ELECTRICAL ENGINEERING

Design of demand management programs for the efficient use of electricity by industrial users

INGENIERÍA ELÉCTRICA

Diseño de programas para la gestión eficiente de la demanda de energía eléctrica en usuarios industriales

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Abstract
Since October 2015 Colombia has suffered a shortage in the capacity to generate electricity due to the significant reduction in the levels of rainfall, a consequence of the climatic phenomenon of El Niño. The drought has caused a possible threat of rationing and the intervention by the regulator which is encouraging the voluntary reduction of energy consumption.

This article proposes to use strategies for obtaining data known as ALL DATA to design demand management programs (DMP) in industrial users. It establishes that the data used must come from technical, economic, social and environmental aspects, so you can have a holistic aspect involved in the consumption of energy.

In addition, it is proposed that the data obtained be supplied by the main agents that make up the marketing chain of electrical energy and finally, to identify the activities that would be developed by the DMP agent using the ALL DATA strategies to ensure the effective strategies in saving energy will continue over time.

Keywords: *ALL DATA strategies, demand management programs, energy efficiency, industrial users.*

Resumen
Colombia desde octubre de 2015 presenta un desabastecimiento en la capacidad de generación de energía eléctrica debido a la reducción significativa en los niveles de lluvia producto del fenómeno climático del Niño. La sequía ha ocasionado una amenaza de posibles racionamientos y la intervención de las tarifas por parte del regulador incentivando la reducción voluntaria del consumo de energía.

En este artículo se propone utilizar estrategias de obtención de datos conocidos como ALL DATA para el diseño de programas de gestión de demanda (PGD) en usuarios industriales. Se establece que los datos utilizados deben provenir de aspectos técnicos, económicos, sociales y ambientales, de manera que se pueda tener una mirada holística de aspectos que intervienen en el consumo de energía.

Adicionalmente, se propone que la obtención de datos sea suministrados por los principales agentes que hacen parte de la cadena de comercialización de la energía eléctrica y finalmente se identifica los actividades que serían desarrolladas por cada agente dentro del diseño de los PGD usando estrategias ALL DATA que permitan asegurar estrategias efectivas en el ahorro energético que perduren en el tiempo.

Palabras Clave: *Estrategias ALL DATA, eficiencia energética, programas de gestión de demanda, usuarios industriales.*

1. Introduction

The demand management programs (DMP) for electricity are a portfolio of strategies to improve the electrical power system on the consumer side (Palensky & Dietrich, 2011). The difference between the strategies implemented to make efficient use of the electrical energy depends on the degree of awareness of the end user that energy is a limited resource (Nguyen & Aiello, 2013) and the degree of modernization of the electricity network, enabling the implementation of next generation devices which can be manipulated by users remotely through applications via the web (Amin et al., 2015). Figure1 shows the main strategies applied to carry out DMP in the world (Law et al., 2012).

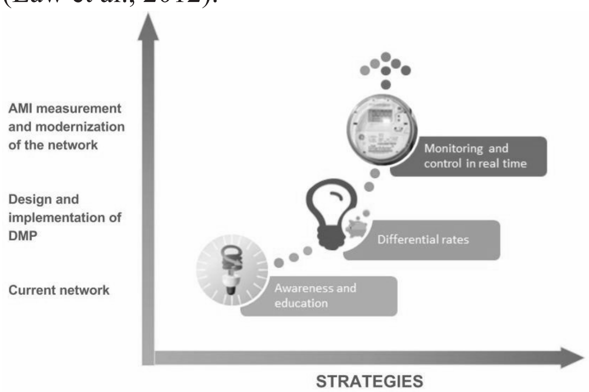

Figure 1. *Strategies vs. evolution of the DMP.*
Source: Own data.

In Figure1 three global strategies are shown which can be implemented simultaneously; however they depend on the conditions of the electrical distribution network for their implementation.

The first strategy that is shown in figure 1 is based on the generation of a passive control of demand, to promote the efficient consumption of electrical energy from the awareness and education of people about the use of this type of energy. The second strategy is linked to a more active control of demand where the user has differential rates depending on the time of day or DMP that will allow the user to control their energy expenditure (Law et al., 2012). The third strategy intends to migrate to sophisticated monitoring and control systems in real time via an intelligent metering system that allows the user to have a real knowledge of their electric power consumption (Martinez & Rudnick, 2012).

The design of a DMP is a convenient cyclical process of continuous feedback through strategies initially covering the education and training of people with knowledge of energy efficiency and the importance of this issue, not only in the reduction of electricity consumption, but also in the relationship to environmental aspects, political and social rights. In this case it is important to know the needs and desires that customers have according to the characteristics of the demand of electrical energy within the production processes (Aalami et al., 2010).

Continuing with the training of staff to optimize energy consumption within the industrial processes, it is desirable to have the participation of the industrial users in the deregulated market, this means making direct contracts with the energy marketer, which would be monthly or annual contracts where they agree the quantities of energy for such periods of time. These users who participate within the deregulated market have measurement devices capable of exchanging information between the different agents of marketing companies, as well as being able to access the consumption data which can be managed (CREG, 2010).

The technology used in measuring devices in the deregulated market is the automatic meter reading (AMR), which allows for unidirectional communication, measurement of electric energy consumption in a given period of time, remote control of the meter and partial management of electric energy (Sioshansi, 2011). To perform an active demand management it is necessary to count with smart metering devices, therefore it is intended that the industrial users migrate from the AMR technology to the AMI (Advanced Meter Infrastructure), which can provide additional benefits such as the measurement of the energy quality, bidirectional communication and total management of the energy consumed (McLaughlin et al., 2009).

This article identifies the activities which characterize demand, manage the energy consumed by industrial users through the integration of activities by the agents who par-ticipate in the exercise for the delivery of energy supply on the basis of technical, economic, social and environmental aspects to be subsequently analyzed through the data analysis strategies called ALL DATA (Doukas et al., 2009), for the design of DMP which are firmly established and stand the test of time.

2. Methodology

From the original taxonomy known as All Data, which classifies in big, small, linked and open data, and whose initial aim was integrated into a system of analysis and production of information, a methodological approach that leads to decision making oriented derived by data (DDD by its initials in English data driven decision). The validity of the conclusions and decisions is guided by the interaction of two elements: the presence of a theoretical framework and the feedback that can be achieved with the context. The first provides the conceptual bases with which to go beyond information to knowledge, reading statistics to the categories of analysis inherent to the field of study being addressed. The second captures the dynamics and evolution of the phenomenon, and incorporates the new paths of the variables and their values. Both provide the feedback for the model.

In the specific case for the design strategies for the development, implementation and evaluation of DMPs, part of the consideration is the large volumes of data or Big data generated by the remote measurement systems (linked data) with which companies today as a consequence of the opportunities of discounts in the electrical energy tariff because of that industrial users are declared generally unregulated users or large customers (CREG, 1998).

The initial questions formulated with regard to this type of industrial consumption of electrical energy make reference to the description and the construction of a demand curve to provide the first elements of the diagnosis; however, these massive volumes of data are insufficient to give a deep understanding of the demands, needs, requirements and limitations for the formulation of a DMP to achieve participation in collective of demand and an efficient use of electrical energy.

The resource of small data, through personal in-terviews and surveys with decision-makers is an essential component in clarifying and sizing the large volumes that only reflect one of the aspects of the problem. The interaction big - small not only gives information product of the confrontation but also allows for the development of a new working hypothesis, to clarify and refine the information contained in the bulk data and above all to collect the perspectives and interests of the user and result in a DMP specific to the company and not only general-purpose.

The consideration of the industrial activity as social in nature makes it imperative to its contextualization in broader areas ranging from local to national and for this purpose the open data constitutes another of the key pieces, to identify the broader dimensions of efficiency, their relationships and potential contributions. In particular it is to create performance scenarios for industrial firms in the areas which in some way has incidence, so there is a need for the energy system to be a system which gives the product of its activity.

From the social perspective, there appear new dimensions which are not originally provided for by the methodological cycle of the DMP design, such as the environmental, economic and social agents and elements that invigorate the market, among several others.

The systemic methodology for the DMP design incorporates information as an articulating axis of the different dimensions, put in place by the demands of interaction between the theoretical framework and the context. The decisions guided by the data pose a sequence that begins with the description and diagnosis and conclude with predictions and prescriptive guidance, translated into a means for promotion and prevention.

3. Results and discussion

The technical part of the DMP seeks to optimize the electrical infrastructure of each user, to be efficient through the energy audits, as well as examine the measurement devices and communication for the user to acquire an active participation by knowing their consumption and other conditions of the state of their electrical system (Muttaqi et al., 2015).

In the economic aspects, the DMP is involved with improving the consumption patterns of the user industry, as well as the coordination of the processes involved in the negotiations of the energy market, as for example the remuneration of incentives for reductions in consumption or the collection of penalties for excess consumption of electrical energy (Rahmani-Andebili, 2016).

In the environmental aspect the DMP contribute to the reduction of Carbon dioxide emissions and the delay of the expansion of infrastructure for the generation of electrical power, because these programs aim to make efficient use through the reduction in consumption and the inclusion of another type of technology that allow you to consume from renewable sources or the environment (Zhou et al., 2016).

From a social aspect it aims to carry out the massive deployment of DMP to provide sustainability by the efficient use of energy, which may provide social construction for the country through the search for a more balanced society in obtaining this resource, essential for the quality of human life, and a collective progress for the country (Miara et al., 2014).

Figure 2 presents an overview of the dimensions that are involved in the design of DMP and is observed in the core strategies ALL DATA, followed by the agents that are directly involved with the design, implementation and refinement of the DMP, and on the outside are the technical, economic, environmental and social aspects which harbour the development of these types of proposals to make them sustainable and long lasting.

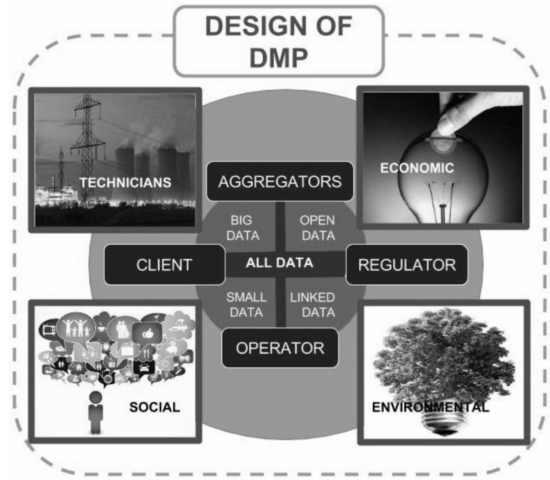

Figure 2. *System for the design of DMP.*
Source: Own data.

In the context of ALL DATA are terms such as BIG DATA, these are directly related to volume, variety and speed of data that are stored, there have also been considered definitions as value, viewing and veracity of the data categorized as SQL, and more recently the NoSQL (Liao et al., 2016), and which take into account both structured and unstructured data, therefore it is necessary to advance the development of the storage of information (Mauro et al., 2015). Followed by small data which relate to the timely data captured for example with technical surveys, sampling schemes, manual collection of data, among others. Open data is free access data, for example data that can be extracted from the statistics that are handled by the government, as well as the regulatory data among others, and finally linked data, these are those that at present it is essential to perform more work, as they relate to data sets that are transmitted via the internet from its origin to the basis of storage and can be produced in small fractions of time, are in the category IoT (Internet of Things) (Martínez-Prieto et al., 2015). In table 1 the various technical, economic, social and environmental aspects are combined with the ALL DATA strategies. The table 1 presents the sources of information for each of the strategies, this information is aiming to have a holistic view of the industrial user and from all points of view to identify the variables that affect, positively and negatively a DMP design.

Table 1. *Summary of data-oriented strategies with key design aspects of DMP for industrial users.*

Aspects	Strategies			
	BIG DATA	**SMALL DATA**	**OPEN DATA**	**LINKED DATA**
TECHNICIANS	Power consumption of the industrial user.	Technological changes and updating electrical equipment.	Information from the network operator, with respect to the variables of the energy service.	Design of virtual platforms for real time information.
ECONOMICS	Economic evaluation of all beneficiaries (company, System, Operator, aggregators).	Market behaviour with respect to the benefits for all agents.	Behaviour of the industrial activity at the national and international level and development factors.	Investments in technological changes in terms of measurement and automation.
SOCIALS	Measurement of incentives for the efficient use of energy.	The reflexion about of the efficient use of energy.	Regulation of the efficient use of energy as well as the incentives for controlling demand.	Friendly customer relation regarding power consumption information through web applications.
ENVIRONMENTALS	Growth of the industry in relation to the increase of CO2 and other types of waste.	Waste management projects developed for the use of clean energies.	Laws and decrees that stimulate the implementation of renewable energies.	Reducing environmental impacts through reductions in energy consumption.

Another important part of DMP design are the actors involved in the implementation, these agents are divided into client, regulator, operator and aggregator. Customers are the users to which it provides the service, in this case the industrial users, followed by the regulator in charge of regulating the electrical power system from generation until retail. The network operator is responsible for performing the technical coordination to provide a service with quality and customer specifications (XM, 2014), and finally proposes to implement in Colombia the figure of a new agent, which is called the aggregator of load which has as function to carry out the negotiations by a small group of members inside of the wholesale energy market (Rodríguez et al., 2013).

Figure 3 presents involving agents within the DMP design with regard to the activities developed for each of the strategies for obtaining data and their relationship with the different technical, economic, environmental and social aspects.

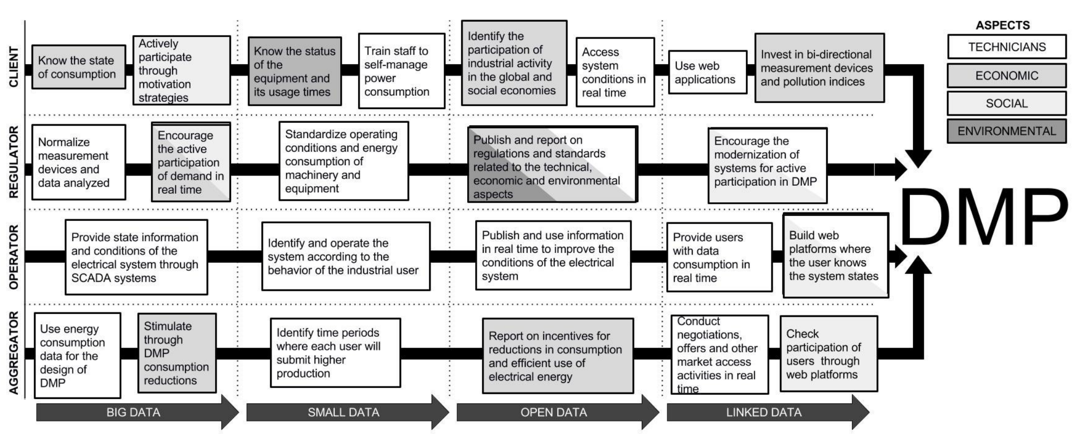

Figure 3. *Activities to develop agents for the design of DMP.*
Source: Own data.

The client is looking to have an active participation and a clear and detailed knowledge about their consumption of electricity, the behaviour of their teams, the evolution and participation of the industrial activity in the country and in the world as well as to make use of that knowledge to optimize their processes and save on the consumption of electrical energy.

The regulator will have focused activities to stimulate the participation of users within the DMP retaining the technical, economic, social and environmental aspects involved in its implementation, the operator has activities linked with the technical part, which ensures the welfare and the correct operation of the electrical power system.

This section will discuss the progress that has been made in the country for the implementation of DMP in the industrial sector, taking into account the relationships of Table 1.

3.1 Technical aspects

For the technical aspects, progress has been made in the process of identifying the behaviour of industrial users through tools such as energy audits, which allow you to have a detailed knowledge of the company and identify the areas where you should pay greater attention concerning energy loss.

In 2011 the ISO 50001standard was introduced, providing the public and private sector organizations management strategies to increase energy efficiency. The standard is intended to provide organizations with a recognized framework for the integration of energy efficiency in their management practices (International Organization for Standardization, 2011).

To apply ISO 50001, companies in the electric sector propose a service called Energy Audits (EA). These are the tools of the management process for energy efficiency, through which it is possible to assess the performance of the equipment that energy systems consumers have in an electrical installation. It is a multidisciplinary activity, which in addition to involving various fields of engineering such as electricity, mechanical, hydraulic, pneumatic, control and informatics, also involves environmental aspects and the administrative and economic evaluation of projects (CNE (National Council of Energy), 2011).

Improving the energy performance can provide rapid benefits to industrial users, maximizing the use of its energy sources and assets related to energy measurement and monitoring, operational control of variables and acquisition of energy services, which reducing both energy cost and consumption. Users in turn contribute positively in reducing depletion of energy resources and mitigating the effects of energy use worldwide (Valencia et al., 2015).

ISO 50001 standard does not set targets to improve energy efficiency. This depends on the user organization or regulatory authorities. This means that any organization, regardless of its current domain of energy management, can implement ISO 50001 to establish a baseline and then improve at a pace appropriate to their context and capabilities. For this reason it is proposed that all the guidelines that are made there happen to be free to use and become a requirement from the regulator agent.

Through the implementation of an energy audit, you can gain valuable information from the company given that it will allow you to know in detail the state of its business and also take decisions with regard to the increase of energy efficiency since these take into account the parameters of operation for all the elements, for example, transformers, machines, lighting and heating, among others.

For the design of DMP it is very important to take into account the data provided by the energy audit, given that these also provide a clear vision of the major reforms that can be performed on the technical aspect, in addition to benefitting the environmental and social aspects, to reducing greenhouse gas emissions and to building more efficient industries (Li et al., 2016).

3.2 Economic aspect

This new interest in the compilation of information brings about the development of a new methodological path for the analysis of the events associated with the energy market. It begins with a description of the market and its past behaviour to push forward the construction of a diagnosis in which you identify the variables and relevant dimensions, its influence in determining the current situation and to serve as a basis for the elaboration of hypotheses about its evolution. A key element in the new decisional scenario is that it constitutes the option to perform simulations, through which it is possible to examine the behaviour of a wide range of solutions and implement them before they reach the market.

These preliminary stages lead to the construction of predictive models (Valencia et al., 2015) capable of building alternative scenarios that reflect the possible routes of the market dynamics, from which determinations are derived in some of the directions in conjunction with actions to prevent negative and undesirable effects.

From the methodological proposals by intelligence business analysis to the Support Vector Machines, including Data mining, Neural Networks, Time Series, and Data Analysis is possible for the challenge of providing reliable bases in the development of responses to the market (López, 2007).

For this study we are taking into account the time series as a methodology to define the behaviour of the industrial users on the basis of the hourly energy consumption, which is essential to the economic aspect as the analysis allows agents to modify the energy market to optimize usage (Shumway & Stoffer, 2010). This has led to the definition of the model which will be applied to the All Data of each industrial user.

The study of the Time Series aims to explain their variations across the prediction of future values and are based on the principle that the current and future values of the series is dependent to some extent on the values that were taken in the past so that the series have an inertia which prevents or makes unlikely overly abrupt changes in short periods of time (Gonzalez et al., 2013) .

This approach corresponds to what Breiman (2001) defined as one of the two possible cultures in the analysis of the temporary series and by extension to the analysis of data, in which the fundamental interest is to identify, assess and validate the mechanism of data generation, a stochastic process responsible for the series in study and a key concept in the construction of the model (Peña, 1993).

Due to its power and effectiveness the ARIMA model is used, formulated by Box and Jenkins in 1976 (Box et al., 1976). It considered the following components, the Autoregressive, the Moving Average and the integration that contribute in the design of the model both in the regular part and the seasonal part. The notation for each one is as follows: the order of the polynomial Autoregressive of the regular part is denoted by *P* and the order of the polynomial Autoregressive seasonal part with *P*, the order of the polynomial of Moving Average in the regular part with *q* and the polynomial of Moving Average in the seasonal part with *Q*; the *d* denotes the order of the differentiation not seasonal, *D* the order of the seasonality and *s* is the seasonal period.

The general notation is as follows:

$$\phi_p(B)\Phi_P(B^s)\nabla^d \nabla_s^D y_t=\theta_q(B)\Theta_Q(B^s)\varepsilon_t \quad (1)$$

Where ε_t is the usual Gaussian Process of white noise, the general model is denoted as $ARIMA(p,d,q)\times(P,D,Q)_s$, the regular components autoregressive and moving average are represented by polynomials $\phi(B)$ and $\theta_q(B)$ order p and q, and the seasonal components autoregressive and moving average by $\Phi_p(B^s)$ and $\Theta_Q(B^s)$, order P and Q, and regular components and seasonal difference by $\nabla^d=(1-B)^d$ and $\nabla_s^D=(1-B^s)^D$; y^t it constitutes the series observed.

3.3 Social and environmental aspects

For the social and environmental aspects, we have designed regulations by the responsible entities social wise, promoting the efficient use of energy by strategies in response to the demand for the end user and in the environmental part we have identified strategies for consumption from renewable energies, among other types of generation, so that greenhouse gases are reduced. In Table 2 we can see the positive regulatory developments in Colombia related to the considerations that directly involve the participation and delivery for the supply of electrical energy to the demand.

***Table 2**. Regulatory framework.*

Rule	Comments
Law 143 of 1994	Through this the electrical energy for the entire supply chain in the national territory is set, in turn authorizing entities that control this service.
Resolution CREG 024, 1995	Regulates the commercial aspects of the wholesale power market in the national grid, which are part of the Rules of Procedure of operation.
Resolution CREG 071, 2006	Adopts the methodology for the remuneration of the reliability charge in the wholesale energy market.
Resolution CREG 063, 2010	Regulates the safety ring reliability charge called voluntarily breakaway demand.
Resolution CREG 116 and 20, 2013	Modification of resolutions CREG 063 of 2010 and 071 of 2006, in connection with the verification and liquidation of the voluntary Breakaway Demand and the calculation of the commercial availability within the actual remuneration of the Individual daily charge for reliability.
Law 1715, 2014	Regulates the integration of non-conventional renewable energies to the national energy system.
Resolution CREG 098, 2014	Regulates the response to the demand of the daily market in conditions of scarcity.
Decree 2492, 2014	Adopts measures in the field of implementation of response mechanisms to demand.
Resolution CREG 011, 2015	Regulates the program in response to demand for the daily market in critical conditions.
Resolution CREG 025, 2016	Adopts the procedure that will be used by the National Center Office to enable the program to respond to the demand in the ideal predispatching, established in Resolution CREG 011, 2015.
Resolution CREG 029, 2016	Defines a scheme of differential rates for set-up costs for the provision of the electric service to regulated users in the National Interconnected System to promote voluntary savings of energy.

Law 143 of 1994 sets electric power as a public good and stipulates the regulators of the service. Then 16 years went by before the CREG (Colombian Regulator) re-defined a resolution for the control of demand, this was through a program of voluntary breakaway demand which is defined in resolution CREG 063 of 2010 (CREG, 2010). This program was created by the CREG to encourage users to reduce their consumption when the system had a state of emergency or critical conditions; these are situations that affect the wholesale energy market when the price of stock exchange of energy is higher than the price of shortages.

Law 1715 of 2014 (Congress of Colombia, 2014) which proposes the implementation of renewable energy and the efficient use of energy, within this same year appears decree 2492 (Ministry of Mines and Energy, 2014) , which called for the implementation of strategies responding to demand. From this decree, CREG published Resolution 011 of 2015 (CREG, 2015) which regulates the response to the demand in the daily market in critical conditions, as is the current case for shortages of the generation capacity due to the presence of the climatic phenomenon known as El Niño. This resolution aims to give reliability to the National Interconnected System, support the obligations of energy, and reduce prices on the stock exchange of energy and costs of the constraints.

Due to the energy crisis that the country is having because of the phenomenon of El Niño that has been recorded since before August 2015, due to the strong hydro-dependence that the country presents, the CREG proposes Resolution 029 of 2016 (CREG, 2016a) which is a proposal for a voluntary energy saving for regulated users, to encourage energy saving by providing a discount to the users who submit consumption below the savings target and generating penalties for users that consume above this saving goal, billing almost double the fee per additional kWh.

Additionally the regulation proposes that non regulated users who have emergency electric plants can receive incentives for disconnecting from the system and consuming from their own plants. The proposed incentives in the last two resolutions have generated energy saving initiatives. Resolution 0295 of 2016 (CREG, 2016) promotes use practices demand response programs voluntary disconnections, and in turn the resolution CREG 029 of 2016 provides a scheme of differential rates, so that they can be used on a permanent basis, they must be articulated with data analysis tools such as the time series that allow the construction of models for the prediction of consumption based on history (Pineda et al., 2015) which allow for better substantiated programs.

The permanence of the DMP in the Colombian energy sector cannot be an isolated exercise to collect and process large volumes of data to move closer to a reality with higher levels of complexity and therefore demand the integration of the dimensions and variables that affect in a significant way, as seen in Figure 2.

4. Conclusions

The DMP in the context of data analysis shows a great potential and a promising future, mainly because it allows you to generate global benefits to society, related to reducing negative impacts to allow for an increase in the reliability of supply through a reduction in the chargeability of the electrical structure and to postpone the need to increase the generation capacity.

In spite of the fact that Colombia has made progress in the development of strategies for the efficient use of energy, as well as for the control of demand in periods of shortages, it is necessary to progress with the whole and periodic implementation of DMP that not only benefit the industrial user, but also other agents in the sector such as the network operator, the aggregators of the market and the entire electrical system in general.

The impact techniques ALL DATA collections mainly focus on capturing data to be analysed can characterize the behaviour of demand. These techniques provide information based on technical, economic, social and environmental aspects, which are used to generate strategic DMP based on models with a systemic structure making them successful.

Systemic design of strategic DMP should take into account the needs and perspectives of users, also include the participation of other actors such as operators, regulators and aggregators, in order to obtain a successful implementation, monitoring and feedback such programs.

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in the form of new research projects, creation and innovation.

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