Barriers to the Diffusion of Combined Heat and Power (CHP) Technology in Canada

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Abstract

Combined heat and power (CHP) production technology, also known as cogeneration, can yield tremendous efficiency gains compared to the independent production of each. These efficiency gains result not only in fuel savings, but greenhouse gas (GHG) emission reductions as well. CHP makes up over 30% of electricity generation in Denmark, Finland, and the Netherlands, but in Canada it accounts for only 7%. This paper explains this discrepancy as the result of the barriers to CHP present in Canada from market (infrastructure and price), regulation (level of access to the electricity grid), information and incentives, and environmental policy.

Acknowledgements

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1. INTRODUCTION

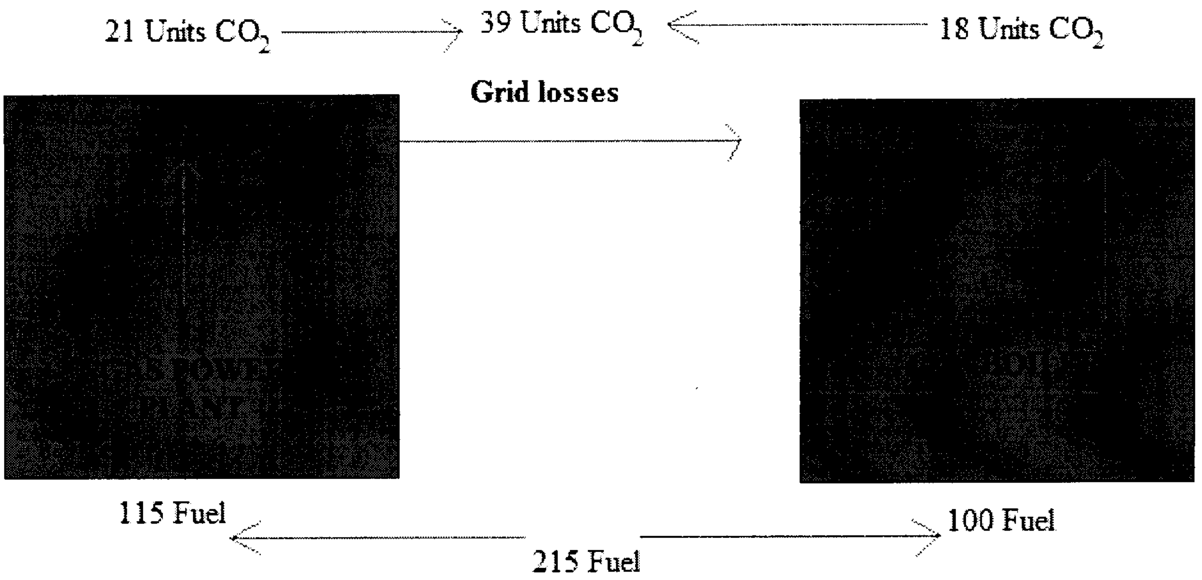
Concern about climate change has led policy makers to ask: what are the most effective means of reducing greenhouse gas (GHG) emissions? In this vein, McKinsey (2007) examines more than 250 ways to prevent or reduce GHG emissions in the United States. The report concludes that US emissions of CO_2 could be reduced by 30-45% by 2030 by expanding the use of existing high potential technologies. Improving efficiency in the production of electricity provides the biggest opportunity for GHG reduction, as conventional generation can be very wasteful. In the industrial sector, the report considers 75 options and cites the merits of combined heat and power (CHP) for reducing GHG emissions. Specifically, CHP could provide 53% of all the "negative cost" emission reductions by 2030 in industry (McKinsey, 2007, p70). This rather remarkable result, that CHP could actually reduce emissions and produce a financial gain, runs contrary to the conventional intuition that there is a cost (and often a substantial one) to reducing emissions.

Rosen (2008) defines CHP, or the equivalent term cogeneration, as the "simultaneous production of two energy forms (electricity, and heat in the form of steam and/or hot water) from one energy source (normally a fossil fuel)". He explains that "cogeneration systems are in use throughout the world (e.g. over 4000 are listed by the Association of Energy Engineers) and the basic technology is well understood and proven".

Figure 1 (next page) depicts the energy flows for separate heat and electricity generation and for CHP generation. By utilizing the heat that would otherwise be wasted, the total efficiency of the CHP system is 76.5%, whereas the separate system has a combined efficiency of 60%. In regards to GHGs, in the example in Figure 1, the separate system produces 39 units of CO_2, while the CHP system produces only 31 units of CO_2.

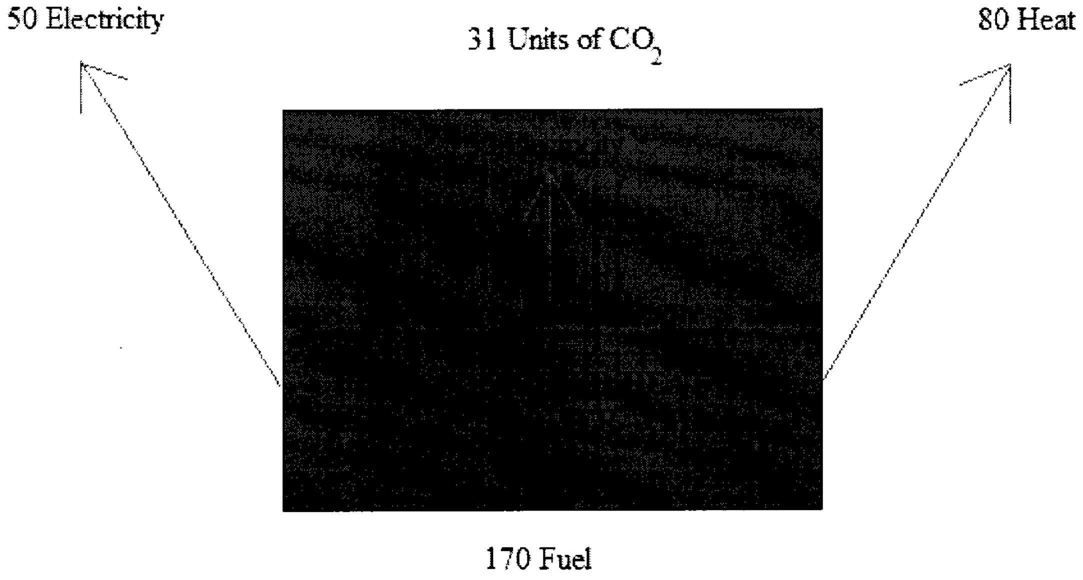
Figure 1: Energy Flows for separate and CHP generation

Separate Production of Heat and Electricity (Natural Gas)



60% EFFICIENT

Combined Heat and Power (Natural Gas)



76.5% EFFICIENT

Source: Kerr, 2008. P10. Combined Heat and Power: Options for Policy Makers

Canada's industrial and energy demands make it well-suited to take advantage of the energy efficiency gains offered by CHP. For instance, 31% of Canada's energy demand in 2007 was for the production of heat for industrial purposes (STATCAN, 2007). In addition, one-fifth of the electricity produced in Canada is produced by the combustion of fossil fuel energy in steam-based electricity-only power plants. In such plants, most of the energy produced by the combustion is waste heat: it is dissipated into the air or pools of cooling water, and is not exploited. These heat-only or electricity-only production plants result in a large amount of wasted energy. In contrast, CHP facilities use a range of technologies to greatly improve energy efficiency by producing at least two products from the same fuel source in the same process. Environment Canada (2006) estimates the benefits of CHP: 30-40% fuel savings and an equivalent reduction in emissions, reductions in chlorofluorocarbons (CFCs) from air conditioning units, and reductions in electricity transmission and distribution (T&D) losses because CHP facilities are usually situated close to where their products are utilized.

These benefits have led to the inclusion of CHP in many national and regional GHG emission reduction strategies. Yet while some countries have been successful in achieving a high share of these technologies, many have not (IEA, 2008, p4). For instance, as of 2008, CHP accounts for over 30% of national electricity generation in Denmark, Finland, and the Netherlands, while in Canada it accounts for only 7% (Nyober and Groves, 2008, p 1). As will be shown, this relatively limited degree of diffusion of CHP in Canada is a result of four broad barriers to the technology present in Canada, relating to market conditions, regulation, information and incentives, and environmental policy. Barriers concerning market conditions arise because the price of electricity often does not reflect the true cost of generation. Regulatory barriers concern the level of access to the electric grid for independent power producers. There are information and incentive barriers to those considering implementing a CHP system because of a lack of information, investment hurdles, and uncertainty. The primary environmental policy barrier is how to allocate energy and emissions between the two products of CHP. A constructive feature of examining CHP in the context of these barriers is that it will identify where research has been undertaken, and where it is needed.

This paper is structured as follows: Section 2 provides a background, explaining the technology of CHP, its global status, and the Canadian state of play. Section 3 analyzes the economic literature according to the four barriers to CHP in Canada. Section 4 concludes and highlights the most promising extensions of the models detailed in Section 3.

2. BACKGROUND

Heat and electricity make up a significant share of overall energy demand in developed countries, for example 60% in the EU in 2005 (IEA, 2008, p6). By increasing supply efficiency in the heat and electricity sectors simultaneously, substantial gains can be made relatively quickly. In traditional fossil fuelled electric power approximately two thirds of the primary energy is lost as "waste" heat. Furthermore, transmission and distribution (T&D) losses of electricity from large central power stations to the end customer contribute additional losses of around 9%. However, technologies like CHP can be used to exploit the potential of waste heat to at least partially meet the heat demands of industries, buildings and cities, and in the process reduce losses associated with T&D (IEA, 2008, p6).

The process of recovering and using the heat output from electricity production for other heating or industrial purposes allows CHP systems to typically convert 75-80% of the original fuel source into useful energy. A majority of modern CHP plants achieve efficiencies of at least 90% (IEA, 2008, p10). Theoretically, almost any fuel can be used for a CHP system, although for modern systems natural gas is the most common. In terms of electrical output, CHP systems can range in size from very small, at 1kWe (kilowatt electric), to massive, at over 500 MWe (megawatt electric).

Since CHP plants are usually designed to meet the heat demand of the operation, any excess electricity can be sold back to the grid or supplied directly to another customer via a distribution system, if one exists. If the operation requires additional electricity, it can be supplied by access to the grid, if present, and if additional heat is required it is typically supplied by stand-by boilers or boost heaters.

For the most part, CHP applications can be classified into three categories: industrial, commercial/institutional, and district heating and cooling (DHC). Industries such as food processing, pulp and paper, chemicals, metals, and oil refining are very energy intensive and thus well-suited for CHP (IEA, 2008, p11). These industries account for more than 80% of the total global electric CHP capacity. Plants in these industries generally have high heat demands independent of daily, seasonal, or weather-related variations. The viability of CHP for an operation in this sector is dependent on the level of heat and electricity demand and the arrangements in place with the electric grid, specifically, those concerning the sale of surplus power and the purchase of back-up power. Access to the electric grid is important because it provides back-up power for CHP plants during maintenance or down times. Also, the availability and price of natural gas, the predominant fuel for most new industrial CHP systems, will be an important determinant in the level of future expansion of industrial CHP.

The implementation of CHP systems in commercial and apartment buildings (often in conjunction with DHC) has been on the rise in the past decade (IEA, 2008, p13). This growth can be mostly attributed to technological advancements and the decreased costs of smaller scale and often pre-packaged units. Examples of commercial and institutional CHP include hotels, offices, and hospitals. These are well suited for CHP because they usually have high energy costs as a percentage of total operating costs, and they have balanced and constant electricity and heat demands. Furthermore, residential "micro" CHP systems are on the verge of being developed and sold at the household level, which would open the doors for a mass market CHP product (IEA, 2008, p14).

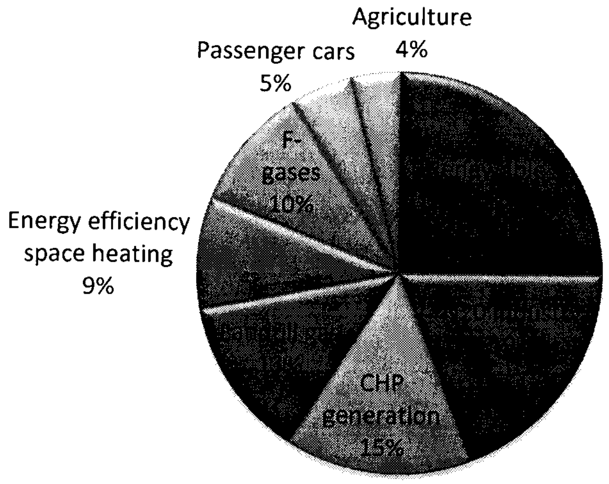
District heating is a system designed to meet low and medium temperature heat demands such as space (a room or house) and water heating by re-using upgraded waste heat from CHP plants, industrial processes, and waste incineration (IEA, 2008, p15). DHC systems, when combined with CHP, are very energy efficient and offer important opportunities for efficiency gains in the heat and electricity sectors. After being heated, the water is transported by a well-insulated network of pipes to the consumer. In this way, district heating can be used to meet the heat demands of residential, public, and commercial buildings in addition to low temperature industrial heat applications.

District cooling operates on the same principles as district heating to provide cooling to residential and commercial buildings. In the winter, district cooling often capitalizes on natural cooling from deep water resources such as bodies of water, and in the summer the process involves using the waste heat from CHP systems to power absorption refrigerators.

Population density will be an important factor in the viability of DHC, as DHC systems depend on condensed demand for space heating and cooling to minimize the heat's travel distance, because installing the heat distribution systems is expensive (IEA, 2008, p15).

In Europe, it has been estimated that CHP was responsible for 15% of the total reduction of GHG emissions (57 megatons) between 1990 and 2005, making it one of the primary methods EU countries have utilized to meet their emission reduction goals (see Figure 2 below for the complete set).

Figure 2: EU GHG emissions reductions shares between 1990-2005



Source: IEA,2008, Combined Heat and Power, p 8

Interestingly, despite increased awareness in Europe, in the US and Japan the share of CHP in the electricity production sector has remained stagnant at around 9% and in Canada at approximately 7% (IEA, 2008, page 7). Remarkably, in Denmark, Finland, Latvia, the Netherlands, and Russia, CHP now accounts for 30-50% of those countries' total power generation (IEA, 2008, page 7). Figure 3 below illustrates the share of CHP in total electricity generation in the G8+5 countries.

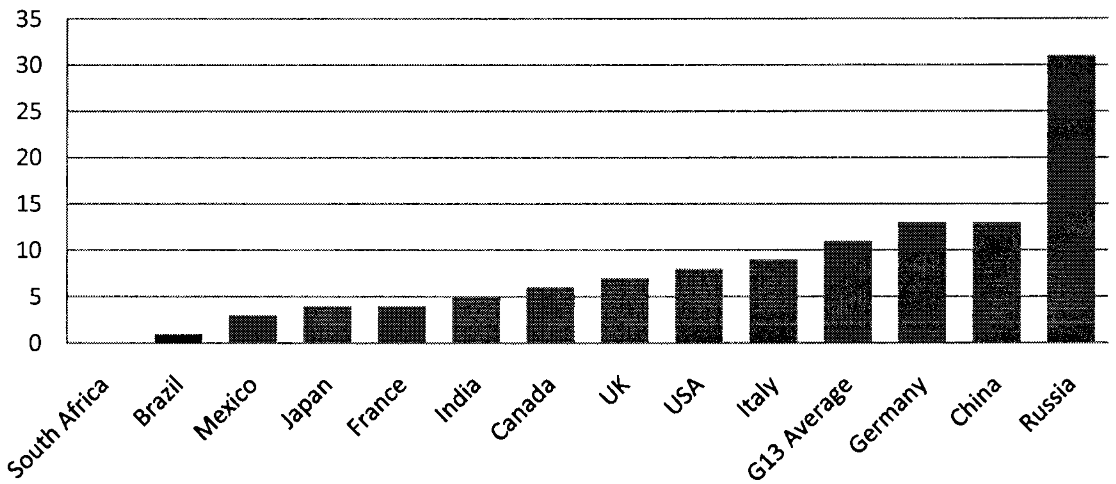


Figure 3: CHP Share of Total Electricity Generation in G8+5 Countries (%)

Source: IEA 2008 - Global CHP/DHC Data – Current Baseline – www.iea.org/g8/chp/global_data.asp

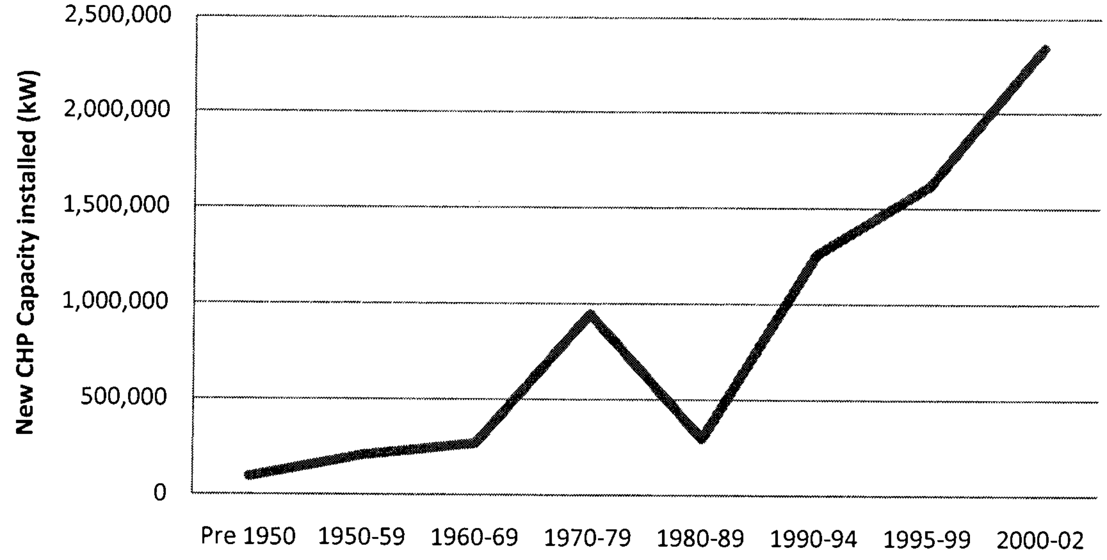
In part, these differences can be explained by national circumstances. In Germany the share of CHP, specifically in district heating and industrial CHP, has increased in response to incentives offered by the government (such as feed in tariffs and guaranteed price paid for renewable generated electricity) (IEA, 2008, p19). In contrast, in Brazil, where the relative residential and commercial heating demands are much lower, the government has based its electricity system on the development of large-scale hydro generation. Russia's relatively high share of CHP is a consequence of its long tradition of DHC networks linked through power plants (IEA, 2008, p19). Differences in measurement- and qualification of CHP- may also be a factor.

CHP facilities in Canada typically have impressive overall efficiencies of between 65% and 85% (Nyboer & Groves, 2008, p1). When evaluated based on heat capacity the pulp and paper sector accounts for 31%, of the total Canadian CHP, while the chemical and oil and gas extraction sectors account for 22% and 20%, respectively.

In terms of the dispersal across Canada, CHP is generally concentrated in areas with high electricity prices and reliable and straightforward access to the electricity grid. Full retail access to the electricity grid in Alberta and to a lesser degree in Ontario, has triggered the development of large CHP projects by utility companies. Of Canada's 7.2GWe of CHP capacity in 2007, Alberta has the largest share with 2.6GWe, and Ontario the next largest with 2.0GWe (Nyboer & Groves, 2008 p16). Together these two provinces account for 64% of total Canadian capacity.

Figure 4 below reveals that there have been two periods of major CHP development in Canada (Strickland & Nyboer, 2002 p13). The first corresponds to a major rise in energy prices in Canada and around the world in the 1970s. It is reasonable to suggest that CHP was implemented in response to this rise in energy prices and the perceived scarcity of energy resources. However, it is important to realize that three facilities installed in the 1970s (in the petroleum and chemicals sectors) account for 64% of the installed capacity during this period. The second period of growth began in 1990 and continued until very recently, with growth beginning to decline in approximately 2006.

Figure 4: New CHP Capacity Installed by Year



Source: Strickland & Nyboer, Cogeneration Potential in Canada, 2002. P 15

Three dynamics stimulated the latest period of growth in CHP (Strickland & Nyboer, 2002 p14). First, electric utilities across Canada responded to public protest over large-scale energy projects by encouraging the development of independent power projects (IPPS) to fulfill some of their resource requirements. Second, smaller CHP systems are becoming more cost-effective. And third, the advent of full retail access to the electricity grid in Alberta. Since 1995 private producers have added almost 2.5GWe of CHP capacity in Alberta.

Yet certain factors have led to a significant decline in CHP installation since 2006. First and foremost is the elevated and unpredictable price of natural gas in many Canadian provinces. These elevated prices reduce the "spark spread", which is the difference between the price of natural gas and the price of electricity. This reduction in the spark spread reduces the viability of CHP, because natural gas is an input price and a low price for electricity reduces the incentive to produce your own. Second is the artificially low price of electricity in Ontario. A number of CHP systems in Ontario, including a large plant in Sarnia, have been closed because they were no longer profitable (Nyboer & Groves, 2008, p15).

CHP systems built in Canada before and after 1990 show a marked difference. While natural gas was used by 58% of CHP systems before 1990, it was used by 90% after. Systems built before 1990 were primarily medium sized (between 10-50Mwe), but since then most are less than 10Mwe. However, it is worth noting that the number of CHP systems above 50Mwe has increased by a factor of three (Strickland & Nyboer, 2002, p14).

There are several universities and hospitals in Ontario and Alberta that have installed small-scale CHP together with DHC systems. Since 1993, Ottawa, Cornwall, Sudbury, London, Markham, and Windsor have built CHP systems that are able to produce 3-5MWe. Remote Fort

MacPherson, in the Northwest Territories, has a diesel-fuelled 1.8 MWe CHP facility. The Ottawa Health Sciences Center hospital is provided DHC by a 68MWe plant that was built by TransAlta Energy in 1992. The federal government has three DHC buildings within National Defence and the National Research Council (Klein, 2003, p3).

3. BARRIERS TO CHP ADOPTION

The "adoption and diffusion of innovative technologies has attracted the attention of economists at least since the seminal studies by Griliches (1957) on hybrid corn and Mansfield (1961) on process technologies in the manufacturing sector, respectively" (Wickhart & Madlener, 2004, p2). Mansfield sought to determine the speed at which firms imitated each other, and thus innovative technology passed along. This work was built on that of Griliches, whose objective was to explain the discrepancy in the use of hybrid corn seed in the US over time. Joskow and Jones (1983) were the first to establish a clear model of CHP adoption. They modelled the decision making process of a cost minimizing industrial firm considering implementing a CHP system.

Given the substantial benefits of CHP discussed thus far, it is crucial to discuss why CHP is not more widespread globally, and in Canada specifically. The IEA argues that while CHP projects appear favourable "on paper", in practice the adoption of CHP is often hindered by significant barriers (IEA, 2008, p27). However, some countries have been successful in increasing the use of CHP and DHC, and the IEA credits their success to "investing in a comprehensive set of policies designed to overcome market barriers and allow them to compete equally in the marketplace" (IEA, 2008, p27).

3.1 Market (Infrastructure and Price) Barriers

North American infrastructure has not facilitated the development of CHP. Power generation consists primarily of large centralized plants located far from where that power will be used. In terms of heating, the IEA contends that there has been a general "lack of integrated urban heating/cooling supply planning" (IEA, 2008, p27) in countries with low rates of CHP.

This paper presents only a brief analysis of the role of infrastructure in CHP adoption. This is an area on which limited work exists and further research would be useful.

There are four significant market price barriers that support conventional power generation over CHP (Strickland & Nyboer, 2002 p32). First, electricity prices are very low in many regions of Canada, and are typically based on the average cost of generation, not the marginal cost. For example, in British Columbia electricity prices are 3.36cents/kWh on average while the marginal cost of new electricity supply is 4.05 cents/kWh, 21% higher than the average price. In Ontario, government subsidies and debt relief for the nuclear industry have led to unnaturally low prices for nuclear electricity.

Second, the difference between the cost of back-up power and the price paid for electricity sold to the grid inhibits the fiscal feasibility of CHP projects. In some regions, the cost of connecting and receiving back-up power from the grid is very high compared to what could be earned by selling electricity to the grid.

Third, transmission tariffs are often based on the average cost of transmitting electricity, not the marginal cost. The rate is the same regardless of how far the electricity must travel to reach the customer. This eliminates one of the key advantages of CHP, which is producing electricity in proximity to the customer. This issue, known as "postage stamp" pricing is likely an important factor for CHP in Canada and further research would be prudent.

Finally electricity prices do not take into account the negative externalities associated with its production in terms of the pollution it creates. If they did, technologies such as CHP would be more competitive.

Kwun and Baughman (1991) explore the fact that "many cogenerators are also large industrial customers of the electric utilities. When a large industrial customer decides to cogenerate some or all of its electricity needs, it can have a significant effect on the production patterns and investment needs of the electric utility" (Kwun & Baughman, 1991, p798). Conversely, this effect of the CHP system on the utility will determine the price the utility will pay the CHP systems for its surplus electricity (buy back rates). And this price in turn will determine the viability of the CHP project itself and its optimal level of electricity production. Kwun and Baughman therefore offer a distinct study modelling the joint optimal planning of the electric utility and CHP system, and specifically take into account the interactions between them.

Kwon and Yun (2003) study the plant-specific data of five CHP plants being operated in the central Seoul metropolitan area. This is an interesting study of the role of infrastructure and the potential rewards of the joint planning of CHP and district heating (DH), which is lacking in North America. All five of the CHP plants in Seoul are operated by the Korea Electric Power Corporation (KEPCO). The Korea District Heating Corporation purchases the heat from KEPCO and provides it to consumers through its own heat transmitting facilities. Introduced to Korea in 1987, district heating through CHP or heat-only production supplied 6.3% of households in 1999. CHP also accounts for 4.3% of total electric power. The authors determine that the cost reduction by the joint production of heat and power by CHP is 13.1% of the total costs of heat-only and electricity-only production.

Rose and McDonald (1991) develop a model to explain the significance of several economic and engineering variables that US pulp and paper industrial firms include in their decision making process when deciding whether to implement a CHP system. Rose and McDonald empirically test their model and conclude that CHP "is determined by the derived demand for electricity, price of purchased electricity, and marginal cost of self-generation" (Rose & McDonald, 1991, p1). Surprisingly, their evidence implies that buyback rates (what the utility pays for surplus electricity) have no impact on the amount of electricity the CHP system demands or supplies. Therefore Rose and McDonald advise that policy be geared to the price of electricity and "factors that affect the plant's marginal cost of producing electricity" in order to encourage CHP adoption (Rose & McDonald, 1991, p1). Pulp and paper facilities are one of the largest utilisers of CHP in Canada, and so to apply Rose and McDonald's model and test their conclusions on Canadian data (if available) would be a natural and valuable extension.

Bonilla (2007) uses cross-sectional time-series in the Dutch and British manufacturing sectors to examine CHP adoption by industry in the 1991 to 2001 period. He focuses on the spark spread and reveals that fuel cost savings is the most important determinant of CHP adoption.

There are many opportunities for possible extensions to Bonilla's model. He examined data from the period 1991 to 2001, but was only able to develop conclusive results for the period 1991 to 1996. This is likely because the specification of the model does not allow it to adequately represent the condition of declining spark spread levels. During the 1991 to 1996 period the spark spread rose by (compounded annual growth rates) 1.9% in the UK and 4.3% in the Netherlands. The rate of growth of the spark spread turns negative in the period 1996 to 2001, -5.4% for the UK and -9.6% for the Netherlands. To amend the model to be able to estimate CHP adoption in the conditions of declining spark spread levels of beyond 1996 would help to justify his approach. In addition, as Bonilla suggests, this model could be tested to clarify the diffusion of other technologies such as diesel engines, gas turbines, combined-cycle plants and fuel cells (Bonilla, 2007, p68).

To apply the model to Canadian data would be a significant contribution as well. This data may be accessible from the basic CHP database being developed by the Canadian Industrial Energy End-Use Data and Analysis Centre (CIEEDAC), which is managed by the Energy and Materials Research Group (EMRG) at Simon Fraser University, headed by Mark Jaccard.

3.2 Regulatory Barriers

A key regulatory barrier to the implementation and successful operation of CHP in Canada is the lack of access to the electricity grid for the sale of surplus electricity in many regions (Strickland & Nyboer, 2002 p33). In response to the government of Alberta providing open access to its electricity grid and making efforts to provide easier access to the market, over 1.2GWe of CHP capacity was installed in the province between 2000 and 2002, more than in any other region. While there may be other factors that contributed to the dissemination of CHP in Alberta, such as higher electricity prices and reliability issues, improved access to the grid and the market are generally considered primary drivers for CHP growth in that province (Strickland & Nyboer, 2002, p33).

Access to the grid to sell excess electricity and obtain back-up electric power is a crucial determinant of CHP viability in Canada. The provinces and territories are at various levels of restructuring. Alberta and Ontario offer both wholesale and retail access, and British Columbia, Québec, and New Brunswick have wholesale access and limited retail access to electricity. Manitoba, Saskatchewan, and the Yukon allow wholesale access. Nova Scotia, Newfoundland, the Northwest Territories, Prince Edward Island, and Nunavut offer neither wholesale nor retail access to the grid (National Energy Board, 2009).

British Columbia, Ontario, and Nova Scotia have net-metering to a limited degree. Net metering measures the difference between the electricity provided versus consumed from the grid with a single meter. It increases the viability of small scale CHP because in some cases the prices to buy versus sell are very different (National Energy Board, 2009 & Strickland & Nyboer 2002).

Fox-Penner (1990) has examined the role of prices (of electricity and fuel) and regulation, at the state level in the US, on the amount of CHP implementation (by state). The Public Utilities Regulation Policies Act (PURPA), passed in 1978, gave qualifying CHP facilities (those who met certain size and efficiency criteria) a federal right to produce electricity and sell all surplus power to their local public utility. The utility was required to purchase this power at a price equal to its own marginal cost of production. This is a valuable study into the role of regulation in CHP development, as the earliest economic work examining CHP adoption by Joskow and Jones (1983) is in the absence of PURPA.

Fox-Penner builds and tests a model that predicts the amount of CHP in a state depending on regulations and prices. He sets out to explore these specific questions:

- Are regulations or prices more important in determining CHP?
- Do differences in state regulations have a significant effect on CHP?
- If regulation has an effect, does it function more as a fixed barrier to CHP or as an ad valorem tax on the amount of CHP?
- Are state specific regulations successful in their goals?

Fox-Penner develops two dependent variables for participation and magnitude. Participation is the individual firm's decision of whether or not to implement a CHP system. Magnitude is the aggregation of this decision across the state level to estimate state wide CHP adoption. He uses data for 49 states (Nebraska excluded) and builds his model with the following independent variables: buyback rates, electric rates, industrial gas price, wages, population, value added (of CHP in the state), and pre-PURPA CHP.

He includes 11 dummy variables accounting for differences in regulation within PURPA. Mostly these differences are the rules in place regarding the determination of an agreement between the state utility and the CHP facility. An example is that PURPA mandates all state utilities to make 'standard offers', meaning agreements to buy and sell electricity with the willing and qualifying CHP facility, according to a specific set of terms. This standard offer takes the form of a tariff or a contract, and this is included as a dummy variable. For the most part, the PURPA rules are meant to reduce the costs of uncertainty and bargaining for both the CHP and the utility.

The results of Fox-Penner's analysis are that state population and several regulatory variables are the most significant predictors of CHP. Prices contribute no explanatory power, with the limited exception of gas prices. He suggests that differences in regulation act as a fixed barrier (rather than an ad valorem tax), creating cost differentials between states.

The regulatory variables that appear the most important are those that directly concern the agreement process between utilities and the CHP facility. These include whether the utility must make standard offer contract paperwork available to a CHP facility upon request, and offer standard offer contracts to all CHP facilities regardless of size.

While the author predicted that both of these variables would increase the probability of CHP in the model, the results indicate they actually decrease it. This suggests that regulations that create conditions and boundaries in negotiations between utilities and qualifying CHP facilities appear to deter CHP adoption rather than encourage it. In response the author suggests that CHP regulation should provide the maximum amount of flexibility for the agreement process between the CHP facility and the utility.

Dismukes and Kleit (1999) explore the effects of electricity market restructuring in Louisiana (US) following the implementation of PURPA in 1978. Interestingly, they examine the difference between those CHP operators who consume all of the power they produce and those who sell surplus to the electric grid. Their model supports the theory that increases in electricity prices leads to increasing CHP levels, particularly for those who sell to the grid. They also note that the ability to switch fuels (adding flexibility as prices of inputs and outputs fluctuate) increases CHP, as does a decrease in the price of natural gas (the primary fuel used by modern CHP systems).

Electricity restructuring in Canada and changes in regulation, especially in Alberta and Ontario, provide an opportunity to utilize the models of Fox-Penner and Dismukes and Kleit, and to test whether their conclusions hold in the Canadian context.

3.3 Information and Incentive Barriers

Companies considering implementing CHP face barriers such as a lack of information and skilled personnel, investment hurdles, and uncertainty.

There are incentives to encourage CHP in Canada, including accelerated capital cost allowances (ACCA) and subsidies. The 2005 Federal Budget established that new ACCA rates would apply only to investments in "green" technology, and contained two important incentives for CHP. Firstly, it created Class 43.2, which further accelerated the ACCA rate from 30% to 50% for renewable energy sources (e.g. wind) and for making efficient use of fossil fuels (e.g. CHP). Second, it expanded Class 43.1 (which gives an ACCA rate of 30%) to include equipment for district energy systems that rely on an efficient CHP system. The 2006 Budget further expanded Class 43.1 and Class 43.2 assets to include CHP systems that use a type of biomass used in the pulp and paper industry, which is commonly referred to as "black liquor" (Starky, 2006).

However, Jaccard et al. (2006) question the effectiveness of incentives in encouraging CHP, and highlight some of the problems with measuring the effectiveness of incentives in general. At the time of its introduction; the federal government estimated that the ACCA would offset 9Mt of GHG emissions between 2008 and 2012. However, in order to be accredited to the ACCA, the newly built CHP facilities resulting in the 9Mt of reduced emissions would need to be in addition to what would have been installed without the policy. Jaccard et al. argue that since CHP has increased steadily, albeit modestly, for the last two decades (recall Figure 8 in section 3.2) in the absence of the new capital policy, CHP would likely continue to increase regardless of whether the policy was implemented (Jaccard et al, 2006, p19). Jaccard et al. also point out that a survey of managers of CHP systems in Canada conducted by CIEEDAC reveals that only approximately one-third of CHP facilities are utilizing the ACCA because of restrictions on the allowance, or they do not know it exists. This reflects an information barrier.

Wickart and Madlener (2007) examine the effects of uncertainty in the decision making process of an industrial firm in either a permanent CHP facility or in heat-only production supplemented by the electricity grid. Their modeling is based on real options theory, which is focused on investment in an uncertain environment, and an intrinsic assumption of the theory is that the investment can be delayed. A feature of their model is that it "explicitly accounts for the value of deferring an investment project that derives from the opportunity to take a better informed decision in the future rather than to invest immediately" (Wickart and Madlener, 2007, p936). This approach allows their model to predict not only the optimal technology (CHP or heat-only boiler), but also the optimal timing of that investment. The authors focus on uncertainty in fuel (input price) and electricity (can be input and output price in CHP). They conclude that as unpredictability increases in these prices, so does the value of delaying the CHP project.

Maribu and Fleten (2008) take a rather counter-intuitive approach, but utilize the conclusion of Wickart and Madlener (2007). They argue that since liberalized markets can lead to more unpredictable energy prices, this uncertainty may inhibit CHP. Typically, it is considered that electricity restructuring increases competition and access to the electric grid, and thereby increases the viability of CHP. Nonetheless, Maribu and Fleten take a distinct focus on a commercial office building in Boston (US) and analyze a prospective investment in four different sized CHP systems (60, 120, 180, 240kW). Next, they apply a Monte-Carlo simulation of future electricity and natural gas prices. For this specific case, their results indicate CHP is a sound investment in commercial buildings. The net present value (NPV) is positive for all sized systems, and the greatest NPV is for the 120kW system. The authors contend that the reason for this is that CHP yields precious flexibility by taking advantage of favourable conditions (high electricity prices, low natural gas prices), and avoiding non-favourable conditions by being able to buy electricity and natural gas from the market. Therefore unpredictability in prices may not be a hindrance to CHP (in contrast to Wickart and Madlener 2007), but it likely remains a deterrent in the planning and investment stage.

Rivers and Jaccard (2005) focus on technology choice in steam generation in industry. They use a choice experiment and their results are from a survey of 259 plant managers at industrial facilities in various capacities across Canada. Respondents were asked to state their preference between a standard efficiency boiler, high efficiency boiler, and a cogeneration system in four hypothetical situations. Each technology was categorized by its capital cost, operation and maintenance costs, fuel costs, and electricity produced (of which only CHP is able). The survey and analysis revealed that, costs being held equal, the technologies were preferred in the following order: high efficiency boilers, CHP, and then standard efficiency boilers.

With these ordered preferences in mind, the authors sought to determine the "responsiveness" of the respondents to different policy instruments, in order to find the best means to appropriately target CHP. They found that altering capital cost is a more powerful way to affect choices than altering annual costs (except changes to electricity). For instance, a $1,000,000 capital cost subsidy increases the new market share for cogeneration by 4.3%, while a $1,000,000 fuel cost subsidy only increases the new market share by 3.0%. Furthermore, the fuel cost subsidy would have to be paid every year while the capital cost subsidy would only be paid once. Also, electricity savings are the most powerful variable in the model, affecting the choice probability six times more than operating costs, and four times more than fuel cost, suggesting firms highly regard the ability to produce their own power (Jaccard and Rivers, 2005, p97).

The authors build on these results and attempt to draw a conclusion for the optimal CHP encouragement strategy. They test the effect of three hypothetical policies aimed at promoting CHP: a 20% capital cost subsidy; a $50/tonne CO_2 tax; and a CHP awareness program. The awareness program, which assumes that those in the group who are "not well informed" about CHP will behave like the "well informed" group after the awareness program, increases the new market share of CHP by 5%. The CO_2 tax increases the new market share of CHP by 6-10%. The capital cost subsidy has the largest impact, increasing new market share of CHP by 19-26%.

While the model is appealing, the authors acknowledge some limitations. First, from their results one cannot conclude that the capital cost subsidy is the optimal policy to encourage CHP adoption. For each policy they have focused on the benefits alone, and have not included the costs. As they mention, "free-rider rates on subsidy programs are often as high as 60-70%, which implies that although the subsidy policy we have modeled here is shown to be quite effective, it is also likely to be the highest cost policy to implement" (Rivers and Jaccard, 2005, p100). An extension of this model would be to evaluate the benefits and the costs of the policies together. Jaccard et al. (2003) provides details on the cost of different GHG reduction policies, and would be a logical starting place in this pursuit.

When Rivers and Jaccard (2005) account for uncertainty with a 95% confidence interval, the capital cost subsidy would increase market share by 12-36% over a thirty year period, challenging the robustness of their policy analysis results. This is related to problems in their survey analysis. These problems could be addressed, and provide a valuable extension, by applying their model to a larger data set, with an improved respondent rate, and with the respondents being more evenly distributed across sectors (rather than the high proportion of CHP prone sectors here).

There are other possibilities for extensions to the model as well. One could re-apply the model including more recent technology prices, as CHP has become increasingly more cost-effective. Also, the analysis of Rivers and Jaccard (2005) focus on steam generation in industry. Another area of the economy could be examined, in terms of the effect of different CHP encouragement policies, such as independent power producers in Alberta and Ontario.

3.4 Environmental Policy Barriers

As emission trading schemes (ETS) are being developed and put into effect worldwide, there has yet to be a consensus on how they should incorporate CHP. The main obstacle is how to allocate energy and emissions between the two products of CHP.

Strickland and Nyboer (2002) build on the work of Phylipsen et al. (1998) to provide methods to address this obstacle. The difficulty is that when the heat producer is different from the electricity consumer, emissions must be allocated to each product in some way, in order to ensure that each party is debited or credited with their share of the GHG emission produced by the CHP facility. They list eight means to allocate the input fuel of the CHP system to both the heat and power products. The input fuel allocation is then multiplied by a GHG emission factor, thereby calculating the share of emissions for each product. We display two of their methods here:

1) Allocation based on energy content of the products

This is the most common method because of its simplicity. The fundamental flaw is that it does not account for the quality of the energy produced. As a result, it underestimates the share of the emissions allocated to the electrical production (Rosen, 2008, p173).

$$C_E = \left\{\frac{E}{E+H}\right\} F\emptyset \qquad C_H = \left\{\frac{H}{E+H}\right\} F\emptyset$$

Where:

C_E = amount of GHG emission allocated to electrical production

C_H = amount of GHG emission allocated to heat production

E = net electricity production of the CHP system

H = net heat production of the CHP system

F = primary fuel consumed by the CHP system

$\emptyset$= GHG emission coefficient (unit of GHG emission produced per unit of primary fuel consumed)

2) Allocation based on exergy content of the products

Rosen (2008) defines exergy as "the maximum amount of work which can be produced by a system or flow of matter or energy as it comes to equilibrium with a reference environment (Rosen, 2008, p173)". More generally, exergy can be thought of as the quality or usefulness of the energy. In this method the allocation of fuel and emissions is less for the heat product than in the previous case.

$$C_E = \left\{\frac{E}{E + \beta H}\right\} F\emptyset \qquad C_H = \left\{\frac{\beta H}{E + \beta H}\right\} F\emptyset$$

Where:

β = ratio of exergy to energy content of heat produced. For reference, the ratio for electricity is 1.0, and for steam at 600 degree its ratio is 0.6.

The exergy method is an attractive allocation method because it accounts for the quality and the quantity of the energy products from CHP. In addition, the method utilizes a simplifying fact, that electrical energy equals electrical exergy. While there is no equality for thermal energy and thermal exergy, Rosen presents ways to express thermal exergy. He suggests that the remainder of the methods (provided by Strickland and Nyboer and simplified by Rosen) add complications and no advantages over the exergy method. Compared to the energy allocation model, which is the most common, "the exergy method avoids underestimating the share of emissions allocated to the electrical product, and allocates a lower portion of the emissions to the thermal product" (Rosen, 2008, p174). For these reasons he concludes that the exergy method is the best way to allocate emissions between the two products of CHP.

Kerr (2008) discusses several options for fairly treating CHP within an ETS. The main hurdle of CHP in an ETS is that with CHP on-site, emissions increase as a consequence of investment in CHP, even while global emissions decrease. In permit auctioning, which is becoming the most common form of permit dissemination in cap and trade ETS, the CHP facility must purchase more allowances than the non-CHP facility, thus putting it at a disadvantage.

Kerr (2008) concludes that the "double benchmarking" approach to the allocation of pollution permits is the best way to ensure ETS recognize the emissions reducing benefits of CHP. "With benchmarking, permits are allocated not according to historic or actual emissions, but on the basis of comparison of a typical - often a 'best available technology' (BAT) – generating plant" (Kerr, 2008, p15). When applied to CHP, the benchmarking approach is known as double benchmarking. A sample CHP plant is given pollution permits according to two standards, one for heat output according to a boiler as a reference, and one for electrical output, according to a central generator as reference.

Verbruggen (2008) argues that if the EU uses benchmarking or double benchmarking for CHP against the separate production of heat and power, this is in fact "external benchmarking" because CHP is compared with a non-CHP process. He contends "*internal* benchmarking (particular CHP activities on best-practice CHP processes of the same technological family) is less arbitrary in gauging the performance of CHP activities" (Verbruggen, 2008, p3075).

In Canada, it is unclear how CHP will be affected by environmental policy. In April 2007 the government released its "regulatory framework for air emissions". Allegedly, the combined effect of the policies within it will be to reduce GHG emissions by 20% below the 2007 level by 2020, and by 65% by 2050. The framework includes the EcoENERGY Renewable Initiative, which provides a subsidy of 1¢/kWh for 10 years for renewable power projects. However, as

Jaccard and Rivers (2007) point out, as a subsidy program, it is vulnerable to free riders, those who receive the benefits from the subsidy yet would have taken on the project regardless (Jaccard and Rivers, 2007, p14).

Nearly 50% of GHG emissions in Canada are generated by a few firms, which are known as the large final emitters (LFEs). LFEs are typically mining and manufacturing firms, thermal electricity generators, and upstream oil and gas companies. The "regulatory framework for air emissions" requires reductions in the GHG intensity of production from each industrial sector of 18% by 2010 compared to 2006 levels, and a further 2% per year until 2015 (Jaccard and Rivers, 2007, p16). LFEs have several options to comply with this policy. They can reduce their emissions, buy permits from the government at a rate of $15 per tonne of CO_2 emitted in 2010 (climbs to $20 by 2013 and rises at the rate of inflation after that), buy permits from other LFEs, buy offset credits, or invest the money in a GHG fund that invests in emerging green technologies.

4. CONCLUSION

Combined heat and power (CHP) production technology, also known as cogeneration, offers tremendous potential to improve energy efficiency and reduce greenhouse gases (GHGs). The limited degree of diffusion of the technology in Canada compared to Europe is the result of market, regulatory, information and incentives, and environmental policy barriers. In spite of this, CHP is common in some sectors, notably pulp and paper and chemical products. Furthermore, electricity market restructuring in Alberta and Ontario is propelling an increase in CHP in these provinces.

From the economic analysis of the barriers to CHP in Canada, the author emphasizes these two most important policy recommendations:

- The price of electricity should reflect the true cost of generation (including the cost of pollution), allowing renewable energy, including CHP, to compete with conventional generation
- Allow full and transparent access to the electric grid, enabling independent power producers to buy and sell electricity from the grid at fair and consistent prices

If the barriers to CHP identified in this analysis are well addressed, they may become opportunities to foster the diffusion of CHP in Canada.

The next step in this research is to develop the most promising extensions highlighted in this paper. These include extending the model of Rose and McDonald (1991) on US pulp and paper industrial firms to Canadian data. The model of Bonilla (2007) can be improved to adequately represent conditions of declining spark spread levels, and could be tested with Canadian data. Electricity market restructuring in Canada provides an opportunity to utilize the models of Fox-Penner (1990) and Dismukes and Kleit (1999). The work of Rivers and Jaccard (2005) could be advanced by improving their survey analysis, using more recent technology prices, and examining another area of the economy. Lastly, contributions to the ongoing debate of how to allocate energy and emissions between the two products of CHP would be welcomed and timely.

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