International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2019, 9(6), 71-78.

Potential Energy Savings and CO_2 Emissions Reduction in Colombia Compressed Air Systems

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Received: 28 April 2019 **Accepted:** 25 August 2019 **DOI:** https://doi.org/10.32479/ijeep.8084

ABSTRACT

Compressed air (CA) is one of the most common systems used in industry. In countries such as Australia, Italia, France, China and USA, energy consumption of CA systems (CASs) contributes about to 10% of the total electricity consumption in industry. In Colombia, this value reaches 8%, highlighting the textile industry, with a 24% of consumption. Despite of all its advantages, CA is expensive, between 10 and 30% of consumed energy reaches the end-use point. Improvements to CASs can achieve between 20 and 60% of energy savings, with pay-back periods lower than two years. These are the reasons that they can be considered as one of the main targetsystems while planning energy efficiency actions in industry. Colombia through different strategies has proposed to implement a group of measures to improve energy efficiency and reduce electricity consumption to 2021 around 7%. Implementation of good practices in CASs is one of them. This paper is showed the share cost, electricity consumption and the savings potential of the CASs in the different divisions of the Colombian manufacturing sector, the main sectors to be involved as well as the potential savings and reduction of dioxide carbon emissions.

Keywords: Compressed Air Systems, Electricity Consumption, Energy Efficiency
JEL Classifications: Q47, L94, N66

1. INTRODUCTION

Worldwide energy consumption increased 10.5% from 2011 to 2016, this behavior will continue, increasing by 35% from 2012 to 2040 (B.P Energy Outlook, 2018; Chikunov et al., 2018). The increase in energy consumption, its high cost, scarcity of resources and growing concerns about climate change, have prompted countries and companies to implement strategies for energy consumption reduction and clean energy generation (Faizah and Husaeni, 2018; Benedetti et al., 2017). As results in 2017, the Global Energy Intensity measured as the (amount of primary energy demand needed to produce one unit of gross domestic product, GDP) fell by 1.7%; continuing with the trend initiated in 2010 (Energy Efficiency, 2018); but still lower than the 2.6 needed to maintain the temperature increase in values lower than 2 degrees Celsius with respect to the industrial level, objective raised in the Framework Convention on Climate Change (COP 21), (Yépez et al., 2018).

The industrial sector currently consumes around a half of all global energy and it remains until 2040 as the largest consumer as an end-use sector, with about 54% of the total energy consumption (Energy Outlook, 2017; Desfiandi et al., 2019). In Colombia industrial sector consumption is the 33% of total energy consumption, equal to 481,429 TJ/year; electricity consumption is a 9.4% of this value equivalent to 12.6 TWh/year (UPME, 2018) and is estimated that will have a growth rate of 52% between 2016 and 2030 (UPME, 2016). The country is responsible for 0.46% of global greenhouse-gas (GHG) emissions, however, if energy efficiency measures are not taken, emissions could increase a 50% by 2030. For that reason, Colombia government has proposed a group of measures to improve energy efficiency and reduce electricity consumption by 2021 around 7%, enacting laws and national resolutions such as National Development Plan (PND), the indicative action plan (PROURE), the Colombian Low Carbon Development Strategy (ECDBC) and Law 1715 (Ocampo et al., 2018). These policies are focused on the objectives proposed in COP 21 in order to reduce 20% of GHG for 2030 considering an inertial scenario (Berruezo and Jiménez, 2017). Good practice implementations in compressed air systems (CASs) is one of the strategies to develop theindicative action plan for energy efficiency 2017-2022 (UPME, 2016).

The use of CA in industrial sector is common, due to its cleanness, speed, constant torque at constant pressure, even at low rotational speeds, and riskless handling. It is often considered the fourth utility after electricity, gas and water at many facilities (Zahlan and Asfour, 2015; Annegret and Radgen, 2003; Bonfà et al., 2017; DoE U. S., 1998). In countries as Australia, Italia, France, China and USA CASs contributes about to 10% of the total electricity consumption in industry while in Colombia this value reach the 8%, equivalent to 1.39 TWh/year) (Saidur et al., 2010; UPME, 2013; UPME, 2014a; UPME, 2014b). However, CASs has been identified as one of the less efficient systems, only between 10 and 30% of consumed energy reaches the point of end-use. Energy is lost as heat, leaks, inefficient uses, amongst others (Mousavi et al., 2014; Corsini et al., 2015). According to the total life cycle costs, the electricity required to operate a CASs is around 75% of total, greater thaninitial investment 13% and compressors maintenance 12%, (Radgen, 2005; European Commission, 2009;Yang, 2009).

In CASs small modifications such as matching supply and demand, reducing pressure settings, reducing average inlet temperature, optimizing air compressor location and mainly reducing leaks may give between 20 and 60% of energy savings with an usual payback lower than two years(Abdelaziz et al., 2011; Vittorini and Cipollone, 2016, Kaya et al., 2002). Besides energy savings, increasing energy efficiency of CASs may ensure other Non-Energy Benefits for the company. The most significant are; more reliable production, capital avoidance, improved product quality, increased production and reduced maintenance; often, these benefits are morevaluable than energy savings (Nehler et al., 2018a; Šešlija et al., 2011; Fleiter et al., 2012). These are reasons why CASs can be considered as one of the main target systems for the implementation of energy efficiency actions at country, region and industry level (Benedetti et al., 2017a).

This paper analyzes the energy efficiency measures that can be applied for CASs in Colombian manufacturing sector, the potential savings that its implementation would have for each of the manufacture divisions and the departments of the country where this measure would have the greatest impact.

2. POTENTIAL ENERGY SAVINGS IN CASS

A CASs is composed by two fundamental areas, Supply and Demand. In the Supply side the inlet air is converted in compressed air through comprises equipment and demand side are responsible to carry the compressed air to end-use applications. The first is intregrated by filters, motors, compressors, controls, drains, intercooler or aftercooler, separators, air dryers and air receiver; while in the demand can be found distribution lines, filters, pressure and flow controls and end-use consumers. Figure 1 shows an example of a CAS design.

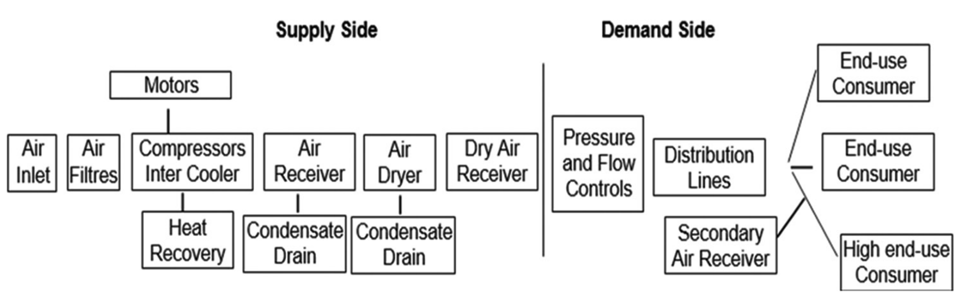
Several options can be proposed in the supply and demand side to improve energy efficiency in a CASs with lower payback periods (Dindorf, 2012; Slobodan et al., 2012; Benedetti et al., 2017a; Vittorini and Cipollone, 2016; Mousavi et al., 2014). Factors such as working pressure, leaks, inlet temperature, energy recovery and maintenance can be optimized; these factors not only improve the efficiency of CASs, also increase the lifetime of the compressor and the ancillary of equipment, along with their operational reliability (Nehler, 2018; Trianni et al., 2016). For that reason, it is important to analyze the system with a holistic view to improve the energy efficiency in CASs. Table 1 resumes these strategies, energy savings, applicability, payback period and costs.

Another actions as substitution of low efficiency by high efficiency motors, adjustable speed drives and more frequently filters replace can give another four percent of energy savings (Radgen and Blaustein, 2001).

3. ELECTRICITY CONSUMPTION IN COLOMBIA SECTORS

Over the last ten years, total energy consumptionin Colombia has had an average annual growth of 3.1%, reaching 1,450,592 TJ/year in 2017. Electricity consumption had a similar behavior with

Figure 1: Compressed air system and elements divided according to supply and demand sides



Source: Prepared by the authors based on data from: (Nehler et al., 2018a; DoE U. S., 1998) anannual growth rate of 3.2%, representing the 14.6% of the total energy consumption, equivalent to 59 TWh/year (UPME, 2018). The Colombian electric power system is based on electricity commercialization process considering trading companies, where industrial users (>0.1 MW) acquire energy in a wholesale market, which operates freely according to supply and demand conditions. The participation of private, public and mixed companies is allowed in order to promote competition among power generation agents, which must comply with regulatory specifications considering power plants >20 MW to define the stock exchange price in a hydrothermal scenario within the wholesale electricity market. Final Electricity Costs is defined in common agreement between the parties under the intervention of the state. In addition, electricity trading companies and non-regulated final users act by entering into electricity contracts. Figure 2 shows the electricity consumption by sectors; manufacturing sector accounted for 21% of this consumption, after the residential sector and commercial public sector with 39% and 27% respectively (UPME, 2018).

3.1. Structure of Colombian Manufacturing Sector

In Colombia, manufacturing sector is formed by 23 divisions, as a product of the revision 3.1 A.C update, through the Statistics Administrative Department (DANE) adopting the revision 4 A.C that is in correspondence with the fourth revision of the International Standard Classification of All Economic Activities (ISIC, Rev 4),(United Nations, 2018; DANE, 2018). This sector is made up of more than 8,000 companies headed by the food sector, representing a 18% of the total, followed by wearing apparel and rubber and plastics products manufactures. Table 2 shows a detailed structure and the number of companies by division.

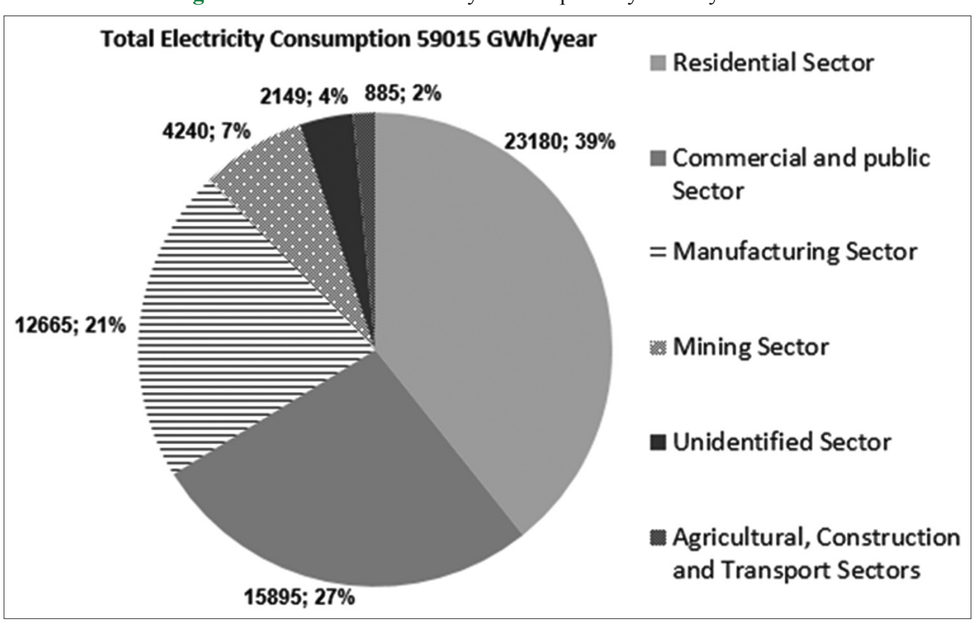
Companies always will seek for an optimal location, with good access to markets, suppliers and a higher concentration of other companies to take advantage of the attraction of mobile production factors. It produces the economy concentration phenomenon and a circular and cumulative causation that leads to an agglomeration of activities that is progressively reinforced. In Colombia (Lotero et al., 2009). Even though different industrial policies have been applied in recent decades, it has not been possible to reduce these regional disparities. This phenomenon, in addition to the armed conflict that hit the country for more than 50 years, has led a large centralization of the manufacturer sector. In the departments of Cundinamarca, Antioquia and Valle del Cauca are registered

Table 1: Strategies for saving electricity in CASs

Energy savings strategy	Annual energy savings %	Applicability %	Potential contribution %	Payback period (Months)	Annual cost ($$)
Using cooler intake air	10	40	4	5	1,400
Compressors controls	10	30	3	8	7,900
Compressors pressure reduction	15	50	7.5	4	2,800
Reducing air leaks	30	53	15.9	3	3,900
Eliminating or reducing compressors air used	25	10	2.5	6	7,300
Air compressor waste heat recovery	20	20	4	10	2,700
Total			36.9		

Source of data: Prepared by the authors based on data from: (Radgen and Blaustein, 2001, Saidur et al., 2010, Benedetti et al., 2017a). Where potential contribution=Annual energy savings applicability, CASs: Compressed air systems

Figure 2: Colombian electricity consumption by sector year 2017



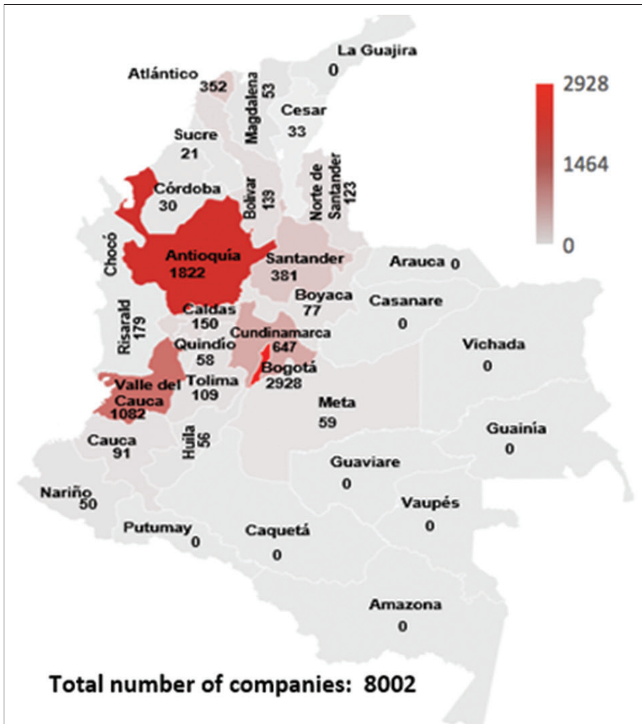
Source: Prepared by the authors based on data from: (UPME, 2018) more than 65% of the companies in the industrial sector which implies a high concentration by regions. Highlighting some divisions such as textile, wearing apparel, printing and reproduction of recorded media, pharmaceuticals, medicinal chemical and botanical product manufactures reaching an 85%. Otherwise, in ten departments do not exist manufacturing sector industries. Figure 3 shows the number of companies in the manufacturing sector by departments. and the number of companies and percentage of concentration per division in these three departments.

Table 2: A detailed structure of Colombia manufacturing section by number of companies

Section	Division	Description	Number of companies	% of total
C. Manufacturing	10	Manufacture of food products	1,528	19.1
	11	Manufacture of beverages.	116	1.4
	12	Manufacture of tobacco products	-	-
	13	Manufacture of textiles	283	3.5
	14	Manufacture of wearing apparel	894	11.2
	15	Manufacture of leather and related products	363	4.3
	16	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	179	2.2
	17	Manufacture of paper and paper products	143	1.8
	18	Printing and reproduction of recorded media	437	5.5
	19	Manufacture of coke and refined petroleum products	115	1.4
	20	Manufacture of chemicals and chemical products	561	7.0
	21	Manufacture of pharmaceuticals, medicinal chemical and botanical products	200	2.5
	22	Manufacture of rubber and plastics products	689	8.6
	23	Manufacture of other non-metallic mineral products	498	6.2
	24	Manufacture of basic metals	172	2.1
	25	Manufacture of fabricated metal products, except machinery and equipment	630	7.9
	26	Manufacture of computer, electronic and optical products	25	0.3
	27	Manufacture of electrical equipment	183	2.3
	28	Manufacture of machinery and equipment n.e.c.	413	5.2
	29	Manufacture of motor vehicles, trailers and semi-trailers	177	2.2
	30	Manufacture of other transport equipment	30	0.4
	31	Manufacture of furniture	369	4.6
		Total	8,002	

Source: Prepared by the authors based on data from: (CIIU revision 4. A.C, DANE, 2018)

Figure 3: Number of companies by department and concentration factor in the three main departments



Section	Division	Number of companies In Bogotá, Antioquia y Valle del Cauca	% of Concentration
C. Manufacturing	10	847	55
	11	55	47,4
	12	-	-
	13	241	85,2
	14	760	85,0
	15	236	65
	16	1210	67,6
	17	109	76,2
	18	373	85,4
	19	52	45,2
	20	390	69,5
	21	170	85,0
	22	534	77,5
	23	238	47,8
	24	103	53,3
	25	464	73,7
	26	18	72
	27	149	81,4
	28	319	77,2
	29	122	68,9
	30	25	83,3
	31	281	76,8
Total		5607	69,7

Source: Prepared by the authors based on data from: (DANE; 2018)

3.2. Electricity Consumption in Manufacturing Divisions. CASs Share and Energy Savings

Figure 4 shows the electricity consumption of manufacturing section between divisions 10 and 31 in 2017. It is noted that two divisions consume near than the 50% of electricity which corresponds to the Manufacture of basic metals and Manufacture of food products sectors.

In Colombian manufacturing sector, the driving force, that includes pumping systems, CASs and other applications, consume more than 70% of the totalelectricity, followed by direct heat and cooling systems (UPME, 2016). A study in more than five hundred of companies in the country showed that energy savings percent in the CASs are around 30% in corrections such as leaks reduction, automation, control and compressors pressure reduction (UPME, 2016, UPME, 2014a).

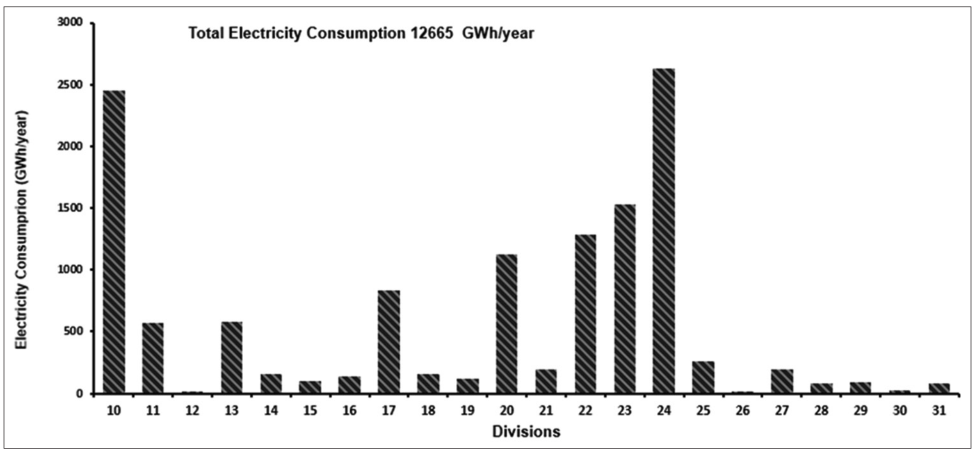
Figure 5 shows the electricity consumption in CASs by divisions for the manufacturing section, the energy costs total share and the energy savings potential considering that there were applied the efficiency measures mentioned above. The CASs electricity share costs in all divisions are around 8% highlighting divisions such as manufactures where it is reached a 24%.

Three divisions consume the 60% of CASs electricity and the total energy savings reach 284.1 GWh/year being the manufacture divisions with most impact the food products with 73.5 GWh/year, rubber and plastics products with 49.3 GWh/year and textiles with 41.7 GWh/year. If it is considered the relationship between the savings potential and the number of companies in these three divisions, to analyze the impact in each company, it can be observed that the implementation of energy efficiency measures in the CASs will have the greater impact in textile manufactures. Table 3 shows these results.

3.3. Potential Energy Savings by Regions

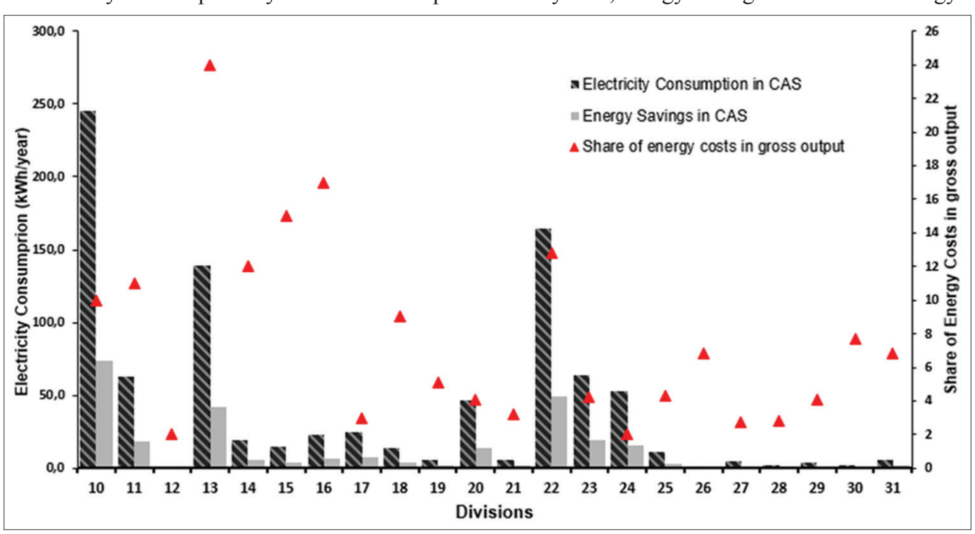
In Colombia, it is estimated that annual losses caused in the country by environmental pollution reach the 1.96 billions USD and nearly 5000 premature deaths. Bogotá and Valle de Aburra in Antioquia represent more than 75% of these values due to their high values of environmental pollution (Echeverri and Hincapié 2012; Jaramillo, 2019). For this reason, in recent years the environmental authorities have had to declare in the city of Medellin atmospheric contingency levels in 2016 (AMVA 2016), red alert phase I in 2017 and alert level in 2018 (AMVA 2018), in Bogota the yellow alert was implemented in February 2019.

Figure 4: Total electricity consumption in Industrial Sector by divisions in 2017



Source: Prepared by the authors based on data from: (UPME BECO, 2018)

Figure 5: Electricity consumption by division in compressed air system, energy savings and share of energy cost 2017



Source: Prepared by authors based on data from: (UPME BECO; 2018; UPME CORPOEMA, 2014; UPME INCOMBUSTION, 2013)

Table 3: Number of companies and energy savings in the three divisions that consume the 60% of CASs electricity

Section	Division	Description	Number of companies	Energy saving MWh/year	Energy savings/Number of companies
C. Manufacturing	10	Manufacture of food products	1,528	73,500	48.2
	13	Manufacture of textiles	283	41,700	147.7
	22	Manufacture of rubber and plastics products	689	49,300	71.55

Source: Prepared by the authors based on data from: (CIIU revision 4. A.C, UPME BECO, 2018). CASs: Compressed air system

Figure 6: Energy savings by departments and CO_2 potential reduction prepared by the authors

Department	Potential of savings GWh/year	% Total	CO_2 Potential reduction Tonnes
Antioquia	61,3	22,3	13015
Amazonas	-	-	-
Arauca	-	-	-
Atlántico	12,7	4,65	2716
Bogotá	86,1	31,4	18342
Bolivar	15,0	5,48	1056
Boyacá	3,29	1,21	699
Caldas	4,34	1,58	924
Casanare	-	-	-
Caquetá	-	-	-
Cauca	4,30	1,57	915
Cesar	1,16	0,42	246
Chocó	-	-	-
Córdoba	1,39	0,51	297
Cundinamarca	24,1	8,78	5123
Guainía	-	-	-
Guaviare	-	-	-
Huila	2,25	0,82	478
La Guajira	-	-	-
Magdalena	2,32	0,85	495
Meta	2,74	1,0	584
Nariño	1,49	054	317
Putumayo	-	-	-
Norte de Santander	3,52	1,28	749
Quindío	1,22	0,44	260
Risaralda	5,28	1,93	1124
Santander	11,7	4,65	2482
Sucre	0,64	0,23	135
Tolima	3,76	1,37	800
Valle del Cauca	35,6	13,0	7590
Vaupes	-	-	-
Vichada	-	-	-
Total		284,12	58349

Source: (UPME BECO; 2018; UPME CORPOEMA, 2014; UPME INCOMBUSTION, 2013)

The potential for energy savings in CASs in the country is distributed very differently among the departments, caused by the economy concentration phenomenon. Bogotá and Antioquia are the departments with the greatest saving potentials, they concentrate more than 50% of energy savings. Figure 6 shows the potential savings by department and the impact in the reduction of CO_2 emissions, considering the specific emission factor for power generation in Colombia of 0.2129 kg Co_2/kWh (Roa and Castellanos, 2018). Total reduction is equivalent to 58,349 tonnes of CO_2/year highlighting the departments of Bogota and Antioquia with 18,342 and 13,015 tonnes respectively.

4. CONCLUSIONS

CASs are widely used in the industrial sector and represent around a 10% of the total electricity consumption. In Colombia this value is 8% and it is equivalent to 1.39 TWh/year. The potential savings in these systems by applying energy efficiency measures such as matching supply and demand, reducing pressure settings, reducing average inlet temperature, optimizing air compressor location and mainly reducing leaks may give between 20 and 60% of energy savings with a usual pay back less than two years In Colombia, this potential is 30%.

The energy savings potential in Colombia due to apply these measures is 284.1 GWh/year where the manufacture divisions with most impact are food products with 73.5 GWh/year, rubber and plastics products with 49.3 GWh/year and textiles with 41.7 GWh/year. If it is considered the relationship between savings potential and the number of companies, the implementation of energy efficiency measures in CASs will have a greater impact in the last one.

Due to the economy concentration, these savings are not equal distributed in all departments, only two of them (Bogotá and Antioquia) have more than 50% of these savings potential equivalent to 147.4 GWh/year. Both departments in recent years have presented problems with environmental pollution, applying these measures will allow them to reduce CO_2 emissions by 18,342 and 13,015 tons of CO_2 respectively. The potential for reducing emissions throughout the country amounts to 58,349 tons of CO2.

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