AN INVESTIGATION INTO THE FACTORS AFFECTING INDUSTRIAL IMPLEMENTATION OF COMBINED HEAT AND POWER (CHP)

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Doctor of Philosophy

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by

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The undersigned, appointed by the dean of the Graduate School,

have examined the dissertation entitled

AN INVESTIGATION INTO THE FACTORS AFFECTING INDUSTRIAL IMPLEMENTATION OF COMBINED HEAT AND POWER (CHP)

Presented by Jorge Fernando Abad Moran

A candidate for the degree of

Doctor of Philosophy

And hereby certify that, in their opinion, it is worthy of acceptance.

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List of Nomenclatures

ARs: Assessment Recommendations

BTU: British Thermal Units

CEPS: Clean Energy Portfolio Standards

CHP TAPs: CHP Technical Assistance Partnerships

CHP: Combined Heat and Power

CO_2: Carbon Dioxide

EE: Energy Efficiency

EERS: Energy Efficiency Resource Standards

FERC: Federal Energy Regulatory Commission

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GW: Gigawatts. 1 GW = 1 x 10^9 Watts

Hg: Mercury

HP: Horse Power

HSM: Hard system methodology

IAC: Industrial Assessment Center

IRB: Institutional Review Board

ITC: Investment Tax Credits

Ktoe: Kilotonne of oil equivalent

kW: Kilowatts. 1 kW = 1,000 Watts

kWh: Kilowatt-hour

LPG: Liquefied Petroleum Gas

MMT: Million Metric Tons

MoIAC: Missouri Industrial Assessment Center

MW: Megawatt. 1 MW = 1 x 10^6 Watts

NO_x: Nitrogen Oxides

ORC: Organic Rankine Cycle

PTC: Production Tax Credits

PURPA: Public Utilities Regulatory Policies Act

QUAD: Quadrillion BTU, 1 Quad = 1 x 10^{15} BTU

RPS: Renewable Portfolio Standards

SHP: Separate Heat and Power

SME: Small and Medium Enterprises, in this dissertation means Small Medium Industries

SO_2: Sulfur Dioxide

SRC: Steam Rankine Cycle

SSM: Soft system methodology

US DOE: US Department of Energy

US EPA: US Environmental Protection Agency

WHP: Waste Heat to Power

WSM: Weighted Scoring Model

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ABSTRACT

This dissertation investigates the factors affecting adoption rate of combined heat and power (CHP). CHP, also known as cogeneration, is an efficient approach to producing electricity and thermal energy simultaneously from a single fuel source close to the point of use. CHP is an energy efficiency (EE) initiative with several economic, environmental and societal benefits. However, its full potential has not been achieved due to the presence of barriers and the creation of what is called “CHP gap” or “CHP paradox”. To overcome this “CHP paradox”, this dissertation developed a framework for the effective promotion and implementation of CHP initiatives. This framework was analyzed using Industrial Assessment Center database and the results of a survey taken by CHP stakeholders. Twelve hypotheses were tested using logistic regression and ANOVA models. It was found that payback period and savings generated by CHP projects are the most important factors that influence CHP adoption rate in the early stages of the CHP evaluation process. During the latest stages of the CHP development project, utilities programs, outreach programs and supportive regulation are the significant factors that influence CHP adoption rate. With the information generated during this dissertation, an implementation guide was developed. This implementation guide takes all stakeholders into consideration and presents two tools that will help industries in the early stages of the CHP decision-making process.

1. Introduction

1.1 Area of the Research

Energy is a key factor for economic growth, industrial competitiveness, employment, and improvement of our quality of life (Abdelaziz et al., 2011, Kandpal and Garg, 1999). Therefore, the rational use of energy is important in order to balance energy availability and consumption (Dias et al., 2004). It is now widely accepted that energy efficiency should be regarded as a source of energy (Wu and Abad, 2013).

Several authors worldwide stress the importance of exerting pressure to reduce energy use, to reduce greenhouse emissions effects, and to change energy sources to more renewable ones (Abadie et al., 2012, Martin et al., 2012, Zografakis et al., 2008). Moreover, if people continue to behave the same way and governments do not change energy policies, by 2030 the world's energy consumption will increase in the order of 33% to 50% (Abdelaziz et al., 2011, Desha and Hargroves, 2010). This is particularly critical in the world's industrial sector and in United States, which represents 37% and 25% of the world's energy consumption respectively (Abdelaziz et al., 2011, Kalam et al., 2012). In the United States, 32% of the total energy is consumed by the manufacturing sector (Masanet, 2010, Alhourani and Saxena, 2009). Under these conditions, research and government initiatives establishing energy efficiency policies (using less energy to provide the same products or services) are extremely important. Moreover, it can be argued that right now is the right moment for energy efficiency (EE) initiatives in the Unites States, based on the 2013 state of the union address, where President Obama defined the goal of doubling US energy productivity by 2030 (U.S. Department of Energy (DOE), 2014a).

Energy efficiency (EE) is recognized as an essential component of climate change and energy policy portfolios. Implementation of these efficiency measures reduces operating cost and greenhouse emissions and increases firms' productivity (Lopes et al., 2012, Abadie et al., 2012). One of the most appealing EE initiatives that industries could implement is combined heat and power (CHP) (Kalam et al., 2012). CHP is an efficient approach to produce electricity and thermal energy simultaneously from a single fuel source close to the point of use (Shipley et al., 2008). As a result of their higher efficiency, CHP systems reduce energy consumption, greenhouse gas (GHG) emissions, and operating costs making industries more competitive (Kerr, 2008, Chittum and Kishmohr, 2014, Kalam et al., 2012). Furthermore, CHP has demonstrated a successful performance during large electricity outages and natural disasters (Athawale and Felder, 2014, Shipley et al., 2008).

According to Kalam et al. (2012) CHP is an implementable solution that can address the growing constraints on a country's energy future. The importance of CHP in the United States can be seen in President Obama's Executive Order of Accelerating Investment in Industrial Energy Efficiency (The White House and Office of the Press Secretary, August 30, 2012), where he established a national goal of 40 new gigawatts of CHP by 2020; that means a 48% increase from the 2014 CHP installed capacity—83 GW in 4,346 facilities—(ICF International, 2015). However, despite all the benefits provide by CHP initiatives, much of these cost-effective investments are not made due to the presence of CHP barriers that create what is called "CHP Gap" or "CHP Paradox" (Athawale and Felder, 2014). It is argued that a way to overcome an EE Gap—in our case a CHP Gap—is by developing a framework that takes into consideration barriers interaction and stakeholders' effects (Wu and Abad, 2013, Chai and Yeo, 2012). This framework is based on a system view approach that promotes an effective implementation of CHP initiatives and increases their adoption rate.

The importance of such a framework increases as a result of the low percentage of CHP as a source of capacity generation in United States (8%) in comparison with other countries such as Denmark, Finland, and Russia (more than 30%) (Hedman et al., 2013a). This framework will be analyzed using the United States as a case study.

1.2 Aim and Objectives of the Dissertation

The main objective of this research is to use a system view approach to develop a framework for the effective implementation of CHP. This framework will consider interactions and effects between barriers and stakeholders, and it will identify the main drivers to overcome CHP barriers and to increase the CHP implementation rate. The scope of this research includes only industrial facilities; it will not cover commercial, hospital, universities and residential sectors. Although due to its general characteristics, the industrial scope could be applied to these others sectors with minor modifications.

In order to analyze the framework, a research model will be developed. This model will be designed to investigate the main barriers and drivers affecting CHP adoption and the interaction effects between stakeholders and barriers. Therefore, it will define general hypotheses applied to all stakeholders and specific hypotheses for each stakeholder.

This research answers the following questions:

1. Is the importance of combined heat and power the same for all stakeholders?

2. What are the main factors affecting the implementation rates in CHP?
3. Are these factors the same for all stakeholders?
4. Are the main factors affecting implementation rates in CHP the same as in heat recovery and other energy efficiency initiatives?
5. What activities have to be performed by each stakeholder in order to increase the industrial adoption of CHP?

Finally, the engineering outcome of this research will be an implementation guide for CHP.

1.3 Methodology used in the Dissertation

This dissertation followed the seven phases presented in Figure 1.1. These phases are:

1. A detailed literature review of the main issues regarding CHP as well as research methods needed to develop effective frameworks and to obtain information from each stakeholder. Also, research about statistical tools needed to evaluate database and survey results. This literature review is a continuous process.
2. Research Characteristics. This topic focuses on the scope of the dissertation, which is presented through objectives, an organized approach as reflected in the table of contents and the establishment of questions, which are systematically answered. The scope was refined with a concentration on industries. The framework and guidelines can, however, be applied to others market sectors such as commercial and residential with some modifications.

3. CHP: Main Issues. The main idea of this phase is to present a thorough understanding of combined heat and power characteristics in order to develop a useful framework and guidelines that will help to increase CHP implementation rates. This step will include technologies, benefits, barriers, drivers, market status and case studies. The case studies will be the CHP market status of the State of Missouri and opportunity of CHP implementation for the cement, glass and metal products industry.

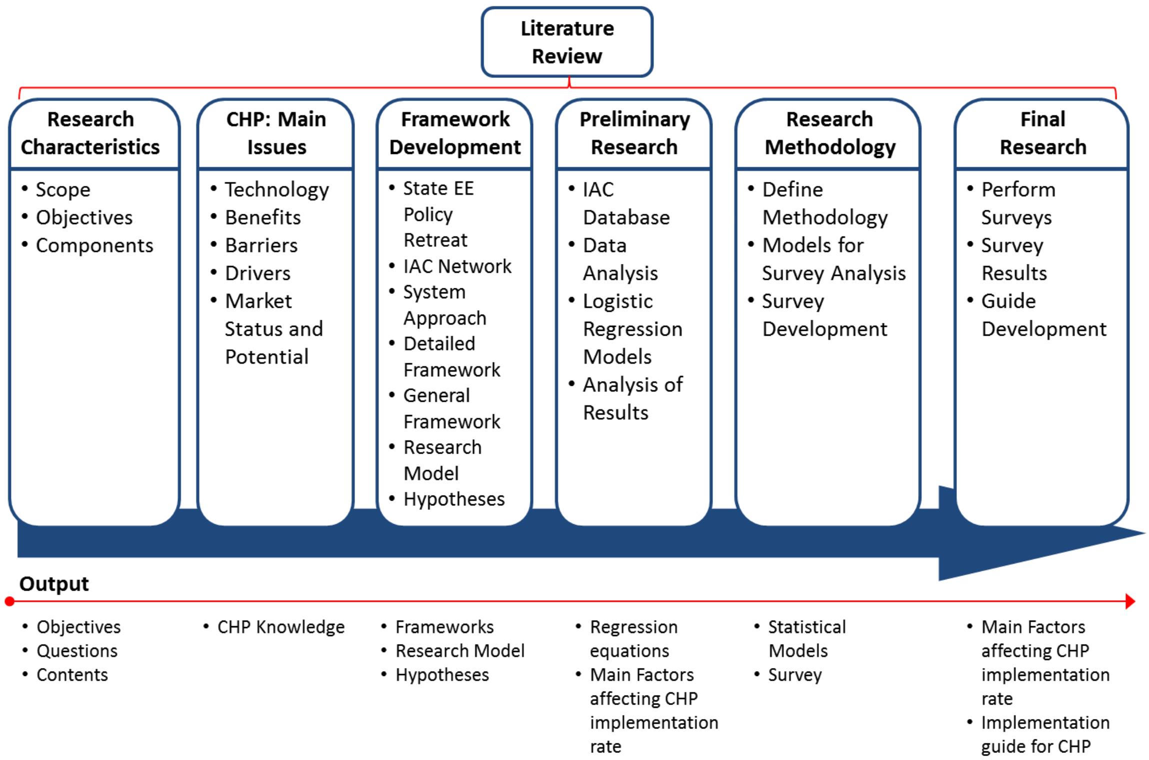


Figure 1.1: Research Process

4. Framework Development. A system theory approach will be used to develop both a detailed and general framework for the effective implementation of CHP. The author’s participation in a state energy efficiency policy retreat (August 2014) and the Missouri Comprehensive State Energy Plan (December 2014-May 2015) will give insight into stakeholders’ information for framework and guideline development. With all this

information a research model and research hypotheses was developed in order to evaluate CHP frameworks.

5. Preliminary Research. The next part of this research evaluates model hypotheses from an industrial perspective and determines the main factors affecting CHP implementation rates. These factors are compared with those affecting waste heat recovery and others EE initiatives. The Industrial Assessment Center (IAC) database and eight different binary logistic regression models were used to carry out these analyses. Four logistic regression models were based on the payback period and four were based on implementation costs and savings.
6. Research Methodology. This phase started with the identification of the methodology needed to evaluate research hypotheses (from all stakeholders' perspective) and with an analysis of surveys. Based on the dissertation objectives, it was decided to use ANOVA and logistic regression models to evaluate survey results and developed a survey specifically designed for this research based on these models.
7. Final Research. This is the final phase of the dissertation. It consists of an analysis of survey results. Descriptive statistic, ANOVA and logistic regression models were used to validate research hypotheses and to identify the main factors affecting the CHP adoption rate from each stakeholder. With the validation of the research hypotheses and CHP Framework, it was possible to develop an implementation guide for CHP.

2. Energy Consumption and Efficiency in the Industrial Sector

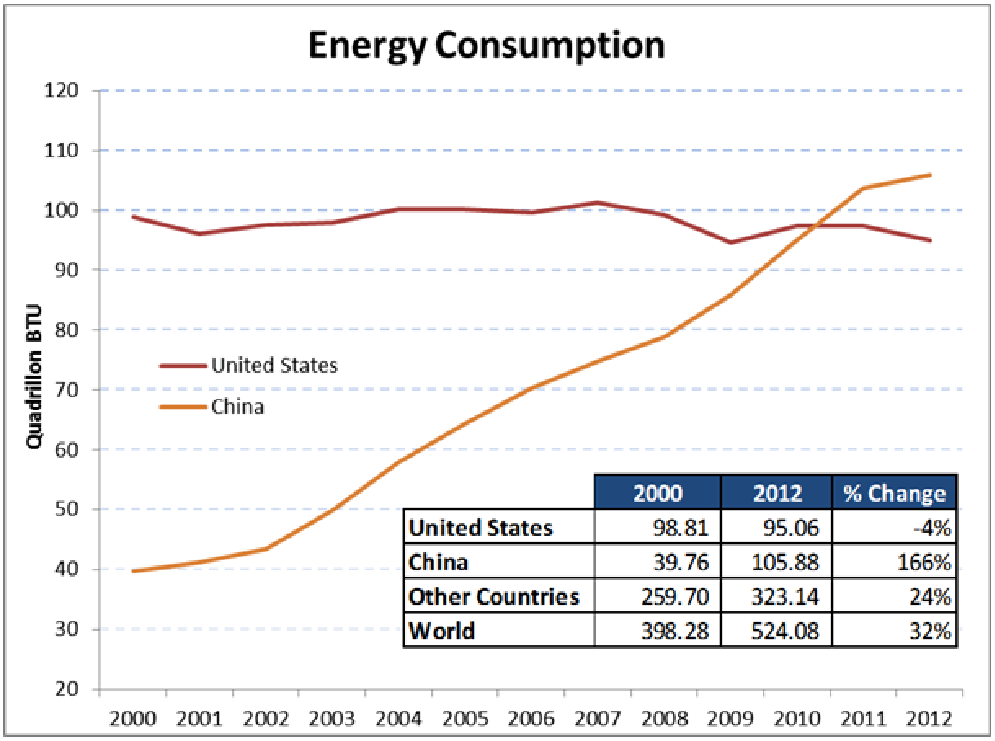
2.1 Background

Energy is crucial to any country's economic success, and energy keeps any economy running. Like other economic inputs, energy limits the speed and quality of economic growth. In other to achieve this growth; countries should use energy more efficiently. Expanding energy supply makes energy services such as lighting, heating, cooling and powering industries more available and affordable (Rhodium Group (RHG), 2013). Moreover, reliable, affordable and secure energy supplies are essential to economic stability and economic development (Kerr, 2008).

Until 2010, the United States was the country that consumed the most energy in the world. After 2010 it was surpassed by China. The United States consumed 98.81 quadrillion BTUs in 2000 and its consumption decreased by 4% to 95.06 quadrillion BTUs in 2012. On the other hand, China increased their consumption by 166% from 39.76 quadrillion BTUs in 2000 to 105.88 quadrillion BTUs in 2012. World energy consumption also increased 32% during the same period from 398.28 quadrillion BTUs in 2000 to 524.08 quadrillion BTUs in 2012. In 2000 the United States represented 25% of the world's energy consumption; this share was reduced to 18% by 2012. China in the same period increased their share from 10% to 20% in 2012 as shown in Table 2.1 and Figure 2.1.

Table 2.1: Share of the Total Primary Energy Consumption (Quadrillion BTUs). Source: U.S. Energy Information Administration (2015)

	2000	2012	% Change
United States	25%	18%	-7%
China	10%	20%	10%
Other Countries	65%	62%	-4%
World	100%	100%	



	2000	2012	% Change
United States	98.81	95.06	-4%
China	39.76	105.88	166%
Other Countries	259.70	323.14	24%
World	398.28	524.08	32%

Figure 2.1: Total Primary Energy Consumption (Quadrillion BTUs).
Source: U.S. Energy Information Administration (2015)

In terms of CO_2 emissions, as can be seen in Figure 2.2, the United States in 2014 was responsible for 14% of worldwide CO_2 emissions, an improvement from the 1990 figure of 19% and the cumulative historical figure of 25%. The country that currently contributes more to emissions is China with 26% in 2014, deteriorating from their 1990 figure of 11%.

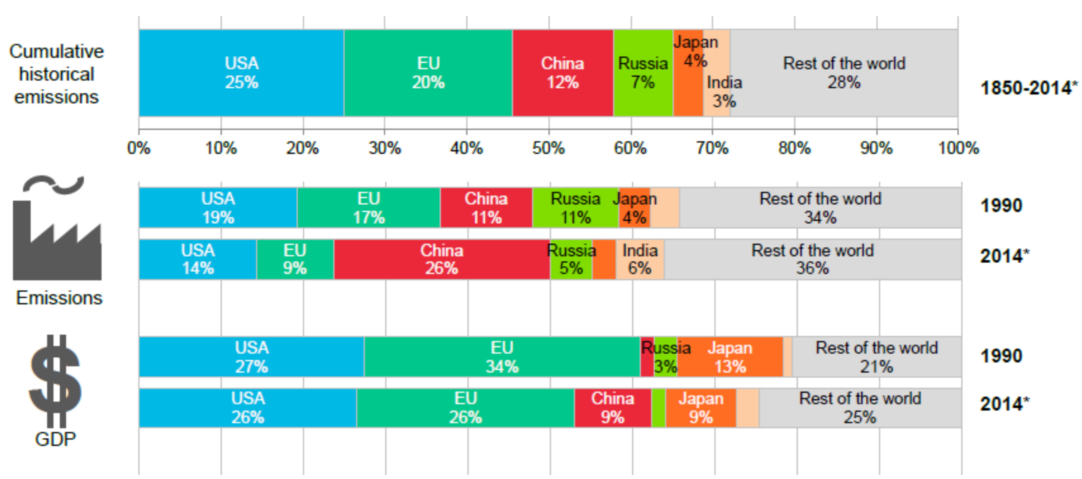


Figure 2.2: Comparative Emissions and GDP by Region.
Source: Bloomberg New Energy Finance (2015)

The United States is becoming less dependent on energy imports. Net energy imports have fallen by over 50% since 2005, reaching levels of 1988 as can be seen in Figure 2.3

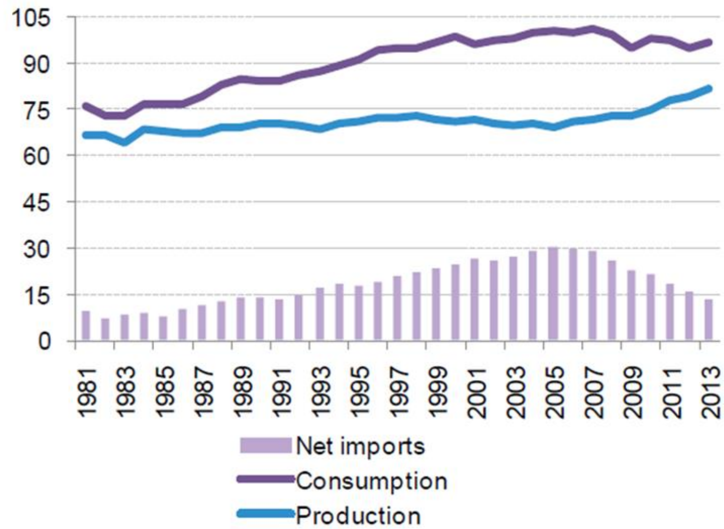


Figure 2.3: US primary energy consumption, production, and net imports, 1981-2013 (Quadrillion BTUs), Source: Bloomberg New Energy Finance (2014)

As can be seen in Figure 2.4 and Figure 2.5, the industrial sector, which includes manufacturing, mining, construction and agriculture, is the largest energy user in the United States. It represented 32% of U.S. energy consumption in 2012 and is forecast to increase to 36% in 2040.

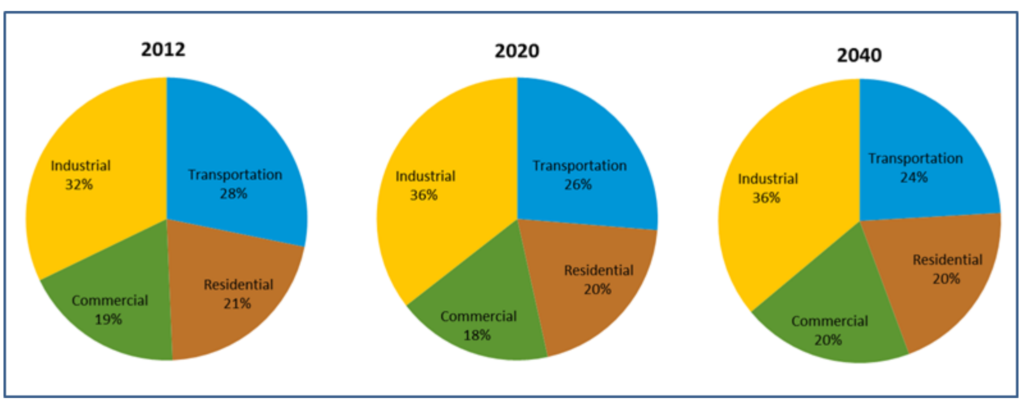
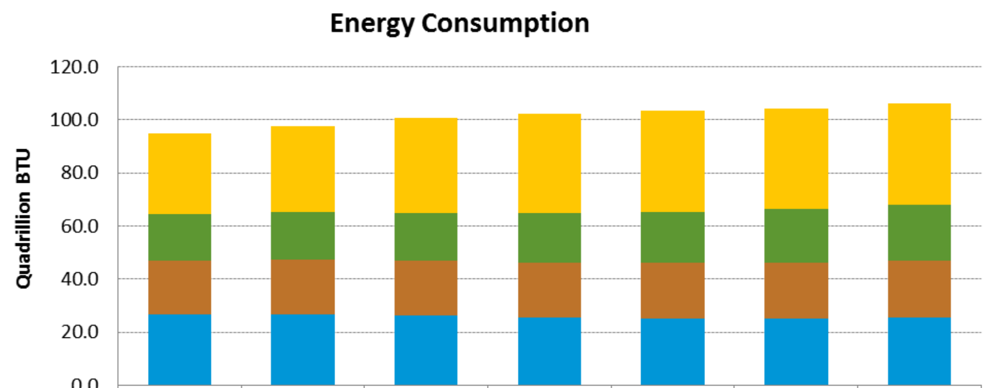


Figure 2.4: Total Primary Energy Consumption (Quadrillion BTUs). Source: U.S. Energy Information Administration (2014)



	2012	2015	2020	2025	2030	2035	2040
Industrial	30.5	32.6	35.8	37.4	37.9	38.0	38.3
Commercial	17.6	17.8	18.1	18.8	19.3	20.0	20.9
Residential	20.1	20.5	20.4	20.6	20.8	21.1	21.5
Transportation	26.8	26.8	26.5	25.7	25.2	25.2	25.6

Figure 2.5: Primary energy use by end-use sector (Quadrillion BTUs). Source: (U.S. Energy Information Administration, 2014)

According to the U.S. Department of Energy (DOE) (2014b), the industrial sector spent over $200 billion each year to power their facilities and has the potential to invest over $100 billion in energy efficiency (EE) initiatives by 2020. This would generate an annual energy savings of $50 billion. Moreover, small and medium industries (SME) that account for 50% of the energy consumed by the industrial sector represent 90% of industrial facilities. Both large industries and SME have a significant opportunity to deploy energy efficiency initiatives and to promote a clean energy economy (Trombley, 2014, Brown et al., 2011)

In the case of Missouri, it spent $26,147 million on energy in 2012. The industrial sector represents 11% of the expenditures and 21% of the energy consumption (372 trillion BTUs). The sector with the biggest consumption and expenditure is the transportation sector with 30% and 58%, respectively. This can be seen in Figure 2.6.

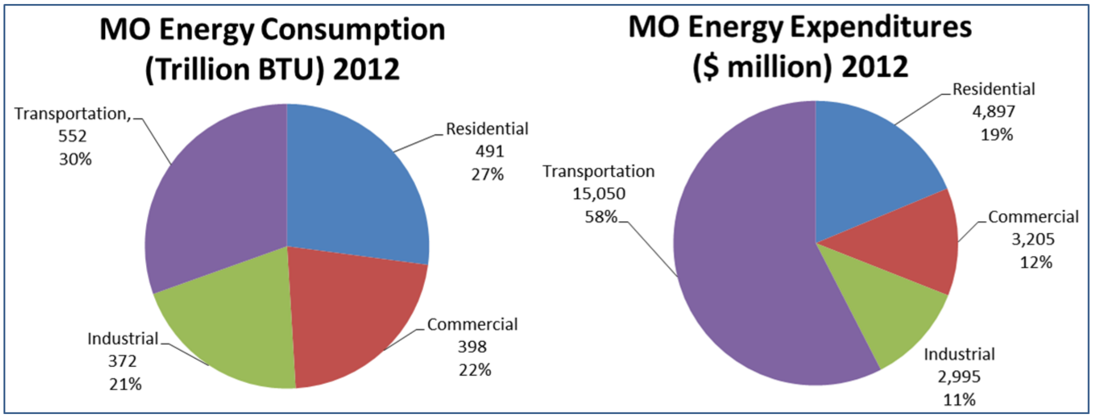


Figure 2.6: MO Energy Consumption and Expenditures.
Source: U.S. Energy Information Administration (2015)

2.2 Energy Productivity and Energy Intensity

There are two energy indicators used for comparisons between countries, regions, sectors, and firms: 1) energy productivity and 2) energy intensity. Both indicators measure the relationship between outputs and inputs, and it is important to note that the unit of the output will depend on the type of comparison and available information. The output could be a production measured in units, by weight, in currency, as a percentage of GDP, etc. The general formulas are as follows:

$$\boldsymbol{Energy\ Productivity} = \frac{Output}{Input} = \frac{Production\ Units}{Energy\ Consumption}$$

$$\boldsymbol{Energy\ Intensity} = \frac{Input}{Output} = \frac{Energy\ Consumption}{Production\ Units}$$

Based on the concepts of these formulas, the bigger the value of energy productivity, the better the performance. On the other hand, in the case of energy intensity, the smaller the value of energy intensity, the better the performance.

United States energy intensity performance over the years can be seen in Figure 2.7. Here two types of energy intensity indicators are used: one utilizing US population as an output and the other utilizing gross domestic product (GDP). Both indicators show in the long run an improvement from 1980 figures, especially energy intensity per 2005 dollar of GDP.

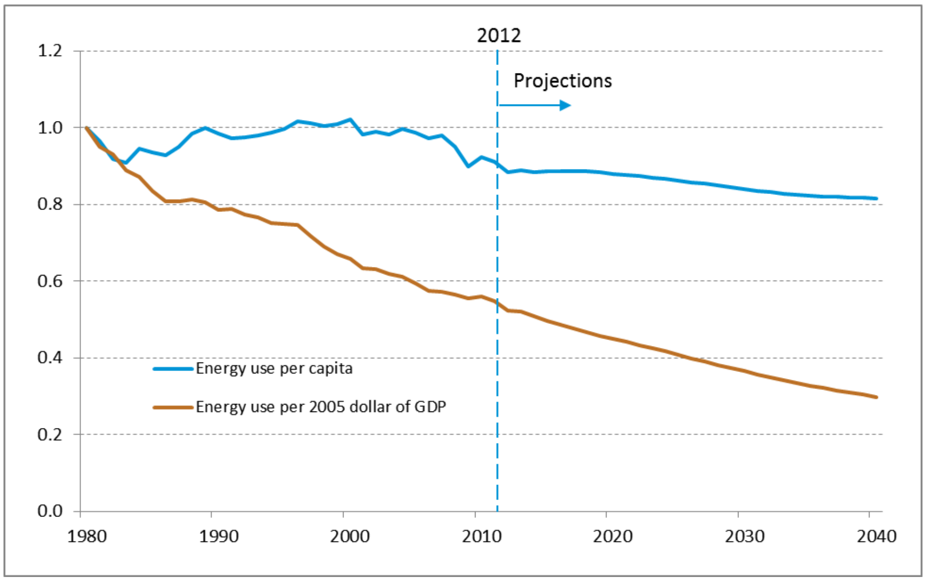


Figure 2.7: Energy Intensity: per capita and per dollar of gross domestic product.
Source: U.S. Energy Information Administration (2014)

The performance of the State of Missouri regarding energy intensity has a different result than US performance. This can be seen in Figure 2.8. While the US has improved in energy intensity, Missouri has worsened.

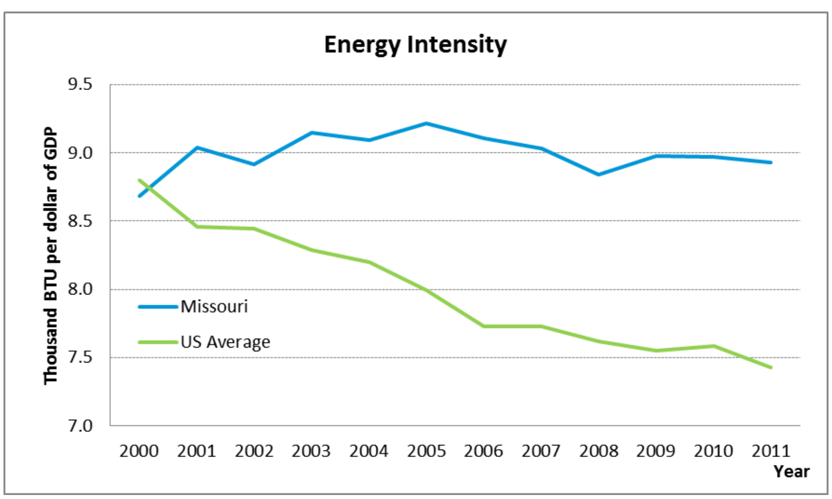


Figure 2.8: Energy Intensity.
Source: U.S. Energy Information Administration (2015)

The US energy productivity performance with the projection of doubling US energy productivity by 2030 (President Obama's goal) can be seen in Figure 2.9. According to the Rhodium Group (RHG) (2013), doubling energy productivity will cost $166 billion a year in additional investment. However, it would create 1.3 million jobs, save $327 billion a year in energy expenses and would reduce emissions of carbon dioxide, nitrogen oxides and sulfur dioxide. Moreover, the US economy would be much more resilient to future energy price variations due to a reduction in the nation's dependence on imported energy from 19% today to 7% by 2030.

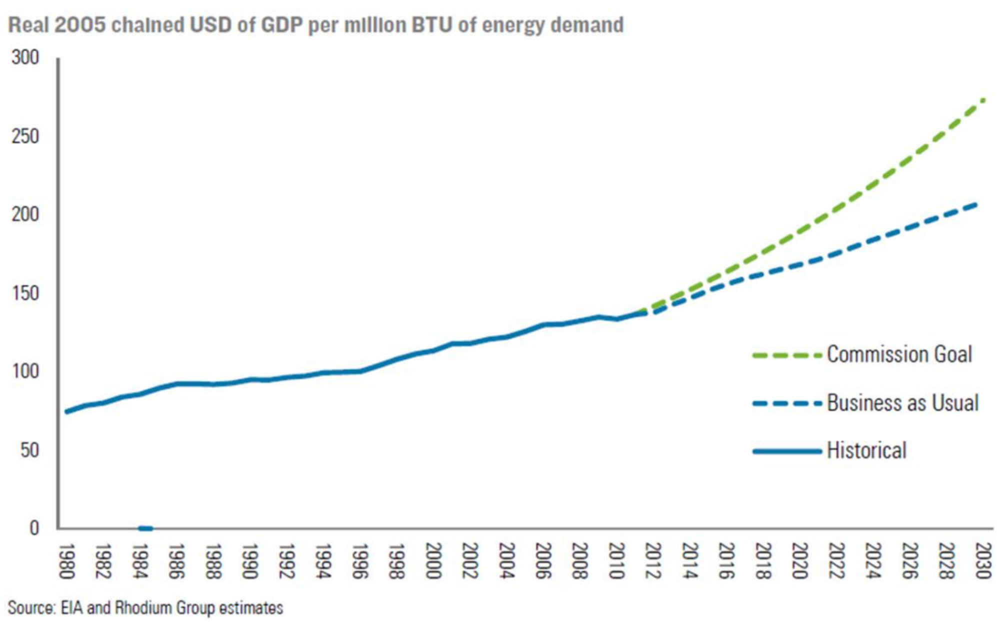


Figure 2.9: US Energy Productivity.
Source: Rhodium Group (RHG) (2013)

Not only can a comparison against its historical performance be done with an energy indicator, but comparisons between countries or companies are also possible. These comparisons can be seen in Figure 2.10 and 2.11. Although US energy productivity and energy productivity of the US manufacturing sector are improving, they still lag behind other industrialized countries such as Germany, Japan, the UK, and northwestern Europe. Simchak and Davis (2013) indicate that industrial processes lost between 20% and 50% of their energy as waste heat.

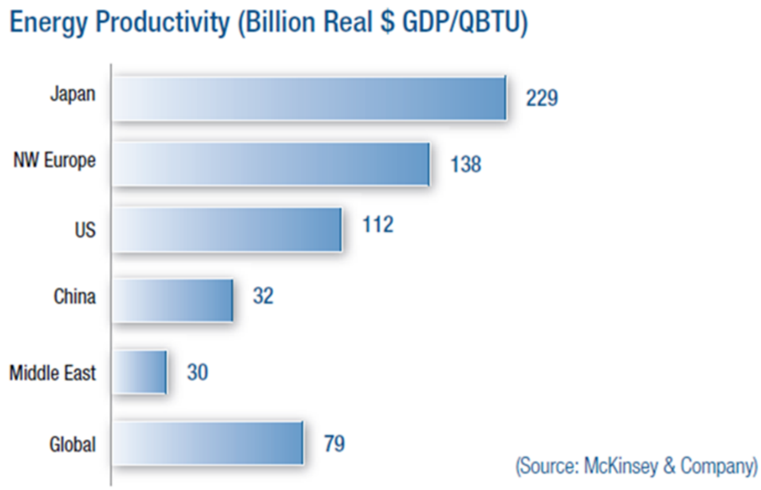


Figure 2.10: Countries Energy Productivity.
Source: Choi Granade et al. (2009)

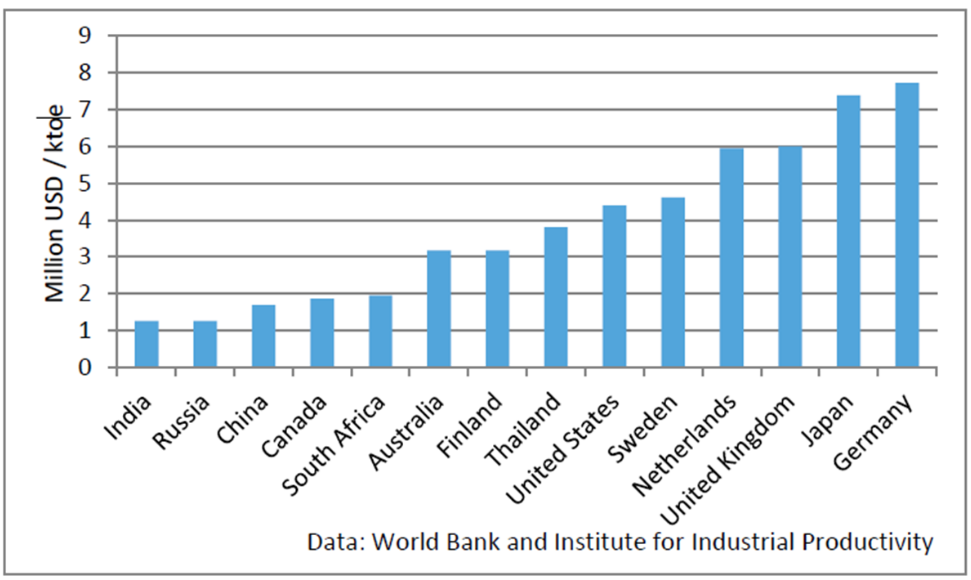


Figure 2.11: Industrial Energy Productivity.
Source: Simchak and Davis (2013)

2.3 Energy Efficiency and Combined Heat and Power

It is clear that Energy Efficiency (EE) initiatives are key elements to increasing a country's competitiveness, decreasing their carbon footprint, decreasing their energy consumption, increasing their energy supply security, and improving a country's energy policy portfolio (Kalam et al., 2012, Nock et al., 2012, Moya, 2013). Furthermore, improving EE is critical to increasing industrial competitiveness. Numerous studies about US industries have shown the potential for cost-effective EE initiatives. However, their implementation has been slow to materialize due to the existence of regulatory, financial, workforce and information obstacles (Brown et al., 2011, Reinaud and Goldberg, 2011).

According to Hayes et al. (2014) and Vaidyanathan et al. (2013), the U.S. has made a lot of progress regarding EE since the 1970s and a huge part of that progress lies in transforming EE into the most abundant energy resource. EE has been responsible for reducing U.S. energy consumption by 50% of what it would have been if business-as-usual had continued (This can be seen in Figure 2.12). Nevertheless, there are EE cost-effective opportunities available to increase this effect further. However, as explained before, several barriers have prevented EE from realizing its full potential.

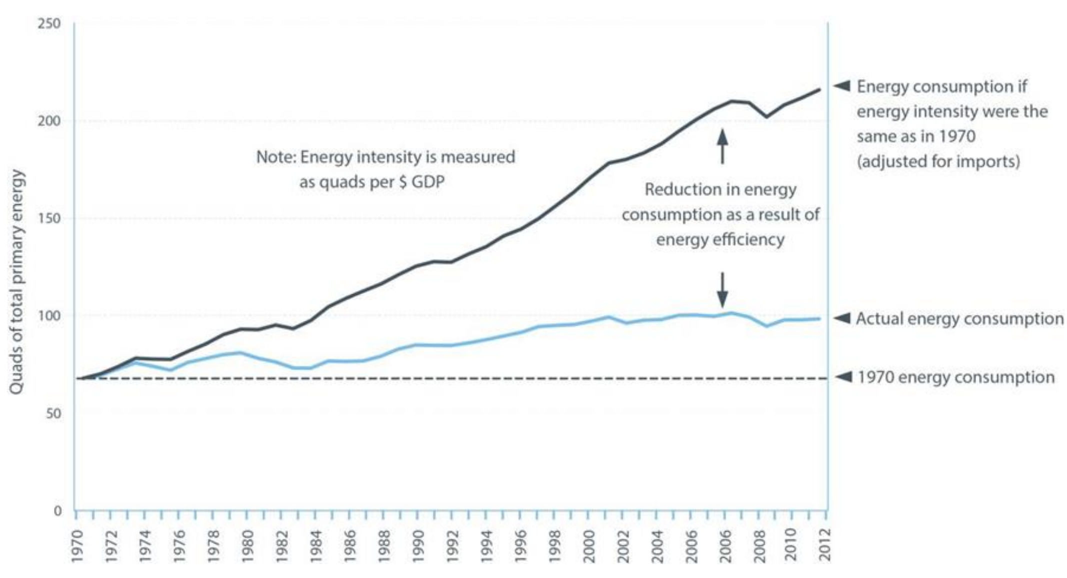


Figure 2.12: The effect of Energy Efficiency.
Source: Hayes et al. (2014)

As indicated by Hawes et al. (2012), EE costs are significantly less than other initiatives cost used to reduce carbon emissions. A comparison of different options can be seen in Figure 2.13

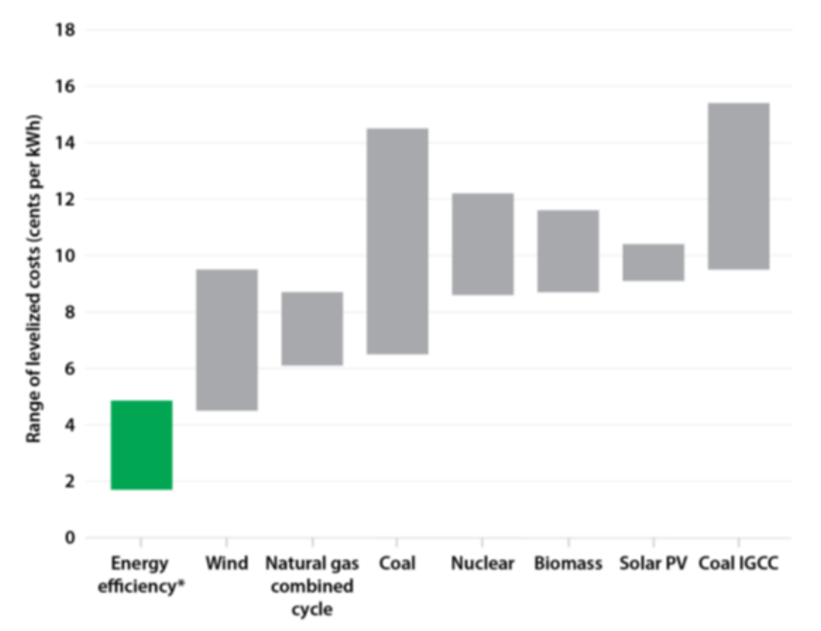


Figure 2.13: Comparison Costs.
Source: Hayes et al. (2014)

Finally, the Rhodium Group (RHG) (2013) indicates that is possible to reduce 22.4% of energy consumption per unit of output in the industrial sector through a combination of EE initiatives and greater implementation of combined heat and power (CHP). Simchak and Davis (2013) pointed out that CHP can improve thermal and electricity production by using waste heat.

3. Combined Heat and Power: A Review of the Main Issues

3.1 Definition of Combined Heat and Power

Combined heat and power (CHP), also known as cogeneration, is an efficient and clean approach to produce electricity and thermal energy simultaneously from a single fuel source (Shipley et al., 2008, Darrow et al., 2014). CHP is a type of distributed generation (also known as distributed energy) because its production takes place at or close to the point of use (Missouri Department of Economic Development. Division of Energy, 2014).

CHP is an integrated system that operates at a higher efficiency than a separate heat and power (SHP) system because heat that is usually wasted is recovered to produce electricity or useful thermal energy (U.S. Environmental Protection Agency (EPA), 2014, Ribeiro, 2014). Figure 3.1 shows that a CHP system uses less input fuel (100 units) in comparison with the amount of fuel needed by SHP (154 units) while providing the same amount of output energy (30 units of electricity and 45 units of heat = 75 units).

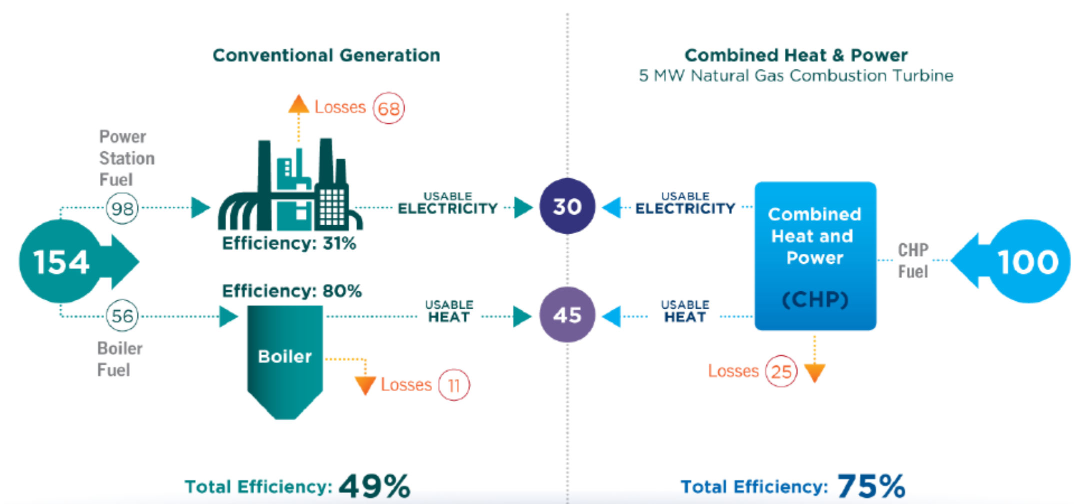


Figure 3.1: CHP Efficiency vs SHP Efficiency.
Source: Hedman et al. (2013a)

The conventional generation system (SHP) consists of two parts: the power station that uses 98 units of fuel to generate 30 units of electricity and the boiler that use 56 units of fuel to generate 45 units of heat. As can be seen, the majority of energy losses are generated in the power generation process. The higher efficiency of the boiler (80%) cannot compensate the inefficiency at the power plant (31%). On the other hand, CHP can minimize energy losses by using an integrated system to produce electricity and heat at the same time. A typical efficiency of a SHP is 45% and for CHP 70% to 90% (depending on what technology is used, type of application, and other factors). As a result of this higher efficiency, CHP systems save fuel and reduce greenhouse gas (GHG) emissions and operating costs (Chittum and Kishmohr, 2014, Kerr, 2008, Hedman et al., 2013a).

As indicated by the U.S. Environmental Protection Agency (EPA) (2015) CHP is an integrated group of technologies which provides onsite electrical generation, direct mechanical power, waste heat recovery for process application, heating, cooling, dehumidification, and seamless integration with the current site infrastructure.

CHP can be designed as a topping cycle system or a bottoming cycle system. The conventional topping cycle system, also known as direct-fired CHP, can be seen in Figure 3.2. First, the fuel is used in a reciprocating engine or gas turbine to generate electricity, and then, the waste heat captured from electricity generation by a heat recovery unit is used to provide steam or heating for industrial applications or cooling and heating as well as hot water to the facility (Hedman et al., 2013b). An optimal configuration of a conventional CHP system is to size it to meet the facility’s heat demand because it is cheaper to transport excess electricity than excess heat. For this reason, CHP can be seen mainly as a source of heat with electric power as a byproduct (Kerr, 2008).

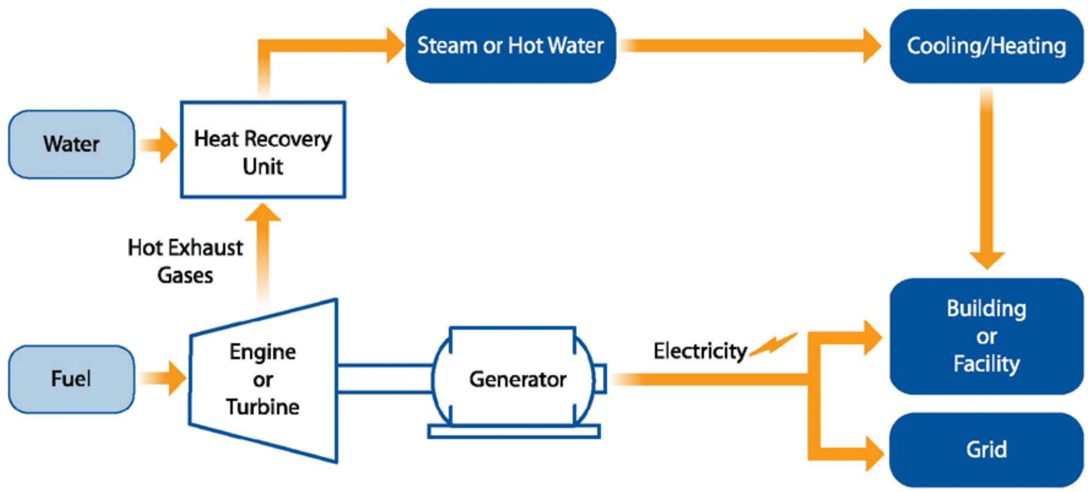


Figure 3.2: Topping Cycle CHP.
Source U.S. Environmental Protection Agency (EPA) (2015)

The less conventional configuration of the CHP system is the bottoming cycle system, also known as the waste heat to power (WHP) or indirect fired CHP. In this type of configuration as can be seen in Figure 3.3, the fuel is first used to provide useful heat to an industrial process, and then its waste heat is recovered to generate electric power. The main benefit of a WHP system is that it uses waste heat from their industrial process to generate electricity without consuming more fuel for this purpose (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012, Hedman et al., 2013b).

According to the U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership (2012), WHP is an unexploited type of CHP and can be used in a variety of industries such as glass, cement, chemical, steel and refineries. The capacity of these systems in generating power depends on the temperature of the waste heat source.

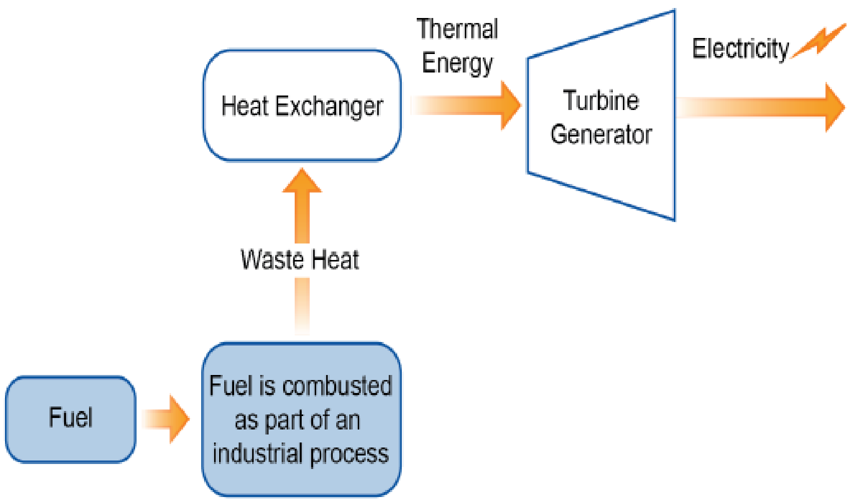


Figure 3.3: Waste Heat to Power: Bottoming Cycle CHP.
Source: U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership (2012)

3.2 CHP Technologies

CHP systems are typically classified by the type of technology that creates energy from fuel. The individual energy producer is called a prime mover. There are five primary types of prime movers: reciprocating engines, steam turbines, gas turbines, microturbines, and fuel cells (Chittum and Kishmohr, 2014, Darrow et al., 2014, Shipley et al., 2008). The prime mover consumes fuel to produce mechanical power to drive a generator to produce electricity. The heat generated by the prime mover can be used for industrial applications or for heating and cooling. The integrated CHP system consists of various related parts and processes such as a prime mover, generator, heat recovery and electrical interconnections.

Reciprocating Engines: This type of technology has been around for more than 100 years and is widely used because it provides a low-cost reliable source of power, a fast start speed, and fast optimal level. Reciprocating engines have exhaust heat characteristics, which make them suitable for producing low pressure steam or hot water. Their size ranges from 10 KW to over 18 MW and they run on a variety of fuels like natural gas, liquefied petroleum gas (LPG), sour gas, landfill gas, biogas, industrial waste gas and manufactured gas (Shipley et al., 2008, Darrow et al., 2014).

Steam Turbines: This is an old and flexible prime mover that uses a thermodynamic cycle called the Rankine cycle. Known as the steam Rankine cycle (SRC), it is the typical prime mover for WHP. It generates electric power from high pressure steam produced in a heat recovery boiler; this steam powers the turbine and generator. Its output ranges from 50 KW to more than 250 MW and the steam turbine system runs on a variety of fuels like natural gas, coal, wood, solid waste, agricultural by-products and oils. Typical applications include industrial and institutional sites with high thermal loads (Darrow et al., 2014, Shipley et al., 2008, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012).

Gas Turbines: Also known as Combustion Turbines, these CHP prime movers produce high temperature and high quality heat from the turbine exhaust. Their turbines can be used to produce steam for onsite industrial applications or for extra electricity generation. They generate low emissions compared to the other fossil-prime movers, which makes this technology very attractive for industries. Their output ranges from 500 kW to more than 300 MW, and they run on a variety of fuels like natural gas, biogas, landfill gas, and petroleum fuels, and they often feature a dual-fuel capability. (Darrow et al., 2014, Shipley et al., 2008)

Microturbines: This type of technology represents small, modular, compact and lightweight gas turbines with power that ranges from 30 kW to 300 kW for a single turbine system and up to 1 MW for modular turbine packages. They are mechanically simple with few moving parts and can run on variety of fuels such as natural gas, liquid petroleum fuels and sour gas. (Shipley et al., 2008, Darrow et al., 2014)

Fuel Cells: This type of technology generates electricity using an electrochemical process. It transforms the chemical energy of hydrogen into electricity and water. The hydrogen can be obtained from various fuel types such as natural gas, methanol, coal gas, and other hydrocarbon fuels. Their power capabilities depend of the type of electrochemical process utilized, and ranges from 200 kW to 1.2 MW. They produce low-noise and low emissions but have a high capital cost. (Darrow et al., 2014, Shipley et al., 2008)

The main characteristics of each type of technology can be seen in Table 3.1

Table 3.1: Prime Mover main characteristics.
Source: (Darrow et al., 2014)

	Technology				
Characteristics	Reciprocating Engines	Steam Turbines	Gas Turbines	Microturbines	Fuel Cells
Overall CHP efficiency (HHV)	77-80%	79-80%	66-71%	63-70%	55-80%
Capacity	10 kW-18 MW	50 KW-250 MW	500 kW -300 MW	30 kW-1 MW	200 kW-1.2 MW
CHP Installed costs ($/kWe)	1,500-2,900	670-1,100	1,200-3,300	2,500-4,300	5,000-6,500
Non-fuel O&M costs ($/kWhe)	0.009-0.025	0.006 - 0.01	0.009-0.013	0.009-.013	0.032-0.038
Availability	96-98%	72-99%	93-96%	98-99%	>95%
Hours to overhauls	30,000-60,000	>50,000	25,000-50,000	40,000-80,000	32,000-64,000
Start-up time	10 sec	1 hr -1 day	10 min -1 hr	60 sec	3 hrs -2 days

In the case of waste heat to power (WHP), additional to the Steam Rankine Cycle (SRC) that was explained in the Steam Turbine section, there are other applicable technologies such as the organic Rankine cycle (ORC) and Kalina cycle.

Organic Rankine Cycle (ORC): This type of technology instead of uses water as a working fluid, utilizes organic fluids with a lower boiling point, higher mass flow, higher vapor pressure and higher molecular mass. These properties of the organic fluid provide better turbine efficiencies than the SRC system and enable waste heat recovery at medium and low temperatures; ORCs can be utilized for temperatures as low as 300 °F (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Kalina Cycle: This type of technology uses a blend of ammonia with water as a working fluid; which enables it to work at the same temperature level with an efficiency rate that is 15% to 25% higher than that of ORC. It can work with waste heat temperatures as low as 200 °F (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012).

The cost for WHP technologies (SRC, ORC and Kalina cycle) are very similar with an installed cost of 2,000 to 4,000 $/kW and operation and maintenance cost of 0.005–0.02 $/kWh. For high temperatures (> 1,200 °F), the technology that can be used is SRC; for medium temperatures (500–1200 °F) SRC works well at > 500 °F; ORC prefers < 800 °F, and Kalina Cycle is optimal < 1,000 °F. For low temperatures (< 500 °F), ORC operates at > 300 °F in gaseous streams and > 175 °F in liquid streams. The Kalina cycle runs well at > 200 °F (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012).

A more detailed analysis of each type of prime mover, including applications, components, performance, cost, emissions, fuels, and availability can be found in Darrow et al. (2014), and a more detailed analysis of WHP can be found in U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership (2012) report entitled "Waste Heat to Power Systems."

3.3 CHP Applications

CHP can be applied in a variety of situation where there are significant needs of electric and thermal loads. Typical applications are found in Chittum and Kishmohr (2014) report entitled "Combined Heat and Power Playbook" and U.S. Department of Energy (DOE) (2009) report entitled "Combined Heat and Power: A Decade of Progress, A Vision for the Future":

Industrial and Manufacturing Facilities, CHP improves energy efficiency in manufacturing operations due to the utilization of waste heat, waste pressure or waste fuel. It can be applied in chemical, cement, glass, refining, paper, ethanol, utilities and metal manufacturing.

Institutional, Municipal and District Facilities, CHP can be applied to facilities such as universities, hospitals, schools, wastewater treatment facilities, landfill facilities, district energy systems, prisons, federal and military facilities.

Commercial Facilities, CHP can be applied to facilities such as commercial office buildings, hotels, airports, and nursing homes. In these cases, CHP systems provide electricity in conjunction with space heating and cooling or water heating.

Residential, Larger CHP system can be applied to provide electricity and heat/cooling or hot water heating to multi-family buildings and micro CHP systems can be applied to meet thermal and electric demand of single-family homes.

Agricultural, CHP system can be applied to take advantage of agricultural waste using it as a fuel while providing electricity to run agricultural equipment and to heat farm facilities.

For WHP applications, the first task is to evaluate the economic feasibility of the WHP system. There are several factors to consider such as the waste heat temperature, variation, availability, and flow rate, waste stream contaminants and composition and annual operating hours of the facility. WHP has proven economically feasible in various industries such as primary metal manufacturing (steel mills, aluminum and metal foundries), non-metallic mineral product manufacturing (cement, alumina, soda ash, gypsum, lime, and glass), petroleum refining, the chemical industry, fabricated metals, natural gas compressor stations, landfill gas energy systems, and oil and gas production. (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

In this dissertation, the focus will be on the industrial application of CHP and WHP. It will not include others sectors.

3.4 Benefits of CHP

CHP systems are a very attractive group of technologies because they can deliver energy, economic, and environmental benefits to different stakeholders. As previously mentioned, these benefits are produced by CHP utilization of heat that would otherwise be wasted in the simultaneous on-site generation of electricity and thermal energy. The benefits by type of stakeholders include the following (Hedman et al., 2013b, Chittum and Farley, 2013b, Hampson and Rackley, 2014, Simchak and Davis, 2013):

End-Users (Industries, Business, Municipalities)

- Reduces energy cost through improved energy efficiency. This leads to lower operating costs and better profits.
- Protects against future energy prices and their price spikes.
- Protects against electric outages. CHP reduces the risk of this costly disruption and improves energy resilience and reliability. In industry, a one-hour outage could cost more than $50,000 in losses (Shipley et al., 2008).
- Offset capital costs in the case of replacement of boilers or backup electric generators.
- Better use of existing fuel resources such as biogas, solid waste, waste heat, biomass.
- Reduces compliance cost regarding better control of air emissions and reduction of other pollutants.

Utilities

- Provides lower cost approach to new generation infrastructure in comparison with other alternatives.
- Faster and more flexible development in comparison with other types of technology generation.
- Reduces the need for new investment in transmission and distribution (T&D) infrastructure; also avoids "peaker" plants and line losses.
- Allows fuel flexibility and protection against fuel prices fluctuation
- Increases grid stability, resilience and reliability with a better handling of congestion, capacity, peak-shaving and power quality
- Reduces compliance cost of environmental regulations

Nation (Society)

- Reduces air emissions resulting in less carbon dioxide (CO_2), mercury (Hg), nitrogen oxide (NO_x), and sulfur dioxide (SO_2). This is a consequence of less fuel consumed in CHP compared to SHP.
- Supports creation of specialized jobs that need skilled labor and market development.
- Reduces dependency on imported fossil fuels and increases energy security.
- Provides a lower cost approach to new energy generation infrastructure.
- Increases industry/business competitiveness through energy efficiency.
- Increases the use of cleaner energy sources

3.5 Current Market Status and Potential

The first units of CHP in the US were installed in the early age of the electric power industry. However, technological innovation in power generation made larger central stations cost effective. By the 1960s, matured and regulated utilities using large-central generating facilities dominated the US electricity market. There were no incentives to utilities to promote client-onsite generation. In 1978, due to the effects of the oil crisis, US Congress passed the Public Utilities Regulatory Policies Act (PURPA) to encourage energy efficient CHP and power generation by renewables. PURPA required utilities to buy energy from qualified facilities (CHP with minimum fuel-specific efficiency standard) at the utilities avoiding cost and providing them with reasonable backup and standby charges. Also in 1978 and 1980 Congress passed tax credits in cogeneration equipment, waste heat boilers and related equipment; and shortened depreciation for CHP systems. PURPA and the tax incentives boosted CHP deployment as shown in Table 3.2. The installed CHP capacity increased from

12 GW in 1980 to 66 GW in 2000—a capacity increase of 450% (U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Shipley et al., 2008)

Table 3.2: Installed and Expected Capacity.
Source: Shipley et al. (2008), The White House and Office of the Press Secretary (August 30, 2012), ICF International (2015)

Year	Installed CHP Capacity (GW)	% Change
1980	12	-
2000	66	450%
2014	83	26%
2020	Expected: 123	48%

The situation for CHP changed in 2000 with the deregulation of the electricity market in several states; with this change, independent power producers could sell energy directly to the market without regulated certification. This increased the CHP deployment from 2000 to 2005 as shown in Figure 3.4.

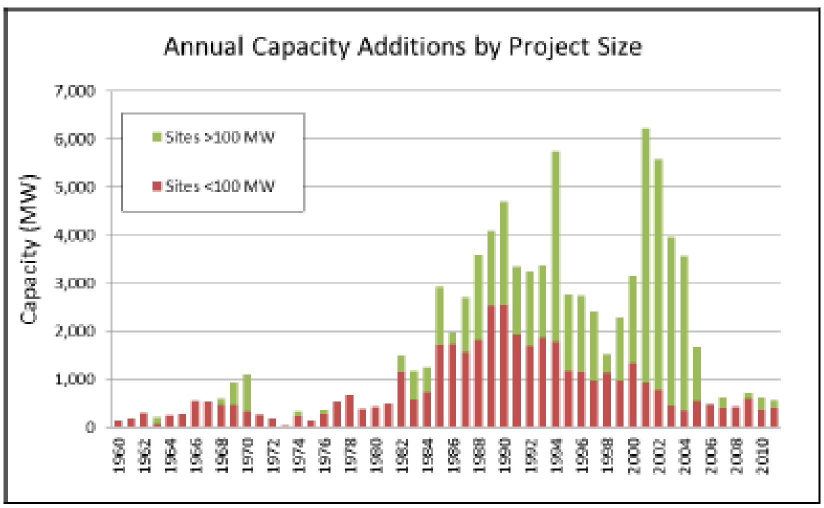


Figure 3.4: Annual Capacity Additions.
Source Hedman et al. (2013a)

However, the Energy Policy Act of 2005 weakened PURPA by authorizing utilities to terminate their obligations with qualified facilities if they operated in competitive markets. All of these changes generated market uncertainty and with the volatile natural gas prices, led to a sharp decline in CHP installations as can be seen in Table 3.2 and Figure 3.4. (Hedman et al., 2013a). From 2000 to 2014, the installed CHP capacity increased from 66

GW to 83 GW, an increase of 26%. In 2012, President Obama's Executive Order of Accelerating Investment in Industrial Energy Efficiency established a national goal of 40 new GW of CHP by 2020 (The White House and Office of the Press Secretary, August 30, 2012) a 48% increase from 2014 figures.

Currently, United States has 83 GW of CHP capacity in 4,346 facilities (ICF International, 2015), representing approximately 8% of the US generating capacity and more than 12% of total MWh generated annually. This amount of installed CHP capacity saves more than 1.9 quads of energy and 248 MMT of CO2 emissions each year compared to SHP. These savings represent taking 45 million cars off the road (Shipley et al., 2008). In Europe, CHP has saved more than 57 megatons of greenhouse gas emissions (15% of reduction) between 1990 and 2005 (Kerr, 2008). However, although CHP can be seen as an important strategy for achieving a cleaner, cost-effective and reliable energy, it is an underutilized resource in the US as shown in Figure 3.5. The 8% share of CHP in capacity generation pales in comparison with other countries like Denmark, Finland, Russia and Latvia who have more than 30%.

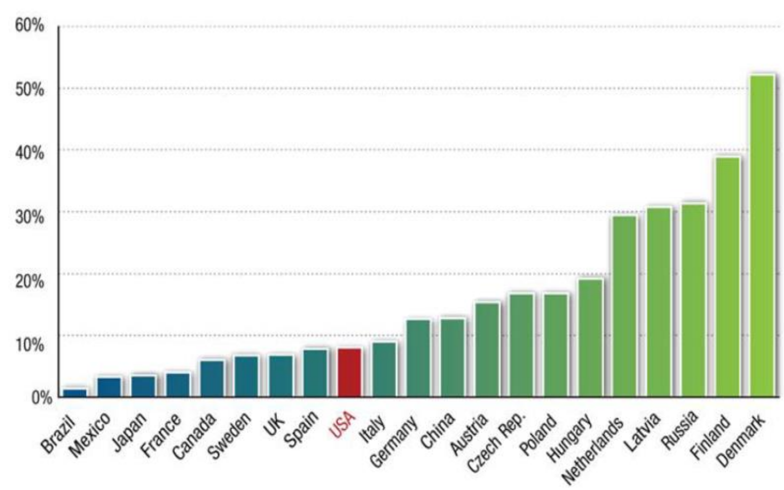
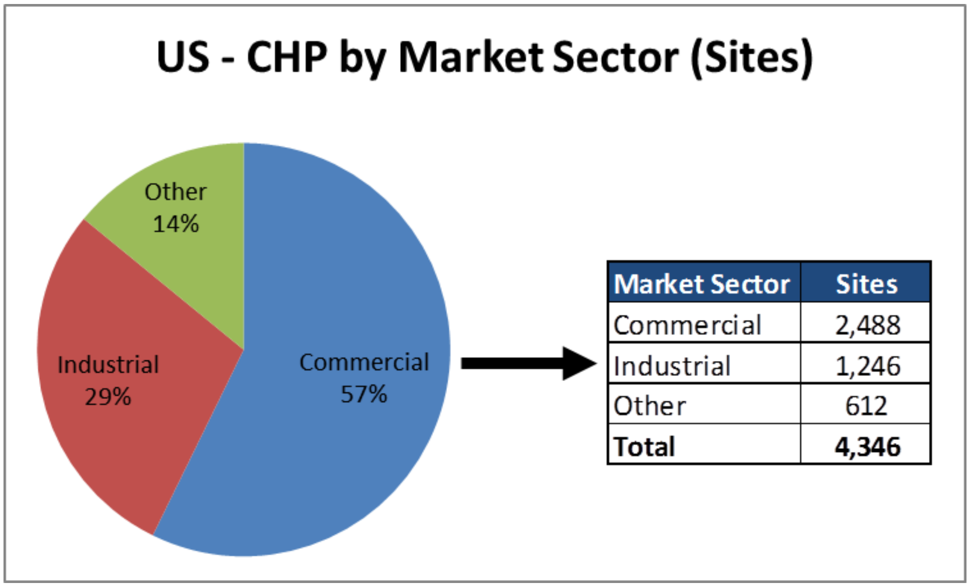


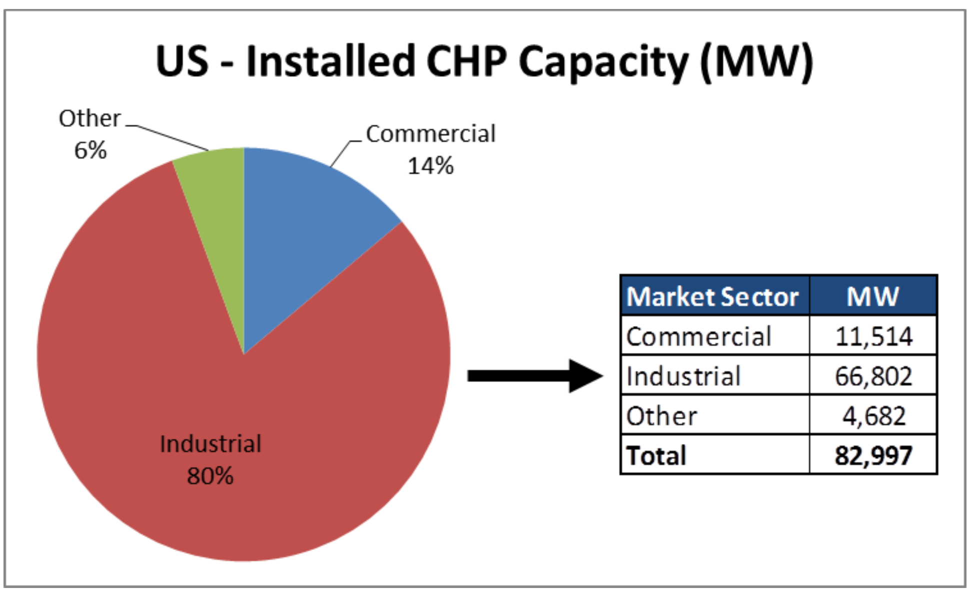
Figure 3.5: CHP as a Percentage of national capacity generation.
Source (Hedman et al., 2013a)

In the US, 57% of the CHPs are installed in the commercial sector (2,488 sites), but only represent 14% of the installed capacity (11,514 MW). On the other hand, the industrial sector is the biggest contributor (80%) in terms of installed capacity (66,802 MW) in only 29% of the sites (1,246 sites). This can be seen in Figures 3.6 and 3.7



Market Sector	Sites
Commercial	2,488
Industrial	1,246
Other	612
Total	**4,346**

Figure 3.6: Numbers of Sites by Market Sector in US.
Source: ICF International (2015)



Market Sector	MW
Commercial	11,514
Industrial	66,802
Other	4,682
Total	**82,997**

Figure 3.7: Installed CHP Capacity by Market Sector in US.
Source: ICF International (2015)

Figures 3.8 and 3.9 show that natural gas is the main fuel for CHP systems, representing 70% of the installed capacity (57,698 MW) and 66% of the facilities (2,872 sites). The second most used fuel is coal with 15% of the installed capacity (12,344 MW) but only in 5% of the facilities (208 sites). Biomass is used by 13% of the facilities (582 sites) but only represents 3% (2,604 MW) of the installed capacity.

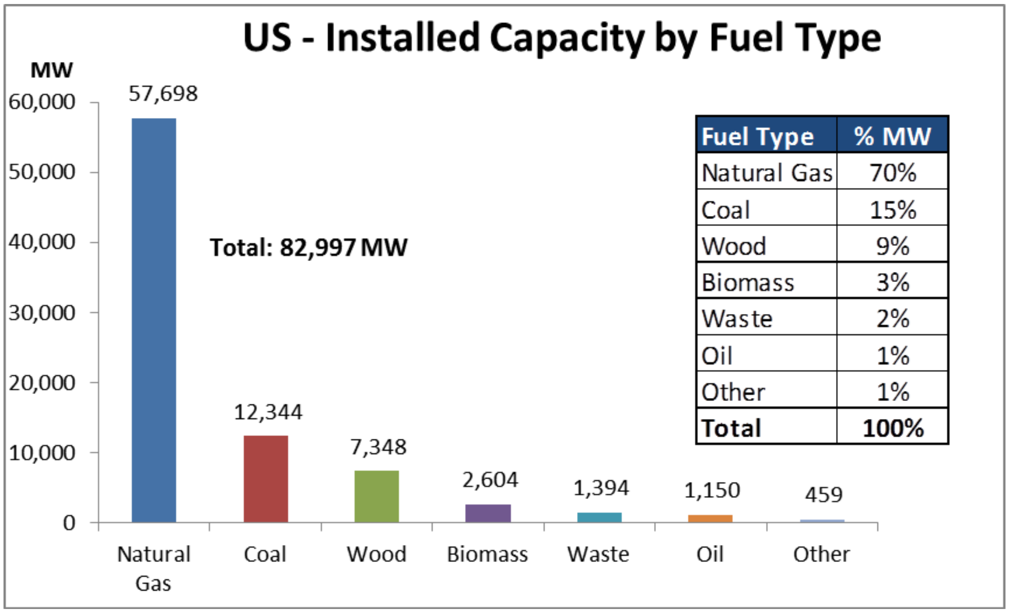


Figure 3.8: Installed CHP Capacity by Fuel Type in US.
Source: ICF International (2015)

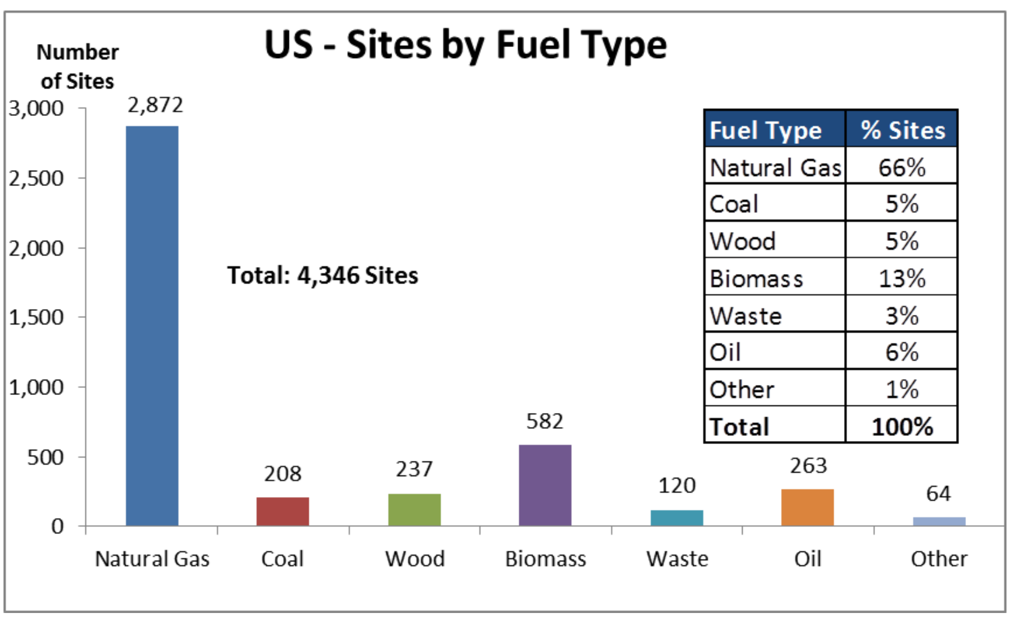


Figure 3.9: Numbers of Sites by Fuel Type in US.
Source: ICF International (2015)

Most of the installed CHP capacity (52%) used combined cycle (43,155 MW) which is only used in 5.2% of the facilities (225 sites). On the other hand, reciprocating engines is the most utilized technology (53% of the sites use this technology) but only represents 2.7% of the installed capacity (2,265 MW). Waste heat recovery technology is used only in 1.8 % of the facilities (78 sites) and represents only 0.6% (470 MW) of the installed capacity. This can be seen in Figures 3.10 and 3.11.

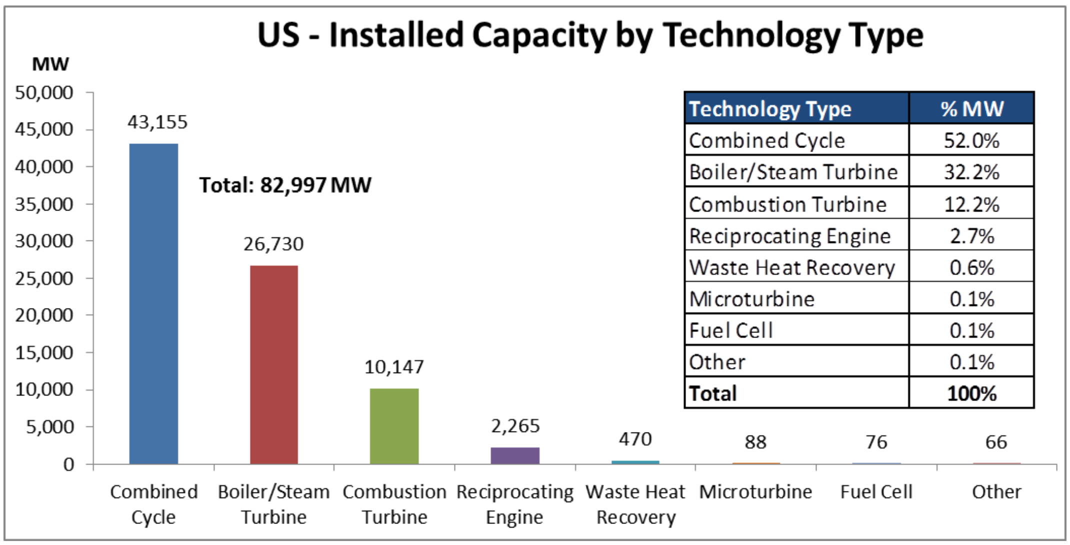


Figure 3.10: Installed CHP Capacity by Technology Type in US.
Source: ICF International (2015)

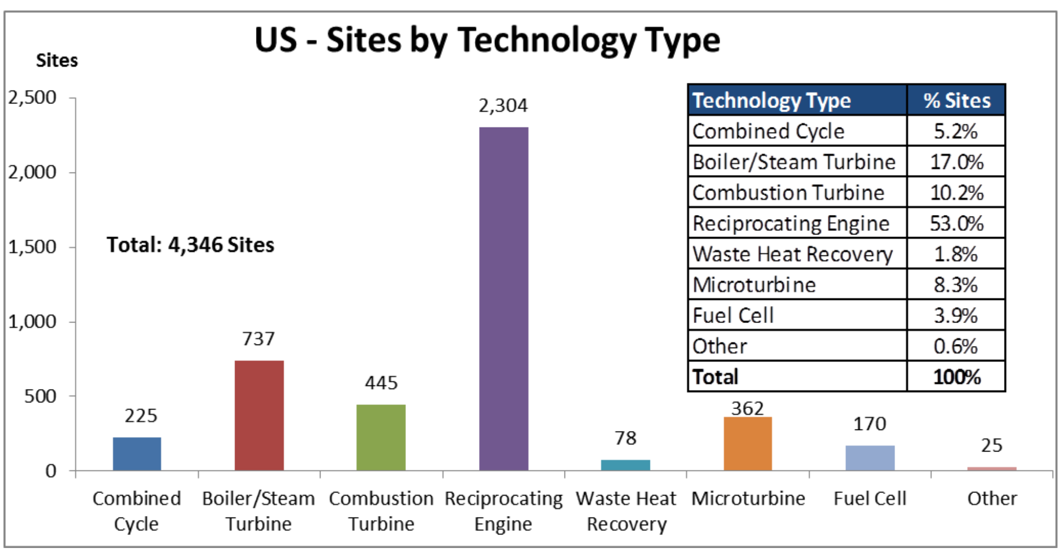
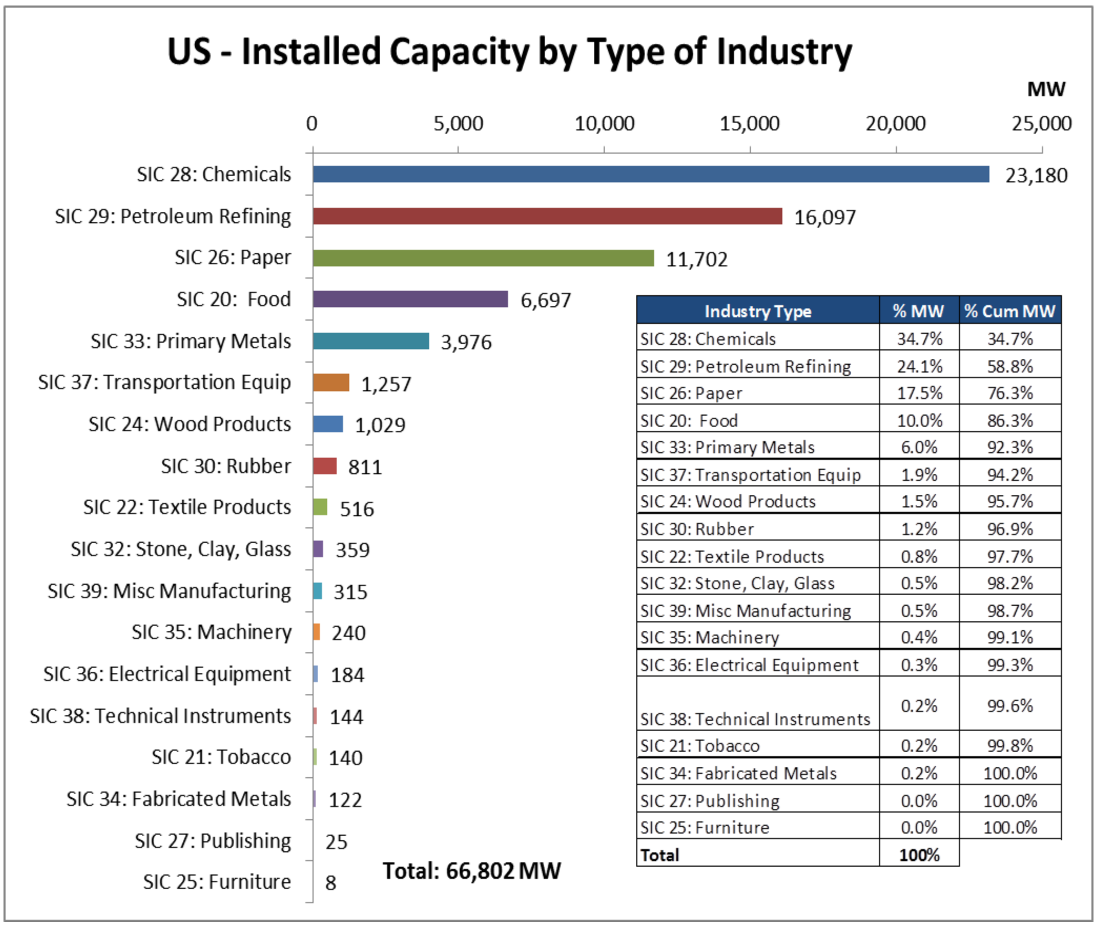


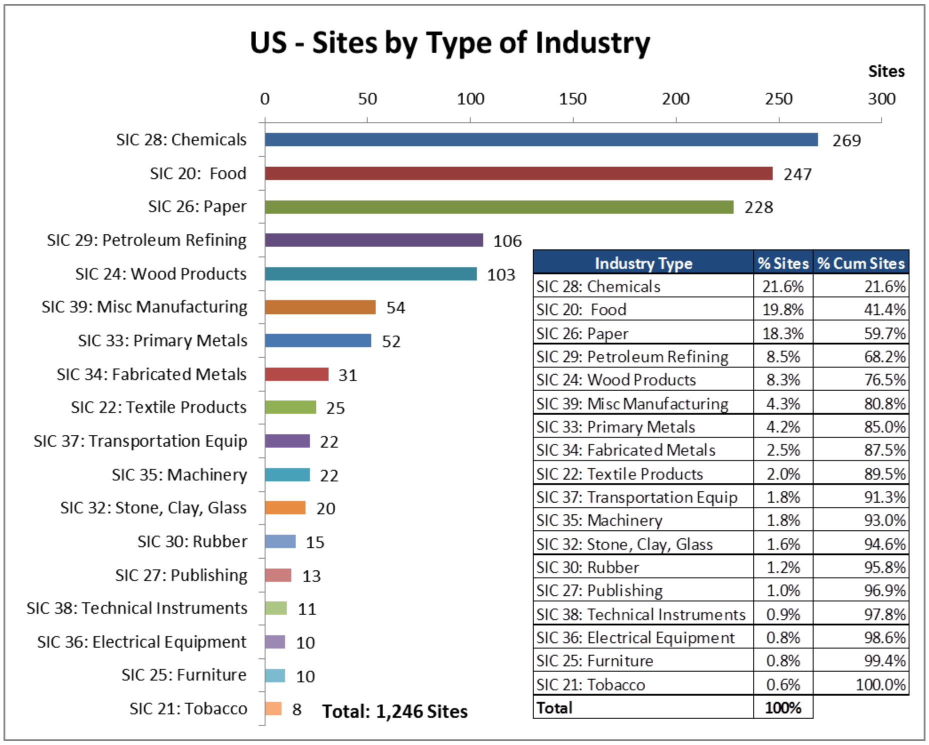
Figure 3.11: Numbers of Sites by Technology Type in US.
Source ICF International (2015)

In the industry sector, the chemical Industry has the biggest installed capacity of CHP with 23,180 MW (34.7%), followed by petroleum refining with 16,097 MW (24.1%), paper with 11,702 MW (17.5%) and food industries with 6,697 MW (10%). These four industries represent 86.3% of CHP installed capacity as shown in Figure 3.12. Moreover, these four industries represent 68.2% of the installed facilities as seen in Figure 3.13. Chemical industries represent 21.6%, food 19.8%, paper 18.3% and petroleum refining 8.5% of the sites that have CHP systems.



Industry Type	% MW	% Cum MW
SIC 28: Chemicals	34.7%	34.7%
SIC 29: Petroleum Refining	24.1%	58.8%
SIC 26: Paper	17.5%	76.3%
SIC 20: Food	10.0%	86.3%
SIC 33: Primary Metals	6.0%	92.3%
SIC 37: Transportation Equip	1.9%	94.2%
SIC 24: Wood Products	1.5%	95.7%
SIC 30: Rubber	1.2%	96.9%
SIC 22: Textile Products	0.8%	97.7%
SIC 32: Stone, Clay, Glass	0.5%	98.2%
SIC 39: Misc Manufacturing	0.5%	98.7%
SIC 35: Machinery	0.4%	99.1%
SIC 36: Electrical Equipment	0.3%	99.3%
SIC 38: Technical Instruments	0.2%	99.6%
SIC 21: Tobacco	0.2%	99.8%
SIC 34: Fabricated Metals	0.2%	100.0%
SIC 27: Publishing	0.0%	100.0%
SIC 25: Furniture	0.0%	100.0%
Total	**100%**	

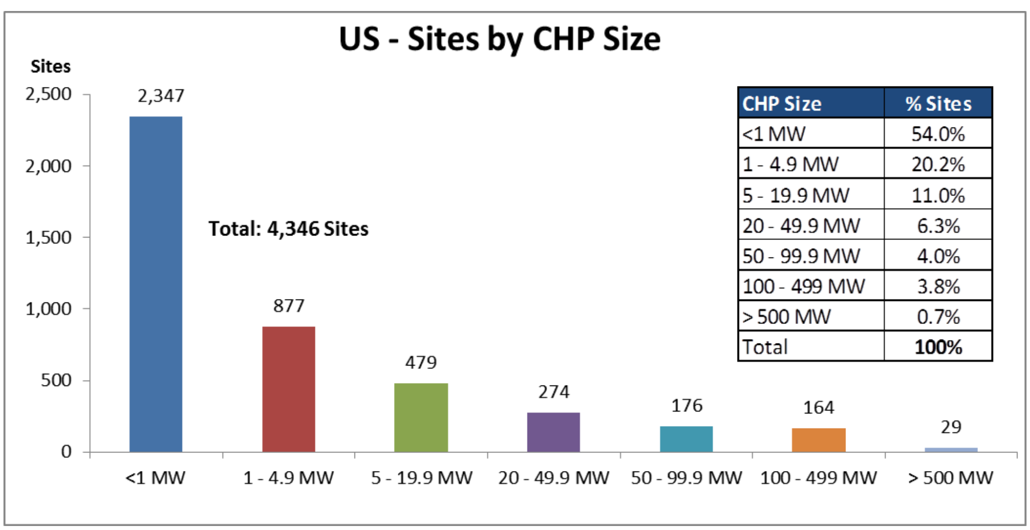
Figure 3.12: Installed CHP Capacity by Type of Industry in US.
Source: ICF International (2015)



Industry Type	% Sites	% Cum Sites
SIC 28: Chemicals	21.6%	21.6%
SIC 20: Food	19.8%	41.4%
SIC 26: Paper	18.3%	59.7%
SIC 29: Petroleum Refining	8.5%	68.2%
SIC 24: Wood Products	8.3%	76.5%
SIC 39: Misc Manufacturing	4.3%	80.8%
SIC 33: Primary Metals	4.2%	85.0%
SIC 34: Fabricated Metals	2.5%	87.5%
SIC 22: Textile Products	2.0%	89.5%
SIC 37: Transportation Equip	1.8%	91.3%
SIC 35: Machinery	1.8%	93.0%
SIC 32: Stone, Clay, Glass	1.6%	94.6%
SIC 30: Rubber	1.2%	95.8%
SIC 27: Publishing	1.0%	96.9%
SIC 38: Technical Instruments	0.9%	97.8%
SIC 36: Electrical Equipment	0.8%	98.6%
SIC 25: Furniture	0.8%	99.4%
SIC 21: Tobacco	0.6%	100.0%
Total	100%	

Figure 3.13: Numbers of Sites by Type of Industry in US.
Source: ICF International (2015)

Figure 3.14 and Figure 3.15 show 164 facilities (in the size 100 to 499 MW) representing 3.8% of the CHP sites concentrating 39% of the installed CHP capacity in the US. Most of the facilities (54%) have CHP system less than 1 MW (2,347 Sites), however these facilities only represent 593 MW (0.7%) of the installed CHP capacity.



CHP Size	% Sites
<1 MW	54.0%
1 - 4.9 MW	20.2%
5 - 19.9 MW	11.0%
20 - 49.9 MW	6.3%
50 - 99.9 MW	4.0%
100 - 499 MW	3.8%
> 500 MW	0.7%
Total	100%

Figure 3.14: Numbers of Sites by CHP Size in US.
Source: ICF International (2015)

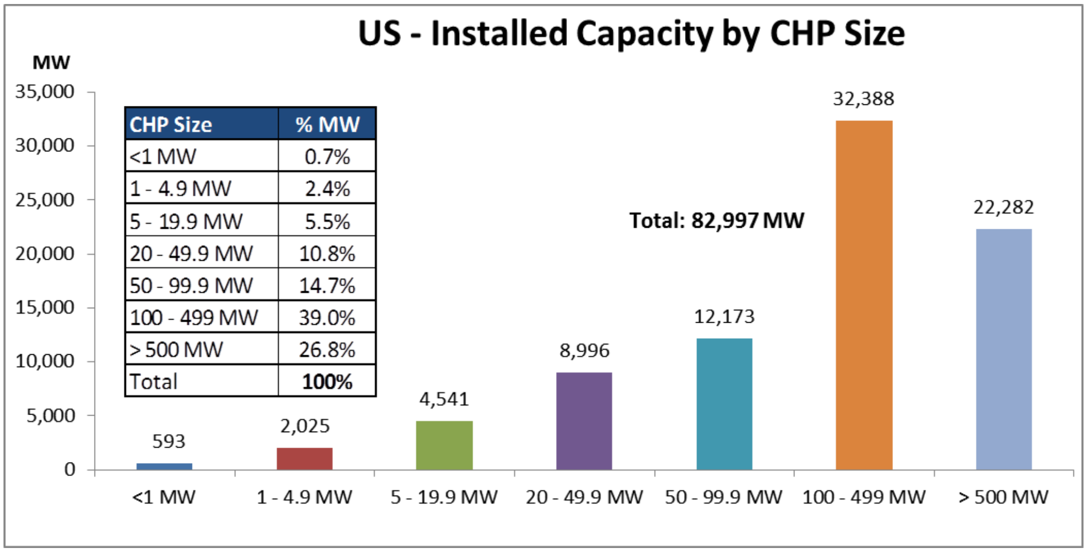


Figure 3.15: Installed Capacity by CHP Size in US.
Source: ICF International (2015)

In Appendix A, additional information is available on types of industry versus types of fuel; types of industry versus types of technology; types of industry versus CHP size; types of fuel vs types of technology; types of technology versus CHP size; and type of fuel versus CHP size.

There are several studies indicating a bright and promising future for CHP. The goal defined by president Obama (40 GW of new CHP) is very achievable when compared with the technical and economic potential of the CHP market. As can be seen from Table 3.3, Hedman et al. (2013a) indicated that the technical potential of CHP is 124.7 GW (56.1 for the industry sector and 68.6 for commercial sector) but this potential does not consider the effect of regulatory barriers, capital costs, payback periods, and other factors that can affect the market potential for CHP (economic potential). They evaluated CHP economic potential for systems less than 100 MW with a sensitivity analysis of three different scenarios: 1) 25% cost reduction in CHP equipment, 2) 15% increase in electricity prices, and 3) 10% decrease in natural gas prices plus the elimination of all CHP systems with a payback period of more than 10 years. They found an economic potential between 41.62 GW to 62.7 GW; however, this could be greater if barriers are eliminated. The U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) (2012) indicated a CHP technical potential of 130 GW (65 GW for industry and 65 GW for commercial sector). They argued that industrial potential could be doubled if all CHP systems were designed to thermal load and there are no barriers to exporting and selling excess electricity. Hampson and Rackley (2014) indicated that if these barriers are eliminated it would increase technical potential by 110 GW, with a total of 240 GW. Choi Granade et al. (2009) estimated a cost-effective CHP potential of 50.4 GW (26.4 GW is from the industry sector) that can be deployed by 2020 with current conditions.

Table 3.3: CHP Technical and Economic Potential.
Source: Hedman et al. (2013a), Choi Granade et al. (2009), Hampson and Rackley (2014), and U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA) (2012)

	Technical Potential (GW)			Economic Potential (GW)
References	Industry	Commercial	Total	
Hedman et al. (2013a)	56.1	68.6	124.7	41.62 - 62.7
Choi Granade et al. (2009)	-	-	-	50.4
DOE & EPA (2012)	65	65	130 - 195	-
Hampson and Rackley (2014)	-	-	130 - 240	-

3.6 Barriers to CHP deployment

There has been low acceptance of CHP despite its technical and economic potential. This lack of acceptance is due to several barriers, which can be grouped under three areas: Business, behavioral and regulatory barriers.

<u>Business Barriers</u>

Capital Constraints and Financing. CHP systems require significant capital costs (upfront costs) as well operation and maintenance costs. This is a long-term investment with different payback periods depending on what type of technology and fuel is used.

Moreover, CHP projects have to compete against others capital investments that could have a better payback period or are part of their core business. The finance availability for CHP upfront costs can be a barrier for some companies, and banks do not normally finance unfamiliar technology (Choi Granade et al., 2009, Shipley et al., 2008, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, Chittum and Farley, 2013b, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Bloomberg New Energy Finance, 2014, Hedman et al., 2013a, Chittum and Kaufman, 2011, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Poor spark spread and low electric rates. Spark spread is the difference between how cheaply CHP systems can generated electricity and heat versus how much it would cost from the utilities. A low electric rate and a higher CHP fuel price (most CHP systems use natural gas) will reduce the spark spread. A poor spark spread will kill a CHP project (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012, Chittum and Kaufman, 2011).

Limited CHP Supply Infrastructure. This is a result of the slowdown of CHP implementation since 2005. CHP is not a major focus for equipment developers. This could change with an increase on CHP deployment (Hedman et al., 2013a, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012)

Technical Issues. In the case of WHP, there are some challenges regarding heat recovery that need to be overcome in order to be a feasible solution. These heat recovery challenges include availability of waste heat (batch or non-continuous), difficulty to consolidate or reach waste heat sources, low volume and seasonal operations, variation in temperature and flow rate, contaminants in the waste heat sources and space limitations, (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

<u>**Behavioral Barriers**</u>

Investment uncertainty and risk. Risks of power generation ownership include fuel prices, power generation sell prices, environmental emission regulations, permitting procedures, and interconnection issues, among others. (Choi Granade et al., 2009, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Hedman et al., 2013a, Chittum and Kaufman, 2011, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Lack of knowledge about CHP. Users and lenders do not know the benefits and potential of CHP. Moreover, it's of paramount importance in critical infrastructure facilities such as hospitals and airports where there is a need of continual services without interruption due to weather and natural disasters. There is a need for technical assistance, demonstrations, and promotion of best practices and lesson learned. (Choi Granade et al., 2009, Hedman et al., 2013b, Shipley et al., 2008, Kerr, 2008, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Bloomberg New Energy Finance, 2014, Hedman et al., 2013a, Chittum and Kaufman, 2011, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Lack of knowledgeable staff. Firms that could potentially benefit from a CHP system seldom have the knowledgeable and skilled staff necessary for CHP installation and operation (Simchak and Davis, 2013, Chittum and Kaufman, 2011, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Utility Attitude. In some places, utilities can make it very difficult (If not impossible) for the deployment of CHP systems. In these cases, utilities view CHP systems as a financial threat for their revenues and misunderstand the benefits of CHP, which even traditional power plants can take advantage of (Chittum and Kishmohr, 2014, Simchak and Davis, 2013, Chittum and Farley, 2013b, Chittum and Kaufman, 2011)

Regulatory Barriers

Lack of interconnection standards. CHP systems require interconnection with the utility grid for back-up, additional power, and the opportunity to sell excess power. This has to be done in a safe, reliable and economic environment. Utilities have to approve how customers on CHP will be connected to the grid. This approval is a complicated process. It is both time consuming and expensive. It requires extensive and costly engineering studies due to the lack of a standardized interconnection process and guidelines between states (Choi Granade et al., 2009, Hedman et al., 2013b, Shipley et al., 2008, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, Kerr, 2008, Chittum and Farley, 2013b, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Bloomberg New Energy Finance, 2014, Hedman et al., 2013a, Chittum and Kaufman, 2011, Gilleo et al., 2014)

Unfair standby rates and exit fees. CHP systems require standby or back-up services in order to take care of preventive and corrective maintenance. The standby rates charged by utilities in order to recover their cost of generation, transmission and distribution (depending of the type of utility) could be excessive, especially when there is an incorrect evaluation between charges and cost of service. Also, an excessive charge can be imposed to customers that want to leave the utility for the same reason. (Choi Granade et al., 2009, Hedman et al., 2013b, Shipley et al., 2008, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, Chittum and Farley, 2013b, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Bloomberg New Energy Finance, 2014, Hedman et al., 2013a, Chittum and Kaufman, 2011)

Input-based regulations. Some states do not consider the environmental benefits of CHP when they use an input-based emissions regulation instead of an output-based emissions regulation. Input-based standards penalize CHP systems for their increased on-site emissions without considering the total emissions reduction produced in the overall grid. they do not recognize the higher efficiency provide by CHP (Choi Granade et al., 2009, Shipley et al., 2008, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Hedman et al., 2013a, Gilleo et al., 2014)

Inability to sell excess power. Typically, CHP systems are sized to meet their thermal loads, which results in an electric power capacity bigger than their electric consumption. This means that CHP system in order to be economically viable should have the capacity to sell excess electric energy back to the grid or to neighbors' facilities at the right prices.

Sometimes the prices utilities are willing to pay for CHP excess energy are unreasonable. Sometimes interconnection standards and procedures make this option impossible. (Hedman et al., 2013b, Chittum and Kishmohr, 2014, Chittum and Kaufman, 2011, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Absence of net metering standards. Net metering standards or rules allow CHP systems to receive credit for electricity generated onsite. The customer-generator is billed or credited for the "net" difference between onsite generation and electric consumption from the grid (Chittum and Kishmohr, 2014, Chittum and Kaufman, 2011, Gilleo et al., 2014)

Absence of feed-in tariff. This is a type of agreement between a customer-owned CHP and the utility where the former is paid an agreed price for the excess power delivered to the grid. The price could be based on avoided cost rates (Shipley et al., 2008, Hedman et al., 2013b, Chittum and Kishmohr, 2014, Chittum and Kaufman, 2011, Gilleo et al., 2014).

CHP is not included in clean energy portfolio standards (CEPS), renewable portfolio standards (RPS) or energy efficiency resource standards (EERS). Currently, many states have encouraged the use of energy efficiency, renewable energy and other clean energy technologies by enforcement of their CEPS, RPS, or EERS requesting their utilities to achieve a minimum amount of EE (demand side) or minimum amount of energy generated by renewable sources (supply side). However, in many cases, although CHP increases energy efficiency because it uses less fuel and in some systems use biomass, waste heat or other types of renewable fuel, CHP are not included in these standards (Hedman et al., 2013b, Chittum and Kishmohr, 2014, Shipley et al., 2008, Simchak and Davis, 2013, Hampson and Rackley, 2014, Chittum and Farley, 2013b, Chittum and Kaufman, 2011, Gilleo et al., 2014, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012).

Rules against utility participation in CHP. Utilities have characteristics that allow them to take advantage of the CHP potential. Traditional utilities are not bound to a lower payback period. Normally their business model is based on long-term investment. They have access to low capital and cheaper funding; they are also usually free from problems with interconnection standards, standby rates and exit fees. In addition, their energy efficiency and renewable generation requirements are compatible with CHP. However, their participation as owners of CHP systems or providing services (operation and maintenance) to CHP owners are not allowed in some states. (Hedman et al., 2013b, Hampson and Rackley, 2014, Chittum and Farley, 2013b, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012)

Utility business model. The business model of the utility (its revenues) is based on the amount of energy (kWh) sold to their customers. This makes utilities discourage any form of customer onsite generation (Shipley et al., 2008, Simchak and Davis, 2013, Chittum and Farley, 2013b, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Chittum and Kaufman, 2011)

Tax Treatment. Unfortunately CHP systems do not have a clear tax depreciation period. It can range from 5 to 39 years. More years for depreciation makes a CHP project uneconomical. In the case of WHP, the federal 10% investment tax credit for CHP systems is not applicable for WHP systems (Shipley et al., 2008, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power (CHP) Partnership, 2012)

Permitting and siting issues. CHP systems have to comply with local regulations regarding safety, environment and health issues. These include permitting on air and water quality, noise, waste disposal, fuel storage, building standards and fire prevention. Local authorities responsible for these permits may not have knowledge about CHP, which makes this process difficult (U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Bloomberg New Energy Finance, 2014, Chittum and Kaufman, 2011)

Table 3.4 shows CHP barriers found while building this dissertation's literature review.

Table 3.4: CHP Barriers

		References													
Category	Barriers	Choi Granade et al. 2009	Hedman et al., 2013b	Shipley et al., 2008	Bloomberg New Energy Finance, 2014	Chittum and Kishmohr, 2014	Simchak and Davis, 2013	Kerr, 2008	Hampson and Rackley, 2014	Chittum and Farley, 2013	DOE & EPA, 2012	Hedman et al., 2013a	Chittum and Kaufman, 2011	Gilleo et al., 2014	EPA & CHP Partnership, 2012
Business Barriers	Capital Constraints and Financing	x		x	x	x	x			x	x	x	x		x
	Poor spark spread and low electric rates												x		x
	Limited CHP Supply Infrastructure										x	x			
	Technical Issues														x
Behavioral Barriers	Investment Uncertainty and Risk	x									x	x	x		x
	Lack of knowledge about CHP	x	x	x	x			x			x	x	x		x
	Lack of knowledgeable staff						x						x		x
	Utility Attitude					x	x			x			x		
Regulatory Barriers	Lack of interconnection standards	x	x	x	x	x	x	x		x	x	x	x	x	
	Unfair standby Rates and exit Fees	x	x	x	x	x	x			x	x	x	x		
	Input Based Regulations	x		x		x	x				x	x		x	
	Inability to Sell Excess Power		x			x							x		x
	Absence of Net metering rules					x							x	x	
	Absence of feed-in tariff		x	x		x							x	x	
	CHP is not included in CEPS, RPS or EERS		x	x		x	x		x	x			x	x	x
	Rules against utility participation in CHP		x						x	x	x				
	Utility business model			x			x			x	x		x		
	Tax Treatment			x											x
	Permitting and Siting issues				x						x		x		

3.7 Key drivers and solution to overcome CHP barriers

There are several drivers that can help to overcome CHP barriers. These drivers from the literature reviewed can be seen in Table 3.5

Table 3.5: CHP Key Drivers

Drivers	References											
	Choi Granade et al.2009	Hedman et al., 2013b	Shipley et al., 2008	Bloomberg New Energy Finance, 2014	Chittum and Kishmohr, 2014	Simchak and Davis, 2013	Hampson and Rackley, 2014	Chittum and Farley, 2013	DOE & EPA, 2012	Hedman et al., 2013a	Chittum and Kaufman, 2011	Gilleo et al., 2014
Supportive Regulations	x	x	x		x	x		x	x	x		x
Incentives and Financial Mechanism	x		x	x	x	x			x		x	x
Outreach and Education	x	x			x	x						x
Favorable spark spread and fuel price				x		x	x	x	x	x	x	
Reliability and Resiliency		x		x			x			x		
GHG trading system, carbon taxes and environmental compliance			x				x	x			x	
Clear Government Support						x	x		x	x		
Pressures on power plants and industrial boilers									x	x		
Lead by an example						x						
Fuel Flexibility			x									
Modular CHP			x									

Supportive Regulations. These regulations have to promote the deployment of CHP systems. These include clear and fair interconnection standards, adequate standby and backup charges, permission to sell excess electricity at reasonable prices, adequate net metering standards and feed-in tariff, implementation of output based emissions standards, simplified environmental and interconnecting permitting process, allowing utilities to participate in the CHP market, allowing CHP as an eligible resource for CEPS, RPS and EERS, which align with utility business models (Choi Granade et al., 2009, Shipley et al., 2008, Hedman et al., 2013b, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, Chittum and Farley, 2013b, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Hedman et al., 2013a, Gilleo et al., 2014).

Incentives and Financial Mechanism. The US federal government has offered some support for the deployment of CHP; however, this support is less substantial than for the other renewables (Bloomberg New Energy Finance, 2014). The idea is to make the CHP market more attractive by giving to CHP the same support as other renewable in terms of upfront capital cost and installation costs, making a shorter payback period. These types of incentives include investment tax credits (ITC), production tax credits (PTC) and direct incentives. ITC lower the financial risks associated with CHP investments allowing a percentage of the investment to be used as a tax credit; hence, PTC use kWh produced by CHP as a tax credit. For direct incentives, the CHP installer will receive a defined payment once the CHP system is in successful operation. Other types of financial mechanisms that support CHP market attractiveness are loans, loan guarantees, grants and bonds (Choi Granade et al., 2009, Shipley et al., 2008, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Chittum and Kaufman, 2011, Gilleo et al., 2014).

Outreach and Education. Awareness of CHP benefits is critical to the future of CHP deployment. There are various actions that can be done in order to increase it among industrial and commercial facilities. These include a national data-base of candidates for CHP projects, technical assistance, technology demonstrations, best practices and lessons learned. Also, outreach efforts providing CHP education to banks and potential lenders could increase the amount of financing funds for CHP projects (Hedman et al., 2013b, Choi Granade et al., 2009, Chittum and Kishmohr, 2014, Simchak and Davis, 2013, Gilleo et al., 2014)

Favorable spark spread and fuel price. Spark spread is the difference between how cheaply CHP systems can generate electricity and heat versus how much it would cost from the utility. A higher electricity price and a lower CHP fuel price (most CHP systems use natural gas) will increase the spark spread. A favorable spark spread will encourage funding of CHP deployment but a poor spark spread will kill a CHP project (Simchak and Davis, 2013, Chittum and Farley, 2013b, Hampson and Rackley, 2014, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Bloomberg New Energy Finance, 2014, Hedman et al., 2013a, Chittum and Kaufman, 2011).

Reliability and Resiliency. Two of the most widely recognized benefits of CHP systems are their reliability and resiliency, especially infrastructure becomes at risk in times of serious weather and natural disasters (Hampson and Rackley, 2014, Hedman et al., 2013b, Bloomberg New Energy Finance, 2014, Hedman et al., 2013a).

GHG trading system, carbon taxes, and environmental compliance. One of the benefits of CHP is the reduction of overall green house gas (GHG) emissions; therefore, CHP should be considered as an eligible resource for any carbon tax, GHG trading system and compliance option (Shipley et al., 2008, Hampson and Rackley, 2014, Chittum and Farley, 2013b, Chittum and Kaufman, 2011)

Clear Government Support. The Executive Order 13624 by President Obama setting a goal of 40 GW of new CHP sent a clear message to the market for greater CHP deployment (Simchak and Davis, 2013, The White House and Office of the Press Secretary, August 30, 2012, Hampson and Rackley, 2014, U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Hedman et al., 2013a)

Pressures on power plants and industrial boilers. There are some events affecting the market power and the industrial sector. In the market sector, a number of announcements regarding coal plant retirements are expected over the next years; furthermore, in the industrial sector, aging boilers and new pollution standards will force industries to replace them. Both scenarios provide an opportunity for CHP deployment (U.S. Department of Energy (DOE) and U.S. Environmental Protection Agency (EPA), 2012, Hedman et al., 2013a)

Lead by an example. Federal and state government can stimulate deployment of CHP in the private sector by implementing CHP in their own facilities and sharing their best practices (Simchak and Davis, 2013).

Fuel Flexibility. Fuel Flexibility can make CHP more economically viable when the CHP prime mover can switch between fuel types. This protects CHP system from fuel price increases and uncertainty. Also, a larger choice of alternative fuels can include the use of renewable fuel sources such as biogas, biomass, and waste heat (Shipley et al., 2008)

Modular CHP. A modular CHP system with direct integration with all its components, such as a plug and play system, will make CHP innovation particularly valuable in small and medium enterprises (SMEs) (Shipley et al., 2008).

3.8 Case Study: State of Missouri

Currently, Missouri has 233 MW of installed CHP capacity in 21 facilities. Most of the CHP are installed in the commercial sector (67% of the sites), and represent 70% of the installed capacity (164 MW). The industrial sector is far behind with only 28% of installed capacity (65 MW) in 29% of the sites (six sites). This can be seen in Figures 3.16 and 3.17

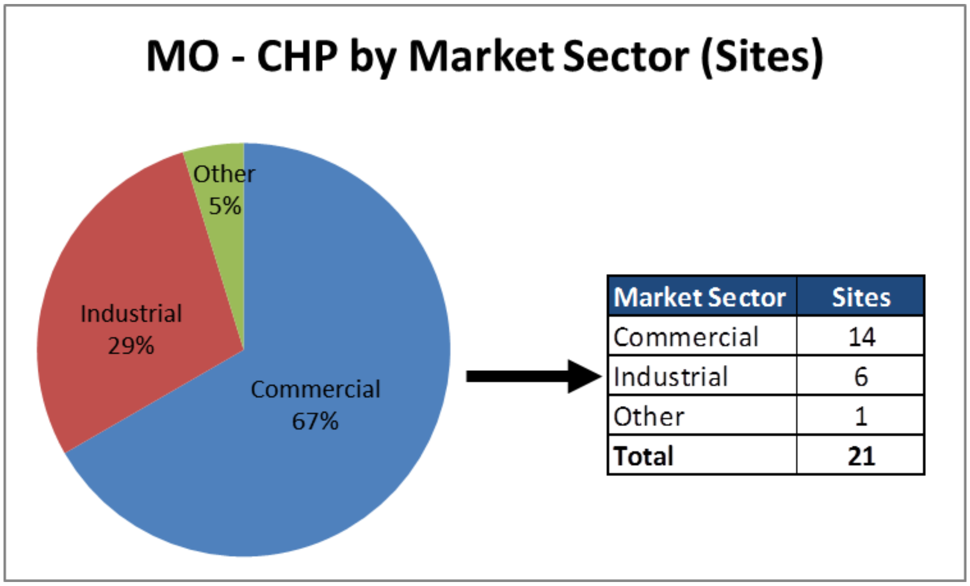


Figure 3.16: Numbers of Sites by Market Sector in Missouri.
Source: ICF International (2015)

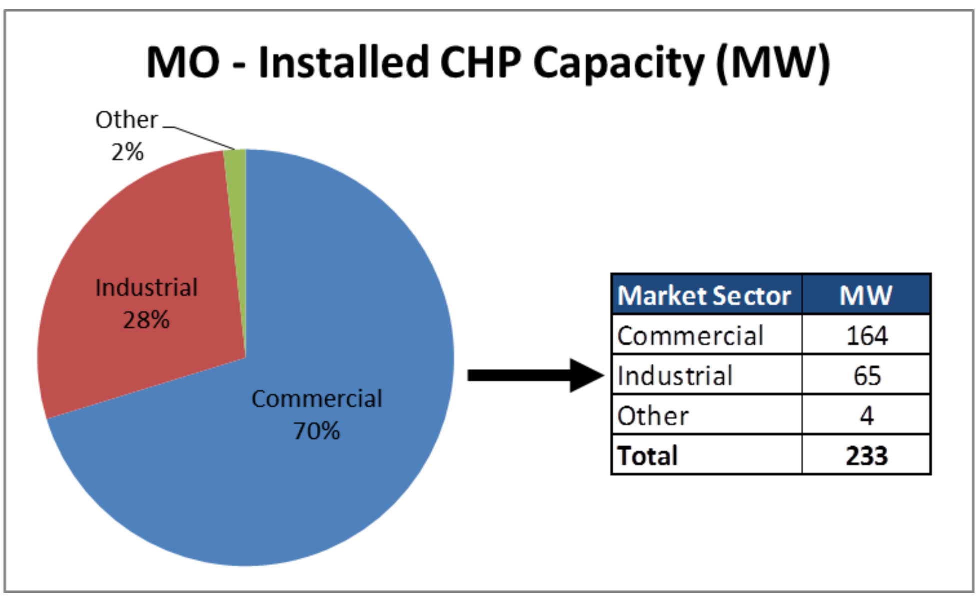
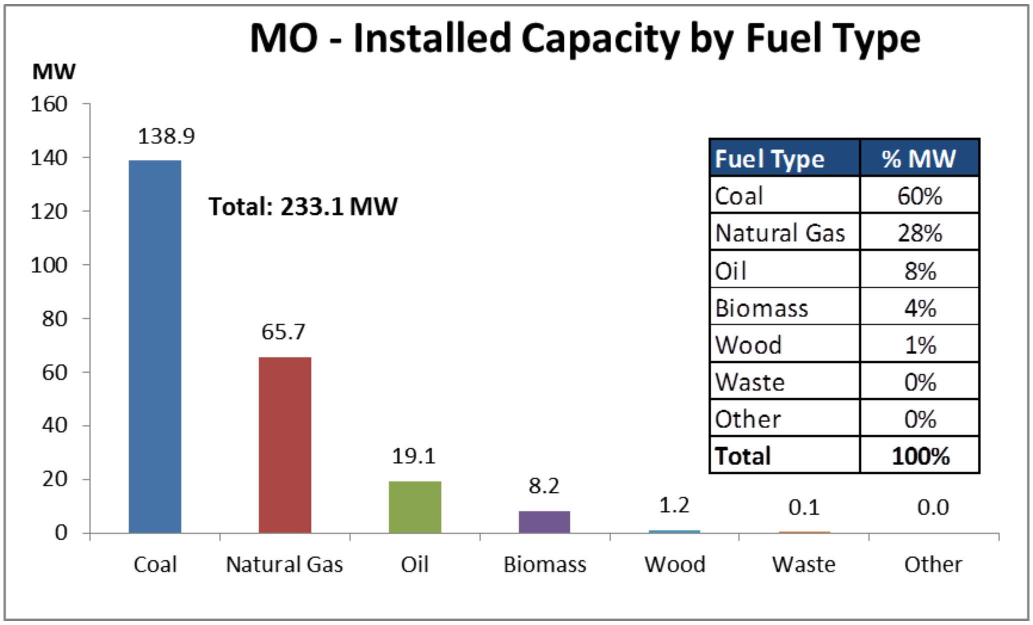


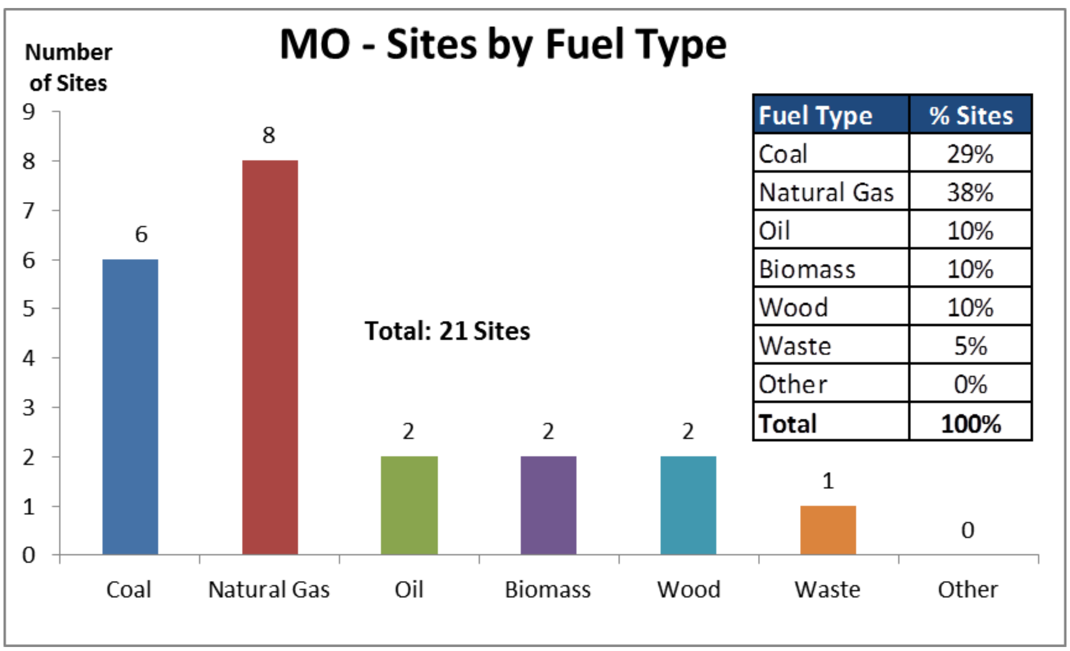
Figure 3.17: Installed CHP Capacity by Market Sector in Missouri.
Source: ICF International (2015)

Figures 3.18 and 3.19 show that coal is the main fuel for Missouri CHP systems, representing 60% of the installed capacity (138.9 MW) but only 29% of the facilities (six sites). The second most used fuel is natural gas with 28% of the installed capacity (65.7 MW), but natural gas rates first in terms of the number of facilities with eight sites (38%).



Fuel Type	% MW
Coal	60%
Natural Gas	28%
Oil	8%
Biomass	4%
Wood	1%
Waste	0%
Other	0%
Total	**100%**

Figure 3.18: Installed CHP Capacity by Fuel Type in Missouri.
Source: ICF International (2015)



Fuel Type	% Sites
Coal	29%
Natural Gas	38%
Oil	10%
Biomass	10%
Wood	10%
Waste	5%
Other	0%
Total	**100%**

Figure 3.19: Numbers of Sites by Fuel Type in Missouri.
Source: ICF International (2015)

Most of the installed CHP capacity (70.4%) uses boiler/steam turbine power (164.1 MW) and represents 42.9% of the facilities (nine sites). Reciprocating engines are the second most used technology (28.6% of the sites use this technology), but they only represent 11.5% of the installed capacity (26.8 MW). Waste Heat Recovery Technology is used only in 4.8 % of the facilities (one site) and represents only 0.0% (0.1 MW) of the installed capacity. This can be seen in Figure 3.20 and 3.21

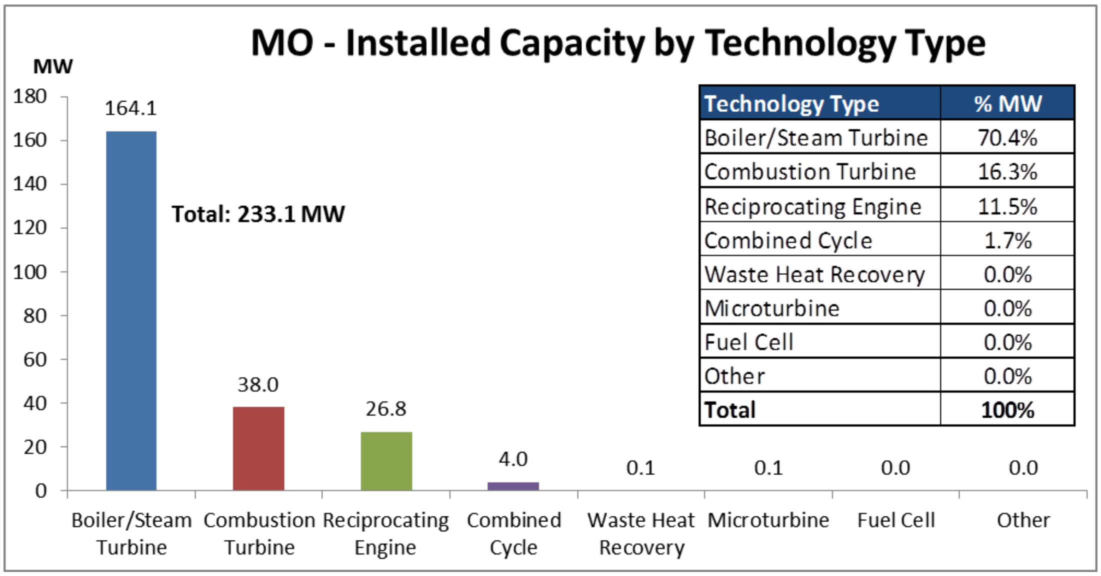


Figure 3.20: Installed CHP Capacity by Technology Type in Missouri.
Source: ICF International (2015)

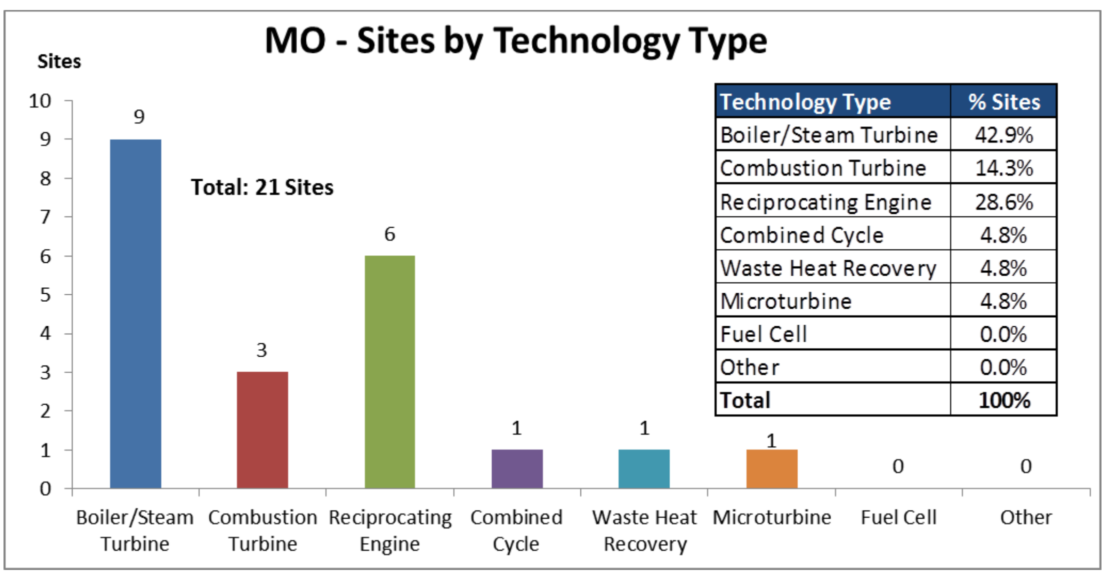


Figure 3.21: Numbers of Sites by Technology Type in Missouri.
Source: ICF International (2015)

By type of facilities, Universities have the biggest installed capacity of CHP with 86.65 MW (37.2%), followed by district energy with 60.55 MW (26%), chemical industries with 35.7

MW (15.3%) and food Industries with 26.1 MW (11.2%). However, district energy and chemical industries have a larger amount of facilities with CHP (four and three, respectively), as shown in Figures 3.22 and 3.23

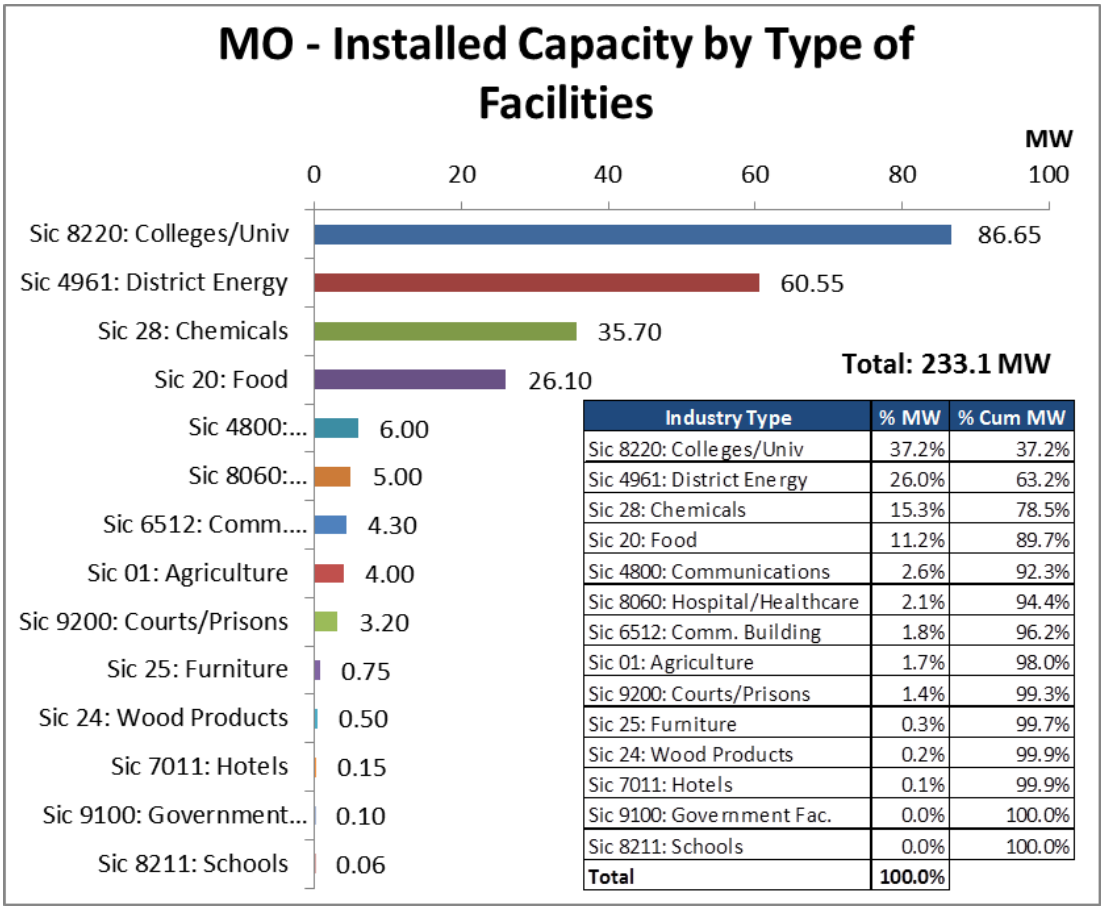
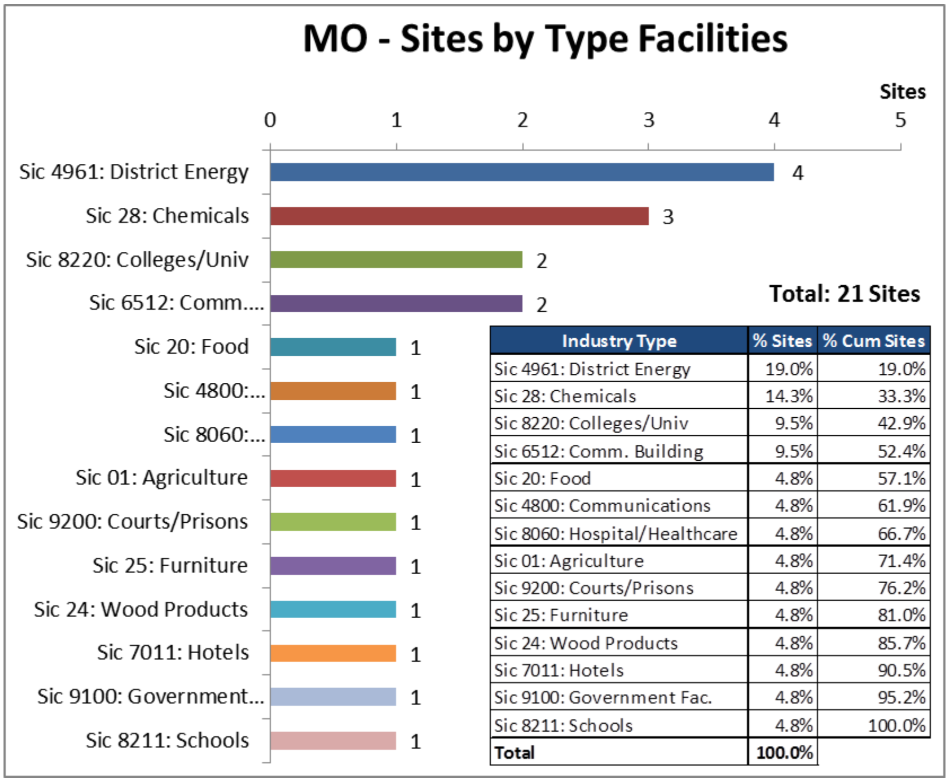


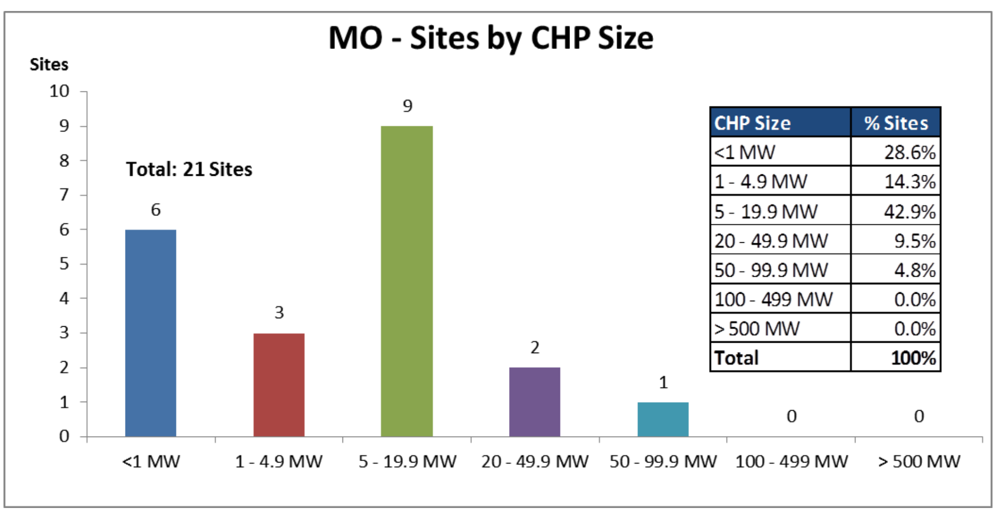
Figure 3.22: Installed CHP Capacity by Type of Facility in Missouri.
Source: ICF International (2015)



Industry Type	% Sites	% Cum Sites
Sic 4961: District Energy	19.0%	19.0%
Sic 28: Chemicals	14.3%	33.3%
Sic 8220: Colleges/Univ	9.5%	42.9%
Sic 6512: Comm. Building	9.5%	52.4%
Sic 20: Food	4.8%	57.1%
Sic 4800: Communications	4.8%	61.9%
Sic 8060: Hospital/Healthcare	4.8%	66.7%
Sic 01: Agriculture	4.8%	71.4%
Sic 9200: Courts/Prisons	4.8%	76.2%
Sic 25: Furniture	4.8%	81.0%
Sic 24: Wood Products	4.8%	85.7%
Sic 7011: Hotels	4.8%	90.5%
Sic 9100: Government Fac.	4.8%	95.2%
Sic 8211: Schools	4.8%	100.0%
Total	100.0%	

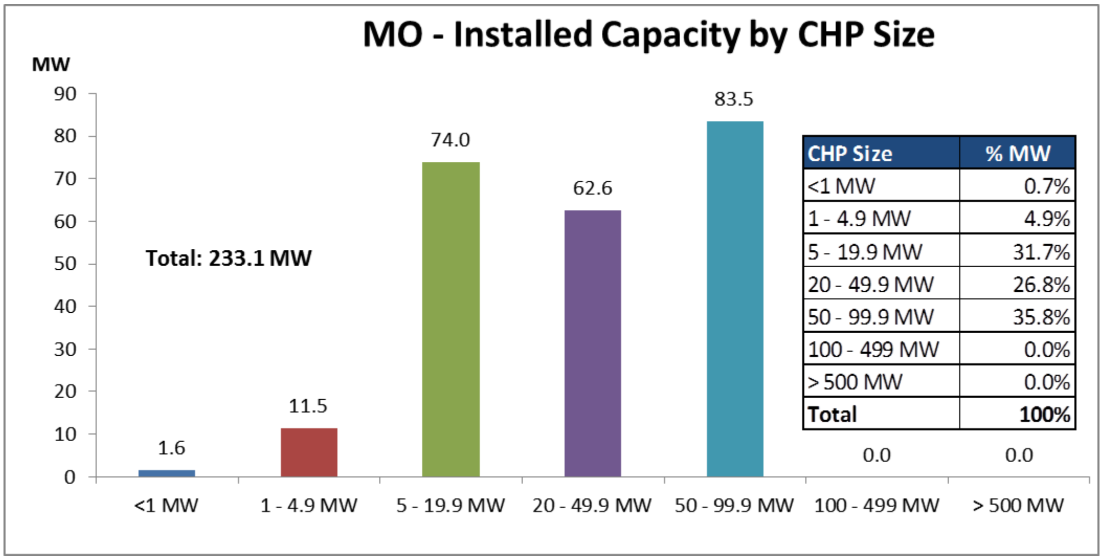
Figure 3.23: Numbers of Sites by Type of Facility in Missouri
Source: ICF International (2015)

Figures 3.24 and 3.25 show one facility (sized 50 to 99.9 MW) representing 4.8% of the CHP sites concentrate 35.8% of the installed CHP capacity in Missouri. Most of the facilities (42.9%) have CHP system between 5 to 19.9 MW (nine sites), and these facilities represent 74 MW (31.7%) of the installed CHP capacity.



CHP Size	% Sites
<1 MW	28.6%
1 - 4.9 MW	14.3%
5 - 19.9 MW	42.9%
20 - 49.9 MW	9.5%
50 - 99.9 MW	4.8%
100 - 499 MW	0.0%
> 500 MW	0.0%
Total	100%

Figure 3.24: Numbers of Sites by CHP Size in Missouri.
Source: ICF International (2015)



CHP Size	% MW
<1 MW	0.7%
1 - 4.9 MW	4.9%
5 - 19.9 MW	31.7%
20 - 49.9 MW	26.8%
50 - 99.9 MW	35.8%
100 - 499 MW	0.0%
> 500 MW	0.0%
Total	**100%**

Figure 3.25: Installed Capacity by CHP Size in Missouri.
Source: ICF International (2015)

According to Chittum and Kaufman (2011), Molina et al. (2011) and the Missouri Department of Economic Development. Division of Energy (2014), Missouri does not have a favorable market for CHP deployment. This is supported from the above figures where Missouri installed CHP capacity is only 233.1 MW in 21 facilities. If Missouri is compared with other states, it ranks 36 in installed capacity (MW) and represents only 0.3% of US installed capacity. Missouri figures pales against other states where there have been developments of CHP projects such as can be found in Texas and California. Texas has 17,538 MW (21.1% of US installed capacity) and California has 8,805 MW (10.06% of US installed capacity). In terms of number of sites, Missouri ranks 33 with 0.5% of CHP facilities located in Missouri. California has 1,315 sites (30.3% of the CHP facilities are located in California) and New York State has 539 sites (12.4% of the CHP facilities are located in New York State). A table with all states ranks in terms of installed capacity (MW) and number of sites can be found in Appendix B.

In the industrial sector, Missouri has only 65 MW of installed CHP capacity in six sites; it ranks 42 in installed capacity (MW) and represents only 0.1% of US industrial CHP capacity.

Other states like Texas have 17,053.1 MW. In terms of the number of sites, Missouri ranks 37 with 0.5% of CHP industrial facilities located in Missouri; other states like California have 197 industrial facilities with CHP. A table with all industrial state ranks in terms of installed capacity (MW) and their respective number of sites can be found in Appendix B.

The limited development of CHP in Missouri is the result of a mixture of different factors, including poor spark spread (lower electricity cost in comparison with other states), utility behavior against CHP, lack of knowledge about benefits of CHP between customers, lenders and utilities and unsupportive state regulations (Molina et al., 2011, Chittum and Kaufman, 2011). Missouri in the 2014 State Energy Efficiency Scorecard in the area of CHP received zero out of five points (Gilleo et al., 2014). In other words, there is no policy support for CHP deployment. The interconnection standard and net metering is only for small renewable-systems (up to 100 kW) and do not include CHP. Even worse, these processes are at the discretion of the utilities. Standby rates are not adequate for CHP. Missouri does not provide any financial incentives and/or financing for CHP. CHP is not included as an eligible technology neither in the energy efficiency resource standard (EERS) nor in the renewable portfolio standard (RPS), and Missouri does not have an output-based emission regulations. As a result of this discouraging environment, only three new CHP plants have been implemented since 2007, which includes a 10.7 MW combustion turbine fueled by natural gas in 2007; a 3.2 MW reciprocating engine fueled by biomass in 2009 and a 5 MW boiler/steam turbine fueled by biomass in 2012. The biggest Missouri CHP is an 83.5 MW source at the University of Missouri-Columbia.

3.9 Case Studies: Industries

The following industrial cases are based on data from the Missouri Industrial Assessment Center (MoIAC) project reports from the year 2014. These real cases are included in order to emphasize CHP opportunities available to industries. However, most of the time, these opportunities are not implemented due to the presence of CHP barriers (Athawale and Felder, 2014). The following represents the types of initiatives that an effective CHP framework would help to implement:

Case Study 1: Glass Manufacturing

This case study is based on Report MO0145 from MoIAC (Wu and Abad, 2014b). It was recommended to this company to recover waste heat from their two melting furnaces to generate electricity (this is a type of bottoming cycle CHP system).

The company uses two air gases regenerative melting furnaces with electric boosting to melt batches for glass production. Each processes glass at approximately 80% of their full capacity. Natural gas is used as the fuel, and combustion air is supplied by 14 fans which measure 12 x 100 HP, 1 x 200 HP, and 1 x 50 HP (for both furnaces) for a total of 1,450 HP. The temperature inside these furnaces is around 2,500 ^{o}F, and generates a large amount of high temperature exhaust heat. The exhaust heat is partially recoverable by the regenerator, which uses the recovered heat to preheat inlet combustion air. The flue gas temperatures were measured at 375 ^{o}F for Furnace 1 and 410 ^{o}F for Furnace 2. The flue gas is discharged directly to the outside. This can be seen in Figure 3.26

Based on approach outlined in Appendix C, the quantity of energy content of exhaust discharge from the glass-melting furnaces can be estimated. It was used a software tool provided by the U.S. Department of Energy, known as PHAST (Process Heating Assessment Tool) to help with the calculations.

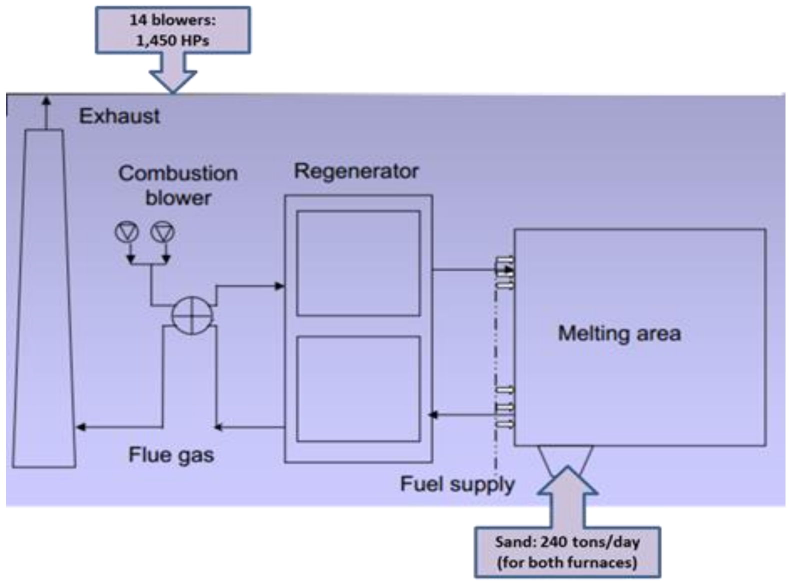


Figure 3.26: Schematic current situation.

For Furnace 1, the calculation is based on the data as shown below:

Fuel:	Natural Gas
Internal temperature:	2,550 ^oF
Exhaust gas temperature:	375 ^oF
Inlet air temperature:	77 ^oF
Oxygen in flue gases	2.2%
Excessive air:	10.5%

Furnace wall area:	8,000 ft^2
Average wall surface temperature:	195 ^oF
Furnace wall opening area:	45 ft^2

Type of load:	batch mix 80% and glass 20%,
Specific heat capacity of load:	0.224 $Btu/lb_m\,^oF$ (solid)
Inlet load temperature:	77 ^oF
Out load temperature:	2,550 ^oF

Furnace capacity:	100 tons
Furnace average load:	92 tons/day (average over 2011-2013)
Rate of load:	7,667 lbs/hour
Number of operating hours:	8,600 hours/year

(Note: fixtures, water cooling losses, etc., are not included in the estimation).

The results are summarized in Figure 3.27 This estimation is for the illustration of potentials only and companies are advised to confirm/check their values:

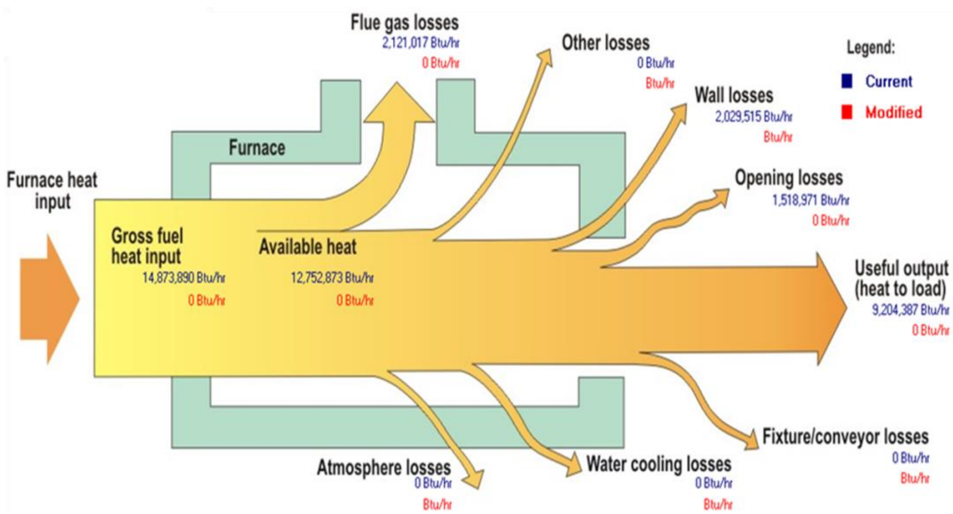


Figure 3.27: Results for Furnace 1

Similarly, the following data are used for Furnace 2:

Fuel:	Natural Gas
Internal temperature:	2,550 ^oF
Exhaust gas temperature:	375 ^oF
Inlet air temperature:	77 ^oF
Oxygen in flue gases	2.2%
Excessive air:	10.5%
Furnace wall area:	8,000 ft^2
Average wall surface temperature:	90 ^oF
Furnace wall opening area:	0 ft^2
Type of load:	batch mix 80% and glass 20%,
Specific heat capacity of load:	0.224 $Btu/lb_m{}^oF$ (solid)
Inlet load temperature:	77 ^oF

Out load temperature:	2,550 ^{o}F
Furnace capacity:	112 tons
Furnace average load:	105 tons/day (average over 2011-2013)
Rate of load:	8,750 lbs/hour
Number of operating hours:	8,600 hours/year

(Note: fixtures, water cooling losses, etc., are not included in the estimation).

The results are summarized in Figure 3.28. This estimation is for the illustration of potentials only, and the company is advised to confirm/check their values.

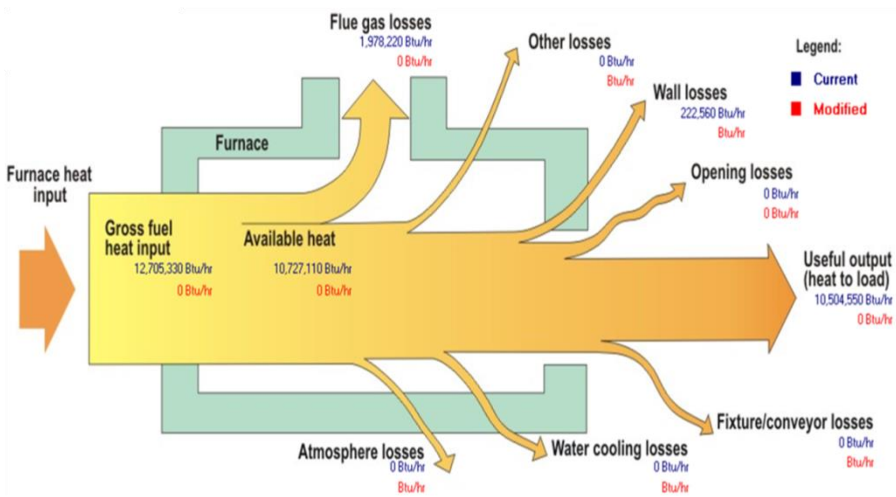


Figure 3.28: Results for Furnace 2

After being used to preheat combustion air, the remaining heat is discharged through the flue gas, which is currently not recovered. This is a missed opportunity for waste-heat conversion to electricity. Ideally, electricity should be generated through the recovery of exhaust heat for use in the plant or, in the case where too much is generated, a portion can be exported to the utility grid.

The analysis provided to illustrate the potentials involved is based on data and assumptions gathered during the audit and on the subsequent communications with the company. However, due to the nature of the technologies involved, it is strongly recommended that the company work with technology specialists to carry out more in-depth investigation.

The process of designing and implementing a cogeneration system has many factors to consider. In this particular case, the suitable option is a “bottoming cycle” approach where electricity is produced from the recovery of heat that is currently rejected outside. Figure 3.29 shows the principle involving a “plug-in” unit that can be installed to the site.

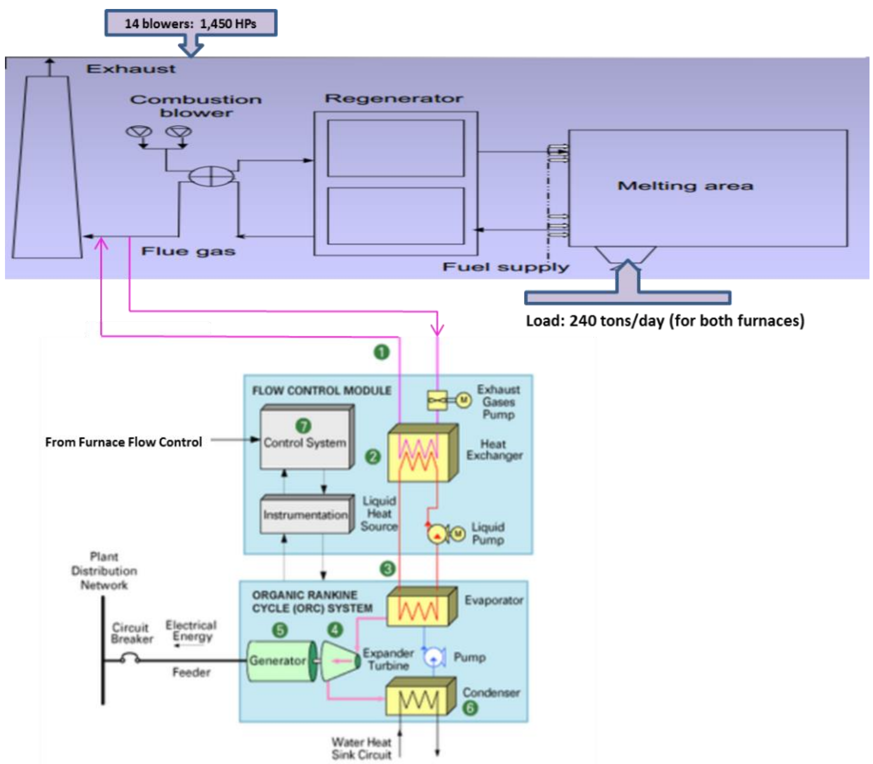


Figure 3.29: Schematic of the Cogeneration System

Traditionally a water/steam combination is used to carry out the heat transfer cycle. A relatively recent development in the field is known as the Organic Rankine Cycle (ORC) technology, where "organic" fluids (instead of water) are used as heat transfer media to allow lower temperature/pressure operation, as shown in the Table 3.6. Due to the "high-quality" waste heat involved here, either approach is applicable.

Table 3.6: Comparison between Steam and Organic Rankine Cycle.
Source: Oland (2004)

Technique	Pro	Con
Steam Rankine Cycle	•Mature technology •Relatively High Efficiency	•High temperature and pressure required •Process needs constant supervision and special certifications
Organic Rankine Cycle	•Mature Technology •Low operating temperature and pressure needed •Permitted for unmanned operation	•Sensitive to ambient outdoor temperatures •Lower thermal efficiency compared to a steam system

Evaluation of Savings

As a conservative estimation, this savings evaluation is based on the ORC system, which has a lower overall efficiency. A higher efficiency and power output can be expected from a steam-Rankine-cycle system. The work potential (WP) is the maximum work that is available from the current flue gases, given by:

$$WP = \eta \dot{E} = \left(1 - \frac{T_o}{T_H}\right) \dot{E}$$

where:

- T_H is the waste heat temperature, and
- T_O is the atmosphere temperature

The net electricity potential is the maximum electricity work (WE) that can be obtained by using a heat recovering unit to drive the ORC generator, given by:

$$WE = \Omega\ WP$$

where Ω is the net system efficiency, which depends on the rate of waste heat recovery, the thermal efficiency of the ORC unit, and the turbine efficiency. Literature and manufacturers report the following typical values:

- Efficiency of waste heat recovery unit: 30%
- Thermal efficiency of ORC unit: 80%
- Turbine efficiency: 90%

Thus the system efficiency is:

$\Omega = 0.3 \times 0.8 \times 0.9 = 0.19 = 19\%$

The following are used from previous results:

- T_H is the current waste heat temperature: 375 °F for Furnace 1, and 410 ^{o}F for Furnace 2.
- T_O is the temperature after heat recover, assumed as 77 °F.
- Flow rate of flue heat: 2.121 MMBtu/hour for Furnace 1, and 1.978 MMBtu/hour for Furnace 2.

The net electricity obtained is therefore:

WE = WE of Furnace 1 + WE of Furnace 2.

WE= 0.19 x [1 – (77/375)] x 2.121 + 0.19 x [1 – (77/410)] x 1.978.

WE = 0.320 MMBtu/hour + 0.305 MMBtu/hour = 0.625 MMBtu/hour.

Since: 1 Btu = 0.000293 kWh, the power of electricity generation that can be expected is given by:

0.625 MMBtu/hour = 625,000 Btu/hour x 0.000293 kWh/Btu = 183 kWh/hour

= 183 kW.

The energy savings created by this recommendation is the reduction in the electricity consumption and demand charge from the grid:

- Reduction in electricity consumption = 183 kW x 8,600 hours/year = 1,574,875 kWh/year.
- Reduction in electricity demand = 183 kW x 12 months/year = 2,196 kW-months/year.
- Cost saving in electricity consumption = 1,574,875 kWh/year x $0.04/kWh = $62,995/year.
- Cost saving in electricity demand = 2,196 kW-months/year x $12.25/ kW-months = $26,901/year.
- Total savings = Cost saving in electricity consumption + Cost saving in electricity demand.

  Total savings = $62,995/year + $26,901/year.

  Total savings = $89,896/year.

Implementation Cost and Payback

The value of $1,500-$2,000/kW is typically quoted in the literature for implementation. Therefore, the estimation of the implementation will cost between:

$1,500/kW x 185kW = $277,500 or $2,000/kW x 185 kW = $370,000

The simple payback period is between:

$277,500 / ($89,896/year) = 3.09 years, or

$370,000/($89,896/year) = 4.12 years

Case Study 2: Cement Manufacturing

This case study is based on Report MO0143 from MoIAC (Wu and Abad, 2014a). It was recommended to this company to recover waste heat from their preheater and clinker cooler to generate electricity (this is a type of bottoming cycle CHP system).

The materials were heated inside the kiln to 2,300 ^{o}F (1,250 ^{o}C). Approximately 50% of the extremely hot kiln exhaust, at 2,025 ^{o}F (1,107 ^{o}C) with a flow rate of 303,500 cfm was used to preheat material, through a number of stages in the cyclone. The discharged gas cools down to 670 ^{o}F (355 ^{o}C). This flow is then cooled down further by water spraying and fan cooling before being discharged into the raw mill and then baghouse for treatment. The remaining flow of heat and the clinkers are cooled quickly through a grate cooler system (to minimize the formation of a glass phase and ensure the maximum yield of alite – which is important for the hardening properties of cement). This process lowers the exhaust to 920 ^{o}F (494 ^{o}C). The temperature of gas discharged from the clinker cooler system is still too high for baghouse emission control. It is, therefore, further cooled by an air/gas cooler with an array of 12 fans, each with a 25 hp motor running at 100% load, which cools the exhaust down to 345 ^{o}F (174 ^{o}C). Flow rate is measured as 303,500 cfm.

In general, waste gas discharged from the kiln exit gases, the clinker cooler system, and the kiln preheater system all contain useful energy that can be converted into power, as pointed out by Worrell and Galitsky (2008). According to this report, the bottom-cycle systems have been installed in many cement plants worldwide and have proven economical, resulting in:

- Power generation between 10 and 23 kWh/ton clinkers
- Electricity savings of 20 kWh/ton clinkers

- Costs for such a system estimated at \$2–4/annual ton clinkers
- Operating costs at \$0.2–0.3/ton clinkers
- As an example, four U.S. cement plants cogenerated 486 million kWh annually

The report concluded by estimating that, assuming that 34% of the energy introduced into long dry kilns are exhausted as waste gas, there is a potential generation of 1,200 GWh/year in the U.S. cement industry.

Estimation of Quantity of Waste Heat from Exhaust

Analysis of the data reveals that waste heat from two sources is available and suitable for the intended purposes as can be seen in Figure 3.30

From preheater:

Average temperature =	670 ^{o}F (355 ^{o}C)
Average temperature after water spray and fan cooling =	153 ^{o}F (67 ^{o}C)
Average flow rate =	303,500 cfm

From clinker cooler:

Average temperature =	920 ^{o}F (494 ^{o}C)
Average temperature after fan cooling =	345 ^{o}F (174 ^{o}C)
Average flow rate =	303,500 cfm

For evaluation the following assumptions were made:

- Steady operating conditions exist over the operating hours.
- Kinetic and potential energy changes are not taken into consideration.

- Air properties are used for exhaust gases.

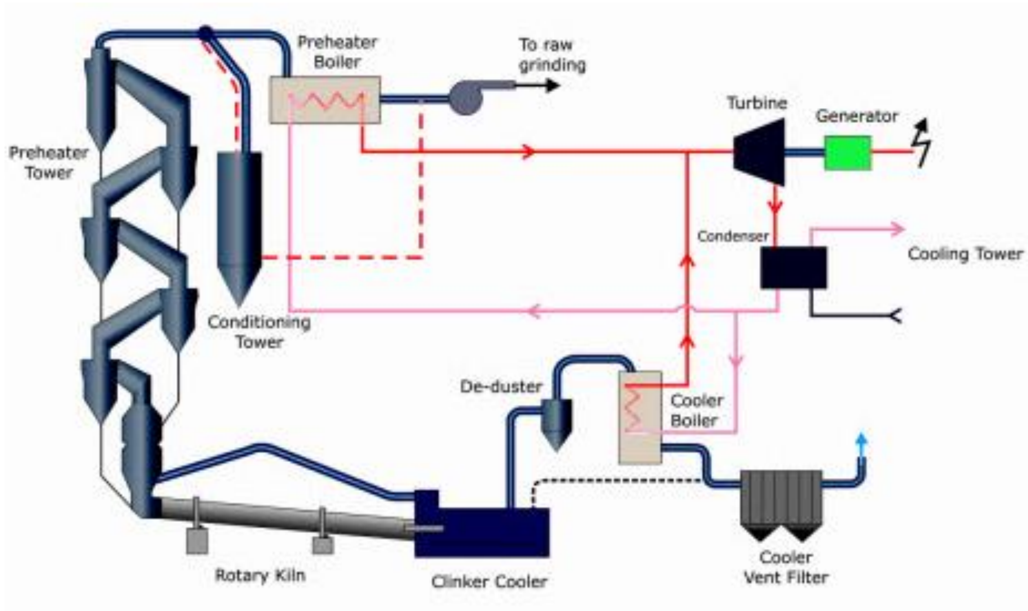


Figure 3.30: Schematic of the Cogeneration System

Each data item and its meaning is listed in Table 3.7 as information needed for the evaluation process.

Table 3.7: Data for the evaluation process

Data Name	Units	Explanation	Typical Value
Q	Btu/hr.	Rate of heat/energy exchanged per hour. Btu: British thermal unit	
C_p	Btu/lb$_m$ ^{o}F	Specific heat capacity	at 78 ^{o}F: 0.24
P	lb$_m$/ft^3	Density of air	at 78 ^{o}F: 0.0735 lb$_m$/ft^3
T	^{o}F	Temperature of flow	
HY	Hours	Operating hours per year	8,760
AES	kWh/year, MMBtu/year	Annual energy savings	
BDC	$/kWh-month	Base Demand Charge	

For energy balance, the heat contained in a certain volume air, V, at the temperature T (^{o}F) is: $Q_T = \rho V c_p$ (Btu/hr) where, c_p is the specific heat capacity in Btu/$lb_m$$^oF$, ρ is the density of the air in lb_m/ft^3, which can be obtained from handbooks according to the air average temperature. In this case:

For the exhaust from preheater at 670 ^oF:

c_p= 191 Btu/lb_m

ρ = 0.034 lb_m/ft^3

For the exhaust from clinker cooler at 920 ^oF:

c_p= 249 Btu/lb_m

ρ = 0.029 lb_m/ft^3

The volume of the flow per hour is calculated as follows:

V_{hour} = Flow rate (cfm) x 60 min/hour

The hourly energy flow is given by: *E* (MMBtu/year) = (ρ V_{hour} c_p) / (1,000,000)

Therefore, the hourly energy flow at each of the sources is given by:

For the exhaust from preheater at 670 ^oF:

$E_{Preheater}$ = (191 Btu/lb_m x 0.034 lb_m/ft^3 x 303,500 cfm x 60 min/hour) / 1,000,000

$E_{Preheater}$ = 118.25 MMBtu/hour

For the exhaust from clinker cooler at 920 ^oF:

$E_{Clinker\ cooler}$ = (249 Btu/lb_m x 0.029 lb_m/ft^3 x 303,500 cfm x 60 min/hour) / 1,000,000

$E_{Clinker\ cooler}$ = 131.49 MMBtu/hour

Therefore:

E_{Total} = 118.25 MMBtu/hour + 131.49 MMBtu/hour = 249.74 MMBtu/hour

In this case, electricity is generated through the recovery of exhaust heat, which can be used exclusively in the plant or, in the case where too much is generated, a portion can be exported to the utility grid. This analysis illustrates the potentials involved based on data and assumptions gathered during the audit, and subsequent communication with the company. However, due to the complexities of the technologies involved, companies are encouraged to work with technology specialists (designers and contractors) to carry out a more in-depth investigation.

Designing and implementing a cogeneration system has many factors to consider. In this case, the suitable option was a “bottoming cycle” approach where electricity is produced from the recovery of heat that is currently ejected into the outside atmosphere.

Traditionally a water/steam combination was used to carry out the heat transfer cycle. A relatively recent development in the field is known as the Organic Rankine Cycle (ORC) technology, where “organic” fluids (instead of water) are used as heat transfer media to allow lower temperature/pressure operation—as shown in the Table 3.6. Due to the “high-quality” waste heat involved here, either approach will be applicable.

Evaluation of Savings

This is a conservative evaluation based on the ORC system, which has a lower overall efficiency. A higher efficiency and power output can be expected from a steam-Rankine-cycle system. The work potential (WP) is the maximum work that is available from the current flue gases, given by:

$$WP = \eta \dot{E} = \left(1 - \frac{T_o}{T_H}\right)\dot{E}$$

where:

- T_H is the waste heat temperature, and
- T_O is the atmosphere temperature

The net electricity potential is the maximum electricity work (WE) obtainable by using a heat recovering unit to drive the ORC generator, which is expressed as:

$$WE = \Omega\ WP$$

where Ω is the net system efficiency which depends on the rate of waste heat recovery, the thermal efficiency of ORC unit, and the turbine efficiency. Literature and manufacturers report the following typical values:

- Efficiency of waste heat recovery unit: 30%
- Thermal efficiency of ORC unit: 80%
- Turbine efficiency: 90%

Thus the system efficiency is:

$\Omega = 0.3 \times 0.8 \times 0.9 = 0.19 = 19\%$

In our evaluation, the following are used from the previously results.

For the exhaust from a preheater set at 670 ^oF:

- T_O is the temperature after heat recovery, assumed as 153 °F to maintain the same temperature of flow to the raw mill
- Flow rate of heat: 118.25 MMBtu/hour

For the exhaust from clinker cooler at 920 ^{o}F:

- T_O is the temperature after heat recovery, assumed as 77 °F, since after this the flow goes directly to the baghouse
- Flow rate of heat: 131.49 MMBtu/hour

Therefore, the net electricity obtained is:

WE = WE of preheater + WE of clinker cooler

WE = 0.19 x [1 – (153/670)] x 118.25 + 0.19 x [1 – (77/920)] x 131.49

WE = 17.34 MM Btu/hour + 22.89 MM Btu/hour = 40.29 MM Btu/hour

Since: 1 Btu = 0.000293 kWh, the power of electricity generation that can be expected is given by:

40.29 MM Btu/hour = 40,290,000 Btu/hour x 0.000293 kWh/Btu = 11,805 kWh/hour

= 11,805 kW

The energy savings created by this recommendation is the reduction in the electricity consumption and demand charge from the grid:

- Reduction in electricity consumption = 11,805 kW x 8,600 hours/year = 101,523,000 kWh/year
- Reduction in electricity demand is given = 11,805 kW x 12 months/year = 141,660 kW-months/year
- Cost saving in electricity consumption = 101,523,000 kWh/year x $0.0361/kWh = $3,664,980/year
- Cost saving in electricity demand = 141,660 kW-months/year x $11.588/ kW-months = $1,641,556/year

- Total savings = Cost saving in electricity consumption + Cost saving in electricity demand

  Total savings = $3,664,980/year + $1,641,556/year

  Total savings = $5,306,536/year

Implementation Cost and Payback

The value of $1,500–$2,000/kW is typically quoted in the literature for implementation. Therefore, the estimation of the implementation cost will be between:

$1,500/kW x 12,000 kW = $18,000,000 or $2,000/kW x 12,000 kW = $24,000,000

The simple payback is between:

($18,000,000) / ($5,306,536/year) = 3.39 years, or

($24,000,000)/($5,306,536/year) = 4.5 years

Case Study 3: Metal Product Industry

This case study is based on Report MO0159 from MoIAC (Wu and Abad, 2014c). It was recommended to this company to recover waste heat from their catalytic oxidation system to generate electricity. Like cement and glass manufacturing, the metal product industry also uses a type of bottoming cycle CHP system. In an effort to comply with emissions regulations, a thermal oxidizer is used to treat the waste streams generated by the plant. While thermal oxidizers are not typically viewed as profit centers, they are required to maintain environmental compliance. The basic operation concept of a thermal oxidizer is purification by fire. The waste streams destroyed by thermal oxidation are maintained for a period of time at an elevated temperature, which in this case goes up to 1,400 ^{o}F in an oxygen-rich environment in order to achieve the desired destruction efficiency. Burning off the waste stream in a thermal oxidizer requires a significant amount of heat input. Data regarding the operation were collected. In summary:

- Waste streams were heated inside to an average of 1,250 ^oF.
- Total average flow rate = 3,360 cfm.

Heat recovery can reduce overall operating cost through heat recovery for cogeneration of electricity. By capturing a portion of the heat of the waste gas, the plant's efficiency can improve and its overall operating costs can be reduced. Figure 3.31 shows how energy from waste gas discharged from the oxidizer can be converted into power,

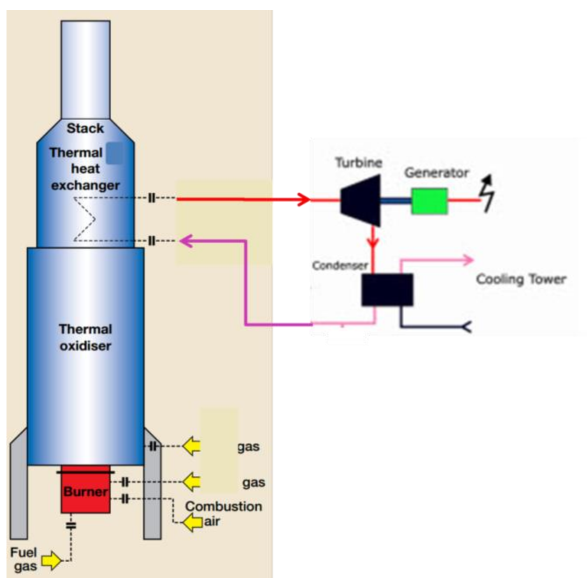


Figure 3.31: Schematic of the Cogeneration System

Estimation of Quantity of Waste Heat from Exhaust

For evaluation, the following assumptions were made:

- Steady operating conditions exist over the operating hours.
- Kinetic and potential energy changes are not taken into consideration.
- Air properties are used for exhaust gases.

Data items and their meanings are listed in Table 3.8 for the evaluation process.

Table 3.8: Data for the evaluation process

Data Name	Units	Explanation	Typical Value
Q	Btu/hr.	Rate of heat/energy exchanged per hour. Btu: British thermal unit	
C_p	Btu/lb_m ^oF	Specific heat capacity	at 78 ^oF: 0.24
P	lb_m/ft^3	Density of air	at 78 ^oF: 0.0735 lb_m/ft^3
T	^oF	Temperature of flow	
HY	Hours	Operating hours per year	8,760
AES	kWh/year, MMBtu/year	Annual energy savings	
BDC	$/kWh-month	Base Demand Charge	

For energy balance, the heat contained in a certain volume of air, V, at the temperature T (^oF) is: $Q_T = \rho V c_p$ (Btu/hr)

where, c_p is the specific heat capacity in Btu/lb_m ^oF and ρ is the density of the air in lb_m/ft^3, which can be obtained from handbooks according to the air average temperature. In this case:

For exhaust at 1,000 ^oF:

c_p= 275 Btu/lb_m

ρ = 0.027 lb_m/ft^3

The volume of the flow per hour is calculated as follows:

V_{hour} = Flow rate (cfm) x 60 min/hour

The hourly energy flow is given by: E (MM Btu/year) = (ρ Vhour cp) / (1,000,000)

Therefore, the hourly energy flow is given by:

E = (275 Btu/lbm x 0.027 lbm/ft3 x 3,360 cfm x 60 min/hour) / 1,000,000

= 1.50 MM Btu/hour

In this case, the power will be in the form of electricity, to be generated through the recovery of exhaust heat, that can be totally used in the plant or, in the case where too much is generated, with a portion exported to the utility grid. The analysis provided to illustrate the potentials involved, is based with data and assumptions gathered during the audit, and the subsequent communications with the company. However, due to the nature of the technologies involved, it is strongly recommend that the company work with specialists to carry out more in-depth investigation.

The process of designing and implementing a cogeneration system has many factors to consider. In this particular case, the suitable option is a “bottoming cycle” approach where electricity is produced from the recovery of heat that is currently ejected outside.

Traditionally water/steam combination is used to carry out the heat transfer cycle. A relatively recent development in the field is known as the Organic Rankine Cycle (ORC) technology, where “organic” fluids (instead of water) are used as heat transfer media to allow lower temperature/pressure operation – as shown in the Table 3.6. Due to the “high-quality” waste heat involved here, either approach will be applicable.

Evaluation of Savings

As a conservative estimation, the evaluation is based on the ORC system, which has a lower overall efficiency. A higher efficiency and power output can be expected from a steam-Rankine-cycle system. The work potential (WP) is the maximum work that is available from the current flue gases, given by:

$$WP = \eta \dot{E} = \left(1 - \frac{T_o}{T_H}\right)\dot{E}$$

where:

- T_H is the waste heat temperature, and
- T_O is the atmosphere temperature.

The net electricity potential is the maximum electricity work (WE) that can be obtained by using a heat recovering unit to drive the ORC generator, given by:

$$WE = \Omega\ WP$$

where Ω is the net system efficiency which depends on the rate of waste heat recovery, the thermal efficiency of an ORC unit, and turbine efficiency. Literature and manufacturers report the following typical values:

- Efficiency of waste heat recovery unit: 30%
- Thermal efficiency of ORC unit: 80%
- Turbine efficiency: 90%

Thus the system efficiency is:

$\Omega = 0.3 \times 0.8 \times 0.9 = 0.19 = 19\%$

In our evaluation, T_O is the temperature after heat recovery, assumed as 77 °F. Therefore, the net electricity obtained is:

WE = 0.19 x [1 – (77/1250)] x 1.5 = 0.27 MMBtu/hour

Since: 1 Btu = 0.000293 kWh, the power of electricity generation that can be expressed as:

0.27 MMBtu/hour = 270,000 Btu/hour x 0.000293 kWh/Btu = 79.11 kWh/hour

= 79.1 kW

The energy savings created by this recommendation is the reduction in the electricity consumption and demand charge from the grid:

- Reduction in electricity consumption = 79.1 kW x 8,600 hours/year = 680,260 kWh/year
- Reduction in electricity demand is given as equal to 79.1 kW x 12 months/year or 949 kW-months/year
- Cost savings in electricity consumption = 680,260 kWh/year x $0.0673/kWh = $45,781/year
- Cost saving in electricity demand = 949 kW-months/year x $5.548/ kW-months = $5,265/year
- Total savings = Cost saving in electricity consumption + Cost saving in electricity demand

  Total savings = $45,781/year + $5,265/year

  Total savings = $51,046/year

Implementation Cost and Payback

The value of $1,500–$2,000/kW is typically quoted in the literature for implementation. Therefore, the estimation of the implementation cost will be between:

$1,500/kW x 79 kW = $118,500 or $2,000/kW x 79 kW = $158,000

The simple payback is between:

($118,500) / ($51,046/year) = 2.32 years, or

($158,000) / ($51,046/year) = 3.10 years

4. Preliminary Research

4.1 System approach to problem solving

System approach (also known as system thinking) is an attempt to explain complexity in a more logical way. The main concept behind this approach is to analyze the situation or event with a system perspective (Wu, 2000, Wright, 1989). Moreover, a systems approach includes viewing the problem holistically, recognizing that the interaction between system elements determines system behavior, that different stakeholders have different purpose and rationalities, and all system are hierarchical in nature (Mingers and White, 2010, Wu, 2000). A system is a set of interrelated components organized in certain way in order to achieve defined goals. Communication, effective feedback and control are prerequisites for a successful performance of the system (Wu, 2000, Khisty and Mohammadi, 2001). Much of its power relies in its ability to discover and explain patterns of behavior in different situations or environments (Chai and Yeo, 2012). Finally, Wright (1989) stressed that the main ideas behind system thinking is that the sum of the parts is less than the whole; the nature of the parts are determined by the whole; if the parts are considered in isolation from the whole, they cannot be understood; and the parts are interdependent and interrelated.

There are two types of systems approach to problem solving, classified according to their relationship with the environment, their behavior and their interaction between their elements: hard system methodology (HSM) and soft system methodology (SSM). Both approaches provide a systemic (holistic view) and systematic (step by step) guidelines to problem solving (Khisty and Mohammadi, 2001).

On the one hand, hard system methodology (HSM) is characterized as having well-defined problems, easy-to-define goals and objectives, defined decision-making processes and quantitative performance measurements (Checkland, 1999). This approach can be classified into three types: system analysis, system engineering and operation research. System analysis deals with costs, risks and effectiveness of different alternatives in order to have a group of feasible options to choose from. System engineering deals with the development of an engineering solution to a system problem. Operation research deals with the construction of mathematical models in order to find an optimal solution to the problem. All three types highlight objectives formulation as the key factor to solving problems successfully; hence, with a systematic approach the best alternative can be selected (Khisty and Mohammadi, 2001).

On the other hand, soft system methodology (SSM) is characterized as having ill-defined problems or difficult to define, complex situations and environments, large number of elements with multiple interaction between them, and systems affected by behavioral influence with diverse perspectives and goals among its different stakeholders (Khisty and Mohammadi, 2001, Chai and Yeo, 2012). The main contribution of SSM is in the analysis of complex situations created by the existence of different perspective about the problem. SSM deals with variety of interests and remains the most commonly used and practical application of systems thinking (Mingers and White, 2010). Finally, Checkland (1999) presented the seven steps of SSM as:

1. The problem situation: Unstructured;
2. The problem situation: Expressed;
3. Root definitions of a relevant system;

4. Making and testing a conceptual model;
5. Comparing conceptual model with reality;
6. Changes: Systemically desirable, culturally feasible;
7. Action to improve the problem situation.

Steps 1, 2, 5, 6 and 7 are happening in the real world and Steps 3 and 4 are the system thinking method. Moreover, these steps are organized into four mental processes: Perceiving (Steps 1 and 2), predicting (Steps 3 and 4), comparing (Step 5), and needs of change and actions (Steps 6 and 7) (Checkland, 1999, Khisty and Mohammadi, 2001)

4.2 Logistic Regression models

Mathematical models called regression models are used to explore the relationship between a single dependent variable (response) with one or more independent variables (regressors or predictors) (Montgomery, 2009). Regression models are built to predict the likelihood of the outcome based on independent variables (Field, 2013)and to fit a set of sample data (Montgomery, 2009).

In the case of two categorical outcomes (binary response), it can be modeled using a binary logistic regression, a generalized linear model based on binomial distribution, which considers the probability of obtaining a specific amount of ones in a series of Bernoulli responses (Pardoe, 2006). Binary logistic regression models are appropriate for predicting the occurrence or non-occurrence of some categorical outcomes from continuous or categorical predictors (Hosmer and Lemeshow, 2000, Alhourani and Saxena, 2009). Moreover, instead of predicting the value of the response from the regressors, it predicts the probability of the outcome occurring given known values of the regressors (Field, 2013).

Logistic regression models transform data using logarithmic transformation in order to express a nonlinear relationship into a linear one, fulfill the linearity assumption and be a valid model. Therefore, it expresses the regression models in logarithmic terms, known as logit (Field, 2013). The logistic regression equation can be written as (Pedhazur, 1997, Pardoe, 2006):

$$Y = \text{Log (odds)} = \text{logit (P)} = \log \frac{P}{1-P} = b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots + b_kX_k$$

where,

- Y is the binary response (dependent variable)
- X_1, X_2,…X_k are the predictors (independent variables)
- b_0, b_1, b_2,….., b_k are the regression parameters

The regression parameters are estimated using the maximum likelihood method, which helps the decision maker to choose those parameters that make observed values most likely to happen (Pardoe, 2006, Field, 2013).

The probability equation for an event (Pedhazur, 1997) in a binary logistic regression is:

$$P(Y) = \frac{e^{\mathrm{b0+b1X1+b2X2+\cdots+bkXk}}}{1 + e^{\mathrm{b0+b1X1+b2X2+\cdots+bkXk}}}$$

Or,

$$P(Y) = \frac{1}{1 + e^{-(\mathrm{b0+b1X1+b2X2+\cdots+bkXk})}}$$

4.3 State Energy Efficiency Policy Retreat and Missouri Comprehensive State Energy Plan

As Director of the Missouri Industrial Center (IAC), Dr. Bin Wu was one of the Planning Committee members of the National Governors Association’s State Energy Efficiency Policy Retreat held on August 19, 2014 at Jefferson City. As an assistant to Dr. Wu, the author was involved extensively in the planning and discussion for this event.

The main objective of this retreat was to share with different types of stakeholders the potential benefits of improving industrial energy efficiency and increasing the deployment of combined heat and power (CHP). It was presented an overview on how EE and CHP can increase industries competitiveness and improve their bottom line, i.e., reduce cost and increase profit. Furthermore, a discussion about how Missouri’s regulatory environment can help to deploy or obstruct EE and CHP initiatives was also presented, which included an outline of how other US states have dealt with interconnection standards, net metering, stand-by rates and utility ownership of CHP systems. Finally, a list of action steps was developed in order to help the State of Missouri achieve their energy, economic and environmental goals.

Another activity that Dr. Wu and the author were involved in was the development of the Missouri Comprehensive State Energy Plan (December 2014 to May 2015). This activity included the participation of more than 300 stakeholders. The main objective of this plan is to comply with Executive Order 14-06 signed by Governor Nixon in June of 2014 to provide a road toward a sustainable and prosperous energy future while improving Missouri’s quality of life and jobs. The plan provides an analysis of Missouri’s renewable and non-renewable resources, and how energy is consumed in Missouri. Based on this analysis and the perspectives and inputs of stakeholders, it provides policy recommendations in order to achieve executive order goals.

Both activities provide very valuable insight about stakeholders’ perspectives and points of view. These perspectives will be used to design the structure of an effective CHP framework and will be considered in the development of the research hypotheses.

4.4 Design a Framework for an effective implementation of CHP

There are several research-based studies dealing with energy efficiency (EE) barriers and the main causes for the existence in what is called the EE Gap or EE Paradox (Palm and Thollander, 2010, Iskin, 2011, Trianni and Cagno, 2012, Fleiter et al., 2011, Tanaka, 2011, Rohdin et al., 2007, Lopes et al., 2012, Abdelaziz et al., 2011). EE barriers have been studied from different perspectives, disciplines and contexts, such as country-specific, region-specific, industry-specific, economical, organizational, behavioral, technological diffusion and many others (Chai and Yeo, 2012, Iskin, 2011); however, these analyses were made mainly in isolated manner without consideration of the interaction and relationship between barriers nor effects between stakeholders (Chai and Yeo, 2012, Wang et al., 2008). According to Chai and Yeo (2012), only three studies analyzed interconnections between barriers (Hasanbeigi et al., 2010, Wang et al., 2008, Nagesha and Balachandra, 2006). A system view approach is crucial in order to overcome the complexity of barrier interactions and stakeholders' effects and to increase EE initiatives adoption (Wu and Abad, 2013, Chai and Yeo, 2012)

The same thinking could be applied to CHP initiatives. Moreover, CHP is more complicated and more capital intensive than most EE initiatives—it is not a low-hanging fruit—and also, there is the presence of the CHP Gap or CHP paradox (Allan et al., 2015, Athawale and Felder, 2014). Thus, it is argued that barrier interactions and stakeholder effects are of paramount importance in CHP implementation; analyzing these factors from a system view perspective is essential. Understanding the interactions will help efforts to remove barriers and to make effective recommendations.

As in the case of EE barriers, several research-based studies and reports have treated CHP barriers and drivers in an isolated manner without considering the interaction between barriers and stakeholders. Their analyses were made from barriers perspectives (Hedman et al., 2013b, Costello, 2014, Allan et al., 2015, Moya, 2013, Kalam et al., 2012, Choi Granade et al., 2009, Shipley et al., 2008) or from stakeholders' perspectives (Chittum, 2013, Chittum and Farley, 2013a, Chittum and Farley, 2013b, Hampson and Rackley, 2014, Hedman et al., 2013a). None of them have analyzed from a system view perspective. Common results of these studies are low penetration and implementation rate of CHP initiatives.

One of the objectives of this research is to use system view approach to develop a framework that takes into consideration interaction and effects between barriers and stakeholders, and from this model, identify the main drivers to overcome CHP barriers and to increase CHP adoption rate. It is a disappointment that with all information available and efforts made by CHP advocates, CHP implementation is still limited. According to Altan (2010), a key factor for an effective government policy is identifying a framework that supports their implementation and control.

Based on system thinking theory and the models developed by Wu and Abad (2013), Chai and Yeo (2012), Hasanbeigi et al. (2010) and Stephenson et al. (2010), this author developed a framework for an effective implementation of CHP. This framework can be seen in Figure 4.1.

This framework takes a system view approach in order to identify points of interaction between barriers and to integrate stakeholder's perspective (their interest and objectives).

Moreover, it stresses the importance of utilizing synergies between stakeholders (knowledge generation and technological transfer through communication and cooperation), institutionalizing a continuous improvement cycle, and understanding that the motivation and capability of each stakeholder are influenced by technologies, energy practices, attitudes, values and beliefs (Wu and Abad, 2013).

The main differences between this CHP framework and the EE framework developed by Wu and Abad (2013) are the number of stakeholders and the complexity of their interaction. The CHP framework has more stakeholders, from industry, utilities, government, universities and third parties (suppliers, advocates), and environmental groups, all of which can influence positively or negatively the implementation decision of CHP. Their interaction is more complex due to the fact that there is no direct interaction between government and industry. Such input has to pass through the utilities especially since, in this case, utilities play a key role in CHP adoption. Each stakeholder is analyzed in terms of motivation, capability, implementation and results as suggested by Chai and Yeo (2012). Finally, for this framework to function properly, it is assumed that all stakeholders' objectives and behaviors are aligned and supported actions needed to overcome CHP implementation barriers are in place.

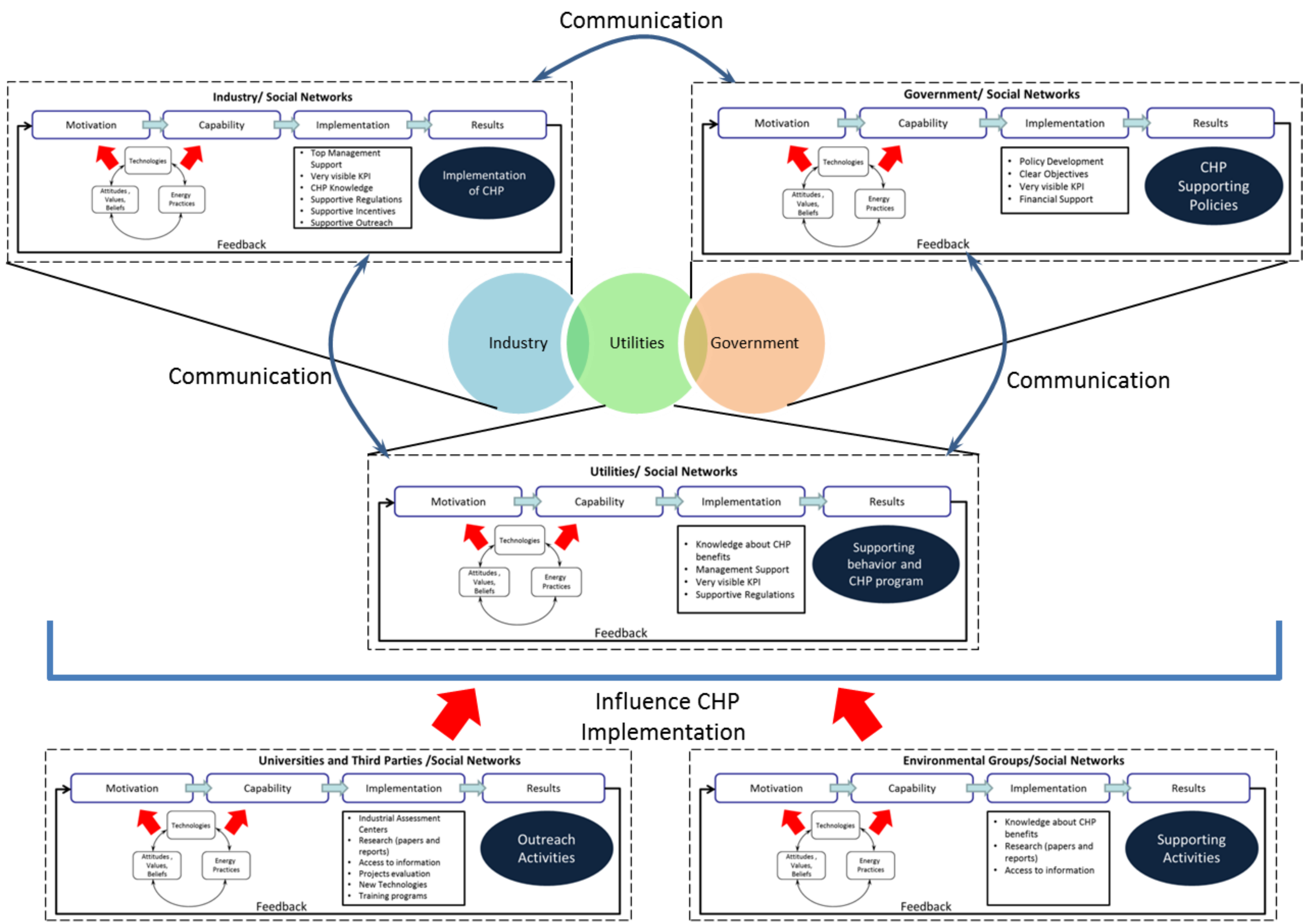


Figure 4.1: Detailed framework for an effective implementation of CHP initiatives

According to Field (2013) the best way to build models is with parsimony (an idea than simpler explanations are preferable than complex ones), meaning models should be kept as simple as possible. With this in mind, a general framework for an effective implementation of CHP initiatives (Figure 4.2) was developed from the detailed framework (Figure 4.1) in order to increase clarity and help with the research model formulation and research hypotheses. It clearly points out that in order to increase the adoption rate of CHP, it is necessary to have outreach activities from universities and third parties, supporting activities from environmental groups, supporting policies from government and supporting behavior and programs from utilities. Also, it highlights the importance of a streamlined communication process between industries, utilities and government.

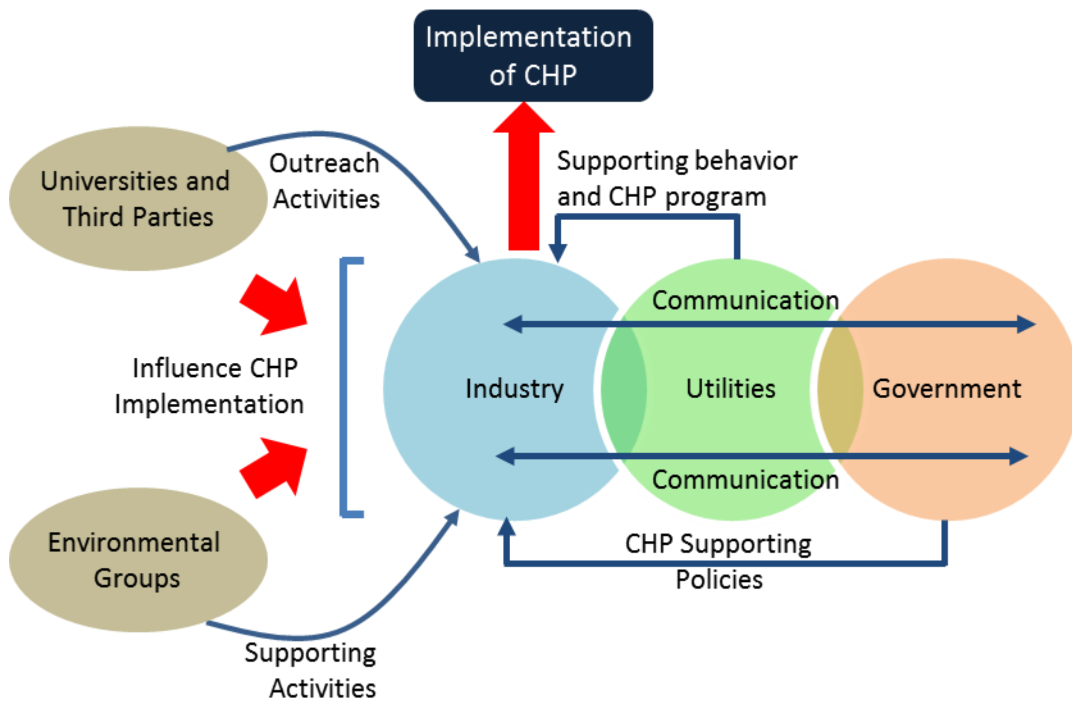


Figure 4.2: General framework for an effective implementation of CHP initiatives

The research model for effective implementation of CHP is based on a general framework (Figure 4.2), which can be seen in Figure 4.3. The research model for this study is designed to investigate the main barriers and drivers affecting CHP adoption and the interaction effects between stakeholders and barriers. Therefore, this research model expands on previous reports and studies focusing on a system view approach of all stakeholders. It will test the interaction/effects of each stakeholder on the implementation rates of CHP. It argues that in order to increase CHP adoption, an alignment of objectives should be in place between stakeholders (Hypothesis 1 to Hypothesis 3) and each one of them should perform specific activities (Hypothesis 4 to Hypothesis 12). Surveys to all stakeholders serve as a research methodology for testing our hypotheses.

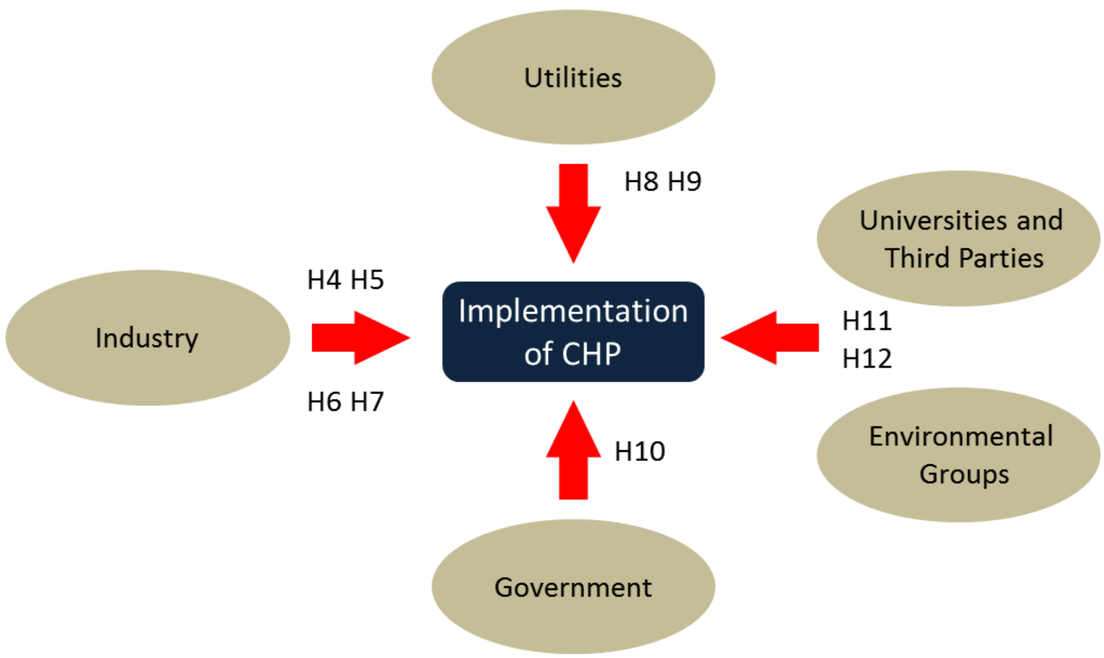


Figure 4.3: Research model for effective implementation of CHP

The hypotheses of the research model are as follows:

General Hypotheses:

H1: The perceived importance of CHP is the same across all stakeholders.

H2: The perceived CHP implementation barriers are the same across all stakeholders.

H3: The perceived CHP drivers are the same across all stakeholders.

Specific Hypotheses:

H4: Payback period impacts CHP Implementation rates.

H5: Implementation cost impacts CHP Implementation rates.

H6: Savings impact CHP Implementation rates.

H7: Rebates impact CHP Implementation rates.

H8: Utilities behavior impact CHP implementation rates.

H9: Utilities programs impact CHP implementation rates.

H10: Regulations impact CHP implementation rates.

H11: Outreach programs impact CHP implementation rates.

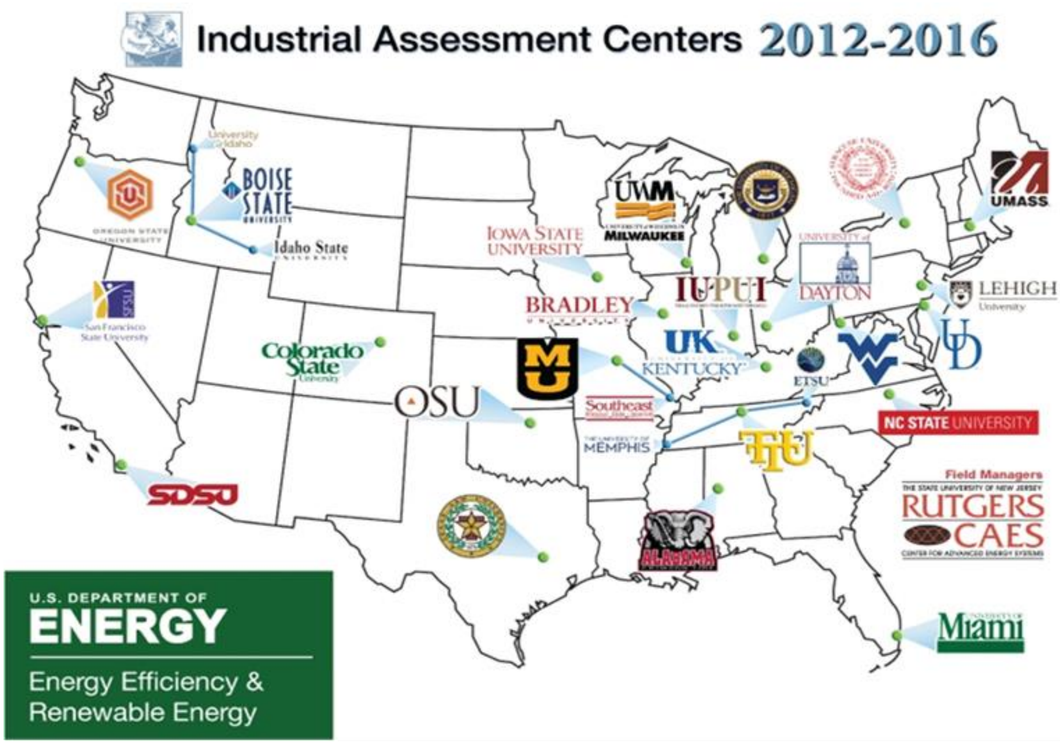
H12: Environmental group support impacts in CHP implementation rates.

A preliminary research was done focusing on main barriers from an industry point of view testing hypotheses H4 to H7. In order to accomplish this objective, information available from the Industrial Assessment Center (IAC) database was used. This database is of interest for several reasons. First, the IAC program is one of the longest running policies of the US Department of Energy (DOE), although its outreach is for small and medium industries. The IAC generates an extensive amount of available data about EE initiatives and their characteristics. Second, it provides the opportunity to focus on industries' behavior regarding EE and CHP initiatives and to do comparison studies of them; it sheds light on factors affecting their adoption rates and similarities if any exist. Third, it provides understanding of the factors that encourage industries to implement CHP initiatives (and the factors that discourage implementation) and to test our Hypotheses H4, H5, H6 and H7.

Finally, regression methods are commonly used to analyze data from historical records (IAC database) and to explore the relationship between two or more variables (Montgomery, 2009). The design of a regression (prediction) model is based on the characteristics of both dependent and independent variables. In our preliminary research, a logistic regression was chosen due to binary characteristic of the dependent variable (implementation status of CHP). The implementation status could be 1 if implemented or 0 if not implemented. According to Alhourani and Saxena (2009), logistic regression models can be used to precisely determine significant factors affecting adoption rates of assessment recommendations. Our logistic regression models will determine the influence of independent variables (predictors or regressors) such as: payback period, implementation costs, savings, rebates and industry characteristics' ability to affect the likelihood of adopting CHP initiatives.

4.5 Industrial Assessment Center Overview

The Industrial Assessment Center (IAC) program involves university-based centers that have been operating since 1976. The purpose of the program is to provide education and training of an energy-savvy workforce as well as to increase small and medium enterprises—industries—(SME) competitiveness by reducing waste and energy consumption, increasing productivity, and preventing pollution (Abadie et al., 2012, Alhourani and Saxena, 2009). More than 50 universities have participated since 1976, and their numbers have varied over the years (Abadie et al., 2012, Blass et al., 2011). For the period of 2012–2016, 24 universities are part of the IAC program and will receive over 30 million dollars of DOE funding. (US Department of Energy, 2014a). The current IAC centers can be seen in Figure 4.4.



Source: US Department of Energy.
http://energy.gov/articles/24-universities-receiving-funding-train-next-generation-energy-efficiency-experts

Figure 4.4: Current IAC Centers

Each center carried out EE-related activities in research, education, energy auditing, and outreach. In particular, they provided energy, waste and productivity audits to small and medium industries (SME) across United States. In addition to these benefits, the IAC program also encourages faculty to develop research and new courses (US Department of Energy, 2014a).

As part of education and training, energy efficiency assessment projects are performed by a team of faculty and students (graduate and undergraduate). These projects include interviews with plant managers, gathering operational data, and a facility walk-through in order to identify areas for improvements (Abdelaziz et al., 2011). Based on the visit, the IAC team prepares a confidential report with recommendations to increase productivity, reduce waste and reduce energy consumption. An average of $50,000 in annual savings has been reported as implemented by industries (US Department of Energy, 2014a). The assessment process can be seen in Figure 4.5. The results of the assessment projects are kept in the IAC database.

Figure 4.5: Industrial energy audit process
Source: Wu (2013)

4.6 Preliminary Research: CHP investment decision using IAC database

The focus of this preliminary research is to find out the main factors affecting CHP investment decisions from industry points of view; it does not consider analyses from others stakeholders as can be seen in Figure 4.6. It does analyze the effect of the payback period (H4), implementation cost (H5), savings (H6) and rebates (H7) based on the likelihood of adopting CHP initiatives using a logistic regression model with information from the IAC database. Moreover, it will investigate difference between factors affecting EE initiatives, CHP initiatives and heat recovery initiatives.

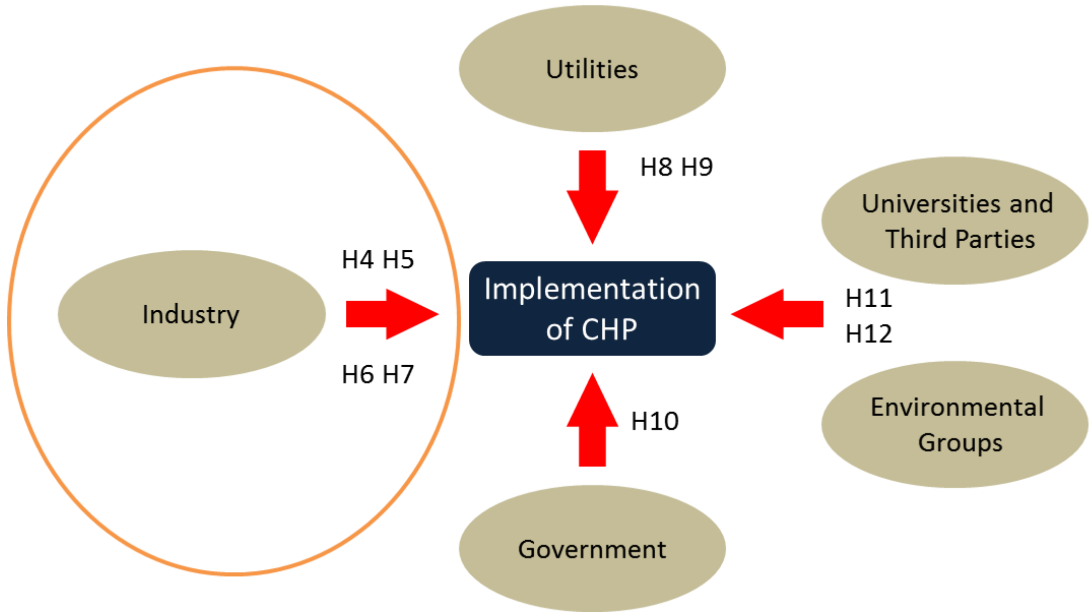


Figure 4.6: Preliminary research for effective implementation of CHP

This preliminary research answered two questions:

1. What are the main factors affecting the implementation rates in combined heat and power systems (testing hypotheses H4, H5, H6 and H7)?
2. Are the main factors affecting implementation rates in CHP systems the same as in heat recovery and others energy efficiency initiatives?

In order to answer these questions, as Figure 4.7 clearly shows, various logistic regression models were performed with various databases. The preliminary research was composed of four parts: A logistic regression model with all IAC data, a logistic regression model with only CHP and heat recovery data, a logistic regression model with only heat recovery data, and a logistic regression model with only CHP data. For each logistic regression, two families of models were used, a model based on the payback period and a model based on costs and benefits. These models are conventionally used in these kinds of studies (Abadie et al., 2012, Anderson and Newell, 2004)

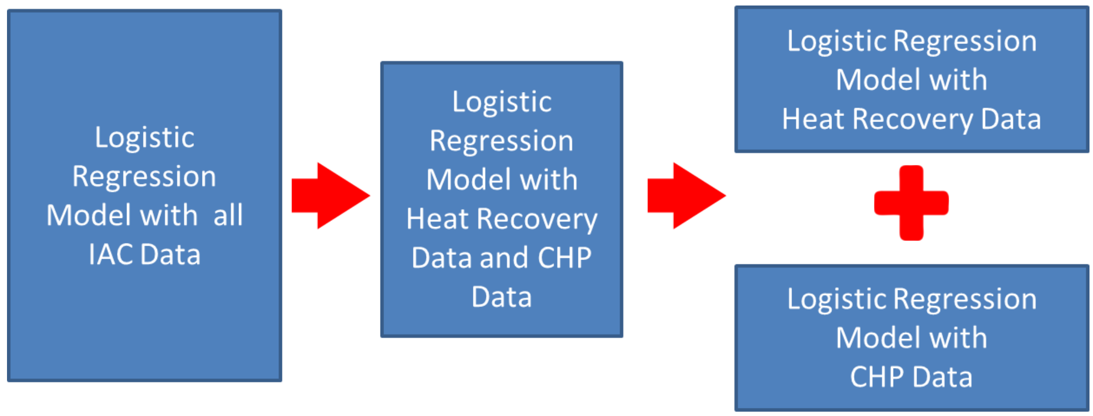


Figure 4.7: Analysis of the preliminary research for effective implementation of CHP

This research used IBM SPSS Statistics 22 software to perform logistic regression models and the variables identified for each model are based on the studies of Anderson and Newell (2004), Alhourani and Saxena (2009), and Abadie et al. (2012). These variables are:

- **Implementation.** This is our dependent variable and indicates the implementation status of assessment recommendations (ARs). It has a binary response: 1 if the recommendation is implemented and 0 if the recommendation is not implemented.
- **Payback.** This is a simple payback period in years (calculated as AR implementation cost divided by its annual savings). It is speculated that smaller payback periods increase the probability of AR implementation. This is a continuous predictor (independent variable).
- **ImpCostFinal.** This is the ARs implementation cost in thousands of dollars. Due to different values of independent variables, it was decided to divide the current cost by 1 K in order to have an adequate regression parameter. It is speculated that a greater up-front cost (implementation cost) decreases the probability of AR implementation. This is also a continuous predictor (independent variable).

- **TotalSavingsFinal**. This is the total annual savings of the ARs in thousands of dollars. Due to different values of independent variables it was decided to divide annual savings by 1 K in order to have an adequate regression parameter. It is speculated that greater annual savings increase the probability of AR implementation. This is a continuous predictor (independent variable).
- **Q_ARs.** This variable indicates the number of ARs given to the company in the report. It is speculated that a bigger number of recommendations decreases the probability of their implementation due to competition between recommendations in a budget constraints environment. It is a scale predictor (independent variable).
- **SalesFinal**. This variable indicates company annual sales in millions of dollars and is one of the variables used to analyze company size in the implementation decision of ARs. It is speculated that the bigger the company, the better the probability of AR implementation due to the existence of investment budgets and knowledgeable staff. Due to different values of independent variables, it was decided to divide annual company sales by 1 M to have an adequate regression parameter. This is a continuous predictor (independent variable).
- **Employees**. This variable indicates how many employees the company has and is another variable used to analyze company size in the implementation decision of ARs. It is speculated that the bigger the company, the better the probability of AR implementation due to the existence of more staff. It is a scale predictor (independent variable).
- **PlantArea.** This is another variable used to analyze company size in the implementation decision of ARs. It indicates the size of the facility in thousands of square feet in order to have an adequate regression parameter. Again, it is speculated that the bigger the

company, the better the probability of AR implementation. It is a scale predictor (independent variable).

- **ProductionHours.** This variable indicates how many annual production hours the company has. It is speculated that more production hours means less probability of AR implementation because they are working at full capacity (busier with their production) and give lower priority for AR implementation. It is a scale predictor (independent variable).
- **ARC**. This categorical independent variable indicates the type of assessment recommendations (ARs). Two dummy variables are created to represent the three types of ARs used in the analysis: Heat recovery = 1, CHP = 2 and others types of EE initiatives = 3. The IBM SPSS Statistics 22 software automatically generates the two dummy variables, and we chose last option as a reference category (Others = 3). The reference category is the 0,0 option. All analyses are going to be evaluated against this reference category. It is argued that there are significant differences between implementation rates of CHP, heat recovery and other EE initiatives due to their complexity, cost and knowledge required.
- **Rebate**. This categorical independent variable indicates the availability or unavailability of a rebate. A rebate can help reduce AR implementation cost and increase the probability of their implementation. A dummy variable is created to represent two possible options: No Rebate = 0 and Rebate Available = 1. The IBM SPSS Statistics 22 software generates automatically the dummy variable and we chose the first option as a reference category (No Rebate= 0). The reference category is the 0,0 option. The analysis is going to be evaluated against this reference category.

- **Region.** This categorical independent variable indicates the region where the industry is located. Three dummy variables are created to represent the four types of regions used in the analysis: Northeast = 1, Midwest= 2, South = 3 and West = 4. The IBM SPSS Statistics 22 software generates automatically the three dummy variables, and we chose the first option as a reference category (Northeast = 1). The reference category is the 0,0,0 option. All analyses are going to be evaluated against this reference category. It is argued that there could be a significant difference between regions.

It is important to indicate, the first idea was to use a state variable instead of a region variable. 51 dummy variables were created to represent 50 states plus the District of Columbia and Puerto Rico. At first, this was seen to be without problem due to the amount of cases for analysis (126,213 ARs); however, this did not hold, and SPSS gave error messages about failure to converge mainly because of incomplete information from some predictors. The goodness-of-fit tests in logistic regression makes the assumption that each alternative frequency (in our case—each state) is greater than 1 and no more than 20% are less than 5. A way to confirm this problem (not meeting the assumption) is to see unreasonably large standard errors (Field, 2013). By analyzing each state and making states that do not comply with this assumption serve as missing data solved the problem. This action solved the problem for the regression models that used all IAC database, CHP and Heat Recovery database and Heat Recovery database. Unfortunately, it did not solve the problem for the CHP database because too many variables were fitted to too few cases (Field, 2013). The possible solutions were to collect more data (which in our case is not possible), drop the variable, or to group states into regions. We chose the last option. Moreover, although it was possible to use states for the first three databases, it cannot help for the comparison analysis between all regression models. It was preferred that all models use the same variables. Finally, states were grouped using the classification of the US Census Bureau (2015).

- **INDINT**. This categorical independent variable indicates the type of manufacturing industry. Industries are classified by their energy intensity according to U.S. Energy Information Administration (1999). Three dummy variables were created to represent the four types of industries used in the analysis: High-energy consumers = 1, high-value added consumers = 2, low-energy consumers = 3 and non-manufacturing = 4. The IBM SPSS Statistics 22 software generated automatically the three dummy variables, and we chose the first option as a reference category (high-energy consumers = 1). The reference category is the 0,0,0 option. All analyses are going to be evaluated against this reference category. It is argued that there could be a significance difference between the different types of manufacturing industries. A more energy intensive industry is probably more likely to implement EE initiatives than others less-intensive industry.

The case of INDINT variables is similar to the case of region variables. The first idea was to use an SIC code instead of an INDINT variable. Thirty-nine dummy variables were created to represent 40 SIC codes. Again, SPSS gave error messages about failure to converge because of incomplete information from some predictors and generated excessively large standard errors. The same procedure was performed to fix errors and all databases were fixed except for the CHP database. Therefore, the same solution was applied to group SIC codes in some intelligent way. Due to the nature of this research, the logical way to group industry is by their energy intensity. It used the classification made by U.S. Energy Information Administration (1999). This classification can be seen in Figure 4.8

Standard Industrial Code	Major Industry Group	Description
High-Energy Consumers		
20 26 28 29 32 33	Food and Kindred Product Paper and Allied Products Chemicals and Allied Products Petroleum and Coal Products Stone, Clay, and Glass Products Primary Metal Industries	The high-energy consumers convert raw materials into finished goods primarily by chemical (not physical) means. Heat is essential to their production, and steam provides much of the heat. Natural gas, byproduct and waste fuels are the largest sources of energy for this group. All, except Food and Kindred Products, are the most energy- intensive industries.
High-Value Added Consumers		
34 35 36 37 38 39	Fabricated Metal Products Industrial Machinery and Equipment Electronic and Other Electric Equip. Transportation Equipment Instruments and Related Products Miscellaneous Manufacturing Industries	This group produces high value-added transportation vehicles, industrial machinery, electrical equipment, instruments, and miscellaneous equipment. The primary end uses are motor-driven physical conversion of materials (cutting, forming, assembly) and heat treating, drying and bonding. Natural gas is the principal energy source.
Low-Energy Consumers		
21 22 23 24 25 27 30 31	Tobacco Manufactures Textile Mill Products Apparel and Other Textile Products Lumber and Wood Products Furniture and Fixtures Printing and Publishing Rubber and Miscellaneous Plastics Leather and Leather Products	This group is the low-energy-consuming sector and represents a combination of end-use requirements. Motor drive is one of the key end uses.
Source: Energy Information Administration, Office of Energy Markets and End Use, Manufacturing Consumption of Energy 1991, DOE/EIA-0512(91).		

Figure 4.8: Classification of Industry by Energy Intensity
Source: U.S. Energy Information Administration (1999)

There are several approaches to perform logistic regression such as the forced entry method, hierarchical method and stepwise method. Stepwise can be divided forward or backward, and these can also be divided in the LR method, conditional method or Wald method. According to Field (2013), forced entry and hierarchical methods are preferred and should be used to build models in a systematic and parsimonious way. In other words, the regression model should be as simple as possible and only include predictors that contribute to the model. Moreover, according to Agresti and Finlay (1986) and Menar (1995), stepwise methods could be used when no previous studies exist and should be avoided for theory testing. Based on this, it was decided to use the forced entry method and hierarchical method for all logistic regression models. After using both methods, the results were the same. This research will present the results of the forced entry method.

Data Analysis and procedures

This research uses information from the IAC database as of 19 December of 2014. It contains 16,712 assessments with 126,213 assessment recommendations (ARs) from 1981 to 2015—a 34-year period (US Department of Energy, 2014b). For the purpose of this study, this data was adjusted as follows:

- Data from 2015, 2014 and some of 2013 were excluded because there was no information about their implementation status. The sample is restricted to status reported as Implemented or not implemented. All other statuses such as not reported, pending, data excluded and unavailable were eliminated. This adjustment reduced data to 122,418 ARs.
- All payback periods with negatives values and with values bigger than 25 years were eliminated. Careful inspection of these records revealed data of dubious quality. Following recommendations by Anderson and Newell (2004), this adjustment reduced data to 118,787 ARs.

- Records with a implementation cost of $0 and savings greater than $5,000 were excluded. Again, dubious quality was the reason for this exclusion and resulted in a sample size of 113,993 ARs.
- There were 13 errors in state information; some records indicate states as A or K. These records were adjusted as missing values.
- In 74 ARs there was no information about a rebate. These records were adjusted as missing values.
- Records showing annual production hours of more than 8,760 (24 hours/day x 365 days/year = 8,760 hours/year) were recoded as missing values. Using the same logic, records showing annual production hours less than 1,040 (5 days/week x 4 hours/day x 52 weeks/year = 1,040 hours/year) were recoded as missing values.
- Data showing a value of 0 in SIC (type of industry) was recoded as missing value.
- Records showing values of 0 in number of employees were recoded as missing values.
- Savings and implementation cost less than $100 were treated as missing values.
- Annual sales less than $30,000 were treated as missing values.
- Plant area less than 2,000 square feet were treated as missing values.

Logistic Regression Model with all IAC Database. Results from SPSS

The main characteristics of the variables studied can be seen in Table 4.1. The implementation rate of EE initiatives is 51%. Average payback period is 1.21 years. Reports had an average 8.6 assessment recommendations (ARs), and companies had in average 182 employees with 5,418 annual production hours.

Table 4.1: Some important characteristics of the variables studied

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Implementation Status of ARs	113,993	0	1	.51	.50
Payback Period (years)	113,993	.00	24.68	1.21	1.56
Total Savings of the Project ($1000)	112,199	.10	7,473.51	17.70	113.92
Implementation Cost ($1000)	96,642	.10	48,000.00	25.72	292.24
Number of ARs in the assessment	113,993	1	33	8.60	3.18
Sales (Million $)	112,837	.03	10,000.00	44.11	181.66
Number of Employees	113,881	1	5,800	182.05	198.40
Annual Production Hours	113,208	1,090	8,760	5,417.88	2,168.38
Plant Area in 1000 ft^2	88,299	2	396,285	364.31	5,676.76
Valid N (listwise)	74,666				

Logistic Regression Model with payback period

In the case of the logistic regression model with payback period, there were 113,993 ARs. 86,863 ARs were used in the model (76.2%). The other 23.8% (27,130 ARs) were not used in the logistic regression due to missing values. This can be seen in Table 4.2.

Table 4.2: Assessment Recommendations (ARs) included in the study
Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	86,863	76.2
	Missing Cases	27,130	23.8
	Total	113,993	100.0
Unselected Cases		0	.0
Total		113,993	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.3 shows the coding system for dependent variables (outcome) and predictors (categorical independent variables).

Table 4.3: Coding System for dependent and independent variables
Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variables Codings

		Frequency	Parameter coding (1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	30,312	0	0	0
	High Value Added Consumers	32,621	1	0	0
	Low Energy Consumers	22,985	0	1	0
	Non-Manufacturing	945	0	0	1
Region where the industry is located	Northeast	11,699	0	0	0
	Midwest	27,126	1	0	0
	South	31,445	0	1	0
	West	16,593	0	0	1
Type of ARs	Heat Recovery	4,092	1	0	
	CHP	317	0	1	
	Others	82,454	0	0	
Implementation Rebate	No Rebate	83,062	0		
	Rebate Available	3,801	1		

Table 4.4 shows model performance by cross tabulating the observed response with the predicted response. Data on the diagonal are correct predictions, and data off the diagonal are incorrect predictions. In Step 1 (with all variables included), the model can correctly predict 20,411 recommendations that would not be implemented, but the model cannot predict 23,595 recommendations. The model can predict a non-implementation rate of 46.4%. In addition, the model can predict 30,703 recommendations that could be implemented, but the model could not predict 12,154. The model can predict implementation at a rate of 71.6%. The overall correct prediction for this model is 58.8%. The baseline model with the constant included (Step 0) can correctly predict 50.7%. After the introduction of variables in Step 1, the model prediction increases to 58.8% accuracy.

Table 4.4: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted: Implementation Status of ARs: Not Implemented	Implemented	Percentage Correct
Step 0	Implementation Status of ARs	Not Implemented	44006	0	100.0
		Implemented	42857	0	.0
	Overall Percentage				50.7

a. Constant is included in the model.

b. The cut value is .500

Classification Table[a]

	Observed		Predicted: Implementation Status of ARs — Not Implemented	Predicted: Implementation Status of ARs — Implemented	Predicted: Percentage Correct
Step 1	Implementation Status of ARs	Not Implemented	20411	23595	46.4
		Implemented	12154	30703	71.6
	Overall Percentage				58.8

a. The cut value is .500

Table 4.5 shows summary statistics for the model. Overall the chi-square statistic is highly significant (p=0.000). The model's explanatory power (variation explained by the model) is shown in the R^2 value from both Cox and Snell (1989) and Nagelkerke (1991). Their values are 0.043 and 0.057, respectively. Abadie et al. (2012) indicated that low values of R^2 are expected when independent variables show great data dispersion (see Table 4.1) and the regression analyses use cross-sectional data. R^2 reported by Abadie et al. (2012) were from 0.0004 to 0.0368. Alhourani and Saxena (2009) and Anderson and Newell (2004) did not report R^2 values. None of them reported Hosmer and Lemeshow (2000) statistic goodness-of-fit test.

Table 4.5: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	3823.621	15	.000
	Block	3823.621	15	.000
	Model	3823.621	15	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	116578.867[a]	.043	.057

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

The results of the prediction model can be seen in Table 4.6. This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that payback periods, sales, production hours, recommendation type, rebates and regions are significant predictors to the model because all of them have a significance value less than 0.05. A one year increase in payback period decreases the odds of implementation by 0.795. This interpretation is reliable because the coefficient interval (0.787 -0.803) does not cross 1. Sales and annual production hours are significant but the direction of the effect is not clear because the coefficient interval includes 1.

Table 4.6: Prediction model variables
Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Payback	-.229	.005	1963.987	1	.000	.795	.787	.803
	Q_ARs	.002	.002	.764	1	.382	1.002	.998	1.006
	SalesFinal	.000	.000	10.256	1	.001	1.000	1.000	1.000
	Employees	.000	.000	1.464	1	.226	1.000	1.000	1.000
	ProductionHours	.000	.000	11.537	1	.001	1.000	1.000	1.000
	PlantArea	.000	.000	.099	1	.753	1.000	1.000	1.000
	ARC			964.436	2	.000			
	ARC(1)	-1.115	.037	885.156	1	.000	.328	.305	.353
	ARC(2)	-1.777	.194	83.540	1	.000	.169	.116	.248
	Rebate(1)	.530	.035	224.391	1	.000	1.699	1.585	1.821
	Region			85.443	3	.000			
	Region(1)	-.102	.023	20.086	1	.000	.903	.864	.944
	Region(2)	-.007	.022	.089	1	.765	.993	.951	1.038
	Region(3)	-.169	.025	45.271	1	.000	.845	.804	.887
	INDINT			.847	3	.838			
	INDINT(1)	-.015	.017	.792	1	.373	.985	.953	1.018
	INDINT(2)	-.008	.018	.192	1	.662	.992	.958	1.028
	INDINT(3)	.008	.068	.015	1	.903	1.008	.882	1.153
	Constant	.411	.035	138.430	1	.000	1.508		

a. Variable(s) entered on step 1: Payback, Q_ARs, SalesFinal, Employees, ProductionHours, PlantArea, ARC, Rebate, Region, INDINT.

Heat Recovery and CHP have lower odds to be implemented than other EE initiatives. In the case of heat recovery, implementation odds are 0.328 times lower and for CHP, they are 0.169 times lower. Having rebates increases the odds of implementation by 1.70 times. Midwest and West regions have lower odds of recommendation implementation than the Northeast region. The Midwest implementation rate is 0.90 times lower and for West, it is

0.85 times lower. All of these interpretations are reliable because their coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = 0.411 - 0.229\ X_1 + X_2 + X_3 - 1.115X_4 - 1.777X_5 + 0.530X_6 - 0.102\ X_7 - 0.169\ X_8$

where:

$X_1 = X_{payback}$
$X_2 = X_{salesFinal}$
$X_3 = X_{ProductionHours}$
$X_4 = X_{ARC(1)}$
$X_5 = X_{ARC(2)}$
$X_6 = X_{Rebate}$
$X_7 = X_{Region(1)}$
$X_8 = X_{Region(3)}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(0.411\ -\ 0.229\ \mathrm{X1}\ +\ \mathrm{X2}\ +\ \mathrm{X3}\ -\ 1.115\mathrm{X4}\ -\ 1.777\mathrm{X5}\ +\ 0.530\mathrm{X6}\ -\ 0.102\ \mathrm{X7}\ -\ 0.169\ \mathrm{X8})}}$$

Logistic Regression Model with cost/benefit

Table 4.7 shows a logistic regression model with costs/benefits of 113,993 ARs: 74,539 ARs were used in the model (65.4%), and the other 34.6% (39,454 ARs) were not used in the logistic regression due to missing values.

Table 4.7: Assessment Recommendations (ARs) included in the study
Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	74,539	65.4
	Missing Cases	39,454	34.6
	Total	113,993	100.0
Unselected Cases		0	.0
Total		113,993	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.8 shows the coding system for dependent variable (outcome) and predictors (categorical independent variables).

Table 4.8: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variables Codings

		Frequency	Parameter coding		
			(1)	**(2)**	**(3)**
Type of Manufacturing Industry	High Energy Consumers	26,429	0	0	0
	High Value Added Consumers	27,633	1	0	0
	Low Energy Consumers	19,639	0	1	0
	Non-Manufacturing	838	0	0	1
Region where the industry is located	Northeast	10,028	0	0	0
	Midwest	23,360	1	0	0
	South	26,528	0	1	0
	West	14,623	0	0	1
Type of ARs	Heat Recovery	4,053	1	0	
	CHP	315	0	1	
	Others	70,171	0	0	
Implementation Rebate	No Rebate	70,925	0		
	Rebate Available	3,614	1		

Table 4.9 shows model performance by cross tabulating the observed response with the predicted response. In Step 1 (with all variables included), the model can correctly predict 38,832 recommendations that would not be implemented, but the model cannot predict 1,518 recommendations. The model can predict a non-implementation rate of 96.2%. In addition, the model can predict 1,964 recommendations that would be implemented, but the model could not predict 32,225. The model can predict implementation at a rate of 5.7%. The overall correct prediction for this model is 54.7%. The baseline model with the constant included (Step 0) can correctly predict 54.1%. After the introduction of variables in Step 1, the model prediction has a small increase to 54.7% accuracy.

Table 4.9: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

Observed			Predicted: Implementation Status of ARs — Not Implemented	Predicted: Implementation Status of ARs — Implemented	Predicted: Percentage Correct
Step 0	Implementation Status of ARs	Not Implemented	40350	0	100.0
		Implemented	34189	0	.0
	Overall Percentage				54.1

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

Observed			Predicted: Implementation Status of ARs — Not Implemented	Predicted: Implementation Status of ARs — Implemented	Predicted: Percentage Correct
Step 1	Implementation Status of ARs	Not Implemented	38832	1518	96.2
		Implemented	32225	1964	5.7
	Overall Percentage				54.7

a. The cut value is .500

Table 4.10 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant (p = 0.000) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.020 and 0.027, respectively.

Table 4.10: Summary statistics for the model
Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	1512.915	16	.000
	Block	1512.915	16	.000
	Model	1512.915	16	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	101310.263[a]	.020	.027

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

The results of the prediction model can be seen in Table 4.11. This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that cost, savings, sales, recommendation type, rebate and region are significant predictors to the model because all of them have a significance value less than 0.05. A dollar increase of $1,000 in the implementation cost decreases the odds of implementation by 0.999 (small effect). This interpretation is reliable because the coefficient interval does not cross 1. Project savings and sales are significant but the direction of the effect is not clear because the coefficient interval includes 1.

Table 4.11: Prediction model variables
Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	ImpCostFinal	-.001	.000	81.853	1	.000	.999	.999	.999
	TotalSavingsFinal	.000	.000	4.459	1	.035	1.000	1.000	1.000
	Q_ARs	-.001	.002	.061	1	.805	.999	.995	1.004
	SalesFinal	.000	.000	7.959	1	.005	1.000	1.000	1.000
	Employees	.000	.000	.002	1	.963	1.000	1.000	1.000
	ProductionHours	.000	.000	.328	1	.567	1.000	1.000	1.000
	PlantArea	.000	.000	.627	1	.428	1.000	1.000	1.000
	ARC			788.618	2	.000			
	ARC(1)	-1.028	.038	740.336	1	.000	.358	.332	.385
	ARC(2)	-1.513	.207	53.454	1	.000	.220	.147	.330
	Rebate(1)	.429	.035	146.745	1	.000	1.536	1.433	1.647
	Region			69.896	3	.000			
	Region(1)	-.027	.024	1.217	1	.270	.974	.928	1.021
	Region(2)	.048	.024	3.995	1	.046	1.049	1.001	1.099
	Region(3)	-.130	.027	23.499	1	.000	.878	.833	.926
	INDINT			2.950	3	.399			
	INDINT(1)	-.025	.018	1.980	1	.159	.975	.941	1.010
	INDINT(2)	-.028	.019	2.121	1	.145	.972	.936	1.010
	INDINT(3)	.012	.072	.029	1	.864	1.012	.880	1.165
	Constant	-.049	.037	1.805	1	.179	.952		

a. Variable(s) entered on step 1: ImpCostFinal, TotalSavingsFinal, Q_ARs, SalesFinal, Employees, ProductionHours, PlantArea, ARC, Rebate, Region, INDINT.

Heat recovery and CHP have lower odds to be implemented than other EE initiatives. Heat recovery odds of implementation is 0.358 times lower and for CHP, it is 0.220 times lower. Having rebates increase the odds of implementation by 1.54 times. The South has higher odds of implementation rate (1.049 times higher) than the Northeast and West has 0.87 times lower than the Northeast. All of these interpretations are reliable because their coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -0.049-0.001X_1 + X_2 + X_3 -1.028X_4 - 1.513X_5 + 0.429X_6 +0.048X_7 - 0.130X_8$

where:

$X_1 = X_{ImpCostFinal}$ $X_4 = X_{ARC(1)}$
$X_2 = X_{TotalSavingsFinal}$
$X_3 = X_{SalesFinal}$
$X_5 = X_{ARC(2)}$
$X_6 = X_{Rebate}$
$X_7 = X_{Region(2)}$
$X_8 = X_{Region(3)}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-0.049-0.001X1 + X2 + X3 -1.028X4 - 1.513X5 + 0.429X6 +0.048X7 - 0.130X8)}}$$

Logistic Regression Model with CHP and Heat Recovery Database. Results from SPSS

The main characteristics of the variables studied can be seen in Table 4.12. The implementation rate of CHP and heat recovery is 27%; average payback period is 1.70 years; reports have an average of 8.65 assessment recommendations (ARs), and companies have an average of 199 employees with 5,677 annual production hours.

Table 4.12: Some important characteristics of the variables studied

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Implementation Status of ARs	6,244	0	1	.27	.44
Payback Period (years)	6,244	.00	24.68	1.70	1.79
Implementation Cost ($1000)	6,181	.10	30,000.00	122.74	800.91
Total Savings of the Project ($1000)	6,229	.10	6,264.80	48.77	209.62
Number of ARs in the assessment	6,244	1	33	8.65	3.38
Sales (Million $)	6,177	.04	10,000.00	51.90	208.80
Number of Employees	6,237	1	4,600	199.08	239.03
Annual Production Hours	6,189	1,090	8,760	5,676.93	2,124.92
Plant Area in 1000 ft2	4,491	3	90,000	306.11	2,246.38
Valid N (listwise)	4,376				

Logistic Regression Model with payback period

In the case of the logistic regression model with payback period, there were 6,244 ARs. 4,409 ARs were used in the model (70.6%), and the other 29.4% (1,835 ARs) were not used in the logistic regression due to missing values. This can be seen in Table 4.13.

Table 4.13: Assessment Recommendations (ARs) included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	4,409	70.6
	Missing Cases	1,835	29.4
	Total	6,244	100.0
Unselected Cases		0	.0
Total		6,244	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.14 shows the coding system for dependent variable (outcome) and predictors (categorical independent variables).

Table 4.14: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variables Codings

		Frequency	Parameter coding		
			(1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	1,907	0	0	0
	High Value Added Consumers	1,496	1	0	0
	Low Energy Consumers	955	0	1	0
	Non-Manufacturing	51	0	0	1
Region where the industry is located	Northeast	763	0	0	0
	Midwest	1,511	1	0	0
	South	1,522	0	1	0
	West	613	0	0	1
Implementation Rebate	No Rebate	4,332	0		
	Rebate Available	77	1		
Type of ARs	Heat Recovery	4,092	1		
	CHP	317	0		

Table 4.15 shows model performance by cross tabulating the observed response with the predicted response. In Step 1 (with all variables included), the model can correctly predict

with 100% accuracy, recommendations that would not be implemented (3,385). However, the model could not predict the implemented ones (0% accuracy). The overall correct prediction for this model is 76.8%. Both models, the baseline one (Step 0) and the model with variables (Step 1) have the same accuracy precision.

Table 4.15: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Implementation Status of ARs		Percentage Correct
			Not Implemented	Implemented	
Step 0	Implementation Status of ARs	Not Implemented	3385	0	100.0
		Implemented	1024	0	.0
	Overall Percentage				76.8

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted		
			Implementation Status of ARs		Percentage Correct
			Not Implemented	Implemented	
Step 1	Implementation Status of ARs	Not Implemented	3385	0	100.0
		Implemented	1024	0	.0
	Overall Percentage				76.8

a. The cut value is .500

Table 4.16 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant (p = 0.000) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.041 and 0.062, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.493 (more than 0.05). This is supported by Figure 4.9. It displays a histogram of the predicted probabilities of recommendation being implemented. A model that correctly predicts the observed data will have the cases cluster at each end of the figure. If the cases are in the middle of the figure (.5), that indicates a 50:50 chance that the model predicted them correctly. It can be seen that a non-implemented rate is better than a predicted implemented rate.

Table 4.16: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	184.522	14	.000
	Block	184.522	14	.000
	Model	184.522	14	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	4594.688[a]	.041	.062

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	7.413	8	.493

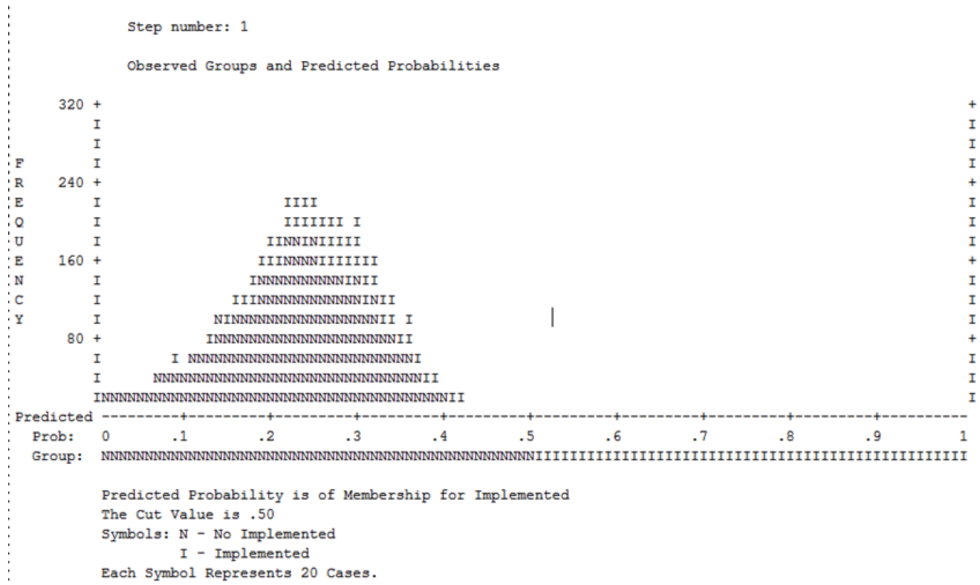


Figure 4.9: Classification Plot

The results of the prediction model can be seen in Table 4.17. This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that payback period, number of recommendations in the report, recommendation type and region are significant predictors to the model because all of them have a significance value less than 0.05. A one year increase in payback period decreases the odds of implementation by 0.77. One more recommendation in the report decreases the odds of implementation by 0.96.

Table 4.17: Prediction model variables
Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Payback	-.266	.032	69.757	1	.000	.767	.720	.816
	Q_ARs	-.038	.011	11.126	1	.001	.963	.942	.985
	SalesFinal	.000	.000	1.383	1	.240	1.000	.999	1.000
	Employees	.000	.000	.642	1	.423	1.000	1.000	1.000
	ProductionHours	.000	.000	2.849	1	.091	1.000	1.000	1.000
	PlantArea	.000	.000	2.009	1	.156	1.000	1.000	1.000
	ARC(1)	.572	.211	7.340	1	.007	1.771	1.171	2.678
	Rebate(1)	-.014	.321	.002	1	.964	.986	.526	1.849
	Region			28.519	3	.000			
	Region(1)	.114	.105	1.179	1	.278	1.121	.912	1.377
	Region(2)	-.360	.110	10.650	1	.001	.698	.562	.866
	Region(3)	-.101	.134	.561	1	.454	.904	.695	1.177
	INDINT			7.371	3	.061			
	INDINT(1)	.180	.086	4.396	1	.036	1.197	1.012	1.416
	INDINT(2)	.053	.099	.288	1	.591	1.055	.868	1.281
	INDINT(3)	.605	.321	3.559	1	.059	1.831	.977	3.432
	Constant	-.845	.282	8.976	1	.003	.430		

a. Variable(s) entered on step 1: Payback, Q_ARs, SalesFinal, Employees, ProductionHours, PlantArea, ARC, Rebate, Region, INDINT.

Heat recovery has a 1.77 times larger odds of being implemented than CHP initiatives. The South has 0.70 times lower odds of being recommended for implementation than the Northeast. All of these interpretations are reliable because their coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -0.845-0.266X_1 -0.038X_2 + 0.572X_3 -0.36X_4$

where:

$X_1= X_{payback}$
$X_2= X_{Q\_ARs}$
$X_3= X_{ARC(1)}$
$X_4= X_{Region(2)}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-0.845-0.266X1 -0.038X2 + 0.572X3 -0.36X4)}}$$

Logistic Regression Model with cost/benefit

In the case of the logistic regression model with costs/benefits, there were 6,244 ARs. 4,368 of the ARs were used in the model (70%); the other 30% (1,876 ARs) were not used in the logistic regression due to a missing values. This can be seen in Table 4.18.

Table 4.18: Assessment Recommendations (ARs) included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	4,368	70.0
	Missing Cases	1,876	30.0
	Total	6,244	100.0
Unselected Cases		0	.0
Total		6,244	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.19 shows the coding system for dependent variable (outcome) and predictors (categorical independent variables).

Table 4.19: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variables Codings

		Frequency	Parameter coding		
			(1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	1,890	0	0	0
	High Value Added Consumers	1,479	1	0	0
	Low Energy Consumers	948	0	1	0
	Non-Manufacturing	51	0	0	1
Region where the industry is located	Northeast	754	0	0	0
	Midwest	1,490	1	0	0
	South	1,513	0	1	0
	West	611	0	0	1
Implementation Rebate	No Rebate	4,291	0		
	Rebate Available	77	1		
Type of ARs	Heat Recovery	4,053	1		
	CHP	315	0		

Table 4.20 shows a model performance by cross tabulating the observed responses with the predicted responses. In Step 1 (with all variables included), the model can correctly predict

with 100% accuracy recommendations that would not be implemented (3,373). However, the model could not predict the implemented ones (0% accuracy). The overall correct prediction for this model is 77.2%. Both models, the baseline one (Step 0) and the model with variables (Step 1) have the same accuracy precision.

Table 4.20: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted: Implementation Status of ARs: Not Implemented	Predicted: Implementation Status of ARs: Implemented	Predicted: Percentage Correct
Step 0	Implementation Status of ARs	Not Implemented	3373	0	100.0
		Implemented	995	0	.0
	Overall Percentage				77.2

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted: Implementation Status of ARs: Not Implemented	Predicted: Implementation Status of ARs: Implemented	Predicted: Percentage Correct
Step 1	Implementation Status of ARs	Not Implemented	3373	0	100.0
		Implemented	995	0	.0
	Overall Percentage				77.2

a. The cut value is .500

Table 4.21 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant (p = 0.000) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.024 and 0.036, respectively. The goodness-of-fit statistics from Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.097 (more than 0.05). This is supported by Figure 4.10. It displays a histogram of the predicted probabilities of recommendation being implemented. It can be seen that Non-implementation is better predicted than implemented.

Table 4.21: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	105.989	15	.000
	Block	105.989	15	.000
	Model	105.989	15	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	4581.712[a]	.024	.036

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	13.469	8	.097

```
             Step number: 1

             Observed Groups and Predicted Probabilities

     400 +                                                                                                    +
         I                                                                                                    I
         I                                                                                                    I
F        I                     I                                                                              I
R    300 +                    III                                                                             +
E        I                    IIII II                                                                         I
Q        I                   IINIIIIII                                                                        I
U        I                  IINNNNIIIII                                                                       I
E    200 +                  NNNNNNINNNII                                                                      +
N        I                 INNNNNNNNNNNI                                                                      I
C        I                 NNNNNNNNNNNNII                                                                     I
Y        I                INNNNNNNNNNNNNII                                                                    I
     100 +               NNNNNNNNNNNNNNNNII                                                                   +
         I               NNNNNNNNNNNNNNNNNI                                                                   I
         I       NNN    NNNNNNNNNNNNNNNNNNNI                                                                  I
         I     NNNNNNNNNNNNNNNNNNNNNNNNNNNNNIN                                                                I
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII

          Predicted Probability is of Membership for Implemented
          The Cut Value is .50
          Symbols: N - No Implemented
                   I - Implemented
          Each Symbol Represents 25 Cases.
```

Figure 4.10: Classification Plot

The results of the prediction model can be seen in Table 4.22. This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that the number of recommendations in the report, recommendation type, regions and industry type are significant predictors to the model because all of them have a significance value less than 0.05. One more recommendation in the report decreases the odds of implementation by 0.963. Heat recovery has 2.926 times higher odds to be implemented than CHP initiatives. The South region has 0.697 times lower odds to implement recommendations than the Northeast and a high value added consumers industry has 1.247 times larger odds to implement recommendations than a high energy consumers industry. All of these interpretations are reliable because their coefficient intervals do not cross 1.

Table 4.22: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	ImpCostFinal	.000	.000	2.503	1	.114	1.000	.999	1.000
	TotalSavingsFinal	.000	.000	2.030	1	.154	1.000	1.000	1.001
	Q_ARs	-.037	.011	10.778	1	.001	.963	.942	.985
	SalesFinal	-.001	.000	2.416	1	.120	.999	.998	1.000
	Employees	.000	.000	1.252	1	.263	1.000	1.000	1.001
	ProductionHours	.000	.000	.808	1	.369	1.000	1.000	1.000
	PlantArea	.000	.000	1.598	1	.206	1.000	1.000	1.000
	ARC(1)	1.074	.228	22.104	1	.000	2.926	1.870	4.579
	Rebate(1)	-.127	.318	.161	1	.689	.880	.472	1.642
	Region			30.316	3	.000			
	Region(1)	.132	.105	1.576	1	.209	1.142	.928	1.404
	Region(2)	-.361	.111	10.613	1	.001	.697	.561	.866
	Region(3)	-.124	.134	.853	1	.356	.883	.679	1.149
	INDINT			9.270	3	.026			
	INDINT(1)	.221	.086	6.524	1	.011	1.247	1.053	1.477
	INDINT(2)	.110	.100	1.214	1	.271	1.116	.918	1.358
	INDINT(3)	.615	.318	3.752	1	.053	1.850	.993	3.447
	Constant	-1.843	.280	43.230	1	.000	.158		

a. Variable(s) entered on step 1: ImpCostFinal, TotalSavingsFinal, Q_ARs, SalesFinal, Employees, ProductionHours, PlantArea, ARC, Rebate, Region, INDINT.

The prediction model can be expressed as:

$Y = -1.843 - 0.037X_1 + 1.074X_2 - 0.361X_3 + 0.221X_4$

where:

$X_1 = X_{Q\_ARs}$
$X_2 = X_{ARC(1)}$
$X_3 = X_{Region(2)}$
$X_4 = X_{INDINT(1)}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-1.843 - 0.037X1 + 1.074X2 - 0.361X3 + 0.221X4\ )}}$$

<u>Logistic Regression Model with Heat Recovery Database. Results from SPSS</u>

The main characteristics of the variables studied can be seen in Table 4.23. The implementation rate of heat recovery initiatives are 28% with an average payback period of

1.52 years. Reports have an average of 8.68 assessment recommendations (ARs), and companies have an average of 198 employees with 5,638 annual production hours.

Table 4.23: Some important characteristics of the variables studied

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Implementation Status of ARs	5,839	0	1	.28	.45
Payback Period (years)	5,839	.00	20.04	1.52	1.46
Implementation Cost ($1000)	5,782	.10	17,000	40.68	386.58
Total Savings of the Project ($1000)	5,824	.10	3,200	27.22	116.92
Number of ARs in the assessment	5,839	1	33	8.68	3.40
Sales (Million $)	5,778	.04	10,000.00	51.91	214.90
Number of Employees	5,832	1	4,600	198	232.46
Annual Production Hours	5,786	1,090	8,760	5,638.25	2,116.84
Plant Area in 1000 ft2	4,167	3	40,000	232.22	823.92
Valid N (listwise)	4,061				

Logistic Regression Model with payback period

In the case of the logistic regression model with payback period, there were 5,839 ARs. 4,088 ARs were used in the model (70%), the other 30% (1,751 ARs) were not used in the logistic regression due to missing values. This can be seen in Table 4.24.

Table 4.24: Assessment Recommendations (ARs) included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	4,088	70.0
	Missing Cases	1,751	30.0
	Total	5,839	100.0
Unselected Cases		0	.0
Total		5,839	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.25 shows the coding system for dependent variable (outcome) and predictors (categorical independent variables).

Table 4.25: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variable Coding

		Frequency	Parameter coding (1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	1,737	0	0	0
	High Value Added Consumers	1,442	1	0	0
	Low Energy Consumers	864	0	1	0
	Non-Manufacturing	45	0	0	1
Region where the industry is located	Northeast	695	0	0	0
	Midwest	1,456	1	0	0
	South	1,416	0	1	0
	West	521	0	0	1
Implementation Rebate	No Rebate	4,039	0		
	Rebate Available	49	1		

Table 4.26 shows model performance by cross tabulating the observed response with the predicted response. In Step 1 (with all variables included), the model can correctly predict with 100% accuracy recommendations that would not be implemented (3,095). However, the model could not predict the implemented ones (0% accuracy). The overall correct prediction for this model is 75.7%. Both models, the baseline one (Step 0) and the model with variables (Step 1) have the same accuracy precision.

Table 4.26: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

Observed			Predicted: Implementation Status of ARs: Not Implemented	Implemented	Percentage Correct
Step 0	Implementation Status of ARs	Not Implemented	3095	0	100.0
		Implemented	993	0	.0
	Overall Percentage				75.7

a. Constant is included in the model.

b. The cut value is .500

Classification Table[a]

Observed			Predicted: Implementation Status of ARs: Not Implemented	Implemented	Percentage Correct
Step 1	Implementation Status of ARs	Not Implemented	3095	0	100.0
		Implemented	993	0	.0
	Overall Percentage				75.7

a. The cut value is .500

Table 4.27 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant (p = 0.000) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.031 and 0.046, respectively. The goodness-of-fit statistics from Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.255 (more than 0.05). This is supported by Figure 4.11. It displays a histogram of the predicted probabilities of recommendation being implemented. It can be seen that a Non-implementation is better predicted than implemented recommendations.

Table 4.27: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	128.677	13	.000
	Block	128.677	13	.000
	Model	128.677	13	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	4404.151[a]	.031	.046

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	10.138	8	.255

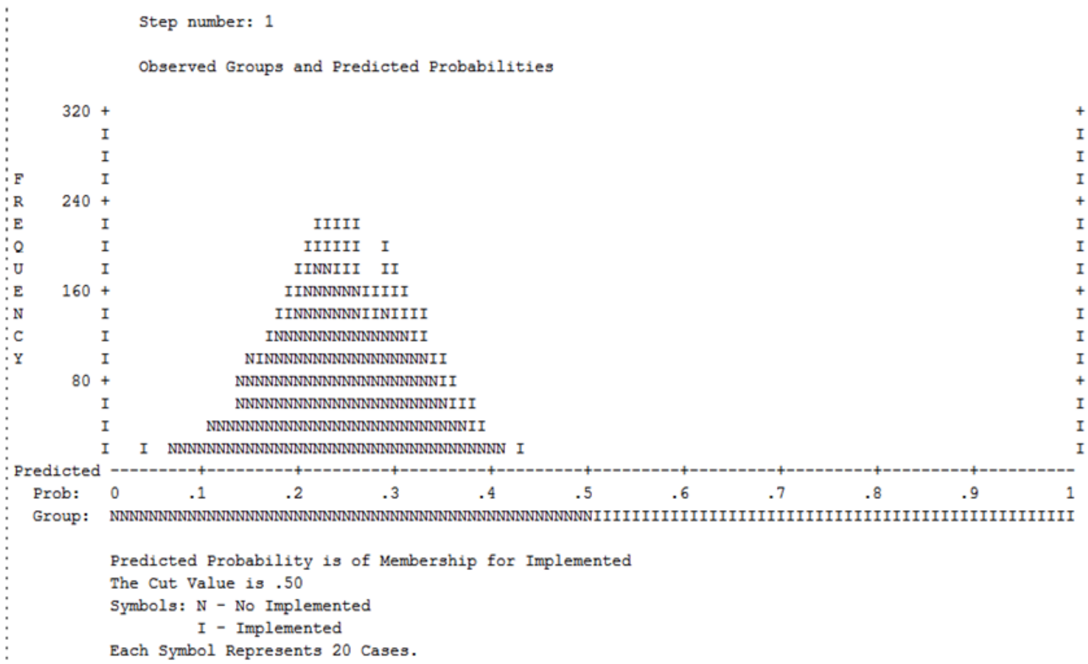


Figure 4.11: Classification Plot

The results of the prediction model can be seen in Table 4.28. This table summarizes the coefficient estimates and Wald test statistic for each variable. It shows that payback period, number of recommendations in the report, annual production hours and region of recommended implementation are significant predictors to the model because all of them have a significance value less than 0.05. A one year increase in the payback period decreases the odds of implementation by 0.776. One more recommendation in the report decreases the odds of implementation by 0.963. The South region has 0.677 times lower odds to implement recommendations than the Northeast region. All of these interpretations are reliable because their coefficient intervals do not cross 1. On the other hand, annual production hours are significant but the direction of the effect is not clear because the coefficient interval includes 1.

Table 4.28: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Payback	-.253	.033	59.110	1	.000	.776	.728	.828
	Q_ARs	-.038	.011	10.974	1	.001	.963	.941	.985
	SalesFinal	.000	.000	1.416	1	.234	1.000	.999	1.000
	Employees	.000	.000	1.296	1	.255	1.000	1.000	1.001
	ProductionHours	.000	.000	4.380	1	.036	1.000	1.000	1.000
	PlantArea	.000	.000	.890	1	.346	1.000	1.000	1.000
	Rebate(1)	-.048	.366	.017	1	.895	.953	.465	1.953
	Region			30.739	3	.000			
	Region(1)	.101	.106	.910	1	.340	1.107	.899	1.363
	Region(2)	-.390	.112	12.128	1	.000	.677	.544	.843
	Region(3)	-.186	.140	1.768	1	.184	.830	.632	1.092
	INDINT			6.144	3	.105			
	INDINT(1)	.194	.087	4.989	1	.026	1.214	1.024	1.439
	INDINT(2)	.036	.102	.127	1	.721	1.037	.849	1.266
	INDINT(3)	.371	.345	1.153	1	.283	1.449	.736	2.849
	Constant	-.231	.188	1.502	1	.220	.794		

a. Variable(s) entered on step 1: Payback, Q_ARs, SalesFinal, Employees, ProductionHours, PlantArea, Rebate, Region, INDINT.

The prediction model can be written in an equation as:

$Y = -0.231 - 0.253X_1 - 0.038X_2 + X_3 - 0.39X_4$

where:

$X_1 = X_{payback}$
$X_2 = X_{Q\_ARs}$
$X_3 = X_{ProductionHours}$
$X_4 = X_{Region(2)}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-0.231-0.253X1\ -0.038X2\ +\ X3\ -0.39X4\ )}}$$

Logistic Regression Model with cost/benefit

In the case of the logistic regression model with costs and benefits, there were 5,839 ARs. 4,049 ARs were used in the model (69.3%), the other 30.7% (1,790 ARs) were not used in the logistic regression due to missing values. This can be seen in Table 4.29.

Table 4.29: Assessment Recommendations (ARs) included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	4,049	69.3
	Missing Cases	1,790	30.7
	Total	5,839	100.0
Unselected Cases		0	.0
Total		5,839	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.30 shows the coding system for dependent variable (outcome) and predictors (categorical independent variables).

Table 4.30: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variable Coding

			Parameter coding		
		Frequency	(1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	1,721	0	0	0
	High Value Added Consumers	1,425	1	0	0
	Low Energy Consumers	858	0	1	0
	Non-Manufacturing	45	0	0	1
Region where the industry is located	Northeast	686	0	0	0
	Midwest	1,435	1	0	0
	South	1,408	0	1	0
	West	520	0	0	1
Implementation Rebate	No Rebate	4,000	0		
	Rebate Available	49	1		

Table 4.31 shows model performance by cross tabulating the observed response with a predicted response. In Step 1 (with all variables included), the model can correctly predict

with 100% accuracy, recommendations that would not be implemented (3,083). However, the model could not predict the implemented ones (0% accuracy). The overall correct prediction for this model is 76.1%. Both models, the baseline one (Step 0) and the model with variables (Step 1) have the same accuracy precision.

Table 4.31: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Implementation Status of ARs		Percentage Correct
			Not Implemented	Implemented	
Step 0	Implementation Status of ARs	Not Implemented	3083	0	100.0
		Implemented	966	0	.0
	Overall Percentage				76.1

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted		
			Implementation Status of ARs		Percentage Correct
			Not Implemented	Implemented	
Step 1	Implementation Status of ARs	Not Implemented	3083	0	100.0
		Implemented	966	0	.0
	Overall Percentage				76.1

a. The cut value is .500

Table 4.32 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant ($p = 0.000$) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.015 and 0.022, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.143 (more than 0.05). This is supported by Figure 4.12. It displays a histogram of the predicted probabilities of recommendations being implemented. It can be seen that non-implementation is better predicted than the implemented.

Table 4.32: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	59.307	14	.000
	Block	59.307	14	.000
	Model	59.307	14	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	4390.015[a]	.015	.022

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	12.185	8	.143

```
             Step number: 1

             Observed Groups and Predicted Probabilities

     320 +                                                                                                    +
         I                                                                                                    I
         I                   I I   I                                                                          I
F        I                   IIIIIIII                                                                         I
R    240 +                  IIIIIIIIII                                                                        +
E        I                  INNNIIIIIII                                                                       I
Q        I                  NNNNNNNNINI                                                                       I
U        I                 INNNNNNNNNNI                                                                       I
E    160 +                 NNNNNNNNNNNNII                                                                     +
N        I                INNNNNNNNNNNNII                                                                     I
C        I                NNNNNNNNNNNNNNII                                                                    I
Y        I               INNNNNNNNNNNNNNNII                                                                   I
      80 +               NNNNNNNNNNNNNNNNNII                                                                  +
         I              INNNNNNNNNNNNNNNNNNI                                                                  I
         I              NNNNNNNNNNNNNNNNNNNNI                                                                 I
         I             NNNNNNNNNNNNNNNNNNNNNNN                                                                I
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII

          Predicted Probability is of Membership for Implemented
          The Cut Value is .50
          Symbols: N - No Implemented
                   I - Implemented
          Each Symbol Represents 20 Cases.
```

Figure 4.12: Classification Plot

The results of the prediction model can be seen in Table 4.33. This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that number of recommendations in the report and regions are significant predictors to the model because all of them have a significance value less than 0.05. One more recommendation in the report decreases the odds of implementation by 0.964 and the South region has 0.678 times lower odds to implement recommendations than the Northeast region. All of these interpretations are reliable because their coefficient intervals do not cross 1.

Table 4.33: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	ImpCostFinal	.000	.000	.671	1	.413	1.000	1.000	1.000
	TotalSavingsFinal	.000	.000	.349	1	.555	1.000	.999	1.001
	Q_ARs	-.037	.012	10.224	1	.001	.964	.942	.986
	SalesFinal	-.001	.000	2.302	1	.129	.999	.999	1.000
	Employees	.000	.000	2.079	1	.149	1.000	1.000	1.001
	ProductionHours	.000	.000	1.809	1	.179	1.000	1.000	1.000
	PlantArea	.000	.000	.360	1	.548	1.000	1.000	1.000
	Rebate(1)	-.159	.363	.192	1	.661	.853	.419	1.737
	Region			32.085	3	.000			
	Region(1)	.115	.107	1.157	1	.282	1.122	.910	1.383
	Region(2)	-.389	.112	11.974	1	.001	.678	.544	.845
	Region(3)	-.208	.140	2.223	1	.136	.812	.618	1.068
	INDINT			7.717	3	.052			
	INDINT(1)	.230	.088	6.908	1	.009	1.259	1.060	1.495
	INDINT(2)	.088	.102	.742	1	.389	1.092	.894	1.335
	INDINT(3)	.385	.343	1.262	1	.261	1.469	.751	2.876
	Constant	-.705	.182	15.037	1	.000	.494		

a. Variable(s) entered on step 1: ImpCostFinal, TotalSavingsFinal, Q_ARs, SalesFinal, Employees, ProductionHours, PlantArea, Rebate, Region, INDINT.

The prediction model can be written in an equation as:

$Y = -0.705 - 0.037X_1 - 0.389X_2$

where:

$X_1 = X_{Q\_ARs}$
$X_2 = X_{Region(2)}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-0.705 - 0.037X1 - 0.389X2)}}$$

Logistic Regression Model with Combined Heat and Power Database. Results from SPSS

The main characteristics of the variables studied can be seen in Table 4.34. The implementation rate of CHP initiatives are 12%. The average payback period is 4.22 years. Reports have in average of eight assessment recommendations (ARs), and companies have an average of 218 employees with 6,232 annual production hours.

Table 4.34: Some important characteristics of the variables studied

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Implementation Status of ARs	405	0	1	.12	.32
Payback Period (years)	405	.00	24.68	4.22	3.38
Implementation Cost ($1000)	399	13.67	30,000.00	1,311.86	2,504.83
Total Savings of the Project ($1000)	405	3.69	6,264.80	358.73	614.27
Number of ARs in the assessment	405	1	23	8.20	3.00
Sales (Million $)	399	.08	748.00	51.74	78.77
Number of Employees	405	13	4,000	217.70	318.77
Annual Production Hours	403	1,920	8,760	6,232.25	2,165.40
Valid N (listwise)	391				

Logistic Regression Model with payback period

In the case of the logistic regression model with payback period, there were 405 ARs. 397 ARs were used in the model (98%), the other 2% (8 ARs) were not used in the logistic regression due to a missing values. This can be seen in Table 4.35.

Table 4.35: Assessment Recommendations (ARs) included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	397	98.0
	Missing Cases	8	2.0
	Total	405	100.0
Unselected Cases		0	.0
Total		405	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.36 shows the coding system for dependent variables (outcomes) and predictors (categorical independent variables).

Table 4.36: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variables Codings

		Frequency	Parameter coding		
			(1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	215	0	0	0
	High Value Added Consumers	64	1	0	0
	Low Energy Consumers	109	0	1	0
	Non-Manufacturing	9	0	0	1
Region where the industry is located	Northeast	81	0	0	0
	Midwest	76	1	0	0
	South	123	0	1	0
	West	117	0	0	1
Implementation Rebate	No Rebate	369	0		
	Rebate Available	28	1		

Table 4.37 shows model performance by cross tabulating the observed response with the predicted response. In Step 1 (with all variables included), the model can correctly predict 348 recommendations that would not be implemented, but the model cannot predict two recommendations. The model can predict a non-implementation rate of 99.4%. In addition, the model can predict four recommendations that would be implemented, but the model could not predict 43. The model can predict implementation at a rate of 8.5%. The overall correct prediction for this model is 88.7%. The baseline model with the constant included (Step 0) can correctly predict 88.2%. After the introduction of variables in Step 1, the model prediction has a small increase to 88.7% accuracy.

Table 4.37: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Implementation Status of ARs		Percentage Correct
			Not Implemented	Implemented	
Step 0	Implementation Status of ARs	Not Implemented	350	0	100.0
		Implemented	47	0	.0
	Overall Percentage				88.2

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

			Predicted		
			Implementation Status of ARs		
Observed			Not Implemented	Implemented	Percentage Correct
Step 1	Implementation Status of ARs	Not Implemented	348	2	99.4
		Implemented	43	4	8.5
	Overall Percentage				88.7

a. The cut value is .500

Table 4.38 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant (p = 0.000) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.091 and 0.177, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.977 (more than 0.05). This is supported by Figure 4.13. It displays a histogram of the predicted probabilities of recommendation being implemented. It can be seen that "Not Implemented" is better predicted than implemented.

Table 4.38: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	38.066	12	.000
	Block	38.066	12	.000
	Model	38.066	12	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	250.712[a]	.091	.177

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.118	8	.977

```
            Step number: 1

            Observed Groups and Predicted Probabilities

       32 +                                                                                                    +
          I                                                                                                    I
          I  NN                                                                                                I
F         I  NN  I                                                                                             I
R      24 +  NN  N                                                                                             +
E         IN NNINNI                                                                                            I
Q         IN NNNNNNI                                                                                           I
U         IN NNNNNNNI  I                                                                                       I
E      16 +N NNNNNNNNN N  I                                                                                    +
N         INNNNNNNNNNNNIN IN                                                                                   I
C         INNNNNNNNNNNNNN IN I                                                                                 I
Y         INNNNNNNNNNNNNN NN N   I                                                                             I
        8 +NNNNNNNNNNNNNNNN N I N                                                                              +
          INNNNNNNNNNNNNNNNNNIN N   I                                                                          I
          INNNNNNNNNNNNNNNNNNNNNNININ  N N   N                                                                 I
          INNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN  NNNI  I  NI N IN NII                                           I
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9         1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII

          Predicted Probability is of Membership for Implemented
          The Cut Value is .50
          Symbols: N - No Implemented
                   I - Implemented
          Each Symbol Represents 2 Cases.
```

Figure 4.13: Classification Plot

The results of the prediction model can be seen in Table 4.39.

Table 4.39: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Payback	-.262	.088	8.783	1	.003	.770	.648	.915
	Q_ARs	-.101	.063	2.585	1	.108	.904	.800	1.022
	SalesFinal	-.010	.005	3.299	1	.069	.990	.980	1.001
	Employees	.001	.001	4.658	1	.031	1.001	1.000	1.002
	ProductionHours	.000	.000	4.918	1	.027	1.000	1.000	1.000
	Rebate(1)	.332	.683	.236	1	.627	1.393	.365	5.316
	Region			5.230	3	.156			
	Region(1)	.149	.558	.071	1	.789	1.161	.389	3.464
	Region(2)	-.344	.528	.424	1	.515	.709	.252	1.996
	Region(3)	.662	.486	1.855	1	.173	1.939	.748	5.027
	INDINT			4.520	3	.211			
	INDINT(1)	-1.143	.643	3.157	1	.076	.319	.090	1.125
	INDINT(2)	.077	.412	.035	1	.852	1.080	.482	2.419
	INDINT(3)	.704	.781	.811	1	.368	2.021	.437	9.339
	Constant	-1.472	.860	2.931	1	.087	.229		

a. Variable(s) entered on step 1: Payback, Q_ARs, SalesFinal, Employees, ProductionHours, Rebate, Region, INDINT.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that payback period, number of employees and annual production hours are significant predictors to the model because all of them have a significance value less than 0.05. A one year increase in the payback period decreases the odds of implementation by 0.77. This interpretation is reliable because its coefficient intervals do not cross 1. On the other hand, number of employees and annual production hours are significant but the direction of the effect is not clear because their coefficient interval includes 1.

The prediction model can be expressed as:

Y = -1.472 -0.262X1 + X2 + X3

where:

$X_1 = X_{payback}$
$X_2 = X_{Employees}$
$X_3 = X_{ProductionHours}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-1.472 - 0.262X1 + X2 + X3\ \ )}}$$

Logistic Regression Model with costs and benefits

In the case of the logistic regression model with costs and benefits, there were 405 ARs. 391 ARs were used in the model (96.5%); the other 3.5% (14 ARs) were not used in the logistic regression due to missing values. This can be seen in Table 4.40.

Table 4.40: Assessment Recommendations (ARs) included in the study
Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	391	96.5
	Missing Cases	14	3.5
	Total	405	100.0
Unselected Cases		0	.0
Total		405	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 4.41 shows the coding system for dependent variables (outcomes) and predictors (categorical independent variables).

Table 4.41: Coding System for dependent and independent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Categorical Variables Codings

		Frequency	Parameter coding		
			(1)	(2)	(3)
Type of Manufacturing Industry	High Energy Consumers	212	0	0	0
	High Value Added Consumers	62	1	0	0
	Low Energy Consumers	108	0	1	0
	Non-Manufacturing	9	0	0	1
Region where the industry is located	Northeast	79	0	0	0
	Midwest	75	1	0	0
	South	122	0	1	0
	West	115	0	0	1
Implementation Rebate	No Rebate	363	0		
	Rebate Available	28	1		

Table 4.42 shows model performance by cross tabulating the observed response with the predicted response. In Step 1 (with all variables included), the model can correctly predict 348 recommendations that would not be implemented, but the model cannot predict two recommendations. The model can predict non-implementations at a rate of 99.4%. In addition, the model can predict six recommendations that would be implemented, but the model could not predict 35. The model can predict implementation at a rate of 14.6%. The overall correct prediction for this model is 90.5%. The baseline model with the constant included (Step 0) can correctly predict 89.5%. After the introduction of variables in Step 1, the model prediction had a small increase to 90.5% accuracy.

Table 4.42: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

Observed			Predicted: Implementation Status of ARs: Not Implemented	Implemented	Percentage Correct
Step 0	Implementation Status of ARs	Not Implemented	350	0	100.0
		Implemented	41	0	.0
	Overall Percentage				89.5

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

Observed			Predicted: Implementation Status of ARs: Not Implemented	Implemented	Percentage Correct
Step 1	Implementation Status of ARs	Not Implemented	348	2	99.4
		Implemented	35	6	14.6
	Overall Percentage				90.5

a. The cut value is .500

Table 4.43 shows summary statistics for the model. It can be seen that the chi-square statistic is highly significant (p=0.000) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.096 and 0.197, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.755 (more than 0.05). This is supported by Figure 4.14. It displays a histogram of the predicted probabilities of recommendation being implemented. It can be seen that "Not Implemented" is better predicted than implemented.

Table 4.43: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	39.642	13	.000
	Block	39.642	13	.000
	Model	39.642	13	.000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	222.821[a]	.096	.197

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	5.021	8	.755

```
            Step number: 1

            Observed Groups and Predicted Probabilities

      40 +N                                                                                                   +
         IN                                                                                                   I
         IN                                                                                                   I
F        IN                                                                                                   I
R     30 +N   I                                                                                               +
E        IN   N                                                                                               I
Q        INI NN NI                                                                                            I
U        INN NNINII                                                                                           I
E     20 +NNNNNNNNN N                                                                                         +
N        INNNNNNNNN NI                                                                                        I
C        INNNNNNNNN NN                                                                                        I
Y        INNNNNNNNN NNI                                                                                       I
      10 +NNNNNNNNNNNNN I                                                                                     +
         INNNNNNNNNNNNN NNII  N                                                                               I
         INNNNNNNNNNNNN NNNNNNN N  N N                                                                        I
         INNNNNNNNNNNNNNNNNNNNNININN NN     I                      I                                          I
Predicted ---------+---------+---------+---------+---------+---------+---------+---------+---------+----------
  Prob:   0        .1        .2        .3        .4        .5        .6        .7        .8        .9          1
  Group:  NNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII

          Predicted Probability is of Membership for Implemented
          The Cut Value is .50
          Symbols: N - No Implemented
                   I - Implemented
          Each Symbol Represents 2.5 Cases.
```

Figure 4.14: Classification Plot

The results of the prediction model can be seen in Table 4.44. This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that only production hours is a significant predictor to the model because production hours have a significance value of less than 0.05. However, the direction of the effect is not clear because its coefficient interval includes 1.

Table 4.44: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	ImpCostFinal	.000	.000	2.454	1	.117	1.000	.999	1.000
	TotalSavingsFinal	.001	.001	1.904	1	.168	1.001	1.000	1.002
	Q_ARs	-.134	.070	3.598	1	.058	.875	.762	1.004
	SalesFinal	-.009	.006	2.804	1	.094	.991	.980	1.002
	Employees	.001	.001	3.361	1	.067	1.001	1.000	1.002
	ProductionHours	.000	.000	9.640	1	.002	1.000	1.000	1.001
	Rebate(1)	.548	.686	.640	1	.424	1.730	.451	6.634
	Region			5.468	3	.141			
	Region(1)	.363	.617	.345	1	.557	1.437	.429	4.817
	Region(2)	-.193	.589	.107	1	.744	.825	.260	2.616
	Region(3)	.862	.542	2.536	1	.111	2.369	.820	6.848
	INDINT			5.834	3	.120			
	INDINT(1)	-2.105	1.043	4.071	1	.044	.122	.016	.942
	INDINT(2)	.348	.425	.671	1	.413	1.417	.616	3.260
	INDINT(3)	.620	.819	.572	1	.450	1.858	.373	9.256
	Constant	-3.213	.945	11.551	1	.001	.040		

a. Variable(s) entered on step 1: ImpCostFinal, TotalSavingsFinal, Q_ARs, SalesFinal, Employees, ProductionHours, Rebate, Region, INDINT.

The prediction model can be written in an equation as:

$Y = -3.213 + X_1$

where:

X_1= XProductionHours

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-3.213\ +\ X1)}}$$

4.7 Results and Discussion

Based on system thinking theory, a detailed and general framework for an effective implementation of CHP was created (Figure 4.1 and Figure 4.2). A research model (Figure 4.3) was defined in order to evaluate such frameworks. The first part of this evaluation was to perform a research study from industry perspective to investigate the main factors affecting the implementation of CHP initiatives. Moreover, in order to have a better understanding, it was decided to carry out a comparison between these factors with those affecting heat recovery and others EE initiatives. Information contained in the IAC database was used to undertake this research.

The logistic regression model was selected as a research technique based on the binary characteristic of the dependent variable. Two different logistic regression models were built: One model was based on the payback period and the other model was based on implementation cost and savings. A total of eight logistic regression models were built: Two models were for analyzed EE initiatives; two were built for CHP and Heat Recovery together; two were built for heat recovery initiatives and two were built for CHP initiatives. Twelve independent variables (regressors) were introduced to the model and a forced entry method was used to identify the significant ones.

A summary of the main research results can be seen in Table 4.45. The meanings of the signs used in the summary follow:

- +, the independent variable has a significance positive influence on the dependent (response) variable, i.e., an increase on the independent variable causes an increase on the dependent variable.
- -, the independent variable has a significance negative influence on the dependent (response) variable, i.e., an increase on the independent variable causes an decrease on the dependent variable.
- ?, the independent variable is a significant factor, but the direction (positive or negative) of the influence is not clear.

- Blank space, the independent variable is not a significant factor for the regression model.

Table 4.45: Summary of the logistic regression models

		Significant Factors					
Database	**Model Type**	**Payback**	**Implementation Cost**	**Savings**	**Sales**	**Q_ARs**	**Production Hours**
All IAC database	Payback period	-			?		?
	Cost-Benefit		-	?	?		
Heat Recovery + CHP Database	Payback period	-				-	
	Cost-Benefit					-	
Heat Recovery Database	Payback period	-				-	?
	Cost-Benefit						
CHP Database	Payback period	-					?
	Cost-Benefit						?

		Significant Factors							
Database	**Model Type**	**Employees**	**ARC1**	**ARC2**	**Rebate**	**Region 1**	**Region 2**	**Region 3**	**INDINT 1**
All IAC database	Payback period		-	-	+	-		-	
	Cost-Benefit		-	-	+		+	-	
Heat Recovery + CHP Database	Payback period		+				-		
	Cost-Benefit		+				-		+
Heat Recovery Database	Payback period						-		
	Cost-Benefit								
CHP Database	Payback period	?							
	Cost-Benefit								

Table 4.45 shows that the payback period, implementation cost, recommendation type, rebate and region are variables that have a significant impact in the EE implementation rate. Savings, sales and production hours could have a significant effect, but it is not clear the direction of their influence. In the case of analyzing CHP and heat recovery together, payback period, the number of recommendations in the report, recommendation types and regions are the variables that have a significant effect in the implementation rates. In the case of heat recovery, payback period, number of recommendations in the report and regions are the variables that have a significant influence in their implementation rate.

Production hours could be included, but it is not clear the direction of its effect. Finally, in the case of CHP, only the payback period is the variable that impacts its implementation rate. Therefore, only this hypothesis (H4) is confirmed. The other hypotheses: Implementation cost impacts CHP Implementation rate (H5); savings impacts CHP Implementation rate (H6) and rebates impact CHP Implementation rate (H7) are rejected. The number of production hours and number of employees could be included, but it is not clear the direction or extent of their effect.

The main conclusions of this preliminary research are the following:

- Payback period is the main variable affecting implementation rate of EE initiatives including CHP.
- It is interesting to note that industry type based on their energy intensity is not a factor that influences implementation rates. The assumption that a more intensive energy industry is more likely to implement EE initiatives or CHP did not hold.
- This research indicates that CHP systems are less likely to be implemented than heat recovery and others EE initiatives.

5. Research Approach and Results

5.1 Research Methodology

The research methodology used in this study can be seen in Figure 5.1. In order to evaluate the CHP framework for effective implementation and explain how to overcome the CHP energy paradox, 12 hypotheses were tested. These hypotheses were defined from the research model explained in chapter 4 (Figure 4.3). The first three hypotheses argued that in order to increase CHP adoption rate, an alignment of objectives should be in place between stakeholders; in order words, the perceived CHP importance, barriers and drivers should be the same for all stakeholders.

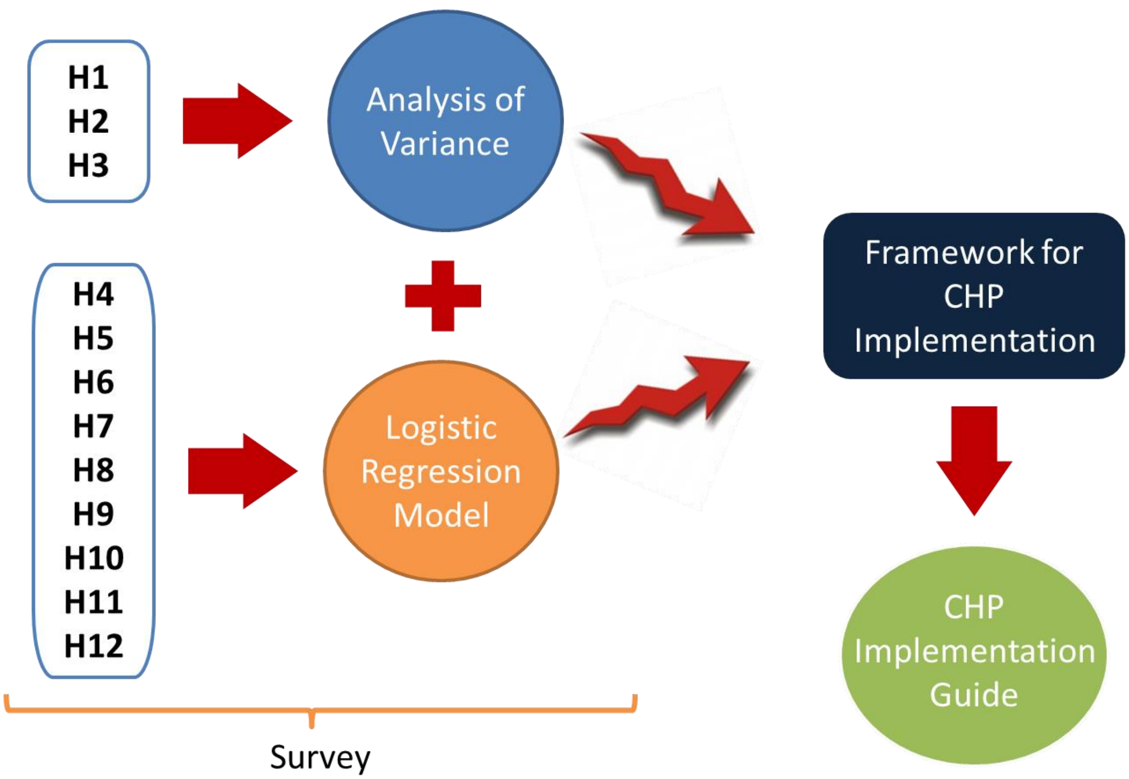


Figure 5.1: Research Methodology

The other nine hypotheses argued that some factors and activities made by stakeholders are partially responsible for the decision to invest or not to invest in CHP. These factors and activities that might impact CHP implementation rates are: payback period, implementation cost, savings, rebates, utilities behavior, utilities programs, regulations, outreach programs, and environmental group support.

In order to test these hypotheses, a survey was used. This is a tool commonly used by researchers to gather data for hypotheses, models and framework evaluations (Chai and Baudelaire, 2015, Suk et al., 2013, Mueller, 2006, Liu et al., 2012, Liu et al., 2014a). The survey used a seven-point Likert scale, and the data were analyzed using variance (ANOVA) method for the first three hypotheses and logistic regression models for the last nine hypotheses.

It was not possible to utilize cross tabulation analysis to identify statistically significant relationships between categorical variables (factors affecting CHP implementation rates among stakeholders). Cross tabulation uses the Chi-Square statistical test, and to use it properly, no more than 20% of the table cells should have values below 5. If this condition is not met, the reported significance might be wrong (SPSS Inc, 2010). In our case, this condition was not met because of survey characteristics (Likert scale) and the way responses were distributed (skewed to the right).

There is a controversy regarding how to evaluate Likert scale data. On one hand, Jamieson (2004) indicates that measurements in these scales are not truly interval. Likert measurements are ordered values where differences between scale values are not equal, i.e., the difference between agree and strongly agree is not the same as the difference between disagree and strongly disagree because these differences are based on subjective perceptions. Therefore, a parametric test such ANOVA cannot be used—neither as a mean nor correlation. The Likert scale data have to be analyzed with a nonparametric test specially in cases of short scales (3 to 5 points) and small samples (SPSS Inc, 2010). On the other hand, according to Norman (2010), if these allegations are correct and parametric tests cannot be used with Likert data, about 75% of all previous research has to be discarded. Norman (2010) also pointed out that a parametric test such as ANOVA due to its robustness can be used with Likert data. It can be used with confidence in cases of unequal variances, non-normal distributions and small sample sizes. Moreover, due to the fact that ANOVA is more powerful than a nonparametric test, i.e., has a greater chance to find true differences (SPSS Inc, 2010) and because the survey in this research used a seven-point Likert scale, it was decided to use ANOVA.

Analysis of Variance (ANOVA) is a statistical test used to determine if significant differences exist between stakeholders regarding their perceived importance of CHP, barriers and drivers. The null hypothesis is that all stakeholders have the same thinking, i.e. there is no difference between groups and the means are the same (SPSS Inc, 2010).

A technique that was considered but not used in this dissertation is a multivariate analysis of variance (MANOVA). The main reason for the MANOVA rejection is that we are concerned more with the relationship and variation between stakeholders than the variation between outcome variables or factors.

Other statistical techniques used in this dissertation were logistic regression models. Logistic regression models are frequently used to analyze historical data and to explore relationships between two or more variables (Montgomery, 2009). This technique was used and explained in Chapter 4. A variation in this chapter is the utilization of the logistic regression model with survey data instead of historical data from the IAC database. This approach is supported in journal articles by Mueller (2006), Liu et al. (2012), Liu et al. (2014a), Suk et al. (2013) and Liu et al. (2014b). Furthermore, this logistic regression analysis followed the approach made by Weiss (1994) and Mueller (2006) where dependent variables have three adopter statuses: 1) a group that has not evaluated CHP nor implemented (labeled non-adopters), 2) a group that has evaluated CHP but has not gone forward with the implementation (labeled searchers), and 3) a group that have evaluated and implemented CHP (labeled adopters).

The results obtained from the survey with both analyses (ANOVA and Logistic regression models) will be used as an input for CHP implementation guide development. Therefore, the guide will consider the views of all stakeholders and will determine from results what the main factors affecting the CHP implementation rate are.

5.2 Survey Development and Data

The survey was an online questionnaire developed in Qualtrics. It was designed with two objectives in mind. First, to find out if CHP importance is the same for all stakeholders and, second to find out the main factors affecting CHP implementation rates. For this reason, the survey was divided into a three-part questionnaire with a total of 36 questions that can be seen in Appendix D.

The first part of the questionnaire consists of a cover letter and seven general questions about types of stakeholder, facility location, facility size, types of business, types of thermal uses, CHP barriers, and CHP drivers. Only industries answered all these questions. The other stakeholders answered only four questions pertaining to type of stakeholder, facility location, CHP barriers and CHP drivers.

The second part of the questionnaire consisted of 18 questions (seven-point Likert scales), divided into three groups. Hence, Part II of this questionnaire asked six questions about perceived importance of CHP; six questions about perceived importance of CHP barriers and six questions about perceived importance of CHP drivers. These questions were analyzed with ANOVA.

The third part of the questionnaire consists of nine seven-point Likert scale questions and two multiple choice questions: Four questions are about the economics factors of CHP; two questions are about utility power plant actions; one question is about government actions; one question is about third parties actions; one question is about environmental group actions; one question was exclusively set aside to be only answered by representatives of industries and utilities about CHP implementation, and one question was reserved for other stakeholders to answer about CHP implementation potential. These questions were analyzed with logistic regression models.

This survey was approved by the University of Missouri Institutional Review Board (IRB). The approval letter from the University of Missouri IRB can be found in Appendix E. The procedure involved filling a voluntary online questionnaire that took less than 10 minutes.

The consent process was done with a cover page in the online survey. This consent indicated that their participation in the research was voluntary, they could withdraw at any time, and the study data would be handled as confidentially as possible.

The survey was emailed to different groups representing CHP stakeholders. These groups can be seen in Table 5.1. An effort was made in order to have representative respondents of each CHP stakeholder. Therefore, the survey was sent to the staff of the American Council for an Energy-Efficient Economy (ACEEE), contact members of CHP partnerships, directors and assistant directors of the CHP Technical Assistance Partnerships (CHP TAPs), energy managers of energy star industries, directors and assistant directors of the Industrial Assessment Center (IAC), managers of industries that received IAC audits, managers of other industries in Missouri, chief operating officer, site and facilities managers from industries with SIC code: 20 (Food Products), 26 (Paper Products), 28 (Chemical Products), 29 (Petroleum and Coal Products), 30 (Rubber and Plastics), 32 (Stone, Clay and Glass), 33 (Primary Metals), 49 (Electric and Gas) bought to InfoUSA, contacts obtained from internet of CHP advocates and federal and state energy officials, officials from the Missouri Department of Economic Development (MO DED), staff from the Missouri Public Utility Alliance (MPUA), contact members of the Missouri Public Utilities, members of the standby rate working group, members of the statewide energy plan and members of the wind coalition.

Table 5.1 shows that 2,774 emails were sent asking for participation in the online survey; 196 emails were not delivered due to incorrect emails, and 83 participants answered saying that they would not participate. In total we had 2,495 potential respondents. The survey was available during a period of about one month from 16 October to 15 November 2015, and three reminders were sent out on 20 October, 27 October and 4 November. During this period 241 people answered the survey, and 219 people completed the survey. Therefore, the response rate of the survey was 9.7%, and the completion rate of the survey was 90.9%.

Table 5.1: Groups receiving online survey

Group	Email Sent	Email Bounced	Opt Out	Total Email
ACEEE	24	-	1	23
CHP Partnership	369	30	14	325
CHP TAPs	32	2	-	30
Energy Star Industries	73	18	-	55
IAC Center	56	2	-	54
IAC Industries	109	13	4	92
Industries	96	17	4	75
InfoUSA	1,730	95	51	1,584
Internet	37	2	4	31
MO DED	9	-	-	9
MPUA	28	8	-	20
Public Utilities	76	3	-	73
Standby rate working group	38	-	-	38
Statewide Energy Plan	90	3	5	82
Wind Coalition	7	3	-	4
Total	**2,774**	**196**	**83**	**2,495**

This dissertation used 241 cases for their analyses. This sample size was consistent with the sample size of similar research which ranged from 66 to 377 cases (Suk et al., 2013, Mueller, 2006, Liu et al., 2012, Chai and Baudelaire, 2015, Liu et al., 2014a). Finally, 37 people required a summary of the survey main findings.

5.3 Survey Results: Descriptive Statistics

As previously stated, the survey was divided in three sections. A review follows.

General Overview of the Respondent

This section consists of seven questions which help to describe the main characteristics of the respondents. The first question deals with the distribution of the respondents, that is, how many people from each stakeholder answered the survey. Table 5.2 shows that 53% of the responses (128 respondents) came from third parties, 24% of the responses (59 respondents) came from industries, 15% of the responses (37 respondents) came from government and 7% of the responses (17 respondents) came from utilities. However, government had the best response rate between stakeholders with 55.2%, followed by third parties with 25.1%, utilities 10.9% and industry with only 3.3%. This can be seen in Table 5.3.

Table 5.2: Distribution of the respondents

Stakeholders		Response	%
Third Parties		128	53%
Industry		59	24%
Government		37	15%
Utilities		17	7%
Total		241	100%

Table 5.3: Response rate by stakeholders

Stakeholders	Total Reponses	Total Email	% Response Rate
Government	37	67	**55.2%**
Third Parties	128	510	**25.1%**
Utilities	17	156	**10.9%**
Industries	59	1,762	**3.3%**
Total Responses	**241**	**2,495**	**9.7%**

These differences in responses among stakeholders might means that government and third parties have more interest and knowledge about CHP than industries and utilities. Therefore, in order to increase awareness and utilization of CHP technology, more efforts in outreach programs should be made in industries and utilities.

It is important to note, that we received only one response from an environmental group. Maybe the reason for this low response lies in how we developed the survey. The survey asked: What type of sector do you work in? The options were non-profit organizations, consulting firms among others. Environmental group could choose one of them. For this reason it was decided to include this response in the third parties responses.

The second question dealt with where the respondent's establishment was located. Most of the respondents' establishments were from Missouri with 79 respondents (33%), followed by Massachusetts and New York with 10 respondents (4%), and the other 142 respondents (59%) were distributed among 36 states. There were 13 states without respondents.

An important issue considered in the development of the third question was to avoid a misunderstanding about the size of the respondent's establishment. This is because some industries belong to a corporation with several facilities. For this reason, it was asked how many people work at your establishment? For the analysis, it was assumed that a small factory employed from 0 to 150 people, a medium factory from 151 to 500 people and a large factory employed more than 500 people. As can be seen from Table 5.4, 32 responses (54%) came from small size factories, 14 responses came from medium factories (24%), and 13 responses came from large factories (22%).

Table 5.4: Size of the Factory

Factory Size		Response	%
Small Firm		32	54%
Medium Firm		14	24%
Large Firm		13	22%
Total		59	100%

The next question deals with the respondent's facility thermal utilization. Table 5.5 shows that 86% of the respondent facilities used heat for their manufacturing processes, 79% for space heating, 59% for space cooling and 61% for water heating.

Table 5.5: Factory thermal needs

Thermal Needs		Response	%
Manufacturing Processes		48	86%
Space Heating		44	79%
Water Heating		34	61%
Space Cooling		33	59%
Other		3	5%

The next step was to find out which CHP barrier found in the literature is the most critical. For this reason, the survey only allowed respondents to choose one barrier from the list. The results for all stakeholders can be seen in Table 5.6, which lists higher payback period (21%), lack of CHP knowledge (13%) and capital availability (12%) as the most critical barriers.

Using a filtering option in Qualtrics, we identified the main barriers according to the response from each stakeholder. From an industry point of view, the same critical barriers were identified: Higher payback period (32%), lack of CHP knowledge (21%) and capital availability (17%). From the government point of view, the same three were identified: Higher payback period (16%), lack of CHP knowledge (16%) and capital availability (14%). From the third parties point of view, the same three were identified: Higher payback period (19%), lack of CHP knowledge (10%) and capital availability (10%). Only utilities had a different point of view. They identified poor spark spread (19%), investment risk (19%) and utilities business models (13%) as the three most important ones.

Table 5.6: CHP Barriers from all respondent

CHP Barriers		Response	%
Higher payback period		49	21%
Lack of CHP knowledge		29	13%
Capital availability		28	12%
Investment risk		19	8%
Other		16	7%
Poor spark spread		15	6%
Utilities business model		14	6%
Utility attitude		14	6%
Unfair standby rate		9	4%
CHP is not included in the Energy Efficiency Resource Standards		7	3%
Permitting regulation		6	3%
Lack of corporation support		6	3%
CHP is not included in the Renewable Portfolio Standards		5	2%
Lack of knowledgeable Staff		4	2%
Inability to sell excess power		3	1%
Lack of interconnection standard		2	1%
Lack of net metering rule		2	1%
Lack of feed-in tariff		2	1%
Input based regulations		1	0%
Tax treatment		0	0%
Total		231	100%

The last question asked about the most important CHP driver. Again the survey allowed each respondent to only choose one driver from the list. The results for all stakeholders can be seen in Table 5.7. Economic incentives (52%), other (10%), corporation support (9%) and supportive regulation (9%) were identified as the most critical CHP driver. It is important to note, that 12 out of 22 comments (55%) indicated that the other option was about cost savings.

Using a filtering option in Qualtrics, we were able to identify the main drivers according each stakeholder. From an industry point of view, almost the same critical drivers were identified: Economic incentives (58%), CHP education (12%), and corporation support (12%). From a government point of view, the three most important were: Economic incentives (43%), CHP fuel flexibility (11%), and CHP education (11%). From third party points of view, the three most important were: Economic incentives (53%), other (11%), and supportive regulations (10%). From utilities point of view, the three most were: Economic incentives (47%), other (20%), and need for environment compliance (20%).

Table 5.7: CHP Drivers from all respondent

Drivers		Response	%
Economic incentives		119	52%
Other		22	10%
Corporation support		21	9%
Supportive regulations		20	9%
CHP education		19	8%
CHP fuel flexibility		13	6%
Need for environment compliance		10	4%
Government example		4	2%
Total		228	100%

<u>Perceived importance</u>

This section consists of three groups of statements that the respondent had to answer using seven-point Likert scales, where 7 is Strongly Agree, and 1 is Strongly Disagree. The first group of statements deals with the perceived importance of CHP. Table 5.8 and Figure 5.2 show that all perceived benefits and importance have similar means.

Table 5.8: Statistics of CHP perceived importance

Statistic	CHP is an important energy efficiency initiative	CHP helps to reduce energy consumption	CHP helps to reduce cost	CHP helps to reduce environmental emissions	CHP helps to improve energy resilience	CHP helps to improve energy reliability
Min Value	1	1	1	1	1	1
Max Value	7	7	7	7	7	7
Mean	6.09	5.91	5.64	5.85	5.93	5.76
Variance	1.35	1.75	1.64	1.30	1.44	1.56
Standard Deviation	1.16	1.32	1.28	1.14	1.20	1.25
Total Responses	225	225	225	225	225	225

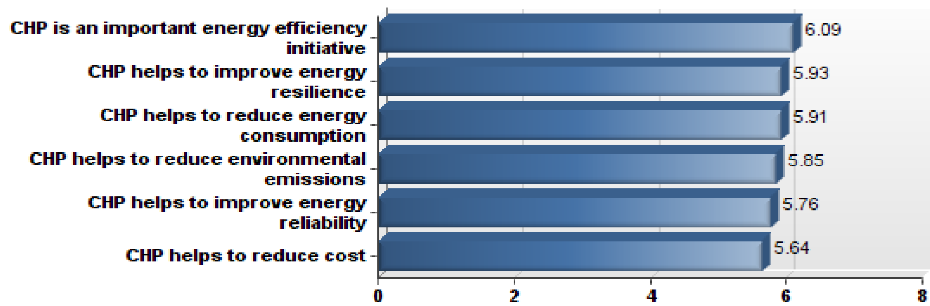


Figure 5.2: CHP perceived importance

Figure 5.2 clearly shows the perceived importance of each CHP attribute; hence, “CHP is an important energy efficiency initiative” had the biggest mean with 6.09, and “CHP helps to reduce cost” has the smallest mean with 5.64. All means indicate that respondents are between somewhat agree and agree in their statements about CHP importance.

The second group of statements deals with the perceived importance of CHP barriers. Table 5.9 and Figure 5.3 shows that the biggest barrier is current utilities attitude toward CHP with a mean of 5.3 and the smallest barrier is current regulations with a mean of 4.81. All means indicate that respondents are between neither agree nor disagree and somewhat agree with the statements about CHP barriers.

Table 5.9: Statistic of perceived CHP barriers

Statistic	Lack of available finance discourages implementation of CHP projects	Current regulation discourages implementation of CHP projects	Current utilities attitude discourages implementation of CHP projects	Project risk discourages implementation of CHP projects	Lack of CHP knowledge discourages implementation of CHP projects	Lack of corporation support discourages implementation of CHP projects
Min Value	1	1	2	1	1	1
Max Value	7	7	7	7	7	7
Mean	5.10	4.81	5.30	5.01	5.20	4.98
Variance	2.11	1.83	1.88	1.69	1.91	1.73
Standard Deviation	1.45	1.35	1.37	1.30	1.38	1.32
Total Responses	224	224	224	224	224	224

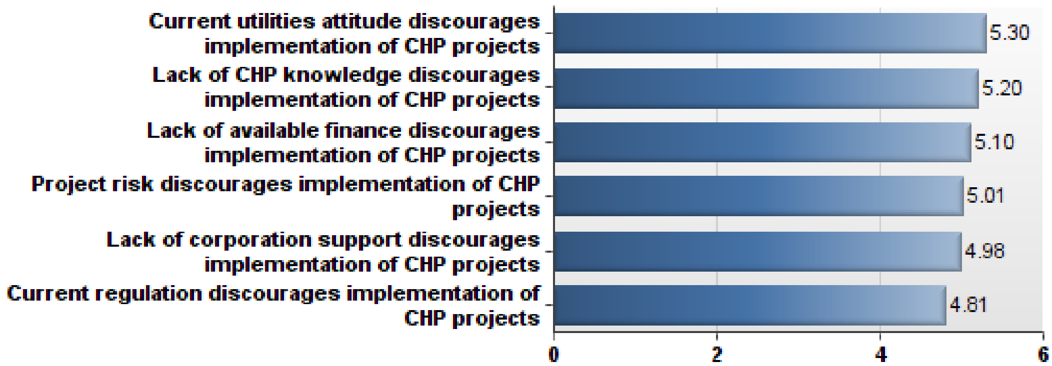


Figure 5.3: Perceived CHP barriers

The last group of statements deals with the perceived importance of CHP drivers. Table 5.10 shows that the biggest driver is economics incentive with a mean of 6.12, and the smallest driver is the inclusion of CHP in renewable portfolio standards programs with 5.51. All means indicate that respondents are between Somewhat Agree and Agree with the statements about CHP drivers.

Table 5.10: Perceived CHP drivers

Importance of CHP Drivers	Total Responses	Mean
Economics incentives helps implementation of CHP projects	222	6.12
Supportive regulations helps implementation of CHP projects	222	5.98
Education helps implementation of CHP projects	222	5.82
If environmental groups advocate CHP as they advocates wind and solar generation, it will help implementation of CHP projects	222	5.78
The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects	222	5.63
The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects	222	5.51

Factors affecting CHP adoption

This section deals with statements that the respondent has to answer using seven-point Likert scales about factors affecting the implementation rate of CHPs. The first statements are about economic factors where respondents selected 7 if they believe the expected value would be a “higher value” and 1 if the expected value would be a “lower value.” Table 5.11 shows that the biggest expected value in a CHP project is savings with a mean of 5.58 and the lowest expected value is rebates with a mean of 4.75.

Table 5.11: Economics Factors

Economics Factors	Total Responses	Mean
Rate the value of the savings generated by CHP projects	221	5.58
Rate the value of the payback period for CHP projects	221	5.45
Rate the value of the implementation costs for CHP projects	221	5.20
Rate the value of the rebates available for CHP projects	221	4.75

Table 5.12 shows respondents’ perception about utilities attitude towards CHP projects using seven-point Likert scales, where 7 means Very Positive Attitude and 1 means Very Negative Attitude. Overall, the utilities attitude when rated was somewhat negative with a mean of 3.39. The highest rate was made by utilities themselves with a mean of 4.4 and the lowest rate was given by third parties with a mean of 3.07.

Table 5.12: Utilities Attitude

Current utilities attitude towards CHP project	Total Responses	Mean
Utilities	15	4.40
Industries	49	4.00
Government	35	3.23
Third Parties	122	3.07
All Stakeholders	221	3.39

Table 5.13 shows respondents’ perception about utilities programs towards CHP projects using eight-point Likert scales, where 7 means Very Positive Program, 1 means Very Negative Program and 0 means No Program At All. Overall, the utilities programs were rated as somewhat negative with a mean of 3.04. The highest rate was made by utilities themselves with a mean of 4.0 and the lowest rate was given by third parties with a mean of 2.75.

Table 5.13: Utilities Programs

Current utilities programs regarding CHP	Total Responses	Mean
Utilities	15	4.00
Industries	49	3.45
Government	35	3.03
Third Parties	122	2.75
All Stakeholders	221	3.04

Respondents were asked to evaluate their perception regarding the complexity of current CHP regulations using seven-point Likert scales, where 7 means Very Complex and 1 means Not Complex At All. Table 5.14 displays an overall mean of 4.78, which represent a neutral position. Utilities rate complexity with the highest mean of 5.27 and industries rate it with the lowest mean of 4.51.

Table 5.14: Government Actions

Current complexity of CHP regulations	Total Responses	Mean
Utilities	15	5.27
Third Parties	122	4.86
Government	35	4.66
Industries	49	4.51
All Stakeholders	221	4.78

Table 5.15 shows respondents' perception about outreach programs using seven-point Likert scales, where 7 means Very Helpful and 1 means Not Helpful. Overall, outreach programs were rated as neutral with a mean of 4.29. The highest rate was made by third parties themselves with a mean of 4.35, and the lowest rate was given by utilities with a mean of 4.13.

Table 5.15: Third Party Actions

Current outreach CHP programs	Total Responses	Mean
Third Parties	122	4.35
Government	35	4.29
Industries	49	4.20
Utilities	15	4.13
All Stakeholders	221	4.29

Respondents were asked to evaluate their perception regarding environmental group attitudes towards CHP projects using seven-point Likert scales, where 7 means Very Positive and 1 means Very Negative. Table 5.16 shows an overall mean of 4.11, which represents a neutral position. The highest rate was made by government with a mean of 4.63 and the lowest rate was by utilities with a mean of 3.80.

Table 5.16: Environmental Group Attitudes

Current environmental group attitudes towards CHP projects	Total Responses	Mean
Government	35	4.63
Industries	49	4.29
Third Parties	122	3.93
Utilities	15	3.80
All Stakeholders	221	4.11

The next step asked industries and utilities about their CHP implementation status in order to identify if they are non-adopters, searchers or adopters. Table 5.17 shows that most of industries and utilities were non-adopters (42%) and only 20% were adopters.

Table 5.17: CHP Implementation Status

Implementation Status for Industries and Utilities		Response	%
My establishment has not adopted and not evaluated CHP technology for their use		27	42%
My establishment has evaluated CHP technology for their use but not gone forward with the adoption to date		24	38%
My establishment has evaluated CHP and adopted the technology		13	20%
Total		64	100%

The final step asked government and third parties about potential implementation of CHP. Table 5.18 shows that according to them, most industries will analyze CHP but will not plan to go forward with the adoption with the current environment (70%). Only 19% will implement CHP.

Table 5.18: CHP Implementation Potential

Implementation Potential		Response	%
With the current CHP environment, industries will not evaluate CHP for their use		16	10%
With the current CHP environment, industries will evaluate CHP for their use but will not go forward with the adoption		109	70%
With the current CHP environment, industries will evaluate CHP for their use and will adopt it		30	19%
Total		155	100%

5.4 Survey Results: Analysis of Variance

This section analyses were performed using ANOVA in IBM SPSS Statistics 23.

One of the results of the survey was the low response rate. This low response rate could potentially introduce some non-response bias. Following the Chai and Baudelaire (2015) procedure, we used wave analysis to test non-response bias by grouping responses according to the date when they were recorded and comparing the means of these groups. Four groups were made: 1) before the first reminder, 2) between the first and second reminder, 3) between second and third reminder, and 4) late responses; and three statements were utilized: 1) CHP is an important energy efficiency initiative, 2) CHP helps to reduce energy consumption, and 3) CHP helps to reduce cost. The null hypotheses were that all groups have the same means.

The results of the non-response bias test performed with the statement “CHP is an important energy efficiency initiative” can be seen in Table 5.19. The null hypothesis of the Levene test is that the variances are equal. We cannot reject this null hypothesis because the p-value 0.069 is more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.07. This value is more than 0.05

(not significant); therefore, we cannot reject the null hypothesis of equal means between groups.

Table 5.19: Non-response bias test for CHP is an important energy efficiency initiative

Test of Homogeneity of Variances

CHP is an important energy efficiency initiative

Levene Statistic	df1	df2	Sig.
2.393	3	221	.069

ANOVA

CHP is an important energy efficiency initiative

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	9.520	3	3.173	2.389	.070
Within Groups	293.520	221	1.328		
Total	303.040	224			

The results of the non-response bias test performed with the statement "CHP helps to reduce energy consumption" can be seen in Table 5.20. The null hypothesis of the Levene test of equal variances is rejected because the p-value 0.009 is less than 0.05 (significant); therefore, we used the Welch test, which can make adjustments for unequal variance. Both the Welch and Brown-Forsythe test showed a p-value of more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between groups.

Table 5.20: Non-response bias test for CHP helps to reduce energy consumption

Test of Homogeneity of Variances

CHP helps to reduce energy consumption

Levene Statistic	df1	df2	Sig.
3.986	3	221	.009

Robust Tests of Equality of Means

CHP helps to reduce energy consumption

	Statistic[a]	df1	df2	Sig.
Welch	.911	3	121.692	.438
Brown-Forsythe	.958	3	214.848	.414

a. Asymptotically F distributed.

The results of the non-response bias test performed with the statement "CHP helps to reduce cost" can be seen in Table 5.21. The null hypothesis of the Levene test is not rejected because the p-value of 0.076 is more than 0.05 (not significant); therefore, were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.184. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between groups.

Table 5.21: Non-response bias test for CHP helps to reduce cost

Test of Homogeneity of Variances

CHP helps to reduce cost

Levene Statistic	df1	df2	Sig.
2.322	3	221	.076

ANOVA

CHP helps to reduce cost

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.953	3	2.651	1.627	.184
Within Groups	360.163	221	1.630		
Total	368.116	224			

All results showed that p-values were not significant, and we could not reject the null hypotheses of equal means; that is, there was no evidence of a significant difference between the means of the four groups, and there is no evidence of a non-response bias.

H1: The perceived importance of CHP is the same across all stakeholders

This hypothesis was tested using six statements. The results of the first statement “CHP is an important energy efficiency initiative” can be seen in Table 5.22. The null hypothesis of the Levene test is not rejected because the p-value of 0.803 is more than 0.05 (not significant); therefore, we were able use ANOVA F statistic. The ANOVA test showed a p-value of 0.143. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.22: Stakeholders alignment test for CHP is an important energy efficiency initiative

Descriptives

CHP is an important energy efficiency initiative

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.84	.955	.135	5.57	6.11	4	7
Utilities	15	5.87	1.246	.322	5.18	6.56	3	7
Government	36	6.00	1.146	.191	5.61	6.39	2	7
Third Parties	124	6.25	1.221	.110	6.03	6.47	1	7
Total	225	6.09	1.163	.078	5.94	6.25	1	7

Test of Homogeneity of Variances

CHP is an important energy efficiency initiative

Levene Statistic	df1	df2	Sig.
.330	3	221	.803

ANOVA

CHP is an important energy efficiency initiative

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.337	3	2.446	1.828	.143
Within Groups	295.703	221	1.338		
Total	303.040	224			

The results of the second statement “CHP helps to reduce energy consumption” can be seen in Table 5.23. The null hypothesis of the Levene test is not rejected because the p-value 0.066 is more than 0.05 (not significant); therefore, we were able to use ANOVA F statistic. The ANOVA test shows a p-value of 0.522. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.23: Stakeholders alignment test for CHP helps to reduce energy consumption

Descriptives

CHP helps to reduce energy consumption

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.80	1.125	.159	5.48	6.12	2	7
Utilities	15	5.53	1.407	.363	4.75	6.31	2	7
Government	36	6.08	.967	.161	5.76	6.41	3	7
Third Parties	124	5.94	1.467	.132	5.68	6.20	1	7
Total	225	5.91	1.321	.088	5.73	6.08	1	7

Test of Homogeneity of Variances

CHP helps to reduce energy consumption

Levene Statistic	df1	df2	Sig.
2.434	3	221	.066

ANOVA

CHP helps to reduce energy consumption

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.952	3	1.317	.752	.522
Within Groups	387.088	221	1.752		
Total	391.040	224			

The results of the third statement "CHP helps to reduce cost" can be seen in Table 5.24. The null hypothesis of Levene test is not rejected because the p-value 0.464 is more than 0.05 (not significant); therefore, we were able to use ANOVA F statistic. The ANOVA test showed a p-value of 0.615. This value was more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.24: Stakeholders alignment test for CHP helps to reduce cost

Descriptives

CHP helps to reduce cost

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.56	1.110	.157	5.24	5.88	3	7
Utilities	15	5.40	.986	.254	4.85	5.95	4	7
Government	36	5.50	1.082	.180	5.13	5.87	2	7
Third Parties	124	5.73	1.426	.128	5.48	5.99	1	7
Total	225	5.64	1.282	.085	5.47	5.80	1	7

Test of Homogeneity of Variances

CHP helps to reduce cost

Levene Statistic	df1	df2	Sig.
.857	3	221	.464

ANOVA

CHP helps to reduce cost

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.978	3	.993	.601	.615
Within Groups	365.138	221	1.652		
Total	368.116	224			

The results of the fourth statement “CHP helps to reduce environmental emissions” can be seen in Table 5.25. The null hypothesis of Levene test is not rejected because the p-value 0.371 is more than 0.05 (not significant), therefore we were able to use ANOVA F statistic. The ANOVA test showed a p-value of 0.584. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.25: Stakeholders alignment test for CHP helps to reduce environmental emissions

Descriptives

CHP helps to reduce environmental emissions

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.70	1.035	.146	5.41	5.99	3	7
Utilities	15	5.67	1.175	.303	5.02	6.32	4	7
Government	36	5.83	.910	.152	5.53	6.14	4	7
Third Parties	124	5.94	1.235	.111	5.72	6.15	1	7
Total	225	5.85	1.140	.076	5.70	6.00	1	7

Test of Homogeneity of Variances

CHP helps to reduce environmental emissions

Levene Statistic	df1	df2	Sig.
1.050	3	221	.371

ANOVA

CHP helps to reduce environmental emissions

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.545	3	.848	.650	.584
Within Groups	288.317	221	1.305		
Total	290.862	224			

The results of the fifth statement “CHP helps to improve energy resilience” can be seen in Table 5.26. The null hypothesis of the Levene test was not rejected because the p-value 0.121 was more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.007. This value is less than 0.05; therefore, it is significant, and we had to reject the null hypothesis of equal means between stakeholders; that is, there is a significant difference between stakeholders regarding the energy resilience benefit.

Post hoc tests were performed to discover which stakeholder means differed from each other. If the confidence interval included zero, a mean difference was not significant. According to Field (2013), Hochberg's GT2 and Gabriel's post hoc test were designed to manage different sample sizes, and Hochberg's GT2 is better than Gabriel's test when sample sizes are very unequal. Therefore, it was decided to use Hochberg's test. It can be seen that utilities had significant differences when compared with government and third parties. Utilities think differently than government and third parties about energy resilience.

Table 5.26: Stakeholders alignment test for CHP helps to improve energy resilience

Test of Homogeneity of Variances

CHP helps to improve energy resilience

Levene Statistic	df1	df2	Sig.
1.958	3	221	.121

ANOVA

CHP helps to improve energy resilience

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.160	3	5.720	4.135	.007
Within Groups	305.702	221	1.383		
Total	322.862	224			

Descriptives

CHP helps to improve energy resilience

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.66	1.062	.150	5.36	5.96	3	7
Utilities	15	5.13	1.506	.389	4.30	5.97	3	7
Government	36	6.11	1.090	.182	5.74	6.48	3	7
Third Parties	124	6.08	1.200	.108	5.87	6.29	1	7
Total	225	5.93	1.201	.080	5.77	6.09	1	7

Multiple Comparisons

Dependent Variable: CHP helps to improve energy resilience

	(I) Type of Stakeholder	(J) Type of Stakeholder	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Hochberg	Industry	Utilities	.527	.346	.563	-.39	1.45
		Government	-.451	.257	.394	-1.13	.23
		Third Parties	-.421	.197	.186	-.94	.10
	Utilities	Industry	-.527	.346	.563	-1.45	.39
		Government	-.978*	.361	.043	-1.94	-.02
		Third Parties	-.947*	.322	.021	-1.80	-.09
	Government	Industry	.451	.257	.394	-.23	1.13
		Utilities	.978*	.361	.043	.02	1.94
		Third Parties	.030	.223	1.000	-.56	.62
	Third Parties	Industry	.421	.197	.186	-.10	.94
		Utilities	.947*	.322	.021	.09	1.80
		Government	-.030	.223	1.000	-.62	.56

*. The mean difference is significant at the 0.05 level.

Table 5.27 shows the results of the sixth statement: “CHP helps to improve energy reliability.” The null hypothesis of the Levene test of equal variances was rejected because the p-value 0.010 was less than 0.05 (significant); therefore, we used the Welch test that can make adjustments for unequal variance. Both Welch and Brown-Forsythe tests showed a p-value of less than 0.05 (significant); therefore, we rejected the null hypothesis of equal means between stakeholders showing that a significant difference exists between stakeholders regarding energy reliability benefit. We performed the post hoc test to discover which stakeholder means differed from each other. According to SPSS Inc (2010), for different sample sizes and unequal variances, the most powerful test is Games-Howel. We used both the Games-Howel and Tamhane tests for comparison purposes and found no significant differences. Figure 5.4 shows all error bars to have values in common; hence, the conclusion is that no difference exists between stakeholders regarding energy reliability.

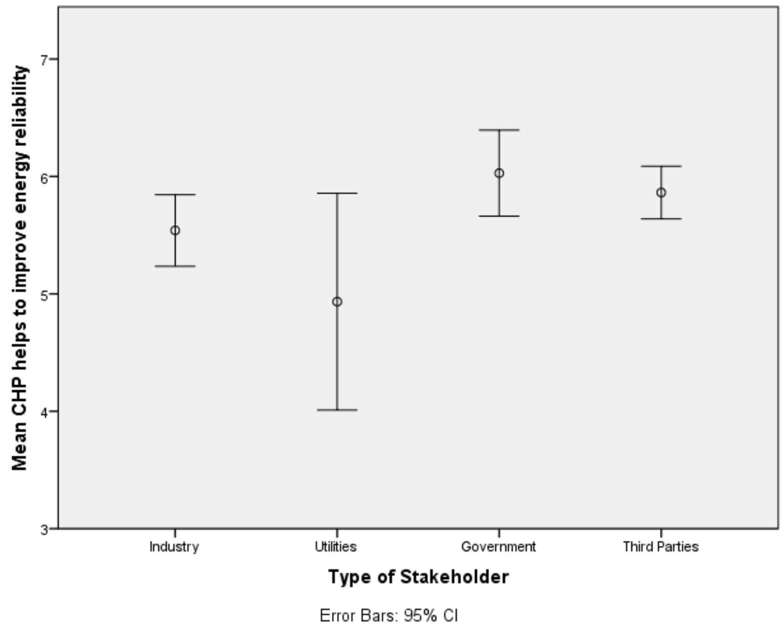


Figure 5.4: Error Bars for energy reliability

Table 5.27: Stakeholders alignment test for CHP helps to improve energy reliability

Descriptives

CHP helps to improve energy reliability

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.54	1.073	.152	5.24	5.84	3	7
Utilities	15	4.93	1.668	.431	4.01	5.86	3	7
Government	36	6.03	1.082	.180	5.66	6.39	3	7
Third Parties	124	5.86	1.264	.114	5.64	6.09	1	7
Total	225	5.76	1.249	.083	5.59	5.92	1	7

Test of Homogeneity of Variances

CHP helps to improve energy reliability

Levene Statistic	df1	df2	Sig.
3.885	3	221	.010

Robust Tests of Equality of Means

CHP helps to improve energy reliability

	Statistic[a]	df1	df2	Sig.
Welch	2.853	3	51.092	.046
Brown-Forsythe	3.190	3	50.924	.031

a. Asymptotically F distributed.

Multiple Comparisons

Dependent Variable: CHP helps to improve energy reliability

	(I) Type of Stakeholder	(J) Type of Stakeholder	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Tamhane	Industry	Utilities	.607	.457	.740	-.75	1.96
		Government	-.488	.236	.227	-1.12	.15
		Third Parties	-.323	.190	.437	-.83	.19
	Utilities	Industry	-.607	.457	.740	-1.96	.75
		Government	-1.094	.467	.167	-2.46	.27
		Third Parties	-.930	.445	.280	-2.26	.41
	Government	Industry	.488	.236	.227	-.15	1.12
		Utilities	1.094	.467	.167	-.27	2.46
		Third Parties	.165	.213	.970	-.41	.74
	Third Parties	Industry	.323	.190	.437	-.19	.83
		Utilities	.930	.445	.280	-.41	2.26
		Government	-.165	.213	.970	-.74	.41
Games-Howell	Industry	Utilities	.607	.457	.558	-.69	1.90
		Government	-.488	.236	.173	-1.11	.13
		Third Parties	-.323	.190	.327	-.82	.17
	Utilities	Industry	-.607	.457	.558	-1.90	.69
		Government	-1.094	.467	.123	-2.41	.22
		Third Parties	-.930	.445	.199	-2.20	.34
	Government	Industry	.488	.236	.173	-.13	1.11
		Utilities	1.094	.467	.123	-.22	2.41
		Third Parties	.165	.213	.866	-.40	.73
	Third Parties	Industry	.323	.190	.327	-.17	.82
		Utilities	.930	.445	.199	-.34	2.20
		Government	-.165	.213	.866	-.73	.40

H2: The perceived CHP implementation barriers are the same across all stakeholders

This hypothesis was tested using six statements. The results of the first statement "Lack of available finance discourages implementation of CHP projects" can be seen in Table 5.28. The null hypothesis of the Levene test of equal variances was rejected because the p-value of 0.024 is less than 0.05 (significant); therefore, we used the Welch test that was able to make adjustments for unequal variance. Both Welch and Brown-Forsythe test showed a p-value less than 0.05 (significant); therefore, we rejected the null hypothesis of equal means between stakeholders; that is, a significant difference does exist between stakeholders regarding lack of available finance barrier. The Games-Howel post hoc test was performed to discover which stakeholder means differ from each other. It can be seen that government and third parties have significant differences regarding their view of available finance. This can also be seen in Figure 5.5, where error bars of government and third parties do not have values in common.

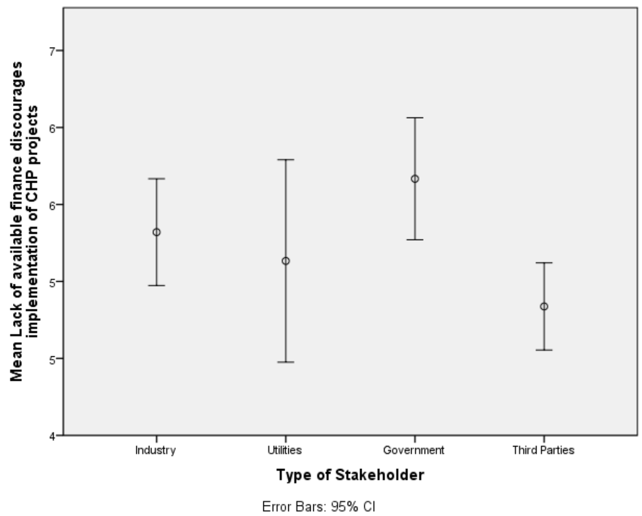


Figure 5.5: Error Bars for available finance

Table 5.28: Lack of available finance discourages implementation of CHP projects

Descriptives

Lack of available finance discourages implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.32	1.220	.172	4.97	5.67	3	7
Utilities	15	5.13	1.187	.307	4.48	5.79	3	7
Government	36	5.67	1.171	.195	5.27	6.06	3	7
Third Parties	123	4.84	1.586	.143	4.55	5.12	1	7
Total	224	5.10	1.452	.097	4.91	5.29	1	7

Test of Homogeneity of Variances

Lack of available finance discourages implementation of CHP projects

Levene Statistic	df1	df2	Sig.
3.207	3	220	.024

Robust Tests of Equality of Means

Lack of available finance discourages implementation of CHP projects

	Statistic[a]	df1	df2	Sig.
Welch	4.115	3	55.524	.010
Brown-Forsythe	4.727	3	113.530	.004

a. Asymptotically F distributed.

Multiple Comparisons

Dependent Variable: Lack of available finance discourages implementation of CHP projects

	(I) Type of Stakeholder	(J) Type of Stakeholder	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Games-Howell	Industry	Utilities	.187	.352	.951	-.78	1.16
		Government	-.347	.260	.546	-1.03	.34
		Third Parties	.483	.224	.142	-.10	1.07
	Utilities	Industry	-.187	.352	.951	-1.16	.78
		Government	-.533	.363	.471	-1.53	.46
		Third Parties	.296	.338	.818	-.65	1.24
	Government	Industry	.347	.260	.546	-.34	1.03
		Utilities	.533	.363	.471	-.46	1.53
		Third Parties	.829*	.242	.005	.19	1.46
	Third Parties	Industry	-.483	.224	.142	-1.07	.10
		Utilities	-.296	.338	.818	-1.24	.65
		Government	-.829*	.242	.005	-1.46	-.19

*. The mean difference is significant at the 0.05 level.

The results of the second statement “Current regulation discourages implementation of CHP projects” can be seen in Table 5.29. The null hypothesis of the Levene test is not rejected because the p-value of 0.705 is more than 0.05 (not significant); therefore, we can use the ANOVA F statistic. The ANOVA test showed a p-value of 0.488. This value is more than 0.05 (not significant); therefore, we were not able to reject the null hypothesis of equal means between stakeholders.

Table 5.29: Current regulation discourages implementation of CHP projects

Descriptives

Current regulation discourages implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	4.66	1.222	.173	4.31	5.01	2	7
Utilities	15	4.60	1.595	.412	3.72	5.48	1	7
Government	36	5.08	1.402	.234	4.61	5.56	1	7
Third Parties	123	4.81	1.363	.123	4.57	5.06	1	7
Total	224	4.81	1.354	.090	4.63	4.99	1	7

Test of Homogeneity of Variances

Current regulation discourages implementation of CHP projects

Levene Statistic	df1	df2	Sig.
.468	3	220	.705

ANOVA

Current regulation discourages implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	4.476	3	1.492	.812	.488
Within Groups	404.269	220	1.838		
Total	408.746	223			

The results of the third statement "Current utilities attitude discourages implementation of CHP projects" can be seen in Table 5.30. The null hypothesis of the Levene test is not rejected because the p-value 0.330 is more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.000. This value is less than 0.05; therefore, it is highly significant, and we rejected the null hypothesis of equal means between stakeholders; that is, a significant difference does exist between stakeholders regarding current utilities attitudes. Hochberg's test was performed to discover which stakeholder means differed from each other. It can be seen that utilities had significant differences of opinion when compared with government and third parties; and industry had significant differences with third parties. Utilities view differently their attitudes towards CHP than government and third parties. Industries view differently utilities attitudes towards CHP than third parties. This is confirmed in Figure 5.6, where error bars of utilities, government and third parties do not have values in common, as well as in industries and third parties.

Table 5.30: Current utilities attitude discourages implementation of CHP projects

Descriptives

Current utilities attitude discourages implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	4.90	1.329	.188	4.52	5.28	2	7
Utilities	15	4.27	1.624	.419	3.37	5.17	2	7
Government	36	5.61	1.103	.184	5.24	5.98	3	7
Third Parties	123	5.50	1.345	.121	5.26	5.74	2	7
Total	224	5.30	1.371	.092	5.12	5.48	2	7

Test of Homogeneity of Variances

Current utilities attitude discourages implementation of CHP projects

Levene Statistic	df1	df2	Sig.
1.150	3	220	.330

ANOVA

Current utilities attitude discourages implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	32.620	3	10.873	6.185	.000
Within Groups	386.737	220	1.758		
Total	419.357	223			

Multiple Comparisons

Dependent Variable: Current utilities attitude discourages implementation of CHP projects

	(I) Type of Stakeholder	(J) Type of Stakeholder	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
						Lower Bound	Upper Bound
Hochberg	Industry	Utilities	.633	.390	.487	-.40	1.67
		Government	-.711	.290	.086	-1.48	.06
		Third Parties	-.604*	.222	.042	-1.19	-.01
	Utilities	Industry	-.633	.390	.487	-1.67	.40
		Government	-1.344*	.407	.007	-2.43	-.26
		Third Parties	-1.237*	.363	.005	-2.20	-.28
	Government	Industry	.711	.290	.086	-.06	1.48
		Utilities	1.344*	.407	.007	.26	2.43
		Third Parties	.107	.251	.999	-.56	.77
	Third Parties	Industry	.604*	.222	.042	.01	1.19
		Utilities	1.237*	.363	.005	.28	2.20
		Government	-.107	.251	.999	-.77	.56

*. The mean difference is significant at the 0.05 level.

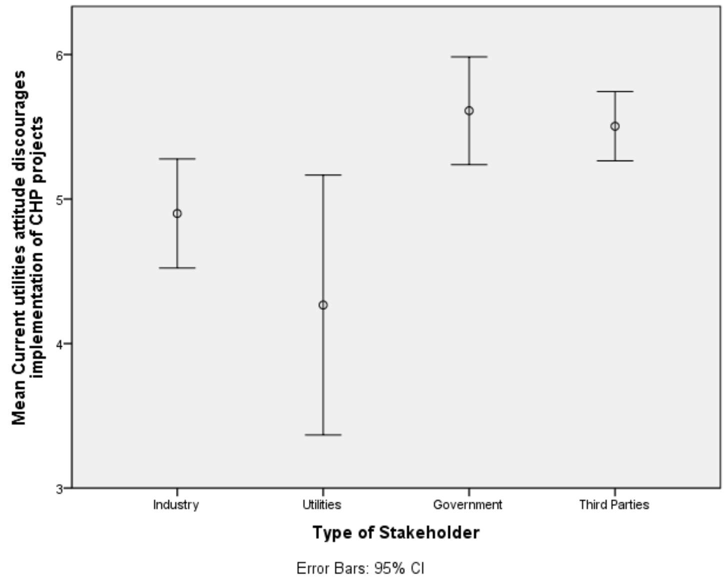


Figure 5.6: Error Bars for utilities attitude

The results of the fourth statement "Project risk discourages implementation of CHP projects" can be seen in Table 5.31. The null hypothesis of the Levene test is not rejected because the p-value of 0.331 is more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.056. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders

Table 5.31: Project risk discourages implementation of CHP projects

Descriptives

Project risk discourages implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	4.74	1.259	.178	4.38	5.10	2	7
Utilities	15	5.20	.862	.223	4.72	5.68	4	7
Government	36	4.67	1.309	.218	4.22	5.11	2	7
Third Parties	123	5.20	1.328	.120	4.96	5.43	1	7
Total	224	5.01	1.298	.087	4.84	5.18	1	7

Test of Homogeneity of Variances

Project risk discourages implementation of CHP projects

Levene Statistic	df1	df2	Sig.
1.146	3	220	.331

ANOVA

Project risk discourages implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	12.645	3	4.215	2.552	.056
Within Groups	363.337	220	1.652		
Total	375.982	223			

Table 5.32 shows the results of the fifth statement "Lack of CHP knowledge discourages implementation of CHP projects." The null hypothesis of the Levene test was not rejected because the p-value of 0.287 was more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.046. This value is less than 0.05 and is, therefore, significant; hence we rejected the null hypothesis of equal means between stakeholders; that is, a significant difference exists between stakeholders regarding CHP knowledge. Hochberg's test was performed to discover which stakeholder means differ from each other. It can be seen that utilities are significantly different from industries. Utilities view CHP knowledge differently than industries. This is confirmed in Figure 5.7, where error bars of utilities and industries do not have values in common.

Table 5.32: Lack of CHP knowledge discourages implementation of CHP projects

Descriptives

Lack of CHP knowledge discourages implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.38	1.176	.166	5.05	5.71	2	7
Utilities	15	4.27	1.387	.358	3.50	5.03	2	6
Government	36	5.14	1.417	.236	4.66	5.62	2	7
Third Parties	123	5.25	1.418	.128	5.00	5.51	1	7
Total	224	5.20	1.381	.092	5.01	5.38	1	7

Test of Homogeneity of Variances

Lack of CHP knowledge discourages implementation of CHP projects

Levene Statistic	df1	df2	Sig.
1.266	3	220	.287

ANOVA

Lack of CHP knowledge discourages implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	15.151	3	5.050	2.709	.046
Within Groups	410.206	220	1.865		
Total	425.357	223			

Multiple Comparisons

Dependent Variable: Lack of CHP knowledge discourages implementation of CHP projects

	(I) Type of Stakeholder	(J) Type of Stakeholder	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Hochberg	Industry	Utilities	1.113*	.402	.036	.05	2.18
		Government	.241	.298	.961	-.55	1.03
		Third Parties	.128	.229	.994	-.48	.74
	Utilities	Industry	-1.113*	.402	.036	-2.18	-.05
		Government	-.872	.420	.210	-1.99	.24
		Third Parties	-.985	.373	.052	-1.98	.01
	Government	Industry	-.241	.298	.961	-1.03	.55
		Utilities	.872	.420	.210	-.24	1.99
		Third Parties	-.113	.259	.998	-.80	.57
	Third Parties	Industry	-.128	.229	.994	-.74	.48
		Utilities	.985	.373	.052	-.01	1.98
		Government	.113	.259	.998	-.57	.80

*. The mean difference is significant at the 0.05 level.

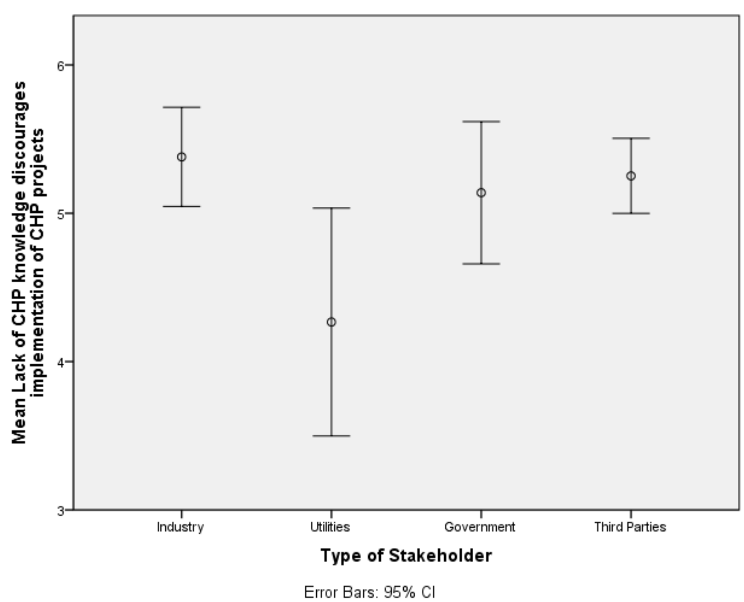


Figure 5.7: Error Bars for CHP knowledge

The results of the sixth statement “Lack of corporation support discourages implementation of CHP projects” can be seen in Table 5.33. The null hypothesis of the Levene test was not rejected because the p-value of 0.788 is more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. ANOVA test showed a p-value of 0.382. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders

Table 5.33: Lack of corporation support discourages implementation of CHP projects

Descriptives

Lack of corporation support discourages implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	4.82	1.335	.189	4.44	5.20	1	7
Utilities	15	4.87	1.187	.307	4.21	5.52	2	6
Government	36	5.31	1.142	.190	4.92	5.69	3	7
Third Parties	123	4.96	1.369	.123	4.71	5.20	1	7
Total	224	4.98	1.317	.088	4.80	5.15	1	7

Test of Homogeneity of Variances

Lack of corporation support discourages implementation of CHP projects

Levene Statistic	df1	df2	Sig.
.351	3	220	.788

ANOVA

Lack of corporation support discourages implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.339	3	1.780	1.026	.382
Within Groups	381.549	220	1.734		
Total	386.888	223			

H3: The perceived CHP drivers are the same across all stakeholders

This hypothesis was tested using six statements. The results of the first statement “Economics incentives helps implementation of CHP projects” can be seen in Table 5.34. The null hypothesis of the Levene test of equal variances was rejected because the p-value 0.016 was less than 0.05 (significant); therefore, we used the Welch test, which can make adjustments for unequal variance. The Welch test showed a p-value of less than 0.05 (significant); therefore, we rejected the null hypothesis of equal means between stakeholders; that is, there is a significant difference between stakeholders regarding economic incentives. The Games-Howel post hoc test was performed to discover which stakeholder means differ from each other. It can be seen that industries and third parties have significant difference regarding their view of economic incentives. This can also be seen in Figure 5.8, where error bars of industry and third parties do not have values in common.

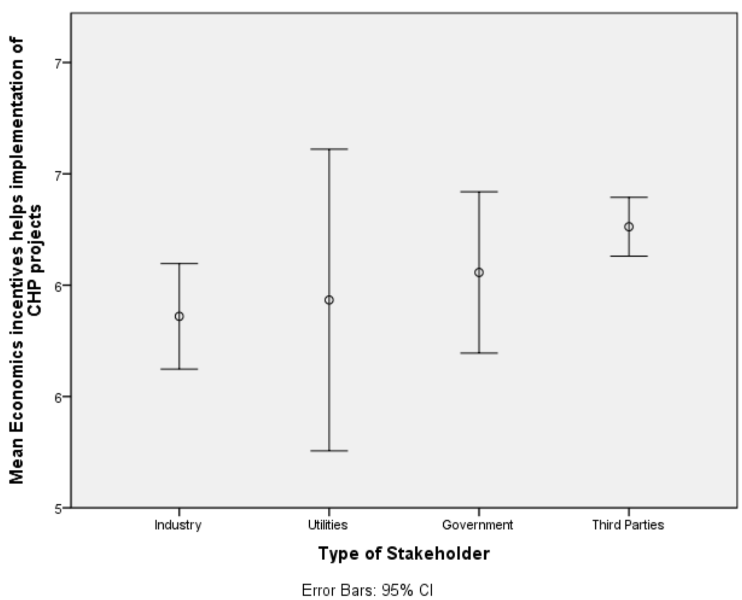


Figure 5.8: Error Bars for Economic Incentives

Table 5.34: Economics incentives helps implementation of CHP projects
Descriptives

Economics incentives helps implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.86	.833	.118	5.62	6.10	4	7
Utilities	15	5.93	1.223	.316	5.26	6.61	4	7
Government	35	6.06	1.056	.178	5.69	6.42	3	7
Third Parties	122	6.26	.736	.067	6.13	6.39	4	7
Total	222	6.12	.864	.058	6.00	6.23	3	7

Test of Homogeneity of Variances

Economics incentives helps implementation of CHP projects

Levene Statistic	df1	df2	Sig.
3.503	3	218	.016

Robust Tests of Equality of Means

Economics incentives helps implementation of CHP projects

	Statistic[a]	df1	df2	Sig.
Welch	3.124	3	47.601	.034
Brown-Forsythe	2.090	3	56.692	.112

a. Asymptotically F distributed.

Multiple Comparisons

Dependent Variable: Economics incentives helps implementation of CHP projects

	(I) Type of Stakeholder	(J) Type of Stakeholder	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Games-Howell	Industry	Utilities	-.073	.337	.996	-1.03	.88
		Government	-.197	.214	.793	-.76	.37
		Third Parties	-.402*	.135	.020	-.76	-.05
	Utilities	Industry	.073	.337	.996	-.88	1.03
		Government	-.124	.363	.986	-1.13	.88
		Third Parties	-.329	.323	.741	-1.26	.60
	Government	Industry	.197	.214	.793	-.37	.76
		Utilities	.124	.363	.986	-.88	1.13
		Third Parties	-.205	.190	.705	-.71	.30
	Third Parties	Industry	.402*	.135	.020	.05	.76
		Utilities	.329	.323	.741	-.60	1.26
		Government	.205	.190	.705	-.30	.71

*. The mean difference is significant at the 0.05 level.

The results of the second statement, "Supportive regulations help implementation of CHP projects" can be seen in Table 5.35. The null hypothesis of the Levene test of equal variances was rejected because the p-value of 0.030 is less than 0.05 (significant); therefore, we used the Welch test that was able to make an adjustment for unequal variance. Both Welch and Brown-Forsythe tests showed a p-value of more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between groups

Table 5.35: Supportive regulations help implementation of CHP projects

Test of Homogeneity of Variances

Supportive regulations helps implementation of CHP projects

Levene Statistic	df1	df2	Sig.
3.040	3	218	.030

Descriptives

Supportive regulations helps implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.64	.985	.139	5.36	5.92	3	7
Utilities	15	6.07	1.033	.267	5.49	6.64	4	7
Government	35	6.06	.938	.158	5.74	6.38	3	7
Third Parties	122	6.08	.799	.072	5.94	6.23	4	7
Total	222	5.98	.895	.060	5.86	6.10	3	7

Robust Tests of Equality of Means

Supportive regulations helps implementation of CHP projects

	Statistic[a]	df1	df2	Sig.
Welch	2.648	3	49.096	.059
Brown-Forsythe	2.656	3	77.722	.054

a. Asymptotically F distributed.

The results of the third statement "The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects" can be seen in Table 5.36. The null hypothesis of the Levene test is not rejected because the p-value was 0.861, which is more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.116. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.36: The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects

Descriptives

The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.30	1.147	.162	4.97	5.63	2	7
Utilities	15	5.87	1.125	.291	5.24	6.49	4	7
Government	35	5.69	1.105	.187	5.31	6.07	3	7
Third Parties	122	5.72	1.100	.100	5.52	5.92	2	7
Total	222	5.63	1.121	.075	5.48	5.78	2	7

Test of Homogeneity of Variances

The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects

Levene Statistic	df1	df2	Sig.
.251	3	218	.861

ANOVA

The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	7.411	3	2.470	1.992	.116
Within Groups	270.301	218	1.240		
Total	277.712	221			

Table 5.37 shows the results of the fourth statement “The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects.” The null hypothesis of the Levene test was not rejected because the p-value 0.913 was more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test showed a p-value of 0.276. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.37: The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects

Descriptives

The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.24	1.255	.177	4.88	5.60	2	7
Utilities	15	5.80	1.474	.380	4.98	6.62	2	7
Government	35	5.66	1.110	.188	5.28	6.04	4	7
Third Parties	122	5.55	1.214	.110	5.33	5.77	1	7
Total	222	5.51	1.228	.082	5.35	5.68	1	7

Test of Homogeneity of Variances

The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects

Levene Statistic	df1	df2	Sig.
.175	3	218	.913

ANOVA

The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.849	3	1.950	1.297	.276
Within Groups	327.611	218	1.503		
Total	333.459	221			

The results of the fifth statement "Education helps implementation of CHP projects" can be seen in Table 5.38. The null hypothesis of the Levene test is not rejected because the p-value of 0.597 is more than 0.05 (not significant); therefore, we were able to use the ANOVA F statistic. The ANOVA test shows a p-value of 0.463. This value is more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between stakeholders.

Table 5.38: Education helps implementation of CHP projects

Descriptives

Education helps implementation of CHP projects

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.76	1.001	.142	5.48	6.04	2	7
Utilities	15	5.53	.915	.236	5.03	6.04	4	7
Government	35	5.80	.797	.135	5.53	6.07	4	7
Third Parties	122	5.89	.880	.080	5.74	6.05	3	7
Total	222	5.82	.898	.060	5.71	5.94	2	7

Test of Homogeneity of Variances

Education helps implementation of CHP projects

Levene Statistic	df1	df2	Sig.
.628	3	218	.597

ANOVA

Education helps implementation of CHP projects

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	2.081	3	.694	.859	.463
Within Groups	176.068	218	.808		
Total	178.149	221			

Table 5.39 shows the results of the sixth statement "If environmental groups advocate CHP as they advocate wind and solar generation, it will help with the implementation of CHP projects." The null hypothesis of the Levene test of equal variances is rejected because the p-value of 0.044 is less than 0.05 (significant); therefore, we use the Welch test that can make adjustments for unequal variance. Both Welch and Brown-Forsythe tests show a p-value of more than 0.05 (not significant); therefore, we cannot reject the null hypothesis of equal means between groups.

Table 5.39: Environmental groups actions

Descriptives

If environmental groups advocate CHP as they advocate wind and solar generation, it will help with the implementation of CHP projects.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Industry	50	5.68	.999	.141	5.40	5.96	2	7
Utilities	15	5.67	1.345	.347	4.92	6.41	4	7
Government	35	5.74	1.268	.214	5.31	6.18	3	7
Third Parties	122	5.84	1.106	.100	5.65	6.04	2	7
Total	222	5.78	1.122	.075	5.63	5.93	2	7

Test of Homogeneity of Variances

If environmental groups advocate CHP as they advocate wind and solar generation, it will help with the implementation of CHP projects.

Levene Statistic	df1	df2	Sig.
2.745	3	218	.044

Robust Tests of Equality of Means

If environmental groups advocate CHP as they advocate wind and solar generation, it will help with the implementation of CHP projects.

	Statistic[a]	df1	df2	Sig.
Welch	.341	3	50.007	.796
Brown-Forsythe	.285	3	70.075	.836

a. Asymptotically F distributed.

5.5 Survey Results: Logistic Regression Analysis

This research uses IBM SPSS Statistics 23 software to perform logistic regression models. The methodology followed in this part of the research can be seen in Figure 5.9. In this research, it was not possible to mix the data from government and third parties with the data of industries and utilities. These data cannot be analyzed together because industries and utilities can evaluate and implement CHP. In other words, they can give us information regarding CHP implementation in their facilities. On the other hand, government and third parties can only evaluate CHP and its potential: They can only give us information about the implementation likelihood of CHP. Therefore, both sets of data were analyzed separately.

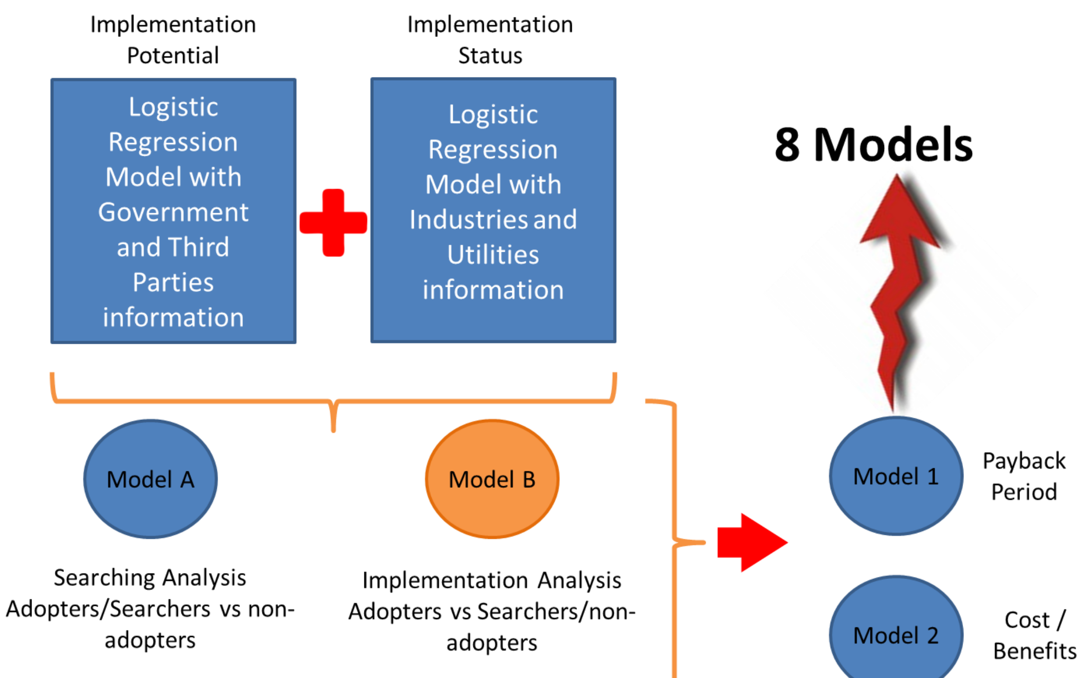


Figure 5.9: Methodology for logistic regression models

Additionally, it was decided to follow Mueller (2006) approach; hence, we divided our data into three groups: 1) non-adopters, 2) searchers and 3) adopters. Therefore, we had two models: 1) Model A, which analyzed adopters/searchers vs. non-adopters, and 2) Model B, which analyzed adopters vs. searchers/non-adopters. Model A analyzed the relationship between CHP searchers and no searchers, and Model B analyzed the relationship between CHP adopters and non-adopters. It was argued that factors affecting decision making during different stages of the implementation process could have been different; in other words, what is important during a preliminary analysis is not necessarily important during the final stages. Furthermore, we followed the procedures of Anderson and Newell (2004), Alhourani and Saxena (2009), Abadie et al. (2012) to once again divide these two models (A and B) into logistic regression models using payback periods or using implementation costs and savings (this is the same procedure that was followed in the preliminary analysis in chapter 4). In total, we analyzed the following eight models:

Third parties and government data:

1. Searching Model A1: with payback period

   Dependent variable: 1 for potential adopters and searchers and 0 for potential non-adopters

2. Searching Model A2: with implementation cost and implementation savings

   Dependent variable: 1 for potential adopters and searchers and 0 for potential non-adopters

3. Implementation Model B1: with payback period

   Dependent variable: 1 for potential adopters and 0 for potential non-adopters and searchers

4. Implementation Model B2: with implementation cost and implementation savings

   Dependent variable: 1 for potential adopters and 0 for potential non-adopters and searchers

Industries and Utilities data:

1. Searching Model A1: with payback period

   Dependent variable: 1 for adopters and searchers and 0 for non-adopters

2. Searching Model A2: with implementation cost and implementation savings

   Dependent variable: 1 for adopters and searchers and 0 for non-adopters

3. Implementation Model B1: with payback period

   Dependent variable: 1 for adopters and 0 for non-adopters and searchers

4. Implementation Model B2: with implementation cost and implementation savings

   Dependent variable: 1 for adopters and 0 for non-adopters and searchers

The independent variables that were used in these models are from hypotheses H4: Payback period impacts CHP implementation rates; H5: Implementation Cost impacts CHP implementation rates, H6: Savings impact CHP implementation rates, H7: Rebates impact CHP implementation rates, H8: Utilities behavior impacts CHP implementation rates, H9: Utilities programs impact CHP implementation rates, H10: Regulations impact CHP implementation rates, H11: Outreach program impacts CHP implementation rates, and H12: Environmental Group supports impact in CHP implementation rates. All this information was gathered in the survey using a seven-point Likert scale. The dependent variable was gathered in the survey in the last question.

<u>Third parties and government data:</u>

Table 5.40 shows the main characteristics of the variables studied. The searching potential is 90%. The mean value of the payback period is 5.6; implementation cost is 5.2, and utilities program 2.82 among other data.

Table 5.40: Some important characteristics of the variables studied

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Searching Potential	155	0	1	.90	.305
Rate the value of the payback period for CHP projects	157	1	7	5.60	1.325
Rate the value of the implementation costs for CHP projects	157	1	7	5.20	1.386
Rate the value of the savings generated by CHP projects	157	2	7	5.64	1.193
Rate the value of the rebates available for CHP projects	157	1	7	4.70	1.591
Current utilities attitude towards CHP project	157	1	7	3.10	1.388
Current utilities programs regarding CHP	157	0	7	2.82	1.860
Current complexity of CHP regulations	157	1	7	4.82	1.131
Current outreach CHP programs	157	1	7	4.34	1.375
Current environmental groups attitude towards CHP projects	157	1	7	4.08	1.276
Valid N (listwise)	155				

Searching Model A1: Logistic Regression Model with payback period

In the case of searching model A1 with payback period, there were 165 responses; 155 responses were used in the model (93.9%), the other 6.1% (10 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.41. Table 5.42 shows the coding system for dependent variables (outcomes)

Table 5.41: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	155	93.9
	Missing Cases	10	6.1
	Total	165	100.0
Unselected Cases		0	.0
Total		165	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.42: Coding System for dependent variables

Dependent Variable Encoding

Original Value	Internal Value
No Searching	0
Searching Potential	1

Table 5.43 shows model performance by cross tabulating the observed response with the predicted response. In both Step 0 and Step 1 (with all variables included), the model can correctly predict 89.7%.

Table 5.43: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Searching Potential		Percentage Correct
			No Searching	Searching Potential	
Step 0	Searching Potential	No Searching	0	16	.0
		Searching Potential	0	139	100.0
	Overall Percentage				89.7

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted		
			Searching Potential		Percentage Correct
			No Searching	Searching Potential	
Step 1	Searching Potential	No Searching	1	15	6.3
		Searching Potential	1	138	99.3
	Overall Percentage				89.7

a. The cut value is .500

Table 5.44 shows summary statistics for the model. It can be seen that the chi-square statistic is significant ($p = 0.05$) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.086 and 0.176, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.963 (more than 0.05).

Table 5.44: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	13.855	7	.050
	Block	13.855	7	.050
	Model	13.855	7	.050

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	89.100[a]	.086	.176

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.475	8	.963

The results of the prediction model can be seen in Table 5.45.

Table 5.45: Prediction model variables

Variables in the Equation

								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Payback	.411	.205	4.013	1	.045	1.508	1.009	2.254
	Rebates	-.220	.209	1.103	1	.294	.803	.532	1.210
	Utilities Attitude	.180	.299	.364	1	.546	1.198	.667	2.151
	Utilities program	.102	.202	.256	1	.613	1.108	.745	1.646
	Regulation	.365	.252	2.088	1	.148	1.440	.878	2.362
	Outreach	.348	.223	2.442	1	.118	1.416	.915	2.191
	EnGroup Attitude	.392	.257	2.319	1	.128	1.480	.894	2.451
	Constant	-4.403	2.127	4.286	1	.038	.012		

a. Variable(s) entered on step 1: Payback, Rebates, Utilities_Attitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that the payback period is the only significant predictor to the model, which has a significance value of less than 0.05. A one point increase in the payback period increases the odds of searching by 1.508. This interpretation is reliable because its coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -4.403 + 0.411X_1$

where:

$X_1 = X_{payback}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-4.403+0.411X1\ )}}$$

Searching Model A2: Logistic Regression Model with implementation cost and savings

In the case of searching model A2 with implementation cost and savings, there were 165 responses. 155 responses were used in the model (93.9%). The other 6.1% (10 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.46. Table 5.47 shows the coding system for dependent variables (outcomes)

Table 5.46: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	155	93.9
	Missing Cases	10	6.1
	Total	165	100.0
Unselected Cases		0	.0
Total		165	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.47: Coding System for dependent variables
Dependent Variable Encoding

Original Value	Internal Value
No Searching	0
Searching Potential	1

Table 5.48 shows model performance by cross tabulating the observed response with the predicted response. In Step 0, the model can correctly predict 89.7%. In Step 1 (with all variables included) the model can correctly predict 91%.

Table 5.48: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Searching Potential		Percentage Correct
			No Searching	Searching Potential	
Step 0	Searching Potential	No Searching	0	16	.0
		Searching Potential	0	139	100.0
	Overall Percentage				89.7

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

Observed			Predicted: Searching Potential: No Searching	Predicted: Searching Potential: Searching Potential	Predicted: Percentage Correct
Step 1	Searching Potential	No Searching	4	12	25.0
		Searching Potential	2	137	98.6
	Overall Percentage				91.0

a. The cut value is .500

Table 5.49 shows summary statistics for the model. It can be seen that the chi-square statistic is significant (p = 0.002) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.145 and 0.299, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.961 (more than 0.05).

Table 5.49: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	24.321	8	.002
	Block	24.321	8	.002
	Model	24.321	8	.002

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	78.635[a]	.145	.299

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	2.515	8	.961

The results of the prediction model can be seen in Table 5.50.

Table 5.50: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	ImpCost	.353	.216	2.676	1	.102	1.424	.932	2.175
	Savings	.774	.254	9.294	1	.002	2.168	1.318	3.564
	Rebates	-.413	.252	2.689	1	.101	.662	.404	1.084
	Utilities_Attitude	.110	.301	.133	1	.716	1.116	.618	2.015
	Utilities_program	.256	.212	1.459	1	.227	1.291	.853	1.955
	Regulation	.230	.283	.662	1	.416	1.259	.723	2.194
	Outreach	.377	.237	2.538	1	.111	1.458	.917	2.318
	EnGroup_Attitude	.471	.272	2.986	1	.084	1.601	.939	2.730
	Constant	-7.121	2.454	8.421	1	.004	.001		

a. Variable(s) entered on step 1: ImpCost, Savings, Rebates, Utilities_Attitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that savings is the only significant predictor to the model because it has a significance value less than 0.05. A one point increases in the savings increases the odds of searching by 2.168. This interpretation is reliable because its coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -7.121 + 0.774\, X_1$

where:

$X_1 = X_{savings}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-7.121+0.774\mathrm{X1}\ \ )}}$$

Implementation Model B1: Logistic Regression Model with payback period

In the case of implementation model B1 with payback period, there were 165 responses. 155 responses were used in the model (93.9%), the other 6.1% (10 responses) were not used in the logistic regression due to a missing values. This can be seen in Table 5.51. Table 5.52 shows the coding system for dependent variables (outcomes)

Table 5.51: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	155	93.9
	Missing Cases	10	6.1
	Total	165	100.0
Unselected Cases		0	.0
Total		165	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.52: Coding System for dependent variables

Dependent Variable Encoding

Original Value	Internal Value
No Implementation	0
Potential Implementation	1

Table 5.53 shows model performance by cross tabulating the observed response with the predicted response. In Step 0 the model can correctly predict 80.6%, and in Step 1 (with all variables included) the model can correctly predict 84.5%.

Table 5.53: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted: Potential for implementation – No Implementation	Predicted: Potential for implementation – Potential Implementation	Predicted: Percentage Correct
Step 0	Potential for implementation	No Implementation	125	0	100.0
		Potential Implementation	30	0	.0
	Overall Percentage				80.6

a. Constant is included in the model.

b. The cut value is .500

Classification Table[a]

	Observed		Predicted: Potential for implementation – No Implementation	Predicted: Potential for implementation – Potential Implementation	Predicted: Percentage Correct
Step 1	Potential for implementation	No Implementation	124	1	99.2
		Potential Implementation	23	7	23.3
	Overall Percentage				84.5

a. The cut value is .500

Table 5.54 shows summary statistics for the model. It can be seen that the chi-square statistic is significant (p = 0.002) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.133 and 0.213, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.618 (more than 0.05).

Table 5.54: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	22.172	7	.002
	Block	22.172	7	.002
	Model	22.172	7	.002

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	130.139[a]	.133	.213

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	6.259	8	.618

The results of the prediction model can be seen in Table 5.55.

Table 5.55: Prediction model variables

Variables in the Equation

								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	Payback	.190	.222	.726	1	.394	1.209	.782	1.869
	Rebates	.246	.167	2.171	1	.141	1.279	.922	1.773
	UtilitiesAttitude	.009	.197	.002	1	.965	1.009	.686	1.484
	Utilities_program	.420	.166	6.397	1	.011	1.522	1.099	2.108
	Regulation	.110	.210	.275	1	.600	1.117	.739	1.686
	Outreach	-.163	.176	.855	1	.355	.850	.601	1.200
	EnGroup_Attitude	.322	.194	2.761	1	.097	1.380	.944	2.016
	Constant	-6.323	1.912	10.933	1	.001	.002		

a. Variable(s) entered on step 1: Payback, Rebates, UtilitiesAttitude, Utilitiesprogram, Regulation, Outreach, EnGroupAttitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that utilities program is the only significant predictor to the model because it has a significance value of less than 0.05. A one point increases in utilities programs increases the odds of implementation by 1.522. This interpretation is reliable because its coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -6.323 + 0.420\ X_1$

where:

$X_1 = X_{\text{utilities programs}}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-6.323+0.420\ \mathrm{X1}\ \ )}}$$

Implementation Model B2: Logistic Regression Model with implementation cost and savings

In the case of implementation Model B2 with implementation cost and savings, there were 165 responses. 155 responses were used in the model (93.9%), and the other 6.1% (10 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.56. Table 5.57 shows the coding system for dependent variables (outcomes)

Table 5.56: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	155	93.9
	Missing Cases	10	6.1
	Total	165	100.0
Unselected Cases		0	.0
Total		165	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.57: Coding System for dependent variables

Dependent Variable Encoding

Original Value	Internal Value
No Implementation	0
Potential Implementation	1

Table 5.58 shows model performance by cross tabulating the observed response with the predicted response. In Step 0 the model can correctly predict 80.6%, and in Step 1 (with all variables included) the model can correctly predict 81.9%.

Table 5.58: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Potential for implementation		Percentage Correct
			No Implementation	Potential Implementation	
Step 0	Potential for implementation	No Implementation	125	0	100.0
		Potential Implementation	30	0	.0
	Overall Percentage				80.6

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted		
			Potential for implementation		Percentage Correct
			No Implementation	Potential Implementation	
Step 1	Potential for implementation	No Implementation	122	3	97.6
		Potential Implementation	25	5	16.7
	Overall Percentage				81.9

a. The cut value is .500

Table 5.59 shows summary statistics for the model. It can be seen that the chi-square statistic is significant ($p = 0.004$) for the overall model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.135 and 0.216, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.384 (more than 0.05).

Table 5.59: Summary statistics for the model

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	22.561	8	.004
	Block	22.561	8	.004
	Model	22.561	8	.004

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	129.750[a]	.135	.216

a. Estimation terminated at iteration number 5 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	8.526	8	.384

The results of the prediction model can be seen in Table 5.60.

Table 5.60: Prediction model variables

Variables in the Equation

								95% C.I.for EXP(B)	
		B	S.E.	Wald	df	Sig.	Exp(B)	Lower	Upper
Step 1[a]	ImpCost	.138	.177	.603	1	.437	1.148	.811	1.624
	Savings	.133	.230	.336	1	.562	1.143	.728	1.793
	Rebates	.207	.177	1.372	1	.241	1.230	.870	1.740
	Utility Reps._Attitude	-.026	.196	.017	1	.895	.974	.663	1.432
	Utilities_program	.454	.166	7.456	1	.006	1.575	1.137	2.183
	Regulation	.120	.210	.327	1	.567	1.128	.747	1.703
	Outreach	-.134	.180	.557	1	.455	.874	.614	1.244
	EnGroup_Attitude	.327	.196	2.780	1	.095	1.386	.944	2.035
	Constant	-6.724	2.044	10.819	1	.001	.001		

a. Variable(s) entered on step 1: ImpCost, Savings, Rebates, Utility Reps._Attitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that utilities program is the only significant predictor to the model because it has a significance value less than 0.05. A one point increase in utilities programs increases the odds of implementation by 1.575. This interpretation is reliable because its coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -6.724 + 0.454\ X_1$

where:

$X_1 = X_{\text{utilities programs}}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-6.724+0.454\ X1\ )}}$$

<u>Industries and Utilities data:</u>

The main characteristics of the variables studied can be seen in Table 5.61. Searching activities is 58%. The mean value of the payback period is 5.09, implementation cost is 5.2, and utilities program is 3.58 among other data.

Table 5.61: Some important characteristics of the variables studied

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation
Searching status for CHP	64	0	1	.58	.498
Rate the value of the payback period for CHP projects	64	1	7	5.09	1.433
Rate the value of the implementation costs for CHP projects	64	3	7	5.20	1.072
Rate the value of the savings generated by CHP projects	64	1	7	5.44	1.332
Rate the value of the rebates available for CHP projects	64	1	7	4.86	1.355
Current utilities attitude towards CHP project	64	1	6	4.09	1.306
Current utilities programs regarding CHP	64	0	6	3.58	1.726
Current complexity of CHP regulations	64	2	7	4.69	.990
Current outreach CHP programs	64	1	7	4.19	1.153
Current environmental groups attitude towards CHP projects	64	2	6	4.17	.952
Valid N (listwise)	64				

Searching Model A1: Logistic Regression Model with payback period

In the case of searching model A1 with payback period, there were 76 responses. 64 responses were used in the model (84.2%), and the other 15.8% (12 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.62. Table 5.63 shows the coding system for dependent variables (outcomes)

Table 5.62: Responses included in the study
Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	64	84.2
	Missing Cases	12	15.8
	Total	76	100.0
Unselected Cases		0	.0
Total		76	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.63: Coding System for dependent variables
Dependent Variable Encoding

Original Value	Internal Value
Not Search	0
Searched	1

Table 5.64 shows model performance by cross tabulating the observed response with the predicted response. In Step 0, the model can correctly predict 57.8%, and in Step 1 (with all variables included) the model can correctly predict 62.5%.

Table 5.64: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Searching status for CHP		Percentage Correct
			Not Search	Searched	
Step 0	Searching status for CHP	Not Search	0	27	.0
		Searched	0	37	100.0
	Overall Percentage				57.8

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted		
			Searching status for CHP		Percentage Correct
			Not Search	Searched	
Step 1	Searching status for CHP	No Search	10	17	37.0
		Searched	7	30	81.1
	Overall Percentage				62.5

a. The cut value is .500

Table 5.65 shows summary statistics for the model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.096 and 0.128, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.904 (more than 0.05).

Table 5.65: Summary statistics for the model

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	80.725[a]	.096	.128

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	3.435	8	.904

The results of the prediction model can be seen in Table 5.66.

Table 5.66: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Payback	.054	.240	.050	1	.823	1.055	.660	1.688
	Rebates	-.228	.259	.773	1	.379	.796	.480	1.323
	Utilities_Attitude	-.447	.313	2.035	1	.154	.639	.346	1.182
	Utilities_program	.351	.231	2.299	1	.129	1.421	.902	2.236
	Regulation	.197	.295	.446	1	.504	1.217	.683	2.168
	Outreach	.412	.280	2.171	1	.141	1.510	.873	2.613
	EnGroup_Attitude	-.093	.312	.090	1	.765	.911	.494	1.678
	Constant	-.497	2.003	.062	1	.804	.608		

a. Variable(s) entered on step 1: Payback, Rebates, Utilities_Attitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that none of the variables are significant predictors to the model because all of them have a significance value of more than 0.05.

Searching Model A2: Logistic Regression Model with implementation cost and savings

In the case of searching model A2 with implementation cost and savings, there were 76 responses. Sixty-four responses were used in the model (84.2%), and the other 15.8% (12 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.67. Table 5.68 shows the coding system for dependent variables (outcomes)

Table 5.67: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	64	84.2
	Missing Cases	12	15.8
	Total	76	100.0
Unselected Cases		0	.0
Total		76	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.68: Coding System for dependent variables

Dependent Variable Encoding

Original Value	Internal Value
No Search	0
Searched	1

Table 5.69 shows model performance by cross tabulating the observed response with the predicted response. In Step 0 the model can correctly predict 57.8% and Step 1 (with all variables included) the model can correctly predict 62.5%.

Table 5.69: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted		
			Searching status for CHP		
			No Search	Searched	Percentage Correct
Step 0	Searching status for CHP	No Search	0	27	.0
		Searched	0	37	100.0
	Overall Percentage				57.8

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

Observed			Predicted: Searching status for CHP – No Search	Predicted: Searching status for CHP – Searched	Predicted: Percentage Correct
Step 1	Searching status for CHP	No Search	11	16	40.7
		Searched	8	29	78.4
	Overall Percentage				62.5

a. The cut value is .500

Table 5.70 shows summary statistics for the model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.101 and 0.136, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicate that the model adequately fits the data because the significance value is 0.056 (more than 0.05).

Table 5.70: Summary statistics for the model

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	80.335[a]	.101	.136

a. Estimation terminated at iteration number 4 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	15.140	8	.056

The results of the prediction model can be seen in Table 5.71.

Table 5.71: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	95% C.I.for EXP(B) Upper
Step 1[a]	ImpCost	-.166	.292	.324	1	.569	.847	.478	1.502
	Savings	.097	.288	.113	1	.737	1.102	.626	1.937
	Rebates	-.228	.265	.741	1	.389	.796	.473	1.339
	Utilities_Attitude	-.452	.312	2.097	1	.148	.636	.345	1.173
	Utilities_program	.332	.229	2.107	1	.147	1.394	.890	2.183
	Regulation	.230	.323	.507	1	.476	1.259	.668	2.372
	Outreach	.442	.293	2.274	1	.132	1.556	.876	2.766
	EnGroup_Attitude	-.073	.318	.053	1	.818	.929	.498	1.735
	Constant	-.155	2.112	.005	1	.942	.856		

a. Variable(s) entered on step 1: ImpCost, Savings, Rebates, Utilities_Attitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that none of the variables are significant predictor to the model because all of them have a significance value of more than 0.05.

Implementation Model B1: Logistic Regression Model with payback period

In the case of implementation Model B1 with payback period, there were 76 responses. Sixty-four responses were used in the model (84.2%). The other 15.8% (12 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.72. Table 5.73 shows the coding system for dependent variables (outcomes)

Table 5.72: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	64	84.2
	Missing Cases	12	15.8
	Total	76	100.0
Unselected Cases		0	.0
Total		76	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.73: Coding System for dependent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Table 5.74 shows model performance by cross tabulating the observed response with the predicted response. In Step 0 the model can correctly predict 79.7% and Step 1 (with all variables included) the model can correctly predict 87.5%.

Table 5.74: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted: Implementation status for CHP: Not Implemented	Predicted: Implementation status for CHP: Implemented	Predicted: Percentage Correct
Step 0	Implementation status for CHP	Not Implemented	51	0	100.0
		Implemented	13	0	.0
	Overall Percentage				79.7

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

	Observed		Predicted: Implementation status for CHP: Not Implemented	Predicted: Implementation status for CHP: Implemented	Predicted: Percentage Correct
Step 1	Implementation status for CHP	Not Implemented	50	1	98.0
		Implemented	7	6	46.2
	Overall Percentage				87.5

a. The cut value is .500

Table 5.75 shows summary statistics for the model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.163 and 0.256, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.126 (more than 0.05).

Table 5.75: Summary statistics for the model

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	53.243[a]	.163	.256

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	12.610	8	.126

The results of the prediction model can be seen in Table 5.76.

Table 5.76: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	Payback	-.295	.302	.949	1	.330	.745	.412	1.347
	Rebates	.202	.303	.445	1	.505	1.224	.676	2.214
	Utilities_Attitude	.020	.368	.003	1	.957	1.020	.496	2.097
	Utilities_program	.166	.302	.303	1	.582	1.181	.653	2.135
	Regulation	.638	.385	2.744	1	.098	1.893	.890	4.029
	Outreach	.831	.403	4.252	1	.039	2.296	1.042	5.057
	EnGroup_Attitude	.009	.382	.001	1	.981	1.009	.477	2.132
	Constant	-8.424	2.974	8.022	1	.005	.000		

a. Variable(s) entered on step 1: Payback, Rebates, UtilitiesAttitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that the outreach program is the only significant predictor to the model because it has a significance value less than 0.05. A one point increases in outreach programs increases the odds of implementation by 2.296. This interpretation is reliable because its coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -8.424 + 0.831\ X_1$

where:

$X_1 = X_{outreach\ programs}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-8.424+0.831\ X1\ )}}$$

Implementation Model B2: Logistic Regression Model with implementation cost and savings

In the case of implementation Model B2 with implementation cost and savings, there were 76 responses. Sixty-four responses were used in the model (84.2%), and the other 15.8% (12 responses) were not used in the logistic regression due to missing values. This can be seen in Table 5.77. Table 5.78 shows the coding system for dependent variables (outcomes)

Table 5.77: Responses included in the study

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	64	84.2
	Missing Cases	12	15.8
	Total	76	100.0
Unselected Cases		0	.0
Total		76	100.0

a. If weight is in effect, see classification table for the total number of cases.

Table 5.78: Coding System for dependent variables

Dependent Variable Encoding

Original Value	Internal Value
Not Implemented	0
Implemented	1

Table 5.79 shows model performance by cross tabulating the observed response with the predicted response. In Step 0 the model can correctly predict 79.7% and Step 1 (with all variables included) the model can correctly predict 84.4%.

Table 5.79: Classification Tables for Step 0 and Step 1

Classification Table[a,b]

	Observed		Predicted: Implementation status for CHP: Not Implemented	Predicted: Implementation status for CHP: Implemented	Predicted: Percentage Correct
Step 0	Implementation status for CHP	Not Implemented	51	0	100.0
		Implemented	13	0	.0
	Overall Percentage				79.7

a. Constant is included in the model.
b. The cut value is .500

Classification Table[a]

Observed			Predicted: Implementation status for CHP — Not Implemented	Implemented	Percentage Correct
Step 1	Implementation status for CHP	Not Implemented	48	3	94.1
		Implemented	7	6	46.2
	Overall Percentage				84.4

a. The cut value is .500

Table 5.80 shows summary statistics for the model. The R^2 value from both Cox and Snell (1989) and Nagelkerke (1991) are 0.206 and 0.324, respectively. The goodness-of-fit statistics of Hosmer-Lemeshow indicates that the model adequately fits the data because the significance value is 0.473 (more than 0.05).

Table 5.80: Summary statistics for the model

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	49.827[a]	.206	.324

a. Estimation terminated at iteration number 6 because parameter estimates changed by less than .001.

Hosmer and Lemeshow Test

Step	Chi-square	df	Sig.
1	7.606	8	.473

The results of the prediction model can be seen in Table 5.81.

Table 5.81: Prediction model variables

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B) Lower	Upper
Step 1[a]	ImpCost	-1.035	.540	3.678	1	.055	.355	.123	1.023
	Savings	-.075	.407	.034	1	.854	.928	.418	2.060
	Rebates	.344	.330	1.091	1	.296	1.411	.739	2.693
	Utilities_Attitude	.142	.381	.138	1	.710	1.152	.546	2.434
	Utilities_program	.141	.292	.234	1	.628	1.152	.650	2.041
	Regulation	.983	.487	4.072	1	.044	2.672	1.029	6.940
	Outreach	1.377	.523	6.922	1	.009	3.962	1.421	11.048
	EnGroup_Attitude	-.201	.411	.239	1	.625	.818	.366	1.829
	Constant	-8.517	3.093	7.582	1	.006	.000		

a. Variable(s) entered on step 1: ImpCost, Savings, Rebates, Utilities_Attitude, Utilities_program, Regulation, Outreach, EnGroup_Attitude.

This table summarizes the coefficient estimates and Wald statistic for each variable. It shows that the supportive regulation and outreach program are the only significant predictors to the model because have a significance value of less than 0.05. A one point increase in outreach programs increases the odds of implementation by 3.962; a one point increase in supportive regulation increases the odds of implementation by 2.672. This interpretation is reliable because its coefficient intervals do not cross 1.

The prediction model can be expressed as:

$Y = -8.517 + 1.377\ X_1 + 0.983\ X_2$

where:

$X_1 = X_{\text{outreach programs}}$
$X_2 = X_{\text{supportive regulations}}$

The probability of implementation can be predicted as:

$$P(Y) = \frac{1}{1+e^{-(-8.517+1.377\ \mathrm{X1}\ +0.983\ \mathrm{X2}\ )}}$$

5.6 Results and Discussion

The first result of the survey was the low response rate by industries and utilities in comparison with government and third parties. This is an indication of the lack of interest and knowledge of industries regarding benefits, advantages and savings potential of CHP. Efforts should be made by government and CHP advocates to identify potential candidates for CHP and educate them about CHP opportunities.

From survey results, it was confirmed that payback period, lack of CHP knowledge and capital availability are the most critical barriers affecting CHP adoption. Furthermore, the most important drivers to support CHP deployment are economic incentives, cost and corporation support. It can be said, the financial potential is the primary thing to look in a CHP project.

The H1 hypothesis about the perceived importance of CHP is the same across all stakeholders was tested using six statements: 1) importance as an energy efficiency initiative, 2) importance in the reduction of energy consumption, 3) importance in the reduction of cost, 4) importance in the reduction of environmental emissions, 5) importance in the improvement of energy resilience, 6) importance in the improvement of energy reliability. The ANOVA results showed that all stakeholders have the same view about all statements except for energy resilience, where utilities have different views from government and third parties.

The H2 hypothesis about the perceived CHP implementation barriers are the same across all stakeholders was tested using six statements: 1) Lack of available finance, 2) Current regulation, 3) Current utilities attitude, 4) Project risk, 5) Lack of CHP knowledge, 6) Lack of corporation support. The ANOVA results showed that 50% of the statements have difference between stakeholders. Regarding lack of available finance, government has different view than third parties; regarding utilities attitude, utilities have a different view than government and third parties, and third parties have different views than industry. Regarding lack of knowledge, industries have a different view than utilities.

The H3 hypothesis about the perceived CHP implementation drivers are the same across all stakeholders was tested using six statements: 1) economics incentives, 2) supportive regulations, and 3) inclusion of CHP in the Energy Efficiency Resource Standards programs, 4) inclusion of CHP in the Renewable Portfolio Standards programs, 5) Education, and 6) Environmental groups support. The ANOVA results showed that all stakeholders have the same view about all statements except for economic incentives, where industries have a different view from third parties.

Based on ANOVA results, efforts should be made in order to create an alignment and synergies between stakeholders. Currently, stakeholders do not perceive barriers that have to be tackled in order to increase CHP adoption rate in the same way. These different views and uncoordinated efforts could generate ineffective programs.

The hypotheses (H4 to H12): payback period, implementation cost, savings, rebates, utilities behaviors, utilities programs, regulations, outreach programs, and environmental group support impact CHP implementation rates were evaluated with logistic regression models. Eight logistic regression models were analyzed; four models looked for factors affecting the searching process for CHP opportunities, and four models looked for factors affecting the CHP implementation process. These factors were evaluated from the perspective of two groups: 1) government and third parties, and 2) industries and utilities.

Based from the results of the logistic regression models, four hypotheses of nine were rejected: 1) implementation cost, 2) rebates, 3) utilities behavior, and 4) environmental group support. These factors do not have significant impact in the implementation rate of CHP. The other five hypotheses were confirmed.

On one hand, payback period and savings generated by CHP projects are statistically significant factors that influence CHP adoption rate in the early stages of the CHP evaluation process. On the other hand, during the latest stages of the CHP development project, utilities programs, outreach programs and supportive regulation are the significant factors that influence CHP adoption rate. These results confirmed that utilities are a key player in the adoption process due to their influence in the three factors identified. These factors will be included in the CHP implementation guide.

6. Implementation Guide for Combined Heat and Power

6.1 Engineering Implication and Objectives

Based on the results of the preliminary research and survey, we will propose an engineering solution to increase the implementation rate of CHP. According to Kossiakoff and Sweet (2003): “Engineering is the application of scientific principles to practical ends.” Furthermore, Moaveni (2011) points out that to solve an engineering problem, four steps are required: 1) problem definition, 2) problem simplification by estimations and assumptions, 3) problem solution or analysis and 4) results verification. Steps one and two were performed in the previous chapters of this dissertation. This chapter deals with step three and step four is beyond the scope of this dissertation. Therefore, in order to provide an engineering solution, an implementation guide for CHP will be developed. Guide is defined by Kossiakoff and Sweet (2003) as to show the way, in other words, to present a path for others to follow from different many possibilities or pathways.

This dissertation explored factors that influence industries to invest in CHP and will propose a guide to help them during all stages of the implementation process. The purpose of this implementation guide is to provide a schematic path that can be followed by industries. This guide is not intended to have a full explanation of each stage of the implementation process. Rather, it aims to promote understanding of steps, analysis, activities, strategies and tools available for the successful adoption of CHP systems. Moreover, the guide presented herein provides the valuable information needed to understand the implementation process and points out key factors for successful CHP application.

6.2 Guide Development

The process followed for the development of the CHP implementation guide can be seen in Figure 6.1. It consists of two stages: 1) knowledge generation and 2) points to be considered for guide development. The output is the CHP implementation guide.

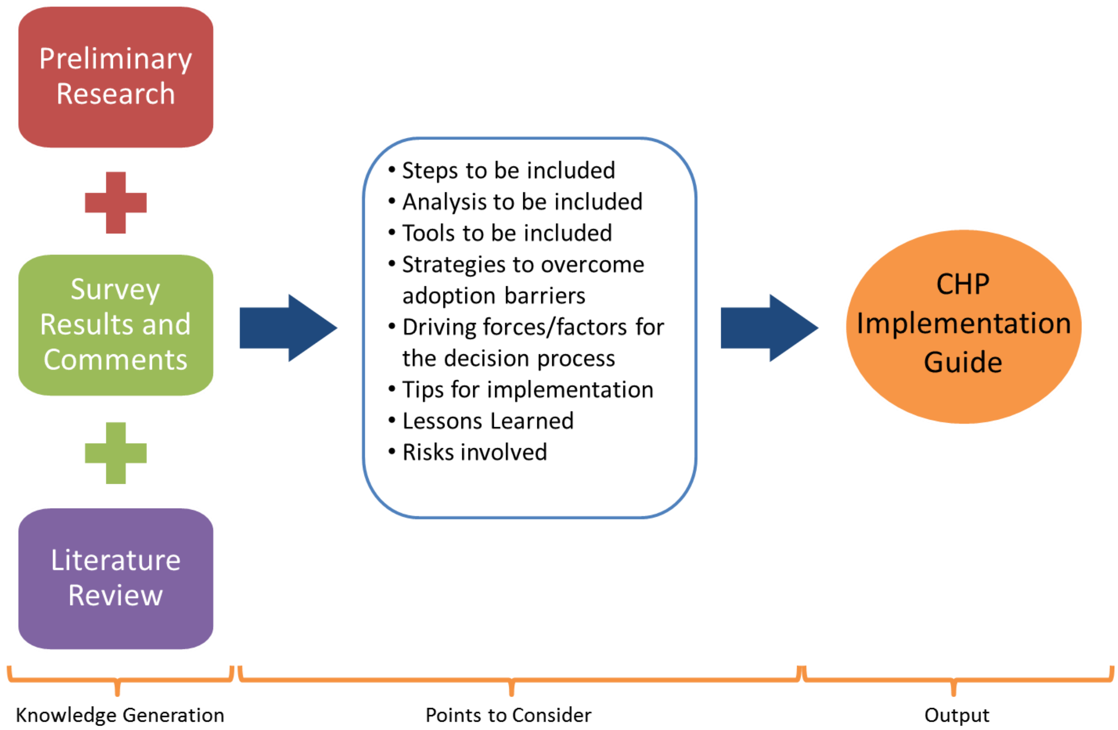


Figure 6.1: Guide Development Process

Figure 6.1 shows how knowledge generation is based on the results of the preliminary research, survey results, and comments made by survey participants to the author in a series of phone interviews as well as literature review of available CHP guides. All the information gathered in different stages of the dissertation produced topics that have to be included in the implementation guide. The types of topics to be included are diverse such as steps, analysis, tools, implementation strategies, decision-making driving forces, implementation tips, lessons learned and risk. It is important to note that while each CHP project requires its own detailed study due to its own characteristics, there are several topics that are common for all of them such as site analysis and feasibility analysis which includes technical and economic studies and regulatory policy considerations, among others. This dissertation will provide a CHP implementation guide that provides industries and stakeholders a clear idea of considerations and steps necessary to implement successful CHP projects.

6.3 Literature Review

The literature review of the CHP Implementation Guide is based on 11 reports and revisions of different CHP advocate webpages such as the CHP Technical Assistance Partnerships (CHP TAPs), US Department of Energy (DOE), US Environmental Protection Agency (EPA), and others. The summary of steps can be seen in Table 6.1. It is important to note that, because this is a summary from different sources; these steps are not necessarily in order or in a logical flow. The steps are as follows:

Identifying a CHP Champion. A CHP Champion is a person who will guide the CHP project from start to end and will help to overcome obstacles and difficulties during the life of the project. This Champion will ensure that the CHP project remains a top priority and continues to inform and seek support from decision makers (U.S. Environmental Protection Agency (EPA) and Combined Heat and Power Partnership, Chittum and Kishmohr, 2014).

Collect Site Data. The objective of this step is to collect information regarding the site that can be used to perform any level of analysis. The information includes facility annual operating hours, monthly electric and fuel bills (covering at least one year), existing heating and cooling systems and a plan for meeting future thermal needs, electrical connections and meters, backup and standby power, fuel, infrastructure connections, heating and cooling

Table 6.1: Summary of the steps in a CHP Guides

Steps	References										
	EPA & Combined Heat and Power Partnership	Reinaud, J., & Goldberg, A. (2011)	National Renewable Energy Laboratory (2013)	Chittum, A., & Kishmohr, S. (2014)	Natural Resources Canada (2005)	Midwest CHP Application Center (2007)	EPA (2014)	Hampson, A., & Rackley, J. (2013)	Oland, C. B. (2004)	Energy and Environmental Analysis (2004)	Carbon Trust. (2004)
Identifying a CHP Champion	x			x							
Collect Site Data						x			x	x	x
Technical Feasibility Assessment									x	x	
Preliminary Analysis	x		x	x		x	x	x	x	x	
Site Screening Analysis						x			x		x
Pre-Feasibility Analysis	x		x	x	x	x	x	x	x	x	x
Feasibility Analysis	x		x	x	x	x	x	x			x
Procurement Process	x		x	x	x		x	x	x		x
Monitoring systems				x	x						x
Operations and Maintenance	x			x	x		x	x			x
Lessons Learned and Earning Recognition				x							x
Financial Considerations		x					x	x			x
Knowledge		x					x	x	x		x
Commitment		x					x	x		x	
Public and market demands		x								x	
Policy obligation		x						x		x	x
Assess local CHP potential							x				
Environmental and Compliance Considerations								x	x	x	x
Assessment Tools								x			
Strategies for Overcoming Implementation Barriers									x		
Energy Saving Audit									x		x
Health, Safety, and Environmental Issues									x		x

connections, room space and ventilation for the CHP system, noise and vibration requirements of the site (Energy and Environmental Analysis and Exergy Partners Corp, 2004, Carbon Trust, 2004, Oland, 2004).

Technical Feasibility Assessment. This step involves selection of the equipment that will be part of the CHP system. This equipment should be compatible with the individual facility's physical characteristics and operating modes. This preliminary conceptual design includes type of fuels, prime movers, heat recovery equipment and sizing options (Oland, 2004, Energy and Environmental Analysis and Exergy Partners Corp, 2004).

Preliminary Analysis. The idea of this step is to evaluate if the facility is a good candidate for a CHP system. It consists of preliminary questions that indicate the viability of a CHP project, that is, if the project plan is economically and technically sound (Chittum and Kishmohr, 2014, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power Partnership, National Renewable Energy Laboratory, 2013, Midwest CHP Application Center, 2007, Hampson and Rackley, 2013, Oland, 2004, Energy and Environmental Analysis and Exergy Partners Corp, 2004)

Site Screening Analysis. The objective of this step is to provide a rough estimate of savings, cost, and a simple payback period of the CHP project. This will provide an indication as to whether further analysis should be carried out (Midwest CHP Application Center, 2007, Oland, 2004)

Pre-feasibility Analysis. This step seeks to provide technical and economic evaluation of the CHP project in order to make a decision as to whether or not to continue the analysis of the project in a specific facility. This step includes activities such as identifying barriers (regulatory, utilities, permitting), identifying CHP technology, determining options and sizing, and initiating conceptual engineering of CHP options and economic analysis with sensitivity analyses. This information can be used to obtain funds or financial commitment for the CHP project (Hampson and Rackley, 2013, Chittum and Kishmohr, 2014, Midwest CHP Application Center, 2007, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power Partnership, Natural Resources Canada, 2005)

Feasibility Analysis. The idea of this step is to optimize the CHP system design and have a more detailed cost analysis than the pre-feasibility analysis. All assumptions made in the pre-feasibility analysis have to be replaced with hard data. This stage includes a detailed engineering layout or record of electrical and thermal characteristics, CHP capacity, construction, operation and maintenance requirements, engineering drawings (designs), timelines, financing and supplier options. This carefully derived information will serve as the basis for obtaining future quotes from suppliers and for obtaining permit processes (Chittum and Kishmohr, 2014, Hampson and Rackley, 2013, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power Partnership, U.S. Environmental Protection Agency (EPA), 2014).

Procurement Process. This stage deals with activities regarding project development such as contractor selection, type of contract, contract development, financing options and permitting requirements. There are several project development options for CHP such as developing the project internally, contracting a “turnkey project” or teaming up with a partner (developers, equipment suppliers or engineering procurement/construction firm). Financing options could include company internal funding, debt financing, equity financing, lease financing, bonds, third party (project developers) financing, build-own-operate (BOO) financing and build-own-transfer (BOT) financing. Permitting requirements include interconnection with utilities, power purchase agreements, pre-construction, construction and operation permits such as environmental impact assessment, air quality, water supply, land use, fire and safety issues, noise and waste management (Oland, 2004, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power Partnership, Chittum and Kishmohr, 2014)

Monitoring Systems. The implemented CHP system should allow monitoring of its performance in order to know if it is operating as efficiently and effectively as possible and achieving the economics, savings and emission reductions defined in the project. This is a key step from a government point of view, especially if the CHP project received an incentive or any type of rebate (Chittum and Kishmohr, 2014, Carbon Trust, 2004)

Operations and Maintenance. The purpose of this step is to ensure a trouble-free operation and maintenance of the CHP system in order to maximize availability, minimize downtime and generates the benefits indicated in the project. Maintenance can be carry out by own personnel or contracted to a third parties (Carbon Trust, 2004, U.S. Environmental Protection Agency (EPA) and Combined Heat and Power Partnership, Chittum and Kishmohr, 2014).

Lessons Learned and Earning Recognition. One important activity that helps future implementation of CHP is to share successful CHP stories and experiences. Sharing this information not only introduces potential industries to CHP, but it also improves the CHP-using company's public image (Chittum and Kishmohr, 2014, Carbon Trust, 2004)

Financial Considerations, Knowledge, Commitment, Public and Market Demands, and Policy Obligations. According to Reinaud and Goldberg (2011), an effective policy instrument is one that can influence industries' decision making process and help them recognize economic and environmental benefits of an energy efficiency project, which in this case, is a CHP project. They identified five driving forces that influence the decision to invest. These are financial considerations, knowledge, commitment to the environment and EE, public and market demands, and policy obligations.

Assessing Local CHP Potential. U.S. Environmental Protection Agency (EPA) (2014) indicates that an initial assessment of the CHP barriers, drivers, fuel availability and local demand will help ensure successful CHP implementation.

Health, Safety, and Environmental Issues and Compliance Considerations. Oland (2004) and Hampson and Rackley (2013) point out that during the planning stage of a CHP project, a careful analysis of health, safety, compliance and environmental issues has to be done. These issues could impose a significant cost to the project or make it impractical. Such issues can include building codes, fire regulations, air and water quality, noise, vibration, electrical hazards, interconnection standards and standby charges.

Assessment Tools. These tools developed by different agencies will help industries in the CHP decision-making process. Examples of these tools are the spark spread estimator and screening tool (Hampson and Rackley, 2013).

Strategies for Overcoming Implementation Barriers. According to Oland (2004), strategies to overcome CHP implementation barriers have to be defined immediately after technical and economical evaluation.

Energy Saving Audit. A walk-through energy audit should be carried out before any CHP assessment is done. The purpose of this step is to identify other energy-efficiency opportunities that could reduce electricity and fuel consumption. If reduction of energy consumption is achieved, a smaller CHP system is required. This step prevents oversizing CHP systems by allowing a coordination of every available energy resource (Oland, 2004, Carbon Trust, 2004).

6.4 Implementation Guide

It is important to point out that this implementation guide is based on the framework for an effective implementation of CHP initiatives, and although it focuses on industries, it considers the perspectives of other CHP stakeholders such as government, utilities and third parties. This is completely different from other available guides, because those guides only consider activities that potential CHP users have to follow.

This guide can be seen in Figure 6.2. It consists of five stages: 1) awareness, 2) planning, design and analysis, 3) building and execution, 4) sustaining and 5) feedback. These stages are designed for industries. The stage tasks are primarily the responsibility of the industrial plant or factory although some steps supported by other stakeholders. Additionally, it has three support stages that are overseen by the government, utilities and third parties. These stages are identification, utilities support and influence on the decision making process, labeled as A, B and C in Figure 6.2.

Before starting the description of each stage with their steps, it is important to note that the CHP decision process is a complex one, involving many different factors. It is not a "low hanging fruit" initiative. In fact, it is a dynamic decision making process with dynamics inputs and specific characteristics depending on the site location.

<u>Stage 1: Awareness</u>

This first stage is probably the most important one. It deals with a lack of awareness about CHP, its benefits and importance. Lack of CHP awareness is one of the survey results and phone interviews. Moreover, this statement is also supported by the low response rate of the online survey. This stage consists of the following three steps:

1. **Energy Audits.** This is one of the activities that can be done in order to increase CHP awareness and knowledge. This step can be carried out by third parties interested in improving energy efficiency such as the Industrial Assessment Center, by CHP advocates or by some kind of government program looking for an increase in CHP adoption. This walk-through audit not only provides a preliminary analysis, but also identifies other "low hanging fruit" energy efficiency opportunities capable of reducing energy consumption. If this reduction is achieved, a smaller CHP is required.

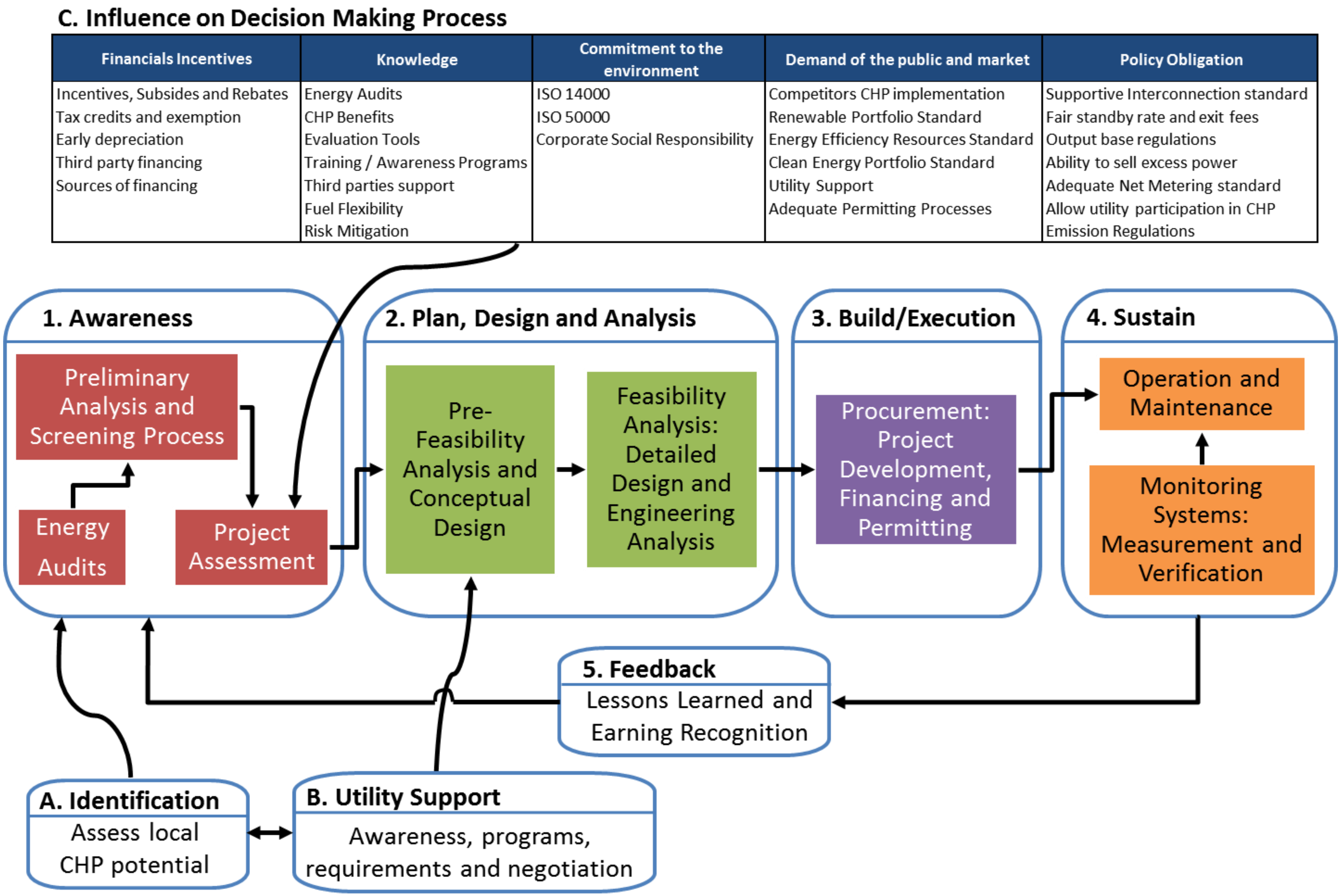


Figure 6.2: Implementation Guide

2. **Preliminary Analysis and Screening Process.** This step is the result of an energy audit or can be carried out by the employed personnel of the industry interested in CHP. The first activity in this step is to collect information on the site such as the facility's annual operating hours, monthly electric and fuel bills (at least one year), existing and planning thermal needs (heating and cooling), and backup electricity generation. With this information, it is possible to perform a preliminary analysis to evaluate if the facility is a good candidate for a CHP system. This analysis provides a rough estimate of the economic viability of the CHP project in terms of savings, cost, and simple payback period. It also provides a sensitivity analysis for risk evaluation. The preliminary analysis indicates if the CHP project should be carried forward. A spreadsheet model was developed to perform the analysis to help industries in the CHP decision-making process. An example of this tool in the form of a case study can be seen in Appendix F.

3. **Project Assessment.** The idea of this step is to perform an overall preliminary assessment of the CHP project. This assessment will include on one hand the payback period and on the other hand implementation difficulty (complexity). These two evaluation criteria were selected based on the results of the preliminary analysis, survey results and participant comments during phone interviews. Project assessment uses two tools: priority (pay-off) matrix and weighted scoring model (WSM).

   The value of the payback period is obtained in the previous step (preliminary analysis), and the value of implementation difficulty will be calculated with WSM. It will use four selection criteria: regulation process, permitting process, access to funding and utility support. These criteria can be seen in Table 6.2. With this information, it is possible to place the CHP project in the corresponding quadrant of the priority matrix.

Table 6.2: Evaluation Criteria

	Criteria			
Score	**Regulation Process**	**Permits Process**	**Access to Funding**	**Utility Support**
100	Extremely Complex	Extremely Complex	No Funding	Very Negative
75	Complex	Complex	Difficult to find	Negative
50	Normal	Normal	Neutral	Neutral
25	Low Complexity	Low Complexity	Easy to find	Positive
0	Not Complex at All	Not Complex at All	Funding Available	Very Positive

The priority matrix can be seen in Figure 6.3. It has four quadrants: implementation, need for financial aid and other benefits, third party support and CHP project rejection.

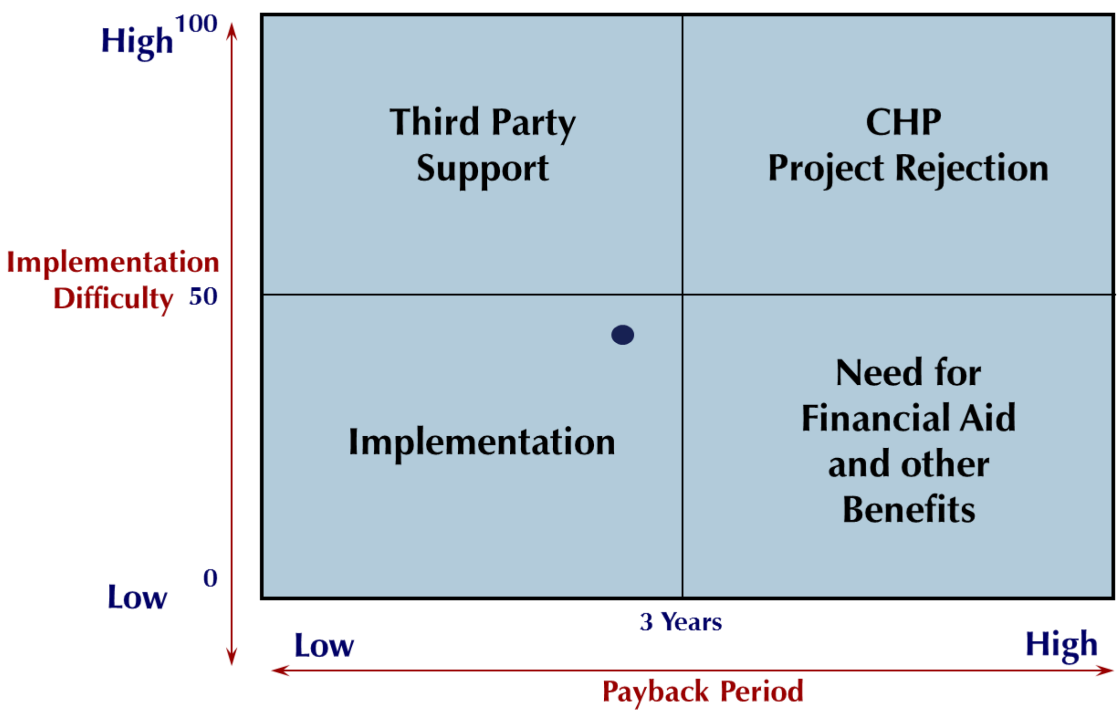


Figure 6.3: Priority Matrix for CHP Assessment

A CHP project is ready to implement when the CHP project has a payback period of less than three years and the difficulty of implementation has a weighted score of less than 50. A Financial Aid situation is when CHP project has a payback period of more than three years and implementation difficulty with a weighted score less than 50. In this case, it is important to include in the preliminary analysis, savings from rebates, financial incentives, subsidies, optimization and replacement of the electricity backup generators and economic savings in the production process resulting from a better energy reliability and resilience. The purpose is to achieve a payback period of less than three years. CHP project rejection occurs when the payback period is more than 3 years and implementation difficulty is more than a weighted score of 50. Third party support is needed when payback period is less than three years but implementation difficulty is more than a weighted score of 50. In this case, it may be necessary to utilize government lobbyists and utilities in order to overcome these difficulties. An example of the application of these tools can be seen in Appendix G.

Stage 2: Plan, Design and Analysis

This second stage is about feasibility studies that have to be performed. They include economic, technical and environmental evaluations. This stage consists of the following two steps:

1. **Pre-feasibility Analysis and Conceptual Design.** This step involves a preliminary conceptual design of the CHP system which consists of the selection of fuels, prime movers, heat recovery equipment and sizing options. An analysis of health, safety, and environmental issues are prepared. It includes building codes, fire regulations, air and water quality, noise, vibration, electrical hazards, interconnection standards and standby charges. Also, it deals with regulatory, permitting and utility barriers. Economic and sensitivity analyses are performed for each CHP option. The technical and economic

information gathered in this step will help to obtain funds or financial commitment and to decide whether or not to continue to the next level of analysis.

2. **Feasibility Analysis: Detailed Design and Engineering Analysis.** The CHP system design will be optimized in this step. This is the last feasibility analysis and will be used for bidding, construction and the permitting process; therefore, it has to be done with hard data and no assumptions. It includes all detailed engineering and drawings, timelines, construction, operation and maintenance requirements, financing and supplier options.

<u>Stage 3: Building and Execution</u>

The objective in this stage is to build the CHP system on time and on budget as specified. It consists of one step:

1. **Procurement: Project Development, Financing and Permitting.** This step deals with activities regarding project development, financing and permitting. Project development includes activities such as determining contract type, contract development and contractor selection. The Project can be done internally, or contracted as "turnkey project" or contracted with a partner (CHP developers/suppliers). There are several financing options such as company internal funds, debt financing, equity financing, lease financing, bonds, third party (project developers) financing, build-own-operate (BOO) financing and build-own-transfer (BOT) financing. The permitting processes include interconnection with utilities, establishing a power purchase agreement, determining what needs to be done in the way of pre-construction, construction and operation permits such as environmental impact assessment, air quality, water supply, land use, fire and safety issues, noise and waste management.

Stage 4: Sustainability of Day-to-day Operations

The objective of this stage is to operate the CHP system as designed without interruption or interference with the day-to-day operation. This requires two steps:

1. **Operations and Maintenance.** Depending of the type of contract, these activities can be performed by employees or by third parties. The goal is to minimize CHP downtime and maximize its availability.

2. **Monitoring.** The objective of this step is to make sure the CHP system operates as efficiently and as effectively as possible and achieves the economical and environmental benefits defined in the project. Compliance with government regulations and requirements is a key activity if the CHP project received any type of incentive, rebate or subsidy.

Stage 5: Feedback

The objective of this stage is to increase awareness and to educate potential users and stakeholders about the economic and environmental benefits of CHP system. It has one step:

1. **Lessons Learned and Earning Recognition.** By sharing their success story and experience with CHP, owners will help potential users in their decision process and will enhance their company's public image as environmental stewards dedicated to developing cleaner, safer and more financially accountable management of our natural and manmade resources.

Support Stage A: Identification

One of the top three barriers identified in the survey was the lack of CHP knowledge, and the lack of industrial interest in CHP. This is mainly because although CHP is not a new technology, industries do not know their benefits and the one's that know are afraid of the risk involved in its implementation process. An identification of industries that could benefit with the utilization of CHP made by the government or advocates looking at CHP deployment is a way to overcome this barrier. Knowing these industries will help to develop programs tailored for their needs, and offer them free energy audits or consultation.

Support Stage B: Utilities Support

In our framework for an effective implementation of CHP initiatives, it was pointed out that Utilities is a key player in CHP deployment. In order to increase CHP adoption rate, it is important to have support from the Utilities. However, survey results indicate that Utilities attitude towards CHP is somewhat negative and Utilities programs for CHP are not existence or are somewhat negative. An effort has to be done in order to change this. More aggressive utility support and their involvement in the development process are necessary in order to reduce risk associated with CHP deployment. If CHP can be seen by utilities as a new way they can deliver power or comply with their Renewable Portfolio Standard, or Energy Efficiency Resources Standard or Clean Energy Portfolio Standard, their attitude towards CHP will change. With a change in attitude, all processes that require utilities participation will be less complex, cheaper, and faster.

Support Stage C: Influence on Decision Making Process

The objective of this stage is to stimulate the decision-making process in order to maximize the CHP implementation rate. We used the five driving forces that influence the decision to invest. These driving forces and the issues of importance are shown in Table 6.3

Table 6.3: Driving Forces for Investment Decision

Financial Incentives	Knowledge	Commitment to the environment
Incentives, Subsides and Rebates	Energy Audits	ISO 14000
Tax credits and exemption	CHP Benefits	ISO 50000
Early depreciation	Evaluation Tools	Corporate Social Responsibility
Third party financing	Training / Awareness Programs	
Sources of financing	Third parties support	
	Fuel Flexibility	
	Risk Mitigation	

Demand of the public and market	Policy Obligation
Competitors CHP implementation	Supportive Interconnection standard
Renewable Portfolio Standard	Fair standby rate and exit fees
Energy Efficiency Resources Standard	Output base regulations
Clean Energy Portfolio Standard	Ability to sell excess power
Utility Support	Adequate Net Metering standard
Adequate Permitting Processes	Allow utility participation in CHP
	Emission Regulations

The most important driving force from an Industry point of view is the financial one. This was confirmed in the preliminary research and survey results, where payback period is the most important factor affecting CHP adoption rate. Therefore availability of economic incentives, subsidies, rebates or other financial aids will support CHP deployment. Working with the other driving forces will also help but to a lesser extent because they are part of the equation, but only a part, and one that customers look at after they make the decision to proceed.

7. Conclusions and Recommendations

7.1 Conclusions and Contributions

This dissertation argued that combined heat and power (CHP) is an energy efficiency initiative that has been undervalued due to its complexity and cost. It is neither a new technology nor a "hanging fruit"; however, CHP has enormous potential to increase energy security and productivity, to reduce cost and environmental emissions. Although the United States is behind other countries such as Denmark and Finland in the utilization of CHP as a source of electricity generation, it is possible to increase the amount of CHP by more than 60 GW. Despite all these benefits and potential, many cost-effective CHP investments are not made because of what is called the "CHP Paradox".

In order to overcome this CHP paradox, this dissertation developed a framework for an effective promotion and implementation of CHP initiatives. This framework is supported by an extensive research in areas of energy efficiency (EE), EE barriers, energy behaviors, energy culture, CHP characteristics, CHP barriers and drivers. It identified five stakeholders: industry, utilities, government, environmental groups and third parties. Moreover, it was developed using a system thinking approach which integrates the view of all stakeholders. To the best of my knowledge and those I worked with, this is the first research to propose a system view approach for developing an integrating framework to increase industrial implementation of CHP initiatives.

Furthermore, it was pointed out that the CHP implementation environment is a complex one due to the fact that interaction between industry and government has to pass through the administrative approval of utilities, making utilities a key player in CHP initiatives. Therefore, an important element of this framework is the communication process between these stakeholders. Also, it stresses the positive effect that promotion and education have in the modification of stakeholders' behavior in order to increase the adoption rate of CHP initiatives.

This dissertation's framework provides insight on the attitudes of stakeholders regarding CHP initiatives and will help policy makers to understand the effects of barriers and drivers on stakeholders; it can also help stakeholders to maximize the impacts of CHP opportunities and the results from CHP implementation.

The developed framework was evaluated using a research model with three general hypotheses that were applied to all stakeholders, which were categorized and discussed as perceived importance, barriers, and drivers. If these are the same among all stakeholders and all hypotheses are applicable, success can be had by those stakeholders who meet the criteria. The author also introduced nine more specific hypotheses affecting CHP acceptance: payback period, implementation cost, savings, rebates, behavior of utilities, utility programs, regulations, outreach programs and the impact of environmental group support in CHP implementation rates.

A preliminary research study was performed to test hypotheses regarding payback period, implementation cost, savings and rebates and to investigate the main factors affecting industrial implementation of CHP initiatives. In order to have a better understanding, it was decided to carry out a comparison between these factors with those affecting heat recovery and others EE initiatives. Information contained in the IAC database was used to undertake this preliminary research.

The logistic regression model was selected as a research technique based on the binary characteristics of the dependent variable. Two different logistic regression models were built--one model was based on payback period and other model was based on implementation cost and savings. In total eight logistic regression models were built—two for analysis of EE initiatives, two for CHP and Heat Recovery initiatives, two for heat recovery initiatives and two for CHP initiatives. Twelve independent variables (regressors) were introduced to the model and the forced entry method was used to identify the significant ones.

There were three main conclusions of this preliminary research. First, payback period is the main variable affecting the implementation rate of CHP and other EE initiatives. Second, industry type based on their energy intensity is not a factor that influences implementation rates. The assumption that a more energy intensive industry is more likely to implement CHP or EE initiatives did not hold. Third, CHP systems are less likely to be implemented than Heat Recovery and others EE initiatives. These results can help policy makers approach the problem of increasing the implementation rate of CHP systems; however, this is only one part of a much bigger picture because it considers only the view of industry and does not include the view of other stakeholders such as utilities, government, environmental groups, universities and third parties. Therefore, additional research was performed in order to integrate the view of all stakeholders and to test our 12 hypotheses.

It was decided to use an online survey developed in Qualtrics as a tool to gather information regarding CHP stakeholders. Most of the survey questions used the seven-point Likert scale with the objective of creating questions that could assess the perceptions of respondents and, thus, create data to perform hypothesis testing. The survey was sent to 2,495 potential respondents, 241 people answered the survey and 219 people completed the survey. Therefore, the response rate of the survey was 9.7% and the completion rate of the survey was 90.9%. However, the response rate of industries was extremely low with 3.3% and response rate of utilities was 10.9%. On the other hand, government response rate was 55.2%, and third parties response rate was 25.1%. These differences might be an indication of lack of interest and knowledge of industries and utilities about CHP benefits. Therefore, in order to increase awareness and utilization of CHP technology, identification of potential candidates for CHP implementation should be made and programs aims should be developed which accommodate the target industry or utility's needs.

Survey results confirmed that the main barriers affecting CHP adoption rate are payback period, lack of CHP knowledge and capital availability. Additionally, economic incentives cost and corporation support were identified as the main drivers.

CHP importance, CHP barriers and CHP drivers among stakeholders were tested with six questions each one of them. A total of 18 questions were asked. ANOVA results indicated that perceptions about CHP importance among stakeholders are very similar except for their perception of energy resilience. The same situation held true with stakeholders' perception of what the main drivers of CHP were with the differences based on economic incentives. However, stakeholder responses to questions on barriers were another story: In 50% of the questions, stakeholders had different views, which points to the need for outreach and education to unify stakeholder views.

Results from logistic regression models confirmed five hypotheses and rejected four hypotheses. The hypothesis that were confirmed are 1) payback period impacts CHP implementation rates, 2) savings impact CHP implementation rates, 3) utilities programs' impact CHP implementation rates, 4) regulations' impact CHP implementation rates, and 5) outreach programs' impact CHP implementation rates.

The hypotheses that were rejected are:

1) Implementation cost impacts CHP implementation rates.

2) Rebates impact CHP implementation rates.

3) Utilities behavior (toward CHP) impacts CHP implementation rates.

4) Environmental group support impacts CHP implementation rates.

Based on the framework for an effective implementation of CHP, results obtained from our logistic regression models and ANOVA analysis, and information gathering through a literature review focusing on CHP guidelines, an implementation guide was developed as an engineering solution to increase the CHP adoption rate. The purpose of this guide is to provide valuable information needed to understand the implementation process and to provide a pathway to CHP implementation that can be followed by industries.

The main difference between our guide and guides available elsewhere is that it considers the perspective of all five stakeholders. Other guides only consider activities that CHP users follow. The guide consists of five main stages: 1) awareness, 2) planning, which includes design and analysis, 3) building and execution, 4) sustaining the system, and 5) feedback. The author also included three support stages: 1) identification, 2) utility support and 3) influence on decision making process. The main stages have to be done by industries, and some steps need the support of others stakeholders. The support stages have to be done by government agencies through funding or policy assistance, utilities through a willingness to work with the industries and to provide CHP programs, and third parties by outreach programs.

Other contributions made in this dissertation were tools to develop the implementation guide. The first tool was a spreadsheet model designed to perform a CHP economic viability assessment with sensitivity analysis. The second tool was a project assessment strategy with priority matrices and a weighted scoring model. Both tools will help industries in the early stages of the CHP decision-making process. It is important to note, that this process is also influenced by the driving forces defined in our guide.

According to our research results payback period is the most important factor affecting CHP adoption rate. Therefore, financial aid such as economic incentives, subsidies, rebates, grants, or other financial assistance are the most important driving force from an industry point of view in the early stages of CHP deployment.

7.2 Recommendations and Future Research

This research has some limitations. One of the limitations was low survey responses by industries and utilities, mainly because of lack of CHP knowledge, which has kept industry from realizing its importance. It is argued that outreach and education about the importance and benefits of CHP could increase this response rate in conjunction with identification of potential industrial users by government and advocates.

Another limitation was the unbalanced sample size from stakeholders. The ideal situation for this survey analysis would be to have the same sample size from each stakeholder, but for reasons explained before, this was not possible. These samples of different size could decrease the statistical power of the data analysis. Therefore, in order to have a better statistical power for data analysis, future research should include a larger and more balanced sample size for all stakeholders.

It is important to note, that our CHP implementation guide does not have a full explanation of each stage of the implementation process. Full explanation was out of the scope of this dissertation because the goal of the guide was to promote understanding of activities, analysis and tools needed for a successful implementation of CHP.

The priority matrix can be modified: Instead of using a payback period in the horizontal axis, it could use a weighted scoring model with different criteria such as payback period, savings generated by energy reliability and resilience, or savings generated by environmental compliance among others.

In order to evaluate our framework for an effective implementation of CHP, this dissertation developed a research model and defined 12 hypotheses. These hypotheses were evaluated with eight logistic regression models with data from the IAC database, eight logistic regression models with data gather in the survey and 18 ANOVA analyses with survey data.

Further research to confirm our results can be done with the motivation, opportunity and ability (MOA) theory and structured equation modelling (SEM). In order to apply these techniques a research to define the appropriate formative and reflective constructs is required.

The initial idea was to do a CHP research focusing in the state of Missouri; however in order to have more responses from the online survey it was decided to have a bigger audience and included all United States. Future research could include only data from Missouri or a specific state in other to obtain specific results and to eliminate distortions caused by the presence of different states with different policies. Finally, a research that can be done in order to complement this investigation is to evaluate if results obtained in this dissertation are the same between the two types of CHP: topping and bottoming cycle.

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Appendix A

Table A.1: Current CHP Installations. Application by Fuel Type

	Biomass		Coal		Natural Gas		Oil		Waste		Wood		Other		Total	
Application	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW
SIC 20: Food	30	556.9	39	1,647.8	148	4,305.4	17	137.2	4	8.4	3	36.7	6	4.6	247	6,697.1
SIC 21: Tobacco	0	0.0	6	138.3	1	0.4	0	0.0	1	1.5	0	0.0	0	0.0	8	140.2
SIC 22: Textile Products	2	10.3	7	190.0	13	299.3	2	14.2	0	0.0	0	0.0	1	2.0	25	515.8
SIC 24: Wood Products	5	11.6	2	51.2	8	184.5	0	0.0	13	109.2	74	667.4	1	5.0	103	1,028.9
SIC 25: Furniture	0	0.0	0	0.0	0	0.0	0	0.0	2	0.3	8	7.9	0	0.0	10	8.2
SIC 26: Paper	12	694.0	38	2,385.1	88	4,249.6	10	139.2	58	3,580.9	20	596.5	2	56.5	228	11,701.8
SIC 27: Publishing	0	0.0	1	3.0	11	19.4	1	2.5	0	0.0	0	0.0	0	0.0	13	24.9
SIC 28: Chemicals	5	18.9	45	3,995.2	173	18,359.8	8	16.7	27	477.1	3	74.5	8	237.3	269	23,179.5
SIC 29: Petroleum Refining	0	0.0	3	195.5	68	14,616.7	5	369.9	26	864.5	0	0.0	4	50.6	106	16,097.2
SIC 30: Rubber	0	0.0	2	209.0	11	575.1	0	0.0	1	27.0	1	0.0	0	0.0	15	811.1
SIC 32: Stone, Clay, Glass	0	0.0	1	125.0	14	156.9	0	0.0	3	50.3	0	0.0	2	27.0	20	359.2
SIC 33: Primary Metals	0	0.0	3	870.0	28	1,951.9	2	37.6	17	1,087.2	0	0.0	2	29.5	52	3,976.2
SIC 34: Fabricated Metals	0	0.0	0	0.0	27	117.6	4	4.8	0	0.0	0	0.0	0	0.0	31	122.4
SIC 35: Machinery	1	4.2	2	15.6	16	209.4	2	3.7	1	7.5	0	0.0	0	0.0	22	240.4
SIC 36: Electrical Equipment	0	0.0	0	0.0	7	180.1	2	2.7	1	0.7	0	0.0	0	0.0	10	183.5
SIC 37: Transportation Equip	2	26.5	2	53.0	14	1,109.3	3	66.3	1	1.8	0	0.0	0	0.0	22	1,256.8
SIC 38: Technical Instruments	0	0.0	0	0.0	8	142.1	1	0.3	0	0.0	1	0.7	1	0.5	11	143.5
SIC 39: Misc Manufacturing	1	0.1	1	25.0	38	227.3	6	3.8	5	57.8	1	0.5	2	0.3	54	314.8
Total Industrial	58	1,322.6	152	9,903.8	673	46,704.8	63	798.9	160	6,274.2	111	1,384.2	29	413.3	1,246	66,801.7

Table A.2: Current CHP Installations. Application by Technology Type

	Boiler/ Steam Turbine		Combined Cycle		Combustion Turbine		Reciprocating Engine		Fuel Cell		Microturbine		Waste Heat Recovery		Other		Total	
Application	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW
SIC 20: Food	81	2,346.7	26	3,503.6	27	628.1	94	207.8	6	4.8	8	1.8	2	3.2	3	1.2	247	6,697.1
SIC 21: Tobacco	7	139.8	0	0.0	0	0.0	1	0.4	0	0.0	0	0.0	0	0.0	0	0.0	8	140.2
SIC 22:Textile Products	9	198.3	3	266.5	5	33.7	7	15.4	0	0.0	0	0.0	0	0.0	1	2.0	25	515.8
SIC 24:Wood Products	83	841.6	2	175.5	0	0.0	7	4.6	0	0.0	0	0.0	11	7.2	0	0.0	103	1,028.9
SIC 25: Furniture	8	7.9	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	2	0.3	0	0.0	10	8.2
SIC 26: Paper	177	8,402.7	19	2,383.5	24	883.5	4	29.4	0	0.0	0	0.0	4	2.8	0	0.0	228	11,701.8
SIC 27: Publishing	2	5.5	0	0.0	2	6.0	9	13.4	0	0.0	0	0.0	0	0.0	0	0.0	13	24.9
SIC 28: Chemicals	107	5,996.4	52	15,329.8	58	1,770.6	30	41.5	3	1.0	5	1.6	13	38.2	1	0.5	269	23,179.5
SIC 29: Petroleum Refining	25	1,020.3	34	13,158.2	34	1,782.1	4	7.1	0	0.0	2	0.2	5	117.6	2	11.7	106	16,097.2
SIC 30: Rubber	5	247.0	3	556.4	1	1.5	5	6.0	0	0.0	1	0.2	0	0.0	0	0.0	15	811.1
SIC 32: Stone, Clay, Glass	3	152.0	2	110.0	4	27.4	8	19.5	0	0.0	0	0.0	3	50.3	0	0.0	20	359.2
SIC 33: Primary Metals	22	1,887.2	4	1,797.0	8	48.7	12	25.5	1	0.6	2	0.2	3	217.0	0	0.0	52	3,976.2
SIC 34: Fabricated Metals	2	12.3	1	56.0	1	37.2	25	16.5	0	0.0	2	0.4	0	0.0	0	0.0	31	122.4
SIC 35: Machinery	4	37.1	2	123.2	2	46.3	14	33.8	0	0.0	0	0.0	0	0.0	0	0.0	22	240.4
SIC 36: Electrical Equipment	0	0.0	1	173.0	2	1.9	4	7.5	0	0.0	2	0.4	1	0.7	0	0.0	10	183.5
SIC 37: Transportation Equip	2	53.0	5	1,122.8	8	65.1	6	14.1	0	0.0	0	0.0	1	1.8	0	0.0	22	1,256.8
SIC 38: Technical Instruments	1	0.7	1	128.0	0	0.0	9	14.8	0	0.0	0	0.0	0	0.0	0	0.0	11	143.5
SIC 39: Misc Manufacturing	5	74.3	2	150.1	6	30.1	25	41.1	1	0.3	12	3.3	2	7.8	1	7.7	54	314.8
Total Industrial	543	21,422.9	157	39,033.5	182	5,362.1	264	498.3	11	6.7	34	8.1	47	446.9	8	23.1	1,246	66,801.7

Table A.3: Current CHP Installations. Application by System Type

	<1 MW		1 - 4.9 MW		5 - 19.9 MW		20 - 49.9 MW		50 - 99.9 MW		100 - 499 MW		> 500 MW		Total	
Application	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**
SIC 20: Food	72	29.8	67	163.9	60	565.2	15	592.5	13	862.9	19	3,847.8	1	635.0	247	6,697.1
SIC 21: Tobacco	1	0.4	2	3.0	3	34.3	1	22.5	1	80.0	0	0.0	0	0.0	8	140.2
SIC 22:Textile Products	5	1.5	5	13.2	7	63.2	5	149.5	2	108.5	1	180.0	0	0.0	25	515.8
SIC 24:Wood Products	30	13.0	24	60.1	34	308.2	11	324.0	3	198.0	1	125.5	0	0.0	103	1,028.9
SIC 25: Furniture	7	3.2	3	5.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	10	8.2
SIC 26: Paper	10	5.4	30	79.5	43	471.9	51	1,740.1	62	4,308.3	31	4,490.6	1	606.0	228	11,701.8
SIC 27: Publishing	3	0.5	10	24.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	13	24.9
SIC 28: Chemicals	36	15.4	66	190.5	45	396.3	38	1,142.9	22	1,570.2	52	11,720.2	10	8,144.2	269	23,179.5
SIC 29: Petroleum Refining	3	0.3	13	40.1	21	180.5	21	741.0	14	958.7	22	5,099.6	12	9,076.9	106	16,097.2
SIC 30: Rubber	4	0.8	4	6.9	1	11.0	2	71.0	0	0.0	4	721.4	0	0.0	15	811.1
SIC 32: Stone, Clay, Glass	5	1.9	6	12.2	4	39.9	3	95.2	1	85.0	1	125.0	0	0.0	20	359.2
SIC 33: Primary Metals	10	1.9	9	22.8	9	75.8	6	167.0	12	850.0	3	448.7	3	2,410.0	52	3,976.2
SIC 34: Fabricated Metals	23	6.8	5	10.3	1	12.2	1	37.2	1	56.0	0	0.0	0	0.0	31	122.4
SIC 35: Machinery	8	3.6	3	9.5	8	75.9	1	28.3	2	123.2	0	0.0	0	0.0	22	240.4
SIC 36: Electrical Equipment	5	2.8	4	7.7	0	0.0	0	0.0	0	0.0	1	173.0	0	0.0	10	183.5
SIC 37: Transportation Equip	3	0.2	6	18.4	6	62.4	3	83.0	2	110.6	1	222.2	1	760.0	22	1,256.8
SIC 38: Technical Instruments	6	3.0	3	6.0	1	6.5	0	0.0	0	0.0	1	128.0	0	0.0	11	143.5
SIC 39: Misc Manufacturing	28	7.6	15	37.0	7	51.1	2	69.0	2	150.1	0	0.0	0	0.0	54	314.8
Total Industrial	259	98.1	275	710.4	250	2,354.3	160	5,263.2	137	9,461.5	137	27,282.0	28	21,632.1	1,246	66,801.7

Table A.4: Current CHP Installations. Fuel Type by Technology

	Boiler/ Steam Turbine		Combined Cycle		Combustion Turbine		Reciprocating Engine		Fuel Cell		Microturbine		Waste Heat Recovery		Other		Total	
Fuel	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW	Sites	MW
Biomass	66	1,670.2	2	52.0	21	257.9	413	583.3	23	20.5	55	17.2	0	0.0	2	3.0	582	2,604.1
Coal	208	12,344.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	208	12,344.1
Natural Gas	154	4,182.6	215	42,541.6	408	9,556.6	1,647	1,267.2	136	55.5	303	69.5	0	0.0	9	25.4	2,872	57,698.4
Oil	34	252.7	5	386.1	8	123.4	215	387.9	0	0.0	1	0.1	0	0.0	0	0.0	263	1,150.2
Waste	135	6,473.6	3	175.5	7	203.6	10	17.4	0	0.0	3	1.3	78	470.3	1	6.0	237	7,347.7
Wood	120	1,393.5	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	120	1,393.5
Other	20	413.0	0	0.0	1	5.5	19	9.3	11	0.3	0	0.0	0	0.0	13	31.2	64	459.2
Total	737	26,729.6	225	43,155.2	445	10,147.0	2,304	2,265.2	170	76.2	362	88.1	78	470.3	25	65.6	4,346	82,997.2

Table A.5: Current CHP Installations. Technology by System Size

	<1 MW		1 - 4.9 MW		5 - 19.9 MW		20 - 49.9 MW		50 - 99.9 MW		100 - 499 MW		> 500 MW		Total	
Primemover	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**
Boiler/Steam Turbine	76	38.2	151	383.6	193	1,930.5	141	4,452.6	110	7,698.7	63	9,986.2	3	2,239.8	737	26,729.6
Combined Cycle	0	0.0	11	36.3	23	228.0	41	1,324.2	40	2,634.0	84	18,890.4	26	20,042.3	225	43,155.2
Combustion Turbine	17	9.0	131	416.3	172	1,629.7	85	2,978.5	23	1,602.6	17	3,511.0	0	0.0	445	10,147.0
Reciprocating Engine	1,699	413.6	522	1,080.1	79	656.2	4	115.2	0	0.0	0	0.0	0	0.0	2,304	2,265.2
Fuel Cell	148	44.9	22	31.3	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	170	76.2
Microturbine	346	65.2	15	17.4	1	5.5	0	0.0	0	0.0	0	0.0	0	0.0	362	88.1
Waste Heat Recovery	46	17.5	22	53.3	4	36.3	3	125.2	3	238.0	0	0.0	0	0.0	78	470.3
Other	15	4.7	3	6.4	7	54.5	0	0.0	0	0.0	0	0.0	0	0.0	25	65.6
Total	2,347	593.2	877	2,024.7	479	4,540.7	274	8,995.7	176	12,173.2	164	32,387.6	29	22,282.1	4,346	82,997.2

Table A.6: Current CHP Installations. Fuel Type by System Size

	<1 MW		1 - 4.9 MW		5 - 19.9 MW		20 - 49.9 MW		50 - 99.9 MW		100 - 499 MW		> 500 MW		Total	
Fuel	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**	**Sites**	**MW**
Biomass	334	113.6	168	343.5	49	455.9	21	641.1	7	465.1	3	584.9	0	0.0	582	2,604.1
Coal	6	2.6	26	63.7	58	537.8	46	1,427.1	32	2,322.7	38	6,400.4	2	1,589.8	208	12,344.1
Natural Gas	1,760	380.7	502	1,185.0	263	2,497.9	142	4,804.6	70	4,869.7	108	23,268.2	27	20,692.3	2,872	57,698.4
Oil	119	52.4	109	241.9	25	207.6	7	257.7	2	120.6	1	270.0	0	0.0	263	1,150.2
Waste	59	22.2	39	101.0	33	341.2	35	1,191.9	57	3,827.2	14	1,864.1	0	0.0	237	7,347.7
Wood	31	15.7	25	63.0	43	440.7	15	438.0	6	436.1	0	0.0	0	0.0	120	1,393.5
Other	38	6.0	8	26.6	8	59.5	8	235.3	2	131.9	0	0.0	0	0.0	64	459.2
Total	2,347	593.2	877	2,024.7	479	4,540.7	274	8,995.7	176	12,173.2	164	32,387.6	29	22,282.1	4,346	82,997.2

Appendix B

Table B.1: All Markets. Current US CHP Installations

State	Sites	% Sites	Number	State	MW	% MW	Number
CA	1,315	30.3%	1	TX	17,538	21.1%	1
NY	539	12.4%	2	CA	8,805	10.6%	2
NJ	227	5.2%	3	LA	6,109	7.4%	3
MA	199	4.6%	4	NY	5,686	6.9%	4
CT	187	4.3%	5	MI	3,449	4.2%	5
PA	161	3.7%	6	AL	3,396	4.1%	6
AK	153	3.5%	7	PA	3,268	3.9%	7
IL	136	3.1%	8	FL	3,236	3.9%	8
TX	123	2.8%	9	NJ	3,082	3.7%	9
WI	100	2.3%	10	OR	2,867	3.5%	10
MI	98	2.3%	11	IN	2,263	2.7%	11
NC	72	1.7%	12	VA	1,737	2.1%	12
OR	67	1.5%	13	WI	1,617	1.9%	13
LA	66	1.5%	14	MA	1,573	1.9%	14
FL	61	1.4%	15	NC	1,544	1.9%	15
OH	54	1.2%	16	SC	1,393	1.7%	16
VA	53	1.2%	17	WA	1,331	1.6%	17
MN	52	1.2%	18	IL	1,327	1.6%	18
GA	45	1.0%	19	GA	1,320	1.6%	19
AL	41	0.9%	20	MN	961	1.2%	20
IN	38	0.9%	21	ME	935	1.1%	21
IA	37	0.9%	22	CT	741	0.9%	22
VT	36	0.8%	23	IA	729	0.9%	23
WA	36	0.8%	24	MD	726	0.9%	24
HI	33	0.8%	25	OK	697	0.8%	25
ME	32	0.7%	26	CO	641	0.8%	26
SC	30	0.7%	27	TN	592	0.7%	27
MD	28	0.6%	28	AR	561	0.7%	28
RI	26	0.6%	29	MS	528	0.6%	29
CO	25	0.6%	30	OH	516	0.6%	30
MS	22	0.5%	31	AK	468	0.6%	31
TN	22	0.5%	32	HI	434	0.5%	32
MO	21	0.5%	33	WV	371	0.4%	33
UT	19	0.4%	34	NV	366	0.4%	34
KS	18	0.4%	35	NM	269	0.3%	35
NE	17	0.4%	36	MO	233	0.3%	36
ID	16	0.4%	37	DE	229	0.3%	37
NH	16	0.4%	38	UT	226	0.3%	38
AR	15	0.3%	39	ID	180	0.2%	39
OK	15	0.3%	40	WY	169	0.2%	40
MT	13	0.3%	41	ND	145	0.2%	41
NV	13	0.3%	42	KS	137	0.2%	42
AZ	11	0.3%	43	KY	127	0.2%	43
NM	11	0.3%	44	RI	114	0.1%	44
WV	11	0.3%	45	NE	105	0.1%	45
WY	11	0.3%	46	AZ	96	0.1%	46
ND	9	0.2%	47	MT	66	0.1%	47
KY	7	0.2%	48	NH	47	0.1%	48
DC	4	0.1%	49	VT	24	0.0%	49
DE	3	0.1%	50	DC	14	0.0%	50
SD	2	0.0%	51	SD	8	0.0%	51
Total	**4,346**	**100%**		**Total**	**82,997**	**100.0%**	

Table B.2: Industrial CHP Installations

State	Sites	% Sites	Number	State	MW	% MW	Number
CA	197	15.8%	1	TX	17,053	25.5%	1
TX	90	7.2%	2	LA	6,060	9.1%	2
NY	80	6.4%	3	CA	4,236	6.3%	3
NJ	62	5.0%	4	NY	3,392	5.1%	4
LA	59	4.7%	5	AL	3,245	4.9%	5
PA	55	4.4%	6	MI	3,068	4.6%	6
IL	48	3.9%	7	NJ	2,813	4.2%	7
MI	48	3.9%	8	FL	2,773	4.2%	8
NC	46	3.7%	9	OR	2,478	3.7%	9
MA	43	3.5%	10	IN	2,158	3.2%	10
CT	37	3.0%	11	PA	2,058	3.1%	11
FL	36	2.9%	12	NC	1,469	2.2%	12
AL	30	2.4%	13	VA	1,374	2.1%	13
OR	29	2.3%	14	SC	1,301	1.9%	14
GA	28	2.2%	15	GA	1,283	1.9%	15
VA	28	2.2%	16	WA	1,161	1.7%	16
WI	27	2.2%	17	MA	1,055	1.6%	17
OH	21	1.7%	18	IL	1,029	1.5%	18
MN	20	1.6%	19	ME	911	1.4%	19
ME	19	1.5%	20	WI	756	1.1%	20
IN	18	1.4%	21	OK	621	0.9%	21
WA	17	1.4%	22	IA	601	0.9%	22
HI	16	1.3%	23	MN	559	0.8%	23
IA	16	1.3%	24	AR	540	0.8%	24
KS	15	1.2%	25	TN	537	0.8%	25
TN	15	1.2%	26	MD	518	0.8%	26
MS	14	1.1%	27	MS	493	0.7%	27
SC	14	1.1%	28	CT	463	0.7%	28
AK	11	0.9%	29	HI	405	0.6%	29
AR	10	0.8%	30	OH	403	0.6%	30
CO	8	0.6%	31	NV	278	0.4%	31
ID	7	0.6%	32	DE	229	0.3%	32
ND	7	0.6%	33	WV	219	0.3%	33
VT	7	0.6%	34	ID	161	0.2%	34
KY	6	0.5%	35	ND	145	0.2%	35
MD	6	0.5%	36	KS	131	0.2%	36
MO	6	0.5%	37	KY	127	0.2%	37
OK	6	0.5%	38	UT	102	0.2%	38
UT	6	0.5%	39	NE	81	0.1%	39
NE	5	0.4%	40	RI	78	0.1%	40
WV	5	0.4%	41	AK	68	0.1%	41
WY	5	0.4%	42	MO	65	0.1%	42
MT	4	0.3%	43	CO	62	0.1%	43
NH	4	0.3%	44	MT	62	0.1%	44
NV	4	0.3%	45	AZ	57	0.1%	45
RI	4	0.3%	46	WY	46	0.1%	46
DE	3	0.2%	47	NM	44	0.1%	47
NM	2	0.2%	48	NH	22	0.0%	48
AZ	1	0.1%	49	VT	6	0.0%	49
SD	1	0.1%	50	SD	5	0.0%	50
DC	0	0.0%	51	DC	0	0.0%	51
Total	**1,246**	**100%**			**66,802**	**100.0%**	

Appendix C

Estimation of Quantity of Waste Heat from Exhaust

The following analysis was carried out to estimate the quantity of waste heat produced by the melting process. The calculation is based on the following:

- Fuel consumption
- Exhaust gas chemical composition and mass flow rate relative to fuel input—calculated based on fuel consumption, quantity of excessive combustion air, and process-specific chemical reactions (natural gas combustion in this case)
- Batch mix composition and flow rate
- Exhaust gas temperature
- Enthalpy hi(t) of each species (calculated or from table)

An explanation of the approach is as follows:

1. Estimation of energy and mass balance

First, we used two furnaces to carry out an analysis of the heating process. In Figure C1 we see the display of both the energy and mass balance involved in the melting process

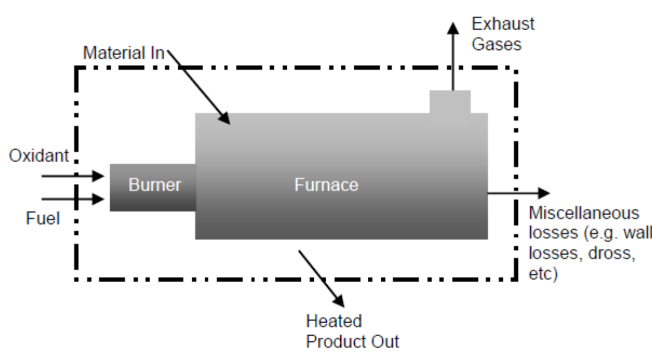

Figure C.1: Energy and Mass Balance

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The energy balance for the furnace is, therefore, given by:

$E_{in} = E_{ex} + E_s + E_{misc}$

where

- E_{in} is the energy input; in this case it is natural gas,
- E_{ex} is the energy lost to exhaust gases,
- E_s is the heat contained in the melt sand and batch leaving the furnace. In this case, no mass loss is involved, and
- E_{misc} is miscellaneous heat losses. In this case, those losses are mainly sidewall and opening heat losses.

Specifically, in this case the estimation of waste heat loss in exhaust gases is based on the fuel consumption and expected specific enthalpy (Btu/lb) of exhaust flow, which depends on the temperature and chemical composition of the exhaust flow, expressed as:

$$\dot{E}_{ex} = \left(\dot{m}\,h(t)\right)_{ex} = \dot{m}_{ex} \sum_i \left(x_i h_i(t)\right)_{ex}$$

where:

- E_{ex} is the exhaust gas waste heat,
- m_{ex} is the exhaust gas mass flow,
- x_i is the mass fraction of each species in the exhaust gas, and
- $h_i(t)$ is the enthalpy of each species i in the exhaust at the exhaust temperature t.

Enthalpy of any substance is measured against a reference state at a certain temperature and pressure. In this case, the enthalpy of waste heat flow is calculated at two reference temperatures: 77 °F and 1,200 °F, used to provide a basis for evaluating the heat attained in the inlet (ambient temperatures at 77 °F) and exhaust (at 1,200 °F) gas flows, respectively.

2. Estimation of exhaust flow rate based on natural gas chemical composition

Since the flow rate of exhaust gases and the mass fraction of each species can be determined from fuel consumption and mass balances, based on reaction equations for the combustion of fuel, we rearranged the previous equation as:

$$\dot{E}_{ex} = \left(\dot{m}\, h(t) \right)_{ex} = \dot{m}_{ex} \sum_i \left(x_i h_i(t) \right)_{ex} = \dot{m}_{fuel} \left(\frac{\dot{m}_{ex}}{\dot{m}_{fuel}} \right) \sum_i \left(x_i h_i(t) \right)_{ex}$$

where the ratio $\left(\frac{\dot{m}_{ex}}{\dot{m}_{fuel}} \right)$ can be found from the proper combustion equations, dependent on the type of fuel involved in the combustion. For example, the main component of natural gas is methane (as shown in the table of natural gas composition), with 10% excess air the exhaust gas composition resulting from methane is given by the following combustion equation:

CH4 + 1.1* 2(O2 + 3.76N2) → CO2 + 2H2O + 0.2O2 + 8.272N2

Table C.1: Typical Natural Gas Composition
(Source: EPA, 1984. Industrial Waste Heat Recovery and the Potential for Emissions Reduction)

Natural Gas (% volume)	
Methane (CH_4)	93.27%
Ethane (C_2H_6)	3.79%
Propane C_3H_8	0.57%
Butane C_4H_{10}	0.29%
Nitrogen	1.19%
Water	0.00%
Carbon Dioxide	0.79%

A similar approach can be used for each species in the fuel.

Table C.2: Approximate exhaust gas composition for natural gas (with 10% excessive air) compared to coal and oil.

Flue Gas Species	Volume %		
	Coal	Oil	Natural Gas
CO2	15.9%	12.9%	9.7%
H2O	7.0%	11.1%	18.7%
SO2	0.1%	0.0%	0.0%
N2	77.0%	76.1%	71.6%

Finally, the fraction of waste heat loss relative to energy input can be expressed as:

$$\frac{E_{ex}}{E_{in}} = \frac{\dot{m}_{fuel}\left(\frac{\dot{m}_{ex}}{\dot{m}_{fuel}}\right)\sum_i (x_i h_i(t))_{ex}}{\dot{m}_{fuel}\, h_c}$$

$$= \frac{\left(\frac{\dot{m}_{ex}}{\dot{m}_{fuel}}\right)\sum_i (x_i h_i(t))_{ex}}{h_c}$$

3. Estimation of heat flow rate of material based on glass composition

Exactly the same approach can be used for the evaluation of heat flow of the load materials through the furnaces:

$$\dot{E}_S = \left(\dot{m}\, h(t)\right)_S = \dot{m}_S \sum_i (x_i h_i(t))_S$$

Appendix D

Mizzou
University of Missouri

University of Missouri at Columbia
Consent to Participate in Research
"An investigation into the factors affecting industrial implementation of CHP (Combined Heat and Power)"

Dear participant,

My name is Jorge Abad. I am a PhD Candidate at the University of Missouri, Columbia working with my faculty advisor, Professor Bin Wu, in the Department of Industrial and Manufacturing Systems Engineering. I would like to invite you to take part in my research study, which investigates the main factors affecting industrial implementation of Combined Heat and Power (CHP), and the interaction effects between stakeholders. It is hoped that the research will shed light on how to increase the rate of CHP implementation.

CHP, also known as cogeneration, is an efficient approach to produce electricity and thermal energy simultaneously from a single fuel source close to the point-of-use. CHP is an integrated system that operates at a higher efficiency than a Separate Heat and Power (SHP) system because heat that is usually wasted is recovered to produce electricity or useful thermal energy. Benefits of this higher efficiency are reduction of energy consumption, reduction of operating cost, and reduction of greenhouse gas emissions. Moreover, CHP systems provide other benefits such as reliability and resiliency of energy supply, a critical attribute in times of natural disasters, catastrophes and electricity outages.

Your participation in this research study is voluntary. You may choose not to participate. If you decide to participate in this research survey, you may withdraw at any time.

The procedure involves filling an online questionnaire that will take less than 10 minutes. Your responses will be confidential and we do not collect identifying information such as your name, email address or IP address. The survey questions will be about your perception regarding different aspect of CHP such as barriers, drivers, economics and stakeholders actions.

The study data will be handled as confidentially as possible. To help protect your confidentiality, the survey will not contain information that will personally identify you. The results of this study will be used for scholarly purposes, and if results of this study are published or presented, identifiable information will not be used.

If you have any questions about this research, please feel free to contact me. I can be reached at (573)529-7858 or at jfm6x2@mail.missouri.edu. If you have any questions about your rights as a participant in this study, please contact the University of Missouri Institutional Review Board at 573-882-3181 or irb@missouri.edu.

If you agree to take part in the research, please click on the "Next" button below

Thank you very much for your participation!

Survey Completion
0% 100%

Next

Mizzou
University of Missouri

What type of sector do you work in? Please, select the most appropriate for you

- Industry
- Utilities
- Government
- University/Education
- Environmental Group
- Developers/Suppliers of CHP
- Non-profit Organization
- Consulting Firm
- Other

Survey Completion
0% 100%

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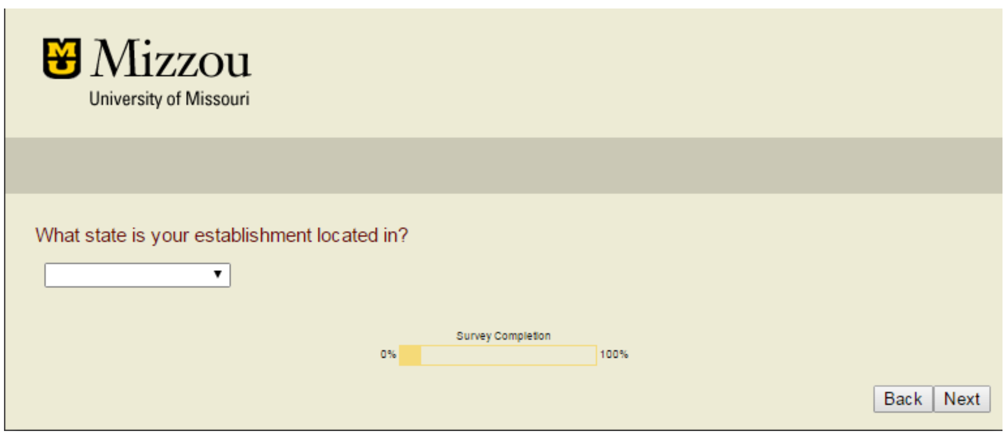

Mizzou
University of Missouri

What state is your establishment located in?

Survey Completion
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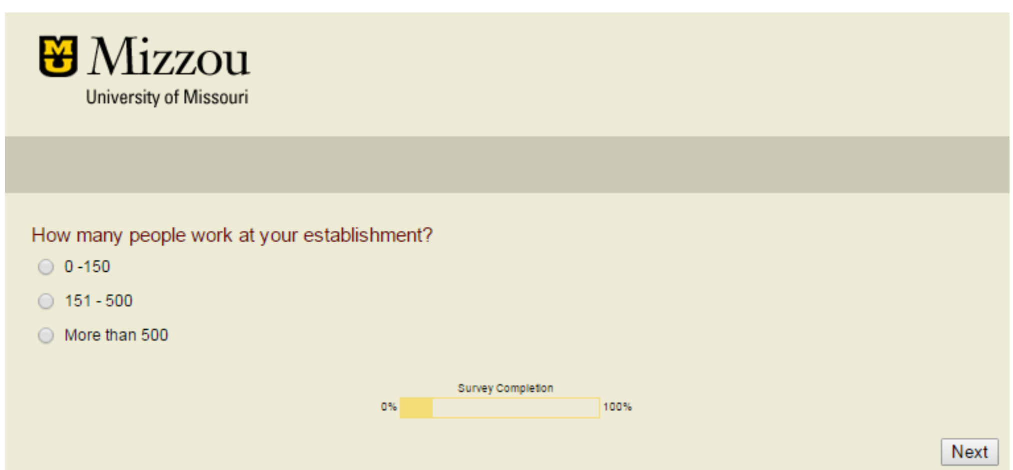

Mizzou
University of Missouri

How many people work at your establishment?

- 0 -150
- 151 - 500
- More than 500

Survey Completion
0% 100%

Next

Mizzou
University of Missouri

Write your establishment's primary line of business or write your SIC code

Survey Completion

0% 100%

Back Next

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University of Missouri

What type of thermal needs does your establishment have? Please mark all that apply.

- ☐ Manufacturing Processes
- ☐ Space Heating
- ☐ Space Cooling
- ☐ Water Heating
- ☐ Other

Survey Completion

0% 100%

Back Next

Mizzou
University of Missouri

There are barriers that inhibit CHP implementation, but usually one predominates. Please mark the **ONE** that you believe is the main barrier

- Permitting regulation
- Lack of feed-in tariff
- Lack of interconnection standard
- Capital availability
- Unfair standby rate
- Lack of corporation support
- Lack of CHP knowledge
- Investment risk
- Lack of net metering rule
- Utilities business model
- Poor spark spread
- CHP is not included in the Energy Efficiency Resource Standards
- Inability to sell excess power
- Utility attitude
- Tax treatment
- Higher payback period
- Lack of knowledgeable Staff
- Input based regulations
- CHP is not included in the Renewable Portfolio Standards
- Other

Survey Completion

0% 100%

Back Next

Mizzou
University of Missouri

There are drivers that encourage CHP implementation, but usually one predominates. Please mark the **ONE** that you believe is the main driver

- Need for environment compliance
- Supportive regulations
- CHP fuel flexibility
- CHP education
- Government example
- Economic incentives
- Corporation support
- Other

Survey Completion

0% 100%

Back Next

Mizzou
University of Missouri

How much do you agree or disagree with the following statements about the perceived importance of CHP?

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
CHP is an important energy efficiency initiative	○	○	○	○	○	○	○
CHP helps to reduce energy consumption	○	○	○	○	○	○	○
CHP helps to reduce cost	○	○	○	○	○	○	○
CHP helps to reduce environmental emissions	○	○	○	○	○	○	○
CHP helps to improve energy resilience	○	○	○	○	○	○	○
CHP helps to improve energy reliability	○	○	○	○	○	○	○

Survey Completion
0% 100%

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Mizzou
University of Missouri

How much do you agree or disagree with the following statements about the perceived importance of CHP barriers?

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Lack of available finance discourages implementation of CHP projects	○	○	○	○	○	○	○
Current regulation discourages implementation of CHP projects	○	○	○	○	○	○	○
Current utilities attitude discourages implementation of CHP projects	○	○	○	○	○	○	○
Project risk discourages implementation of CHP projects	○	○	○	○	○	○	○
Lack of CHP knowledge discourages implementation of CHP projects	○	○	○	○	○	○	○
Lack of corporation support discourages implementation of CHP projects	○	○	○	○	○	○	○

Survey Completion
0% 100%

Back Next

Mizzou
University of Missouri

How much do you agree or disagree with the following statements about the perceived importance of CHP drivers?

	Strongly Disagree	Disagree	Somewhat Disagree	Neither Agree nor Disagree	Somewhat Agree	Agree	Strongly Agree
Economics incentives helps implementation of CHP projects	○	○	○	○	○	○	○
Supportive regulations helps implementation of CHP projects	○	○	○	○	○	○	○
The inclusion of CHP in the Energy Efficiency Resource Standards programs helps implementation of CHP projects	○	○	○	○	○	○	○
The inclusion of CHP in the Renewable Portfolio Standards programs helps implementation of CHP projects	○	○	○	○	○	○	○
Education helps implementation of CHP projects	○	○	○	○	○	○	○
If environmental groups advocate CHP as they advocates wind and solar generation, it will help implementation of CHP projects	○	○	○	○	○	○	○

Survey Completion
0% 100%

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The following questions are about the economic performance of a CHP project. Please rate "higher value" is the value of the economic factor is expected to be high or "lower value" if the value is expected to be low

	Lower Value 1	2	3	Neutral 4	5	6	Higher Value 7
Rate the value of the payback period for CHP projects	○	○	○	○	○	○	○
Rate the value of the implementation costs for CHP projects	○	○	○	○	○	○	○
Rate the value of the savings generated by CHP projects	○	○	○	○	○	○	○
Rate the value of the rebates available for CHP projects	○	○	○	○	○	○	○

Survey Completion
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Mizzou
University of Missouri
Please, rate the following Utilities action regarding CHP projects
Very Negative
Negative
Somewhat Negative
Neutral
Somewhat Positive
Positive
Very Positive
Current utilities attitude towards CHP project
Please, rate the following Utilities action regarding CHP projects
No program at all
Very Negative
Negative
Somewhat Negative
Neutral
Somewhat Positive
Positive
Very Positive
Current utilities programs regarding CHP
Survey Completion
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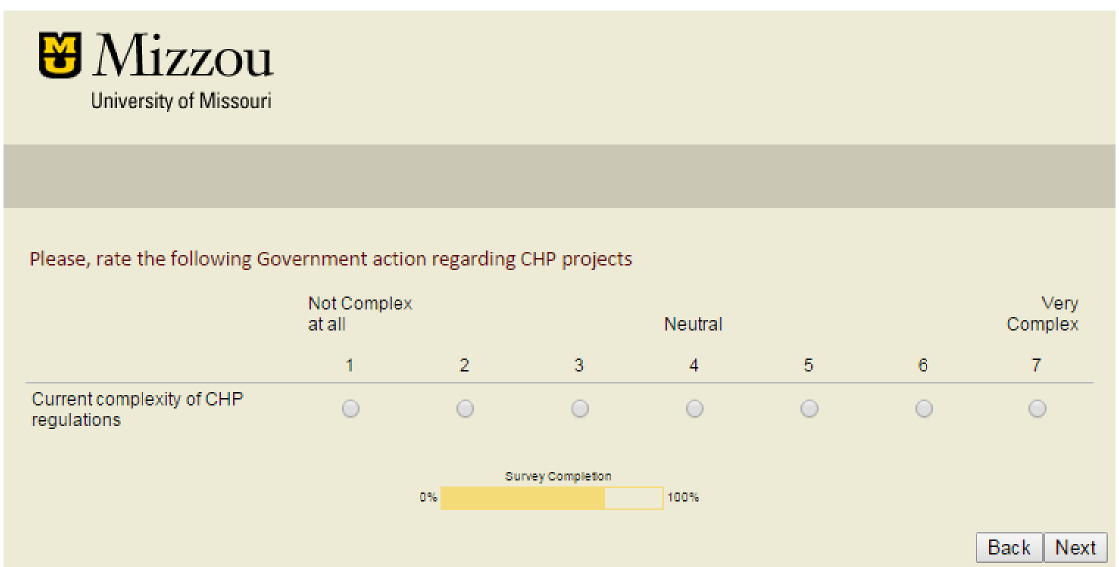
Mizzou
University of Missouri
Please, rate the following Government action regarding CHP projects
Not Complex at all
Neutral
Very Complex
1
2
3
4
5
6
7
Current complexity of CHP regulations
Survey Completion
0%
100%
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Next

Mizzou
University of Missouri

Please, rate the following Universities/Third parties action regarding CHP projects

	Not Helpful 1	2	3	Neutral 4	5	6	Very Helpful 7
Current outreach CHP programs	○	○	○	○	○	○	○

Survey Completion
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Mizzou
University of Missouri

Please, rate the following environmental groups action regarding CHP projects

	Very Negative	Negative	Somewhat Negative	Neutral	Somewhat Positive	Positive	Very Positive
Current environmental groups attitude towards CHP projects	○	○	○	○	○	○	○

Survey Completion
0% 100%

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Mizzou
University of Missouri

Which of the following statements applies to your establishment:

- ○ My establishment has not adopted and not evaluated CHP technology for their use
- ○ My establishment has evaluated CHP technology for their use but not gone forward with the adoption to date
- ○ My establishment has evaluated CHP and adopted the technology

Survey Completion
0% 100%

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Mizzou
University of Missouri
With which of the following statements do you agree:
With the current CHP environment, industries will not evaluate CHP for their use
With the current CHP environment, industries will evaluate CHP for their use but will not go forward with the adoption
With the current CHP environment, industries will evaluate CHP for their use and will adopt it
Survey Completion
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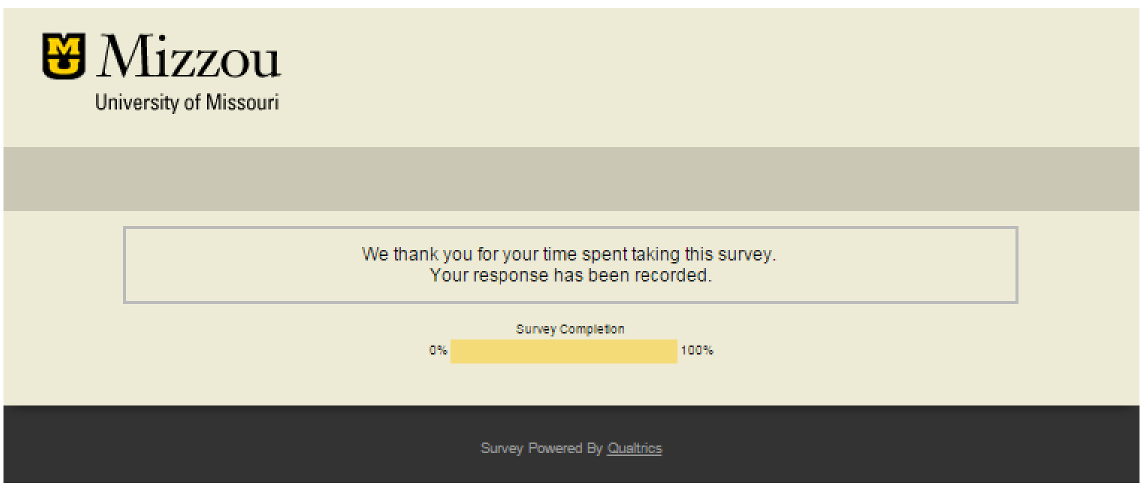
Mizzou
University of Missouri
We thank you for your time spent taking this survey.
Your response has been recorded.
Survey Completion
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Survey Powered By Qualtrics

Appendix E

Institutional Review Board
University of Missouri-Columbia

190 Galena Hall; Dc074.00
Columbia, MO 65212
573-882-3181
irb@missouri.edu

October 14, 2015

Principal Investigator: Jorge Fernando Abad Moran
Department: Industrial/Mfg Sys Engr

Your Exempt Application to project entitled An Investigation into the Effectiveness of Industrial Application of CHP (Combined Heat and Power) was reviewed and approved by the MU Institutional Review Board according to terms and conditions described below:

IRB Project Number	2003771
IRB Review Number	208727
Initial Application Approval Date	October 14, 2015
IRB Expiration Date	October 14, 2016
Level of Review	Exempt
Project Status	Active - Open to Enrollment
Exempt Categories	45 CFR 46.101b(2)
Risk Level	Minimal Risk

The principal investigator (PI) is responsible for all aspects and conduct of this study. The PI must comply with the following conditions of the approval:

1. No subjects may be involved in any study procedure prior to the IRB approval date or after the expiration date.
2. All unanticipated problems, adverse events, and deviations must be reported to the IRB within 5 days.
3. All changes must be IRB approved prior to implementation unless they are intended to reduce immediate risk.
4. All recruitment materials and methods must be approved by the IRB prior to being used.
5. The Annual Exempt Form must be submitted to the IRB for review and approval at least 30 days prior to the project expiration date. If the study is complete, the Completion/Withdrawal Form may be submitted in lieu of the Annual Exempt Form
6. Maintain all research records for a period of seven years from the project completion date.
7. Utilize all approved research documents located within the attached files section of eCompliance. These documents are highlighted green.

If you have any questions, please contact the IRB at 573-882-3181 or irb@missouri.edu.

Thank you,
MU Institutional Review Board

Appendix F

In this appendix, a tool developed by the author is presented as part of an industry case study. The tool is a spreadsheet model with economic and sensitivity analysis, and it was essential to the development of the preliminary analysis used in this study to establish CHP viability. Hence, it has proven capable of analyzing any study in the preliminary research stage.

Case Study 4: Pet Food Industry

This case study is based on the report MZ0185 from MoIAC (Wu and Abad, 2015). It was recommended to this company to implement a Combined Heat and Power (CHP) system.

Existing Practice and Observation

CHP systems are attractive for a number of reasons, including economics, improving greenhouse emissions, thermal efficiency, power reliability and resiliency. However, for be a viable option, the CHP system has to meet the following three conditions:

1. A use for the thermal energy recovered by the CHP system
2. A use for the electricity generated
3. A favorable “Spark Spread”

The spark spread refers to the difference between the cost of electricity ($/MMbtu) and the cost of the fuel ($/MMbtu) consumed by the prime mover of the CHP system. The prime mover is an engine or turbine which, through combustion, produces mechanical energy.

It is believed that with the walk-through audit and with the information given by officials of the company that all three conditions are met and it is possible to implement a CHP system at the facility.

Recommended Approach – Topping Cycle System

In the following, we provide an analysis to illustrate the potentials involved, with data and assumptions gathered during our visit to the pet food company as well as subsequent communications with the company. However, due to the nature of the technologies involved, we strongly recommended that the company work with contractors who specialize in CHP installation to carry out more in-depth investigation. The process of designing and implementing a cogeneration system has many factors to consider. In this particular case, the suitable option would be a “topping cycle” approach where the fuel is first used in a reciprocating engine or gas turbine to generate electricity and then, the waste heat captured from electricity generation by a heat recovery unit is used to provide heating/cooling for the facility. The following analysis only considers heating loads. Additional savings could be obtained if the CHP system included absorption chillers for cooling in the summer and if the company has backup generators that can be replaced by the CHP system.

CHP Evaluation and Sizing

The evaluation is based on the data collected as shown in Table F.1:

Table F.1: Initial Data

Data	Values	Units
Annual Operating Hours	8,760	Hours
Annual Electricity Consumption	28,921,821	kWh
Annual Electricity Cost (including demand)	2,004,174.92	$
Electricity Cost (including demand)	0.069	$/kWh
Annual Gas Consumption	91,457.84	MMBtu
Annual Gas Cost	527,629.15	$
Gas Cost	5.77	$/MMBtu
Average Electric Demand	5,267	KW
Average Gas Used	10.44	MMBtu/hour
Average Heating Load	8.35	MMBtu/hour
Electricity Load Factor	63	%
Boiler Efficiency	80	%
Electrical Generation Efficiency (gas turbine)	30	%
Thermal Recovery Efficiency	41	%
CHP O&M Cost	0.009	$/kWh

Conversion	Values	Units
Annual Electricity Consumption	98,681.25	MMBtu
Electricity Cost (including demand)	20.31	$/MMBtu

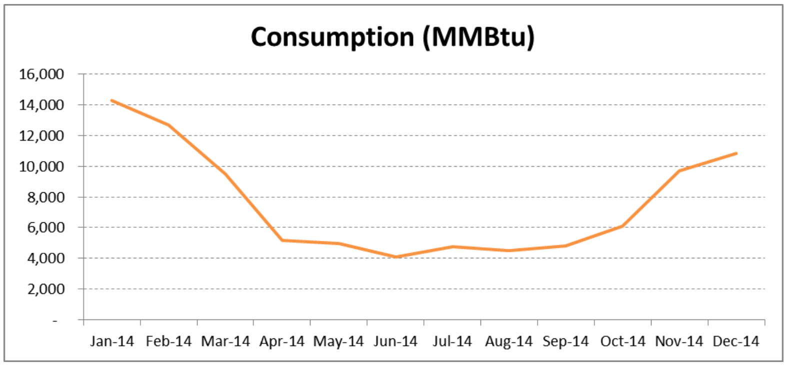
The first step is to determine if this project has a favorable spark spread:

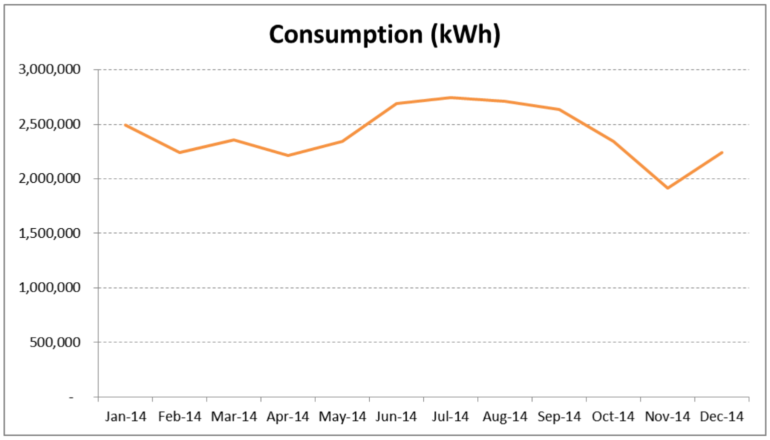
Spark Spread = Electricity Cost ($/MMBtu) − Gas Cost ($/MMBtu)

Spark Spread = 20.31 ($/MMBtu) − 5.77 ($/MMBtu)

Spark Spread = 14.54 $/MMBtu

Therefore, electricity is $14.54 per MMBtu more expensive than natural gas. A spark spread of this value is favorable for CHP if the two other conditions are met. The other two conditions can be seen in the Figure F.1.





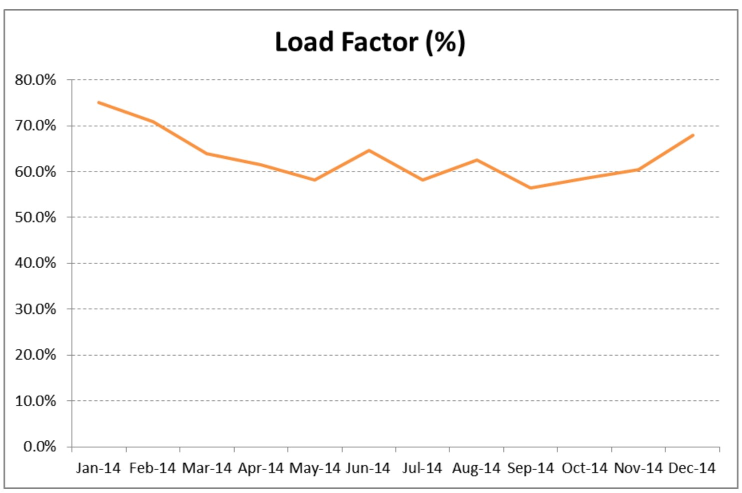


Figure F.1: Energy Consumption and Load Factor

The electricity consumption indicates a consumption difference of approximate 40% between the highest consumption in the summer and the lowest consumption in the winter. Also, the facility has an average electricity load factor of 63%. This indicates that the facility runs their equipment more than 60% of their time. A point of concern is the gas consumption trend. This behavior indicates that most of the natural gas is used for space heating and the gas consumption in summer is low in comparison to winter consumption. This problem can be mitigated with the use of waste heat in the summer time for cooling purpose with absorption chillers. This CHP design will increase thermal need in the summer time and make thermal load very similar all year long. Moreover, it will reduce the electricity consumption in the summer and make more constant the electricity consumption through the year.

The second step is to determine the operating strategy of the CHP project. There are four strategies:

1. The electricity energy requirement is met, but the thermal energy recovered is greater than required. Therefore, it is necessary to sell/export excess thermal energy to neighboring facilities.
2. The electricity energy requirement is met, but the thermal needs are not met. Therefore, additional thermal energy must be purchased from the utility
3. The thermal energy requirement is met, but the electricity requirement is not met. Electricity has to be purchased from the grid. This is a common operating strategy for a CHP system. Connection to the grid provides power redundancy for the facility.
4. The thermal energy requirement is met, but generates excess of electricity. Therefore, this excess electricity should be sold to the grid in a sufficient price to pay the cost of generation.

The strategy can be defined based on the Energy Ratio:

Energy Ratio = Annual Electricity Consumption (MMBtu) /Annual Gas Consumption (MMBtu)

Energy Ratio = 98,681.25 MMBtu / 91,457.84 MMBtu

Energy Ratio = 1.08

This results indicate that the operating strategy for the CHP project should meet all thermal requirements and to purchase extra electricity from the grid. Therefore, the thermal energy requirement would be satisfied with the waste heat recovered from the CHP system. In this analysis the proposed prime mover is a gas turbine.

The next step is to determine the size of the CHP system, as can be seen in Table F.2:

Table F.2: CHP Size Calculation

	Values	Units
Annual Thermal Heating Load		
Annual Gas Consumption (MMBtu)x Boiler Efficiency	73,166.27	MMBtu
This is the amount of energy that will be recovered by the CHP		
Annual Gas required by CHP		
Annual Thermal Heating Load (MMBtu)/Thermal Recovery Efficiency	178,454.32	MMBtu
Annual Electricity Generated by CHP		
Annual Gas required by CHP(MMBtu) x Electrical Generation Efficiency / 0.003412 (MMBtu/kWh)	15,690,591	kWh
CHP Size		
Annual Electricity Generated by CHP (kWh) / Annual Operating Hours (hours) / 1000 (kW/MW)	1.79	MW

As it can be seen, a **1.79 MW** CHP system is recommended.

Cost and Savings Analysis. This can be seen in Table F.3:

Table F.3: Cost and Savings Analysis

Description	Current	With CHP
Electricity Cost	$ 2,004,175	$ 916,875
Gas Cost	$ 527,629	$ 1,029,520
O & M CHP Cost	$ -	$ 141,215
Total Cost	**$ 2,531,804**	**$ 2,087,611**

Savings

Annual Current Cost - Proposed Cost with CHP	$ 444,193.30

Implementation Cost and Payback

Cost of implementation, including materials and labor, are estimated in Table F.4:

Table F.4: Implementation Cost

Description	Cost ($/kW)	kW	Total Cost ($)
Implementation Cost	1,500	1,791	2,686,745
	Total Cost of Implementation		2,686,745

If implemented, the simple payback period will be:

Cost of implementation ($) /Saving ($/Year) = **6.05 years**

Emissions Reduction Analysis

Natural gas emission coefficient is estimated at 117.08 lbs CO_2/MMBtu in Missouri. According to the EPA, the transmission and distribution (T&D) losses for SERC Midwest region is 5.82%. According to the EPA, the Grid Electricity Heat Rate for SERC Midwest region is 8,794 Btu/kWh. This can be seen in Table F.5

Table F.5: Emissions Analysis

	Values	Units
Fuel Use from Displaced On-site Thermal Production (FT)		
Annual Gas Consumption	91,458	MMBtu/year
Fuel Use from Displaced Grid Electricity (FG)		
(CHP Electricity Output (kWh)/(1-T&D Losses))*Grid Electricity Heat Rate (Btu/kWh)/1000000 (Btu/MMBtu)	146,510	MMBtu/year
Fuel Used by the CHP System (FCHP)		
Annual Gas required by CHP	178,454	MMBtu/year
Total Fuel Savings		
(FT + FG) – FCHP	59,513	MMBtu/year

Annual CO_2 emissions reduced = 117.08 CO_2/MMBtu * 59,513 MMBtu/year

Annual CO_2 emissions reduced = **6,967,835.17 lbs/year**

Sensitivity Analysis

In order to know, the effect of different variables in the proposed project, it is important to perform a sensitivity analysis. The variables that will be changed are:

- Gas Prices: from 3.5 $/MMBtu to 9 $/MMBtu
- Electricity Prices: from 0.045 $/kWh to 0.09 $/kWh
- Implementation cost: from 1,000 $/kW to 2,300 $/kW

Gas Prices variation:

The result of natural gas prices fluctuation can be seen in Table F.6 and Figure F.2:

Table F.6: Sensitivity Analysis with gas price variation

Gas Price ($/MMBtu)	Electricity Cost ($/kWh)	Current Cost ($)	Cost with CHP($)	Savings ($)	Implementation Cost ($)	Payback Period (years)
3.50	0.069	2,324,277.36	1,682,680.61	641,596.75	2,686,745	4.19
4.50	0.069	2,415,735.20	1,861,134.93	554,600.27	2,686,745	4.84
5.77	0.069	2,531,804.07	2,087,610.77	444,193.30	2,686,745	6.05
6.50	0.069	2,598,650.88	2,218,043.57	380,607.31	2,686,745	7.06
8.00	0.069	2,735,837.64	2,485,725.06	250,112.58	2,686,745	10.74
9.00	0.069	2,827,295.48	2,664,179.38	163,116.10	2,686,745	16.47

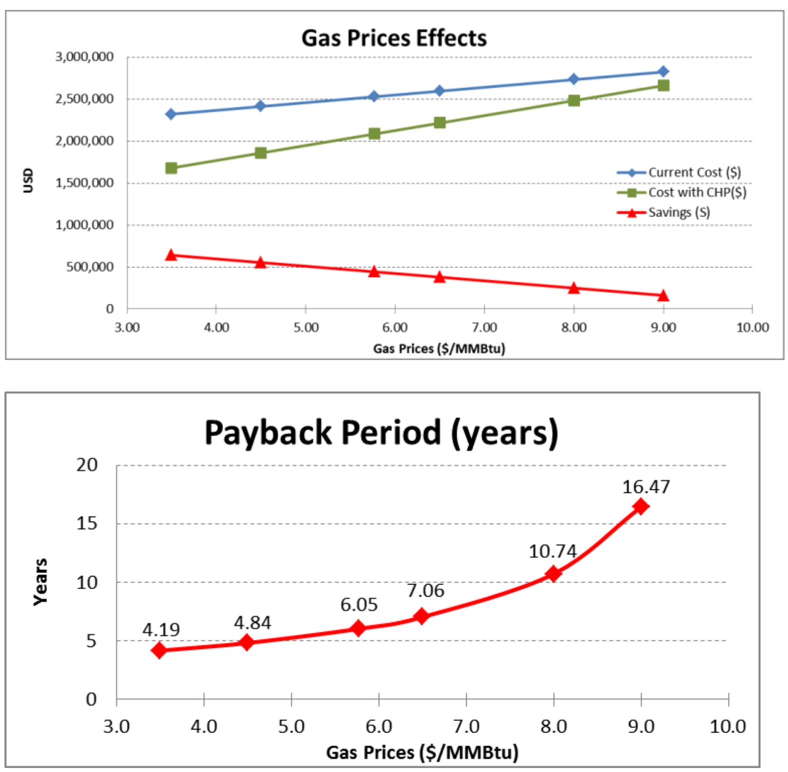


Figure F.2: Gas Prices Effects on Cost, Savings and Payback Period

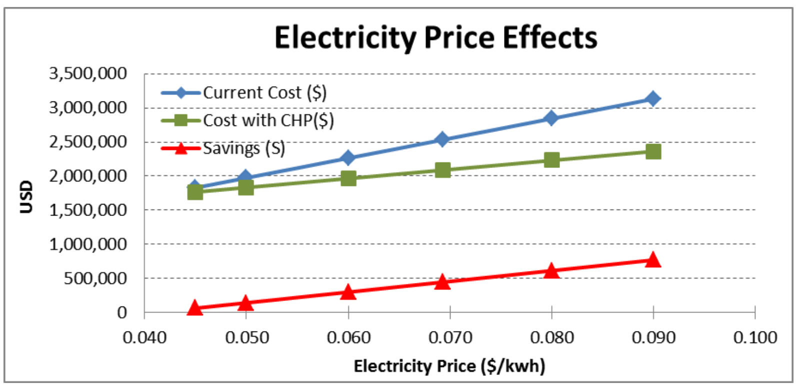
As shown, an increase of natural gas prices will reduce savings (due to the reduction of the spark spread), and exponential increase of the payback period.

Electricity price variation:

The result of electricity prices fluctuation can be seen in Table F.7 and Figure F.3:

Table F.7: Sensitivity Analysis with electricity price variation

Electricity Cost ($/kWh)	Gas Price ($/MMBtu)	Current Cost ($)	Cost with CHP($)	Savings ($)	Implementation Cost ($)	Payback Period (years)
0.045	5.77	1,829,111.10	1,766,140.96	62,970.13	2,686,745	42.67
0.050	5.77	1,973,720.20	1,832,297.11	141,423.09	2,686,745	19.00
0.060	5.77	2,262,938.41	1,964,609.41	298,329.00	2,686,745	9.01
0.069	5.77	2,531,804.07	2,087,610.77	444,193.30	2,686,745	6.05
0.080	5.77	2,841,374.83	2,229,234.01	612,140.82	2,686,745	4.39
0.090	5.77	3,130,593.04	2,361,546.31	769,046.73	2,686,745	3.49



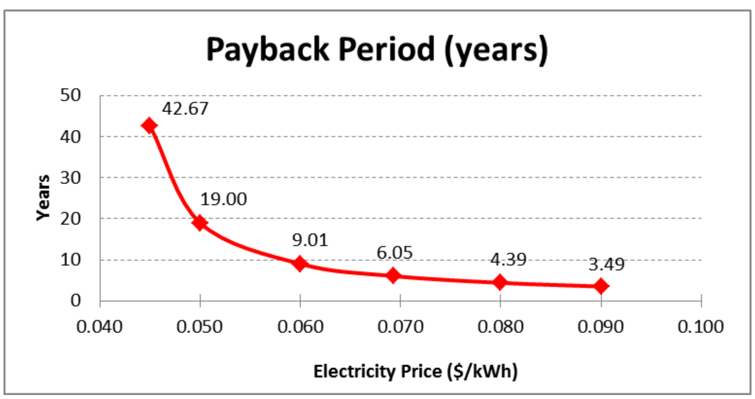


Figure F.3: Electricity Prices Effects on Cost, Savings and Payback Period

As it can be seen, an increase in electricity prices will increase savings (due to an increase of the spark spread), and exponential decrease of the payback period.

Implementation Cost variation:

The result of implementation cost fluctuation can be seen in Table F.8 and Figure F.4:

Table F.8: Sensitivity Analysis with CHP cost variation

Cost ($/kW)	Electricity Cost ($/kWh)	Gas Price ($/MMBtu)	Current Cost ($)	Cost with CHP($)	Savings ($)	Implementation Cost ($)	Payback Period (years)
1,000	0.069	5.77	2,531,804	2,087,611	444,193.30	1,791,163	4.03
1,200	0.069	5.77	2,531,804	2,087,611	444,193.30	2,149,396	4.84
1,500	0.069	5.77	2,531,804	2,087,611	444,193.30	2,686,745	6.05
1,700	0.069	5.77	2,531,804	2,087,611	444,193.30	3,044,978	6.86
2,000	0.069	5.77	2,531,804	2,087,611	444,193.30	3,582,327	8.06
2,300	0.069	5.77	2,531,804	2,087,611	444,193.30	4,119,676	9.27

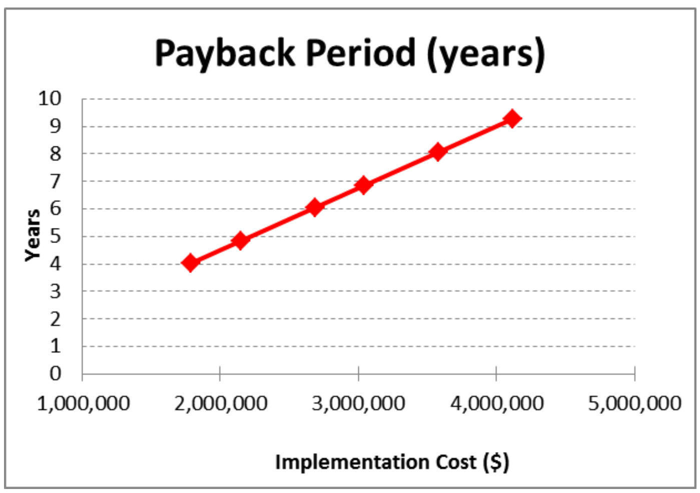


Figure F.4: Implementation cost effect in Payback Period

As it can be seen, an increase of implementation cost will increase the payback period.

An important note to make is that CHP projects are very sensitive to electricity and natural gas prices. As can be seen in the previous figures, the effect of both variables in the payback period is exponential. The variable that has the most effect is electricity price.

Scenarios analysis:

Five different scenarios were evaluated: Worst, Bad, Base, Good and Excellent. These scenarios use the data of Table F.9.

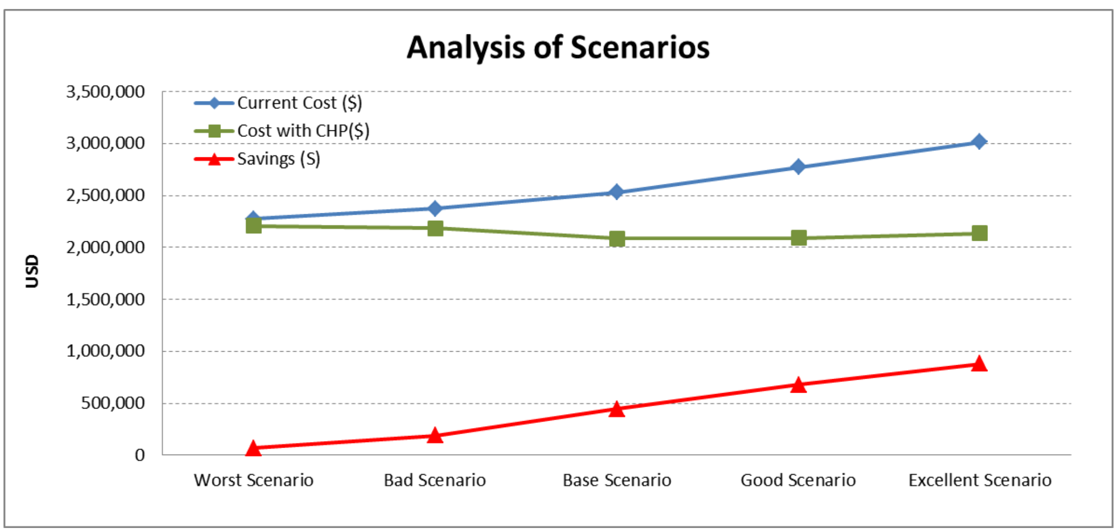
Table F.9: Data for scenario analysis

Scenarios	Gas Price ($/MMBtu)	Electricity Cost ($/kWh)	Implementation Cost ($/kW)
Worst Scenario	7.50	0.055	2,500
Bad Scenario	7.00	0.060	2,000
Base Scenario	5.77	0.069	1,500
Good Scenario	5.00	0.080	1,400
Excellent Scenario	4.50	0.090	1,200

The result of these scenarios can be seen in Table F.10 and Figure F.5

Table F.10: Scenario analysis results

Scenarios	Current Cost ($)	Cost with CHP($)	Savings (S)	Implementation Cost ($)	Payback Period (years)
Worst Scenario	2,276,633.96	2,207,340.38	69,293.57	4,477,908	64.62
Bad Scenario	2,375,514.14	2,184,269.37	191,244.77	3,582,327	18.73
Base Scenario	2,531,804.07	2,087,610.77	444,193.30	2,686,745	6.05
Good Scenario	2,771,034.88	2,091,985.33	679,049.55	2,507,629	3.69
Excellent Scenario	3,014,524.17	2,135,070.47	879,453.70	2,149,396	2.44



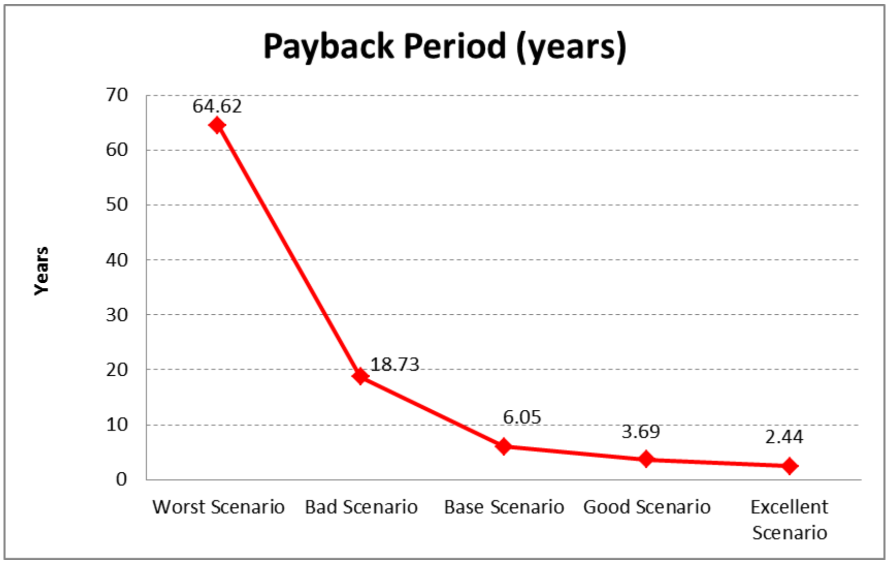


Figure F.5: Scenario analysis results

As it can be seen, depending on the variable fluctuation, this assessment recommendation can generate a savings from more than $69,000 to $880,000, and a payback period from 2.44 years to 64.62 years. Again, this significant difference is due the exponential effects of electricity and natural gas prices.

Appendix G

This appendix presents an example of how to use a weighted scoring model (WSM) and priority matrix. It will assume that the payback period obtained in the preliminary analysis was 2.85 years.

In order to calculate the score of implementation difficulty using WMS, the following procedure must be followed:

1. It is necessary to establish the relative importance of each criterion to the facility; this can be done by giving them a score in a 10 points scale and obtained weighted percentage of each value (A %). These values are subjective and are an expression of what industry thinks is important. This can be seen in Table G.1:

Table G.1: Weighted Score Method

	Weighted Score Method			
Selection Criteria	**Criteria weighting (10 point scale)**	**Criteria Weighting (A) %**	**Score (B)**	**Weighted Score (A*B)**
Regulation Process	10	33.33%	75	25.00
Permits Process	5	16.67%	25	4.17
Access to Funding	5	16.67%	25	4.17
Utility Support	10	33.33%	25	8.33
Total Weighting	30	100%	**TWS**	41.67

2. Scores are awarded (B) for each criterion according to a predetermined scale made by the industry. An example of this type of scale can be seen in Table G.2:

Table G.2: Criteria

	Criteria			
Score	Regulation Process	Permits Process	Access to Funding	Utility Support
100	Extremely Complex	Extremely Complex	No Funding	Very Negative
75	Complex	Complex	Difficult to find	Negative
50	Normal	Normal	Neutral	Neutral
25	Low Complexity	Low Complexity	Easy to find	Positive
0	Not Complex at All	Not Complex at All	Funding Available	Very Positive

3. Calculation of each weighted score (A x B) and the total weighted score (TWS) is obtained. In our example is 41. 67.

Now, we are ready to use the Priority Matrix, with the value of 41.67 of implementation difficulty and 2.85 years of payback period. The result can be seen in Figure G.1

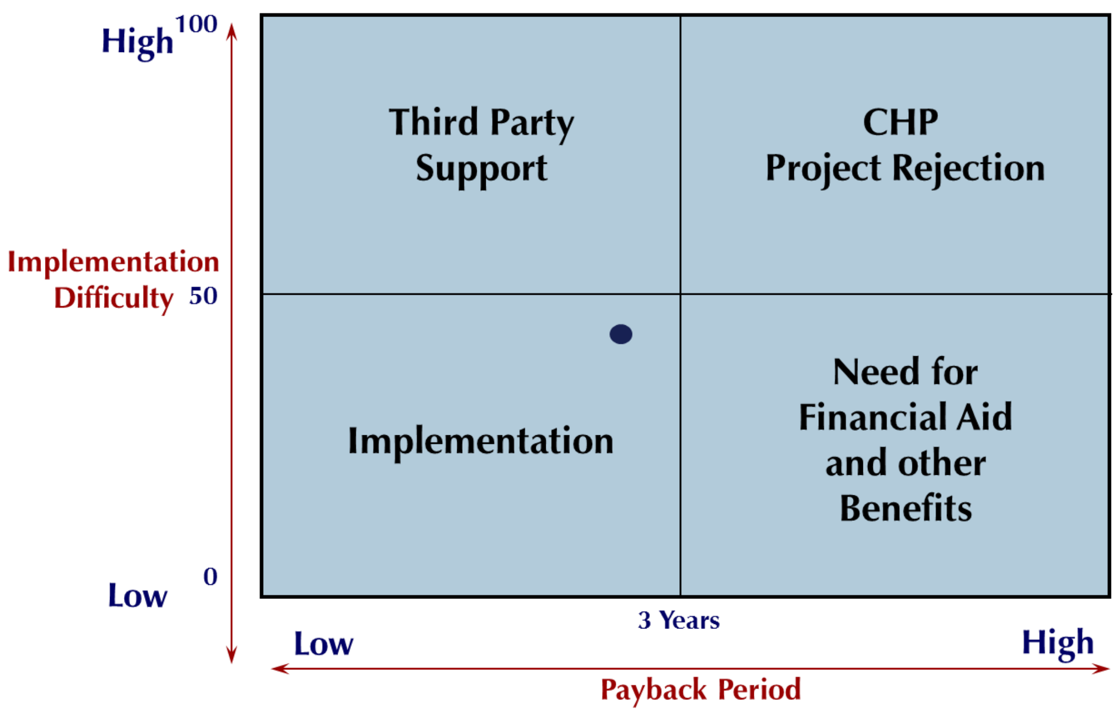


Figure G.1: Priority Matrix

In this example, the result is to move forward the project to the next stage of the implementation process.

Vita

The author, Jorge F. Abad was born in Guayaquil, Ecuador. He holds a Bachelor's degree in Mechanical Engineer from Escuela Superior Politécnica del Litoral (ESPOL), Ecuador in 1995, a Master of Science in Engineering and Management of Manufacturing Systems from Cranfield University, United Kingdom in 1997 and a Master of Science in Business Economics from The University of Manchester, United Kingdom in 1998. He pursued his Ph.D. in Industrial Engineering with a concentration in Manufacturing, Production, and Service Systems at the College of Engineering at the University of Missouri.

He has extensive work experience as consultant and manager in diverse types of industries such as Eternit Ecuatoriana, Continental General Tire, PriceWaterhouseCoopers, and Repsol-YPF. He had more than 15 years as a faculty member at ESPOL and was Associate Dean at the Facultad de Ingeniería Mecánica y Ciencias de la Producción (FIMCP) - ESPOL. He has received scholarships from Fundacyt, DAAD, KOICA, Fulbright and Senescyt for professional courses and his MSc and Ph.D. studies. He received Best FIMCP Professor award in 2008 and 2010, and ESPOL's Educational Merit award in 2000, 2006 to 2010. He is a certified internal energy auditor, he was the Lead Engineer at the Missouri Industrial Center (MoIAC) and performed more than 30 industrial energy audits in Missouri and surrounding states.

His research topics include transportation cost models, outsourcings, inventory policies, warehousing designs, distribution and logistics models, production planning and lean manufacturing. His current research focuses on Energy Efficiency (EE) initiatives, EE barriers, EE evaluations and implementations models, especially Combined Heat and Power applications.