datenum','Format','dd/MM/yyyy')
;%Returns the date for the number kept before
for i=1:31
    a_january=find(day(Date)==i);%It says the positions of the day
    for j=1:length(a_january)
```

```
        s_january=s_january+cons_january(a_january(j));%Keeps the
consumption for the day i
        if (cell2mat(consumption_vector_january(a_january(j)))~=0)
             purchases_january=purchases_january+1;
         end
    end
    purchases_january_vector(i)=purchases_january;
    purchases_january=0;
    sum_january(i)=s_january;
    s_january=0;
end

for i=1:j_january_2
             if strcmp(tariff_vector_january(i),'TARIFF 1  TARIFF')
                for h=i:j_january_2
                    if strcmp(tariff_vector_january(h),'TARIFF 5
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 2
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 3
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 4  TARIFF')
                            break
                    else
                            if
(isnan(customers_vector_january{h})==1)%When the value is 0(NaN), it
returns a 1

                            else
                                if
(strcmp(customers_vector_january(h),customers_vector_january(h+1))==0)

                                c_january_1=c_january_1+1;
                                end
                                if
(cell2mat(consumption_vector_january(h))~=0)

purchases_january_1=purchases_january_1+1;
                                end
                            end
                    end
                end

             elseif strcmp(tariff_vector_january(i),'TARIFF 2
TARIFF')
                for h=i:j_january_2
                    if strcmp(tariff_vector_january(h),'TARIFF 1
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 5
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 3
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 4  TARIFF')
                            break
                    else
                            if
(isnan(customers_vector_january{h})==1)%When the value is 0(NaN), it
returns a 1

                            else
                                if
(strcmp(customers_vector_january(h),customers_vector_january(h+1))==0)
                                c_january_2=c_january_2+1;
```

```
                                end
                                if
(cell2mat(consumption_vector_january(h))~=0)

purchases_january_2=purchases_january_2+1;
                                end
                            end
                        end
                    end
                elseif strcmp(tariff_vector_january(i),'TARIFF 3
TARIFF')
                    for h=i:j_january_2
                        if strcmp(tariff_vector_january(h),'TARIFF 1
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 2
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 5
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 4  TARIFF')
                            break
                        else
                            if
(isnan(customers_vector_january{h})==1)%When the value is 0(NaN), it
returns a 1

                            else
                                if
(strcmp(customers_vector_january(h),customers_vector_january(h+1))==0)
                                c_january_3=c_january_3+1;
                                end
                                if
(cell2mat(consumption_vector_january(h))~=0)

purchases_january_3=purchases_january_3+1;
                                end
                            end


                        end
                    end
               elseif strcmp(tariff_vector_january(i),'TARIFF 4  TARIFF')
                    for h=i:j_january_2
                        if strcmp(tariff_vector_january(h),'TARIFF 1
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 2
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 3
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 5  TARIFF')
                            break
                        else
                            if
(isnan(customers_vector_january{h})==1)%When the value is 0(NaN), it
returns a 1

                            else
                                if
(strcmp(customers_vector_january(h),customers_vector_january(h+1))==0)
                                c_january_4=c_january_4+1;
                                end
                                if
(cell2mat(consumption_vector_january(h))~=0)

purchases_january_4=purchases_january_4+1;
```

```
                                end
                            end


                    end
                end
            elseif strcmp(tariff_vector_january(i),'TARIFF 5  TARIFF')
                for h=i:j_january_2
                    if strcmp(tariff_vector_january(h),'TARIFF 1
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 2
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 3
TARIFF')||strcmp(tariff_vector_january(h),'TARIFF 4  TARIFF')
                            break
                    else
                            if
(isnan(customers_vector_january{h})==1)%When the value is 0(NaN), it
returns a 1

                            else
                                if
(strcmp(customers_vector_january(h),customers_vector_january(h+1))==0)
                                c_january_5=c_january_5+1;
                                end
                                if
(cell2mat(consumption_vector_january(h))~=0)

purchases_january_5=purchases_january_5+1;
                                end
                            end

                    end
                end



    end
end

%For calculating the average purchase per day
for i=1:length(sum_january)
    average_january=sum_january./purchases_january_vector(i);
end

figure('name', 'Monthly variation of energy consumption:
January','position', [0, 0, 700, 400])
bar(sum_january)
ylabel('Energy purchased [KWh]');
xlabel('Day');
ylim([0 5000])
for i=1:length(sum_january)
    TH_january(i) =
text(i,sum_january(i),num2str(purchases_january_vector(i))) ;
end
set(TH_january,'Horizontalalignment','center','verticalalignment','bot
tom')
```

```
c_january=[c_january_1;c_january_2;c_january_3;c_january_4;c_january_5
];
purchases_tariff_1=[purchases_march_1;purchases_april_1;purchases_may_
1;purchases_june_1;purchases_july_1;0;purchases_september_1;purchases_
october_1;purchases_november_1;0;purchases_january_1;purchases_februar
y_1];
figure('name', 'Tariff 1 yearly profile of purchases','position', [0,
0, 700, 400])
bar(purchases_tariff_1)
set(gca,'XTickLabel',{'Mar', 'Apr', 'May', 'Jun', 'Jul','Aug',
'Sep','Oct','Nov','Dec','Jan','Feb'})
ylabel('Number of purchases');
xlabel('Month');

figure('name', 'Monthly variation of purchases: January','position',
[0, 0, 700, 400])
bar(purchases_january_vector)
ylabel('Number of purchases');
xlabel('Day');
```

APPENDIX B - Average energy purchased per day and number of purchases

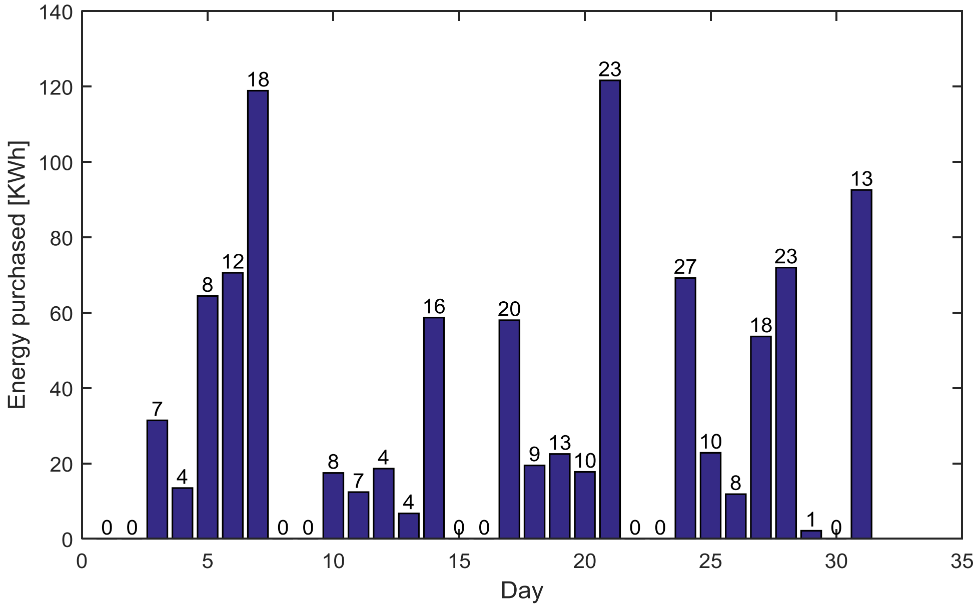

Figure 23: Monthly variation of the average energy purchased [kWh] – March

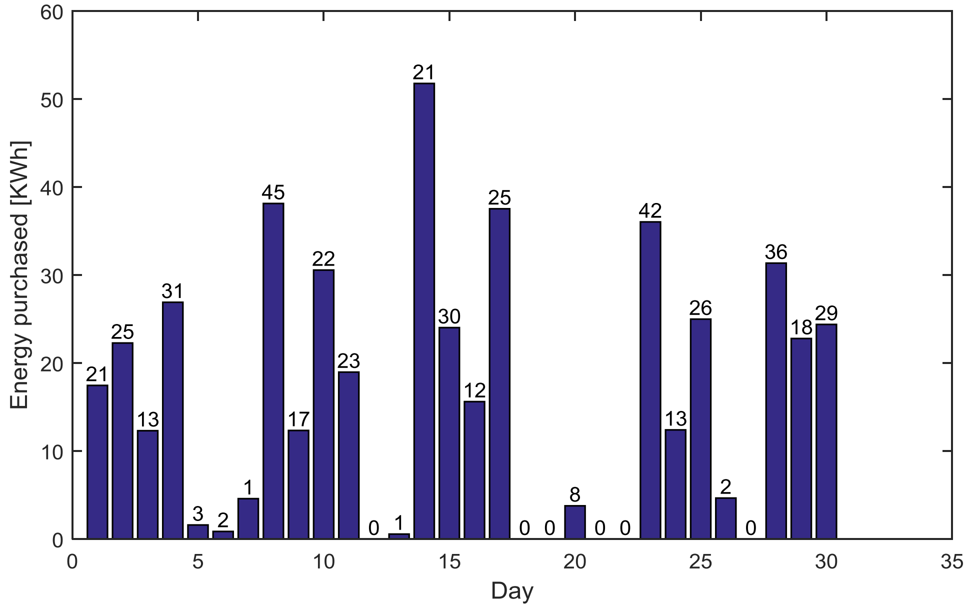

Figure 24: Monthly variation of the average energy purchased [kWh] – April

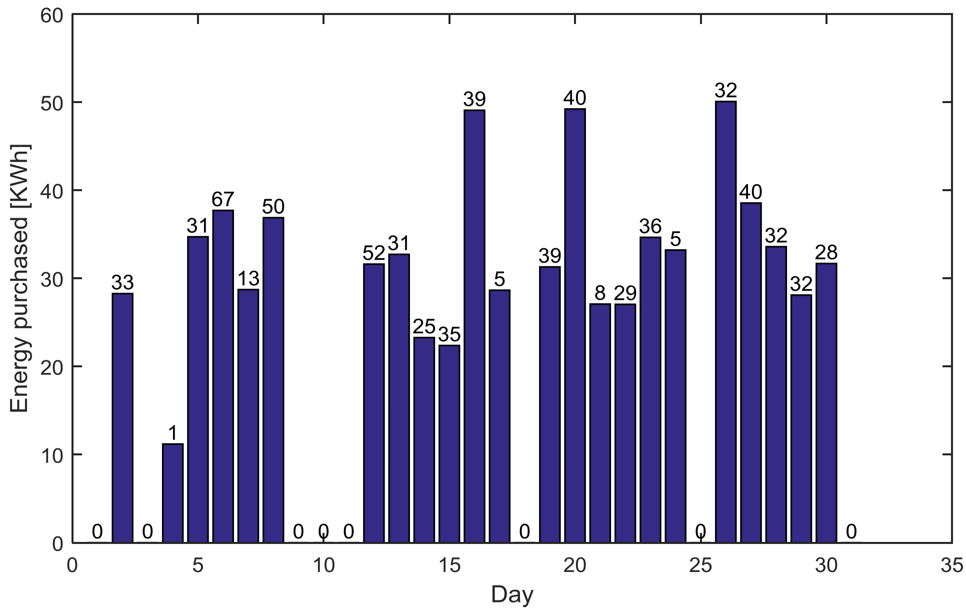

Figure 25: Monthly variation of the average energy purchased [kWh] – May

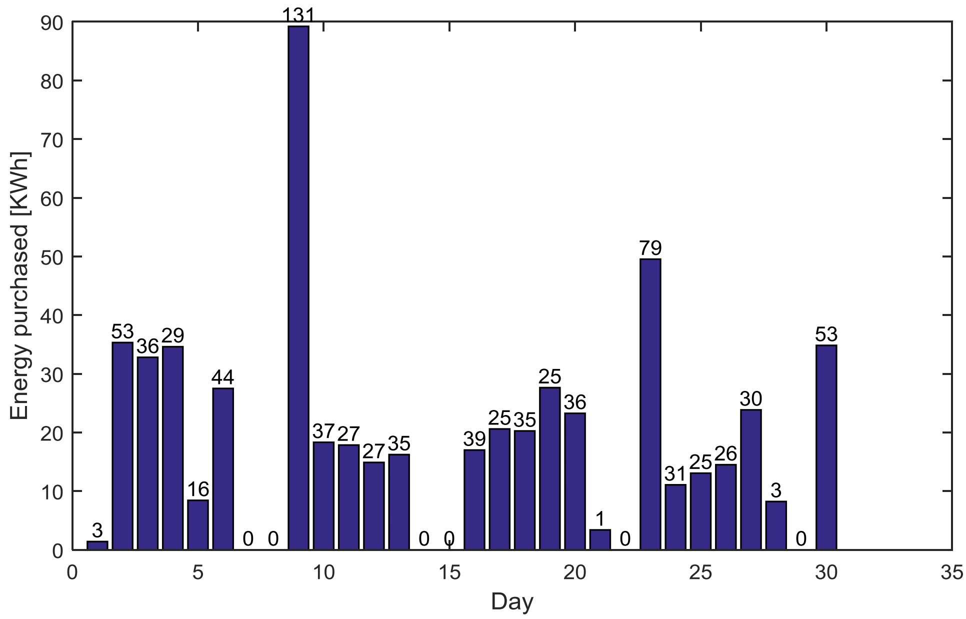

Figure 26: Monthly variation of the average energy purchased [kWh] – June

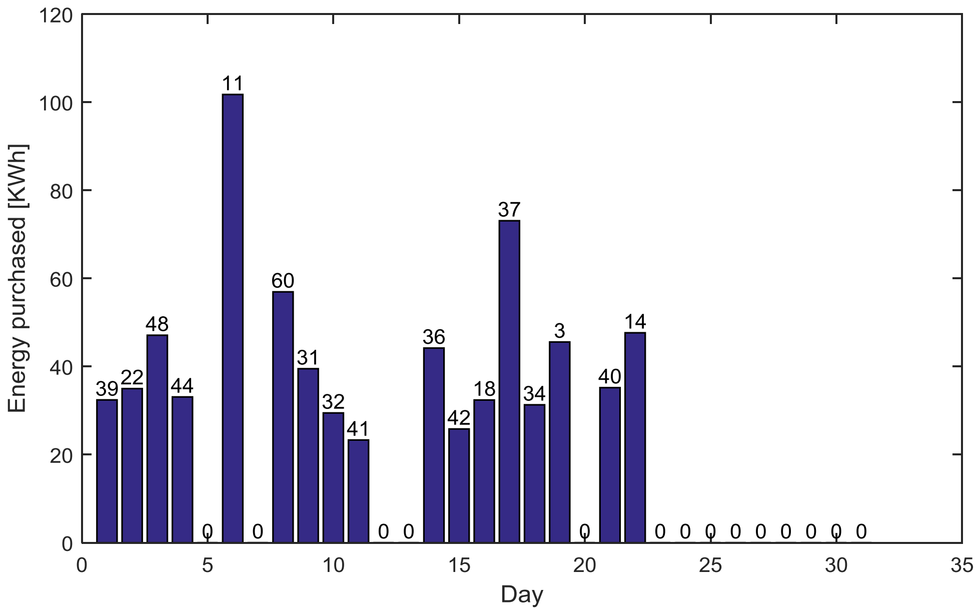

Figure 27: Monthly variation of the average energy purchased [kWh] – July

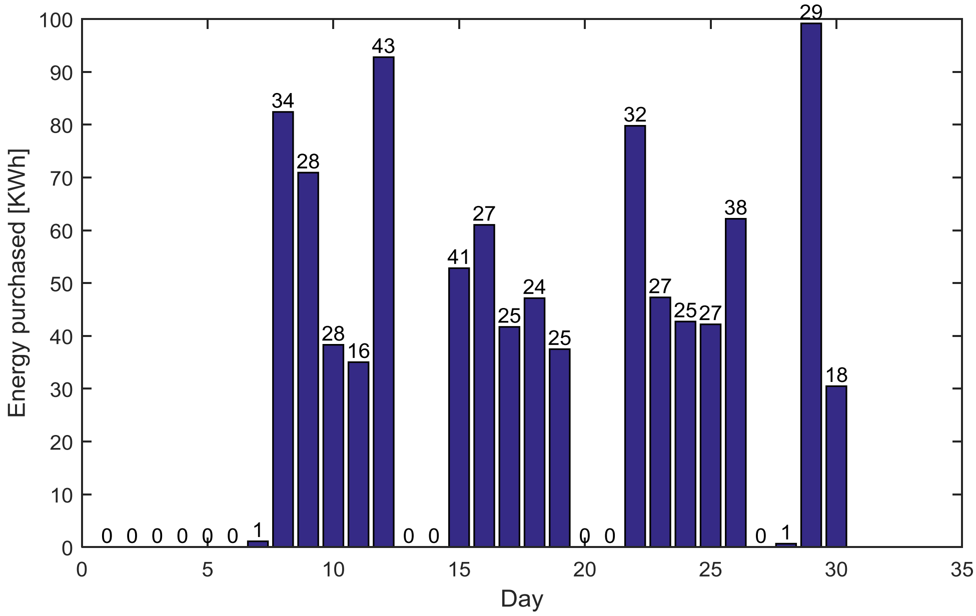

Figure 28: Monthly variation of the average energy purchased [kWh] – September

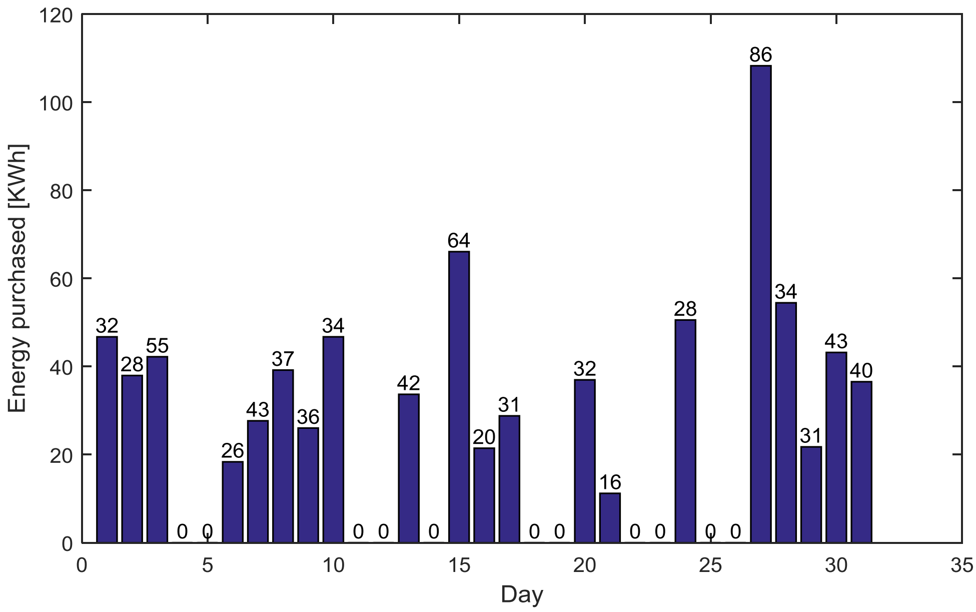

Figure 29: Monthly variation of the average energy purchased [kWh] – October

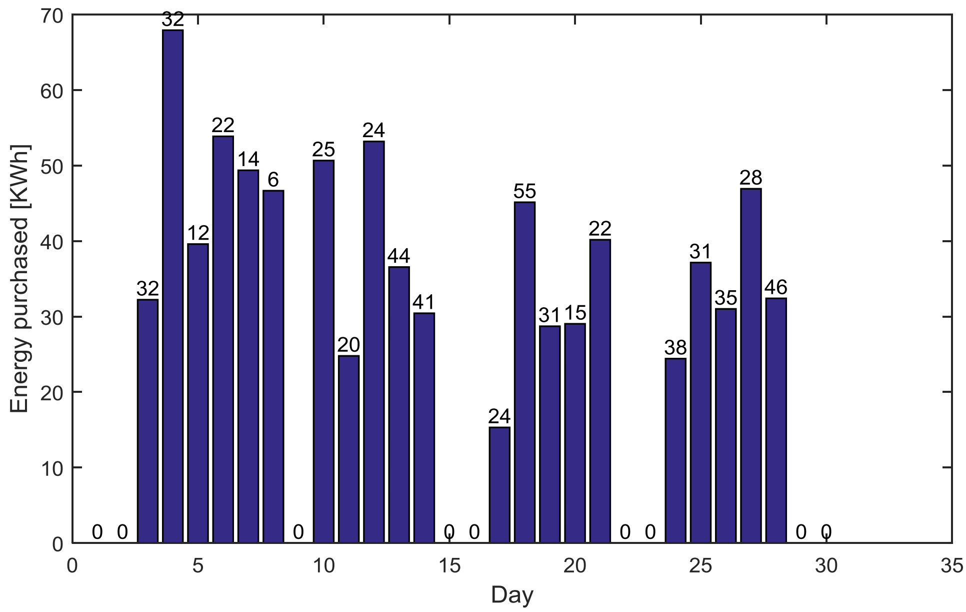

Figure 30: Monthly variation of the average energy purchased [kWh] – November

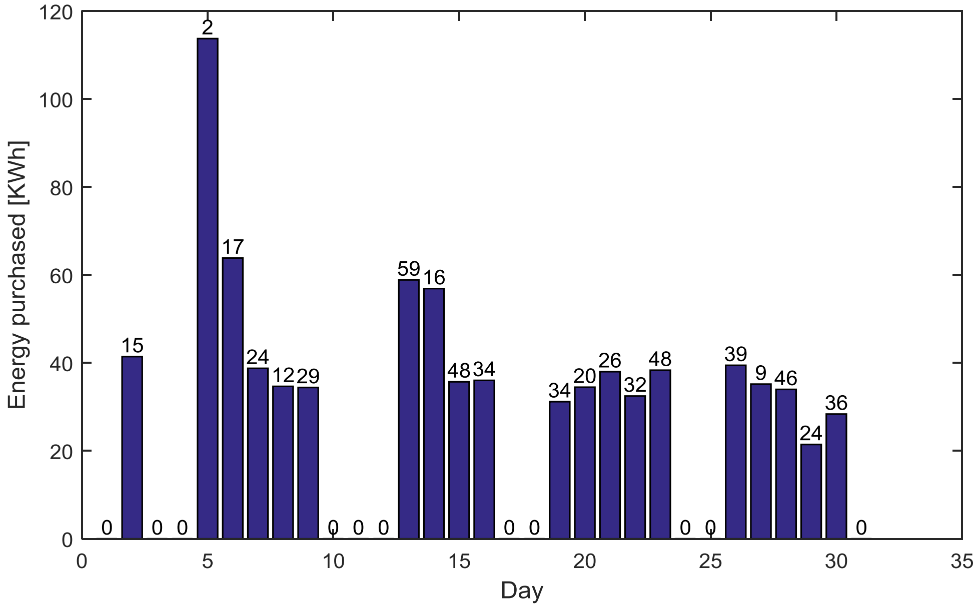

Figure 31: Monthly variation of the average energy purchased [kWh] – January

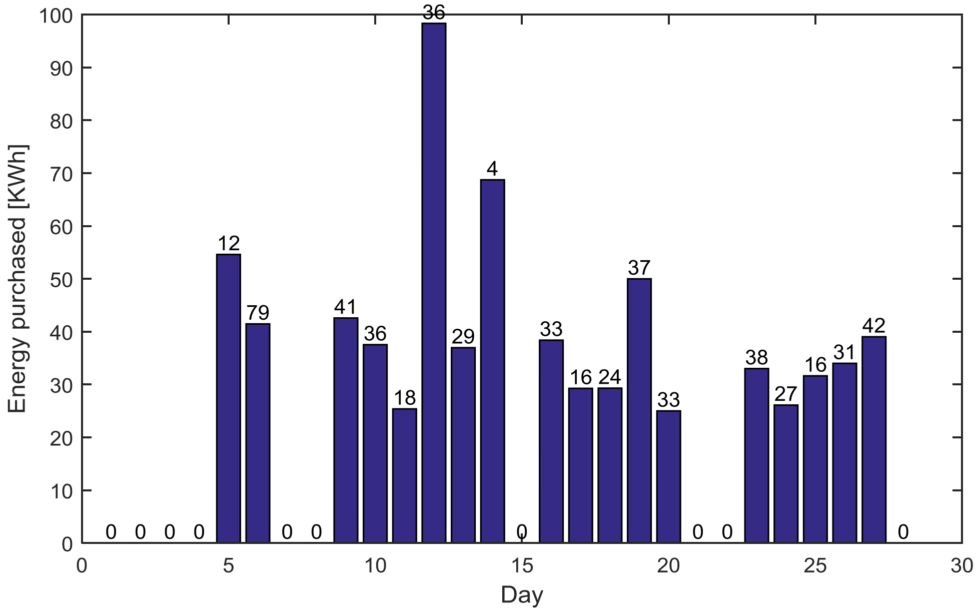

Figure 32: Monthly variation of the average energy purchased [kWh] – February