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Economic and CO_2 Emissions Comparison of District Energy Systems using Geothermal and Solar Energy Resources

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Abstract: District energy (DE) systems provide an important means of mitigating greenhouse gas (GHG) emissions and the significant related concerns associated with global climate change. DE systems can use fossil fuel, renewable energy and waste heat as energy sources, and facilitate intelligent integration of energy systems. In this paper, solar thermal and geothermal energy are compared as energy sources for a district energy system which serves a community including commercial and educational buildings. The DE system is assessed for the considered energy resources in two main ways, by considering CO_2 emissions and economic aspects. The results obtained for the solar and geothermal energy sources are compared to detect trends. The results indicate that solar thermal energy is the most advantageous energy technology for a DE system from an environmental perspective, while geothermal energy is more beneficial from a financial point of view. An examination of the cost distribution for the technologies shows that when solar thermal energy is the main energy supply for a DE system, the system exhibits the highest loan payments and the lowest fuel costs (FCs) and insurance and maintenance (I&M) payments. With geothermal systems, loan payments are lower while the total cost over the life of the technology is higher for the DE system. Using solar thermal and geothermal technologies as the energy supply for a DE system also yields environmental benefits which can lead to financial advantages through such instruments as tax breaks. The study reported here is intended to allow energy technology suppliers to work with communities while accounting appropriately for economic issues and CO_2 emissions associated with these energy technologies.

Keywords: District Energy System, Energy Resources, Environmental Analysis, Economic Analysis.

1. Introduction

DE system is one of the options to reduce greenhouse gas emissions, which are a serious issue that humankind is facing today. DE systems can use fossil fuel, renewable energy and waste heat as energy sources, and facilitate intelligent integration of energy systems. DE systems offer many advantages for society [1]. DE technology and its potential enhancement have been described from different aspects [2].

DE systems are not a new technology, but as a result of energy and environmental concerns, it has gained recognition. Therefore, there has been a growing body of literature on the topic of DE systems. Since the focus of this study is on the energy source of the DE systems, major studies covering energy suppliers are acknowledged through the following sections.

DE technology integrated with combined heat and power has drawn much attention in the last decade, while the number of plants has increased. There is much research reported regarding DE technology and CHP. In one, DE is modeled with CHP and then optimizes the system from environmental and economic points [8]. Curti et al. modeled and optimized the DE system in conjunction with a CHP plant based on centralized and decentralized heat pumps [9]. Their method for modeling and optimization was an environomic approach. In other research, environmental and economic efficiency of DE system and CHP together analysed [10]. A DE system, integrated with a wood-fired-CHP plant, is modeled, then optimised environmentally and financially [11]. The design and comparison of a DE system in a rural community in Nova Scotia with two sources of energy, a biomass heating plant and a cogeneration plant, were investigated [12]. The results show that the biomass heating plant is financially superior.

In another study, two DE systems integrated with CHP plants were analysed from the viewpoint of energy and environmental impact and the results show pros and cons of a CHP plant significantly depend on the site [13]. Zhai et al. analysed the energy and exergy performance of a DE system operating with parabolic solar collectors and fossil fuel in China [14], and state that a DE system assisted with parabolic solar technology has a higher solar energy conversion than solar thermal collectors. Another team conducted research to model DE and CHP, and analysed the environmental aspect of the complete system [15]. In Sweden, the economic impact and the potential for a decrease in CO_2 emissions of a DE system was studied, with a DE system is coupled with biogas while using CHP for gasification [16]. Wetterlund and Soderstrom measure the economic and environmental impact of biomass gasification technology coupled with a DE system [17].

Another study compared the CO_2 payback time for a DE system in Tokyo when working with a geothermal system heat pump and an air heat pump; as expected the geothermal heat pump exhibited less environmental impact [18].

Holmgren and Gebremedhin suggested a model for a DE system which works with waste incineration. They analysed the economic and environmental aspects of the proposed model for policy makers [19]. Eriksson and Carlsson assessed the economic and environmental impact of waste incineration in a generation role for DE systems [20]. Ajah et al.proposes an integrated conceptual model of a DE system assisted by waste heat, showing some sort of fossil fuel to upgrade the recovered heat for DE system. In that study, the feasibility of the proposed model from technical, the environmental and economic aspects are analysed [21]. Fruergaard et al. investigated CO_2 emissions via waste incineration in two different DE networks in Denmark [22]. A DE system in China was assessed economically when waste incineration and CHP are energy suppliers [23].

Lund et al. proposed a comprehensive model for the future (2060) to use 100% renewable energy for running not only a DE system but also other energy applications. In their model, there are different sources of renewable energy, beside waste heat and CHP. They estimate of the cost and CO_2 reduction through a future comprehensive model [24]. Another study in Denmark considers a DE system that works with wind electricity, waste use, biomass use, coal, natural gas, and oil [25]. Ostergaard and Lund [25] replaced an oil burning system with geothermal system and analysed CO_2 two possible scenarios.

The purpose of this study is to compare solar thermal collectors and ground source heat pumps (GSHPs) used by DE systems. The solar and geothermal energy technologies are defined in terms of financial characteristics and CO_2 emissions (as an indicator of environment impact).

2. Methodology

A typical DE system consists of several energy users which are connected to an energy plant through a thermal network. Various energy suppliers, including renewable and non-renewable ones, can provide energy for the DE system individually or as group. In a heat processing centre, the energy of the resources is processed and readied for supply to the thermal network, which distributes energy to consumers.

2.1. Environmental Impact

Main CO_2 emission is an indicator for environmental impact of a product or procedure, because increasing CO_2 in the atmosphere results in an increase in the average global temperature [26]. This global warming is believed by many to have a severe irreversible future impact on life forms on the earth.

In this work, the CO_2 emitted from solar and geothermal suppliers is initially estimated in similar conditions. The consistency of performance is important for a fact-based assessment of energy options. In the next step, the CO_2 emitted for solar collectors and GSHP technology is compared to determine the environmental impact of each technology. The CO_2 emission associated with solar and geothermal technology is estimated during the life of the technology.

2.1. Cost Analysis

Initial costs, as well as operating costs during the life of every energy option, are determined in this study through the following terms.

Future monetary value is calculated by considering compound interest [27]:

$$Y_n=Y_0\,(1+IR)^n \qquad (1)$$

where Y_n denotes the future value (in \$) in year n, Y_0 the present value, n the number of years, and IR the inflation rate.

The loan on the product is calculated with the capital recovery factor, which results in monthly payment (or capital recovery, in $) M of the loan [27]:

$$M = P\left(\frac{[i\,(1+i)^{N}]}{[(1+i)^{N}-1]}\right) \quad (2)$$

when P denotes the principal in $, i the monthly interest rate, and N the number of monthly payments. This equation is applied to compute a payment of any loan, mortgage, or investment.

The value of money changes over the time. Equation (1) is used here repeatedly to determine the financial value at different times. Equation (2) is applied for the capital recovery for each energy technology. The cost of future repayments, if the entire cost is borrowed from a financial institution, is estimated. The payments of the original investment significantly affect the financial characteristics of each energy supplier.

3. Modeling the District Energy System Energy Supplier

One method of modeling the DE system is through demand profiles of building heat load. Initially, occupants' behaviour in every consumer building needs to be considered, and then the heat load of all consumers is summed. The DE plant is able to cover the total heat load of consumers as well as heat loss of the thermal network and consumers. Thus, the total energy of a DE plant can be quantified by adding total heat loss to total heat load.

Sizing a DE system starts with knowing the consumers' heat demand characteristics. A heat plant is able to satisfy the consumers' heat demand after deducting all losses between the heat plant and the consumers. For the heat plant of a DE system, usually two systems of heating equipment are considered [28]. One system is primary, which provides the main energy and operates on a regular basis. The second is the back up and it operates only when the heating load exceeds the capacity of the primary system. This auxiliary system has smaller capacity and occasionally works during a year. Since the main energy demand is covered by the primary system, it has received more attention and there are various methods to size the primary system. The ASHRAE handbook [28] suggests using the average energy demand (annual demand/12) for sizing the primary system, while Nijjar and Holmgren and Gebremedhin [12, 29] state that 60% to 70% of the peak is adequate for sizing the same. Nijjar [12] uses 60% of the peak for sizing the primary system, and states that a primary system capacity of 60% usually covers 90% of the demand of the DE system. Only 10% of heat demand is covered by the secondary system.

In this study, the sizing of the primary portion of the DE system for solar energy and ground source heat pump (GSHP) are examined in the same situation. For consistency, the auxiliary system remains the same for all energy options. However, the primary system is modeled for solar and geothermal technologies to account for the different energy options. The performance of the DE system in similar circumstances with two energy technologies (solar and geothermal) is then compared.

3.1. Solar Energy

Solar collectors directly convert solar energy to heat, which can be used for heating buildings. Flat solar collectors have a larger market share and are more commonly used in comparison to evacuated tube solar water collectors. The flat plate collector is chosen for this study and its performance is explained.

Solar collectors are sized as the primary system for a DE system. They are coupled with an auxiliary system to cover all heat demands of the DE system during all seasons. Each solar collector has its own heat generation size. The maximum capacity of the primary system divided by the heat generation size of each panel provides the total number of solar collectors. The efficiency of each solar collector is considered.

3.2. Geothermal Energy

In Canada, with its outdoor air temperature fluctuations during the year, geothermal energy can be used for district heating. A geothermal energy system extracts heat from the ground during winter and passes the building's heat back to the ground in the summer.

4. Case Study

Main To demonstrate the application of two energy resources (solar energy and GSHP) in a DE system and to compare their behaviours, a DE system located in Ontario, Canada is considered. The DE system is proposed based on buildings heat loads data in an Ontario climate [30]. Financial aspects of the case study like inflation rate (IR) and interest rate are assumed according to the present financial and industrial markets. The illustrative example can be subsequently applied for any DE system with different properties; the approach for modeling and analysis is the goal of this section. The main objective of this section is to compare consistently various energy resources; HVAC calculations are simplified where convenient for the case study.

The considered DE system covers 25,000 m^2 of urban area, including multi-floor buildings. Building one is a four-floor office building. Building three is a three story educational building. The proposed DE system operates with various energy resources. For the economic modeling IR is assumed to be 2%, based on central bank of Canada, and interest rate is considered 5%, based on present market values. The insurance and maintenance of equipment is assumed to be 3% of the initial investment, and the total cost for project management is taken to be 10% of the initial investment; these percentages are typical in the industry.

Figure 1. Simplified layout of a DE system

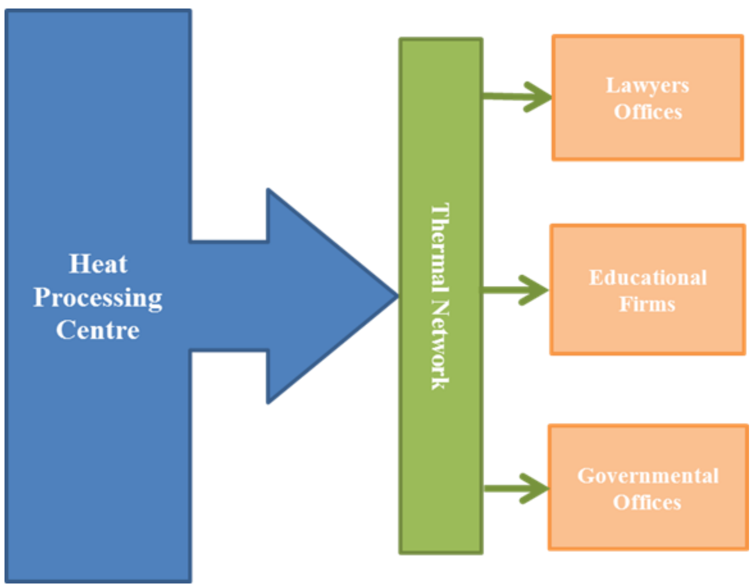


Figure 1 shows a simplified picture of the DE system including consumers, the thermal network, and the heat plant. To customize the heat plant of the DE system, the consumers' heat load is defined by examining all buildings in the system. For instance, institutional building main heat load occurs during business hours in the day, while the late afternoon, evening and night are off peak periods. The heat load of every building in the DE system is defined and summed to determine the overall heat load.

Table 1. Monthly heat/power consumption of the DE system

Month	Peak power (kW)	Energy usage/month (MWh)
Jan	1,720	1,280
Feb	1,340	997
Mar	950	707
Apr	560	417
May	300	223
Jun	150	112
Jul	60	45
Aug	90	67
Sep	310	231
Oct	580	432
Nov	1,020	759
Dec	1,400	1,042
Annual	**Not applicable**	**6,309**

The energy consumption of the DE system is equal to the energy consumption of the three buildings (as shown in Table 1) plus the heat loss of the DE system. The average monthly energy consumption of the proposed DE system is estimated for the Ontario climate by referencing data for buildings in Ontario [30]. It is observed that in late fall, winter and early spring, the energy consumption has a higher value compared with late spring, early fall and summer, due to the ambient temperature variations.

The peak times of the buildings are similar because all buildings are used during weekday working hours with slightly different peak times. Thus, the peak load of the DE system is almost the total of the peak loads of each building. The peak load of the DE system is 1,720 kW which is higher than the energy usage depicted in Table 1. The DE plant needs the capability to cover the peak load.

Both sizing methods (average load and 60%-of-peak) are applied for sizing the primary energy supplier of the proposed DE system, which is tabulated in Table 2. In the average-load method, the outcome of the annual consumption divided by 12 months from Table 1 (8,480/12 = 707 kW or 6,309/12 = 526 MWh) gives the size of the primary system while in the 60%-of-peak approach 60% of the peak load (1,720 × 60% = 1,032 kW or 1,280 × 60% = 768 MWh) determines the size. For the proposed DE system the capacity of the primary system is about 1,032 kW. Hence, the auxiliary system size is the difference between peak (1,720 kW) and capacity of primary system (1,032 kW), which is about 688 kW. Since 1,032 kW and 688 kW are not systems that can be found in the market, the size is rounded. 1,032 kW can be rounded up to 1,100 kW or rounded down to 1,000 kW, while the auxiliary system size can be rounded up to 700 kW or rounded down to 650 kW. To cover the 60% of load, the primary system is round up to 1,100 kW and the auxiliary down to 650 kW. At peak times, both systems (1,100 + 650 = 1,750 kW) cover the peak (1,720 kW).

Table 2. Sizing options for the primary system

	Power (kW)	**Energy (MWh)**
Annual sum	Not applicable	6,309
Monthly average load	707	526
60%-of-peak load	1,302	969

4.2. Solar Energy

To size primary system of the DE system with solar water heaters, 60% of the peak is the sizing method for solar collectors. Thus, solar energy needs to produce 768 MWh, as calculated in earlier sections. A thermal solar collector that generates 1,650 kWh/m^2/year [31] is selected; hence, the monthly solar energy collected is 1,650/12=137.5 kWh/m^2. The monthly amount of sunlight varies during the year. If winter sunlight, which is the lowest level, is considered for sizing the solar collectors, the initial cost rises significantly and there is extra energy during the summer when the consumption is low and days are long. Since there is an auxiliary system to support the primary system, the energy demand for 12 months is assumed evenly divided. The area of the solar collectors is calculated by dividing the needed capacity by the energy generated by one panel, which is 5,590 m^2.

4.2.1. Economical Aspects

The unit price of the solar collectors used here is 400 \$/m^2 [31, 32]. The initial cost (without installation) of the solar collectors with an efficiency of 60% is:

5,590 m^2 × 400 \$/m^2 =\$2,236,000

Provincial and federal governments offer various incentive programs from 10% up to 70% for promoting renewable energy, including solar energy [33, 34]. Rebates depend on the program, building type, business sector, and time. For this study, a 30% governmental incentive is assumed for the initial cost of the solar collectors. By applying the incentive, the initial price reduces to \$1,565,200. There is no monthly fuel use in this energy option. However, 3% of the initial cost is needed for maintenance and insurance for the solar collectors, which is similar to that required for a condensing boiler.

Using equations (1) and (2) the total cost of the DE system over 25 years is the same as Figure 2. The total cost without project management over the life of the solar collectors is \$3,800,000; by adding 10% of project management the overall becomes \$4,100,000.

Figure 2 shows that in the first 10 years of the solar collectors' performance the annual cost is almost three times higher in comparison with the following 15 years. Since the initial investment of the solar collectors is fairly high, the instalment on the loan is also high. Therefore, in the first 10 years annual costs are high. From the 11th year, the annual costs drop drastically since it is only the operating cost that remains. Additional details on the total cost are depicted in Figure 3, where it is observed that the major portion of cost, especially in the first 10 years, is allocated to loan payment.

Figure 2. Annual costs of the solar collectors

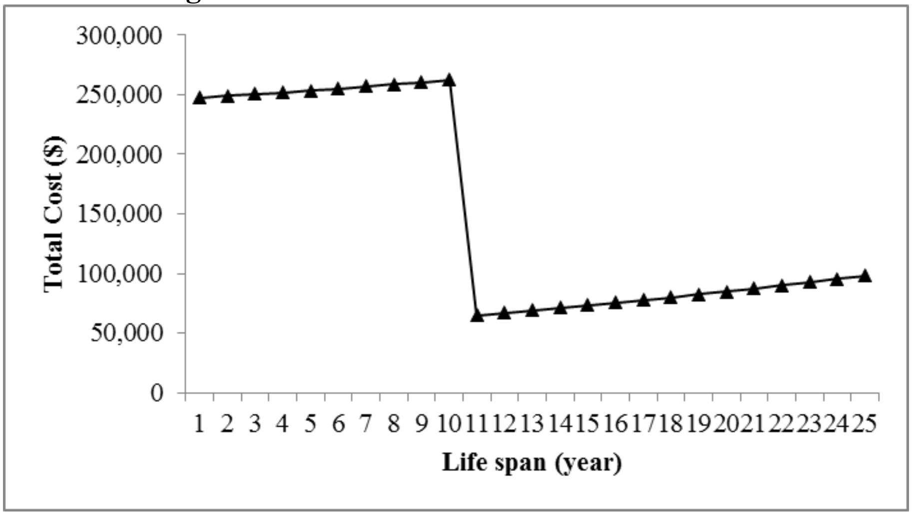
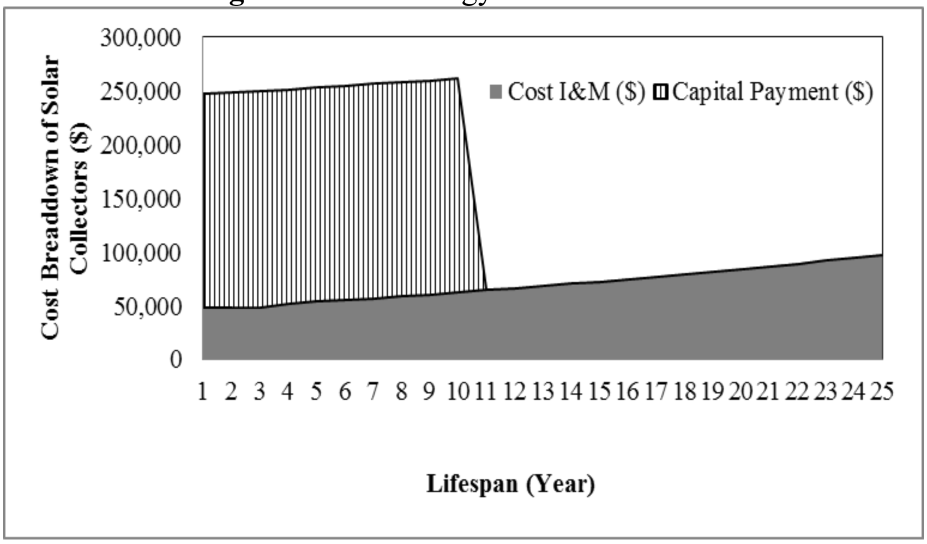


Figure 3. Solar energy's cost breakdown



4.2.2. Environmental Aspects

Since no fuel is used by the primary system when the energy option is solar thermal, there is no CO_2 emission during the 25 years of operation.

4.3. Geothermal Energy

A ground source heat pump is now considered as the energy supplier for the DE system. The capacity of the GSHP is 1,100 kW. To size the GSHP in detail as a primary system, RETScreen software [35] is used. To have a GSHP with a capacity of 1300 kW, when the circulation refrigerant is R-40A, there must be 182 U shaped pipes with a length of 440 m with a cooling COP of 5.1, a heating COP of 4.1, a cooling capacity of 1365 kW, and a heating capacity of 1000 kW. When the COP for heating is 4.1, about one fourth of the energy (325 kW) is supplied by electricity; thus, electricity consumption, cost, and pollution need to be considered for this source of energy.

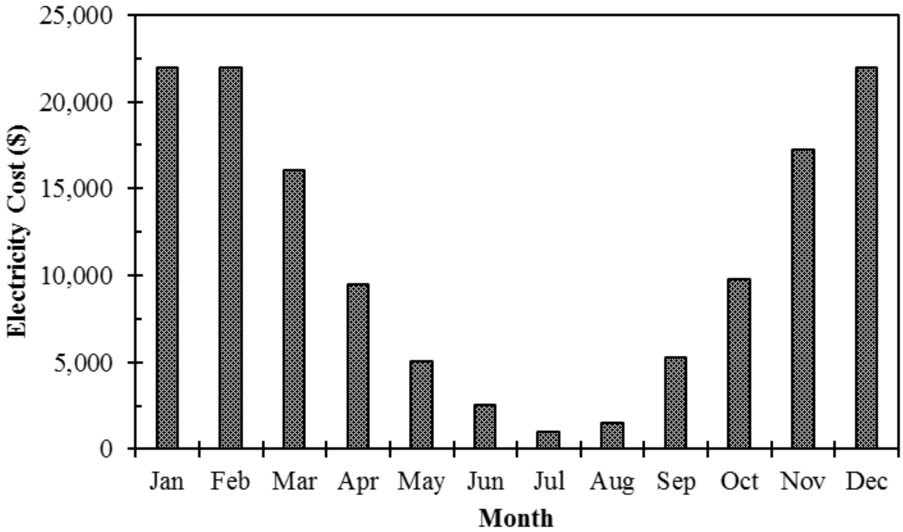
4.3.1. Economic Aspects

The cost of a 55.6 kW GSHP plus the drilling, piping, installation and other system is reported to be $41,353 [31], based on which the cost of the proposed GSHP with a capacity of 1,100 kW is estimated as $818,000. By considering a 30% government for promoting renewable energy, the actual price of the GSHP for the proposed DE system becomes $676,000. This is also the principle value for the loan. The loan conditions are the same as for the previous scenarios.

The cost of electricity on Ontario on average is 0.094 $/kWh over last five years [33]. 325 kW for a month is equal to 234 MWh, and then the average monthly cost of electricity is 22,000 $/month (0.094 $/kWh $\times$ 234 MWh $\times$ 1000) when the GHSP operates at maximum capacity.

In January, February and December, the GSHP operates with a maximum capacity of 1,100 kW and the rest of the load is covered by an auxiliary system, as seen in Figure 4. Thus, maximum electricity usage for heating (cooling is excluded), and apparently the electricity cost, occurs in January, February and December. To have a consistent comparison method, cooling operation electricity consumption of the GSHP is excluded in Figure 4.

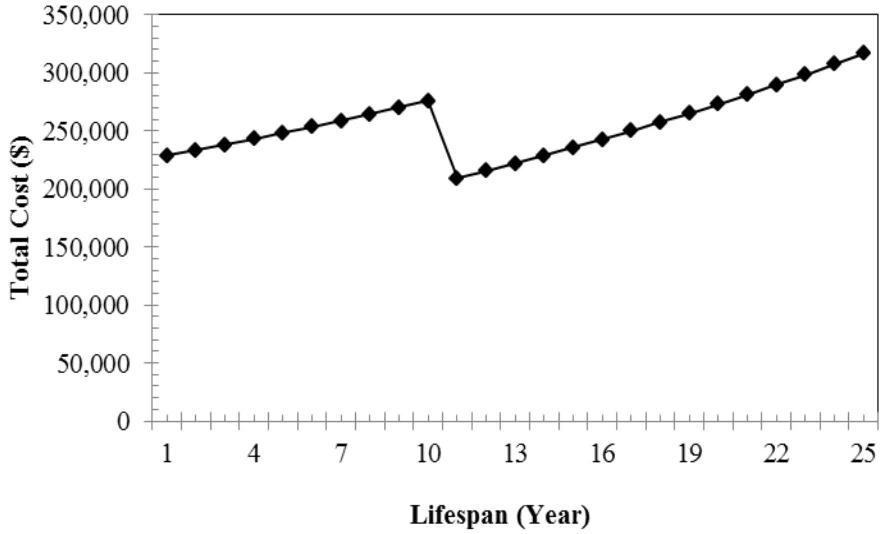
Figure 4. Monthly cost of the electricity for GSHP (only heating operation, cooling is excluded)



Applying equations (1) and (2) to the initial and the monthly cost results in the financial results of a GSHP over a 25 year life, as depicted in Figure 5. There, it is assumed that n = 25, IR = 2%, $I = \frac{5\%}{12}$ for an interest rate of the loan of 5%, and N = 10 × 12 = 120 for a 10-year amortization.

Figure 5 shows that there is a decline in the total cost in the 11th year, by one fourth. From year 11 to 25, the annual cost is only the operating cost, including insurance and maintenance and electricity. The total cost of the GSHP over its 25 year life and without project management costs, comes to $6,400,000; with a 10% project management cost, the overall cost is $7,000,000. To understand the total cost of the GSHP, the major cost items are broken down and presented in Figure 5. That figure shows that the main part of the GSHP cost is operating costs over the life. The capital recovery has a smaller share compared with operating costs.

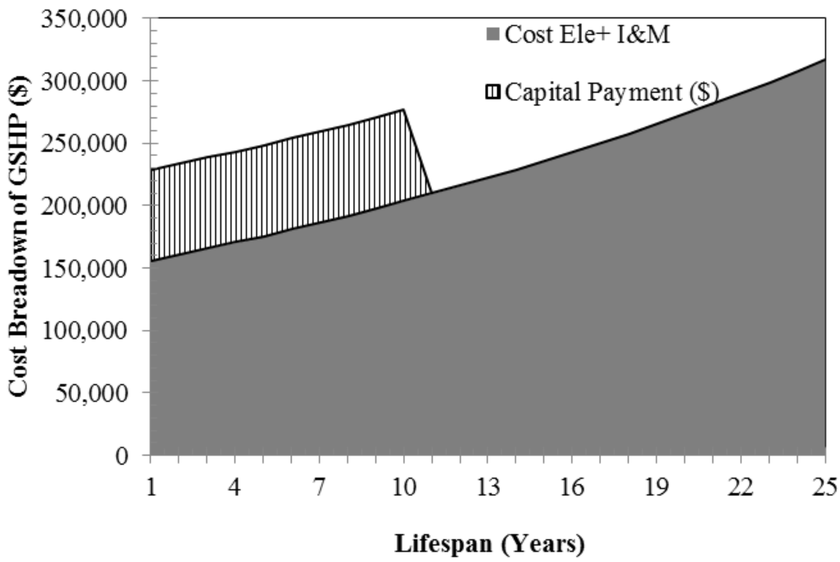
Figure 5. Annual costs for GSHP



4.3.2. Environmental Aspects

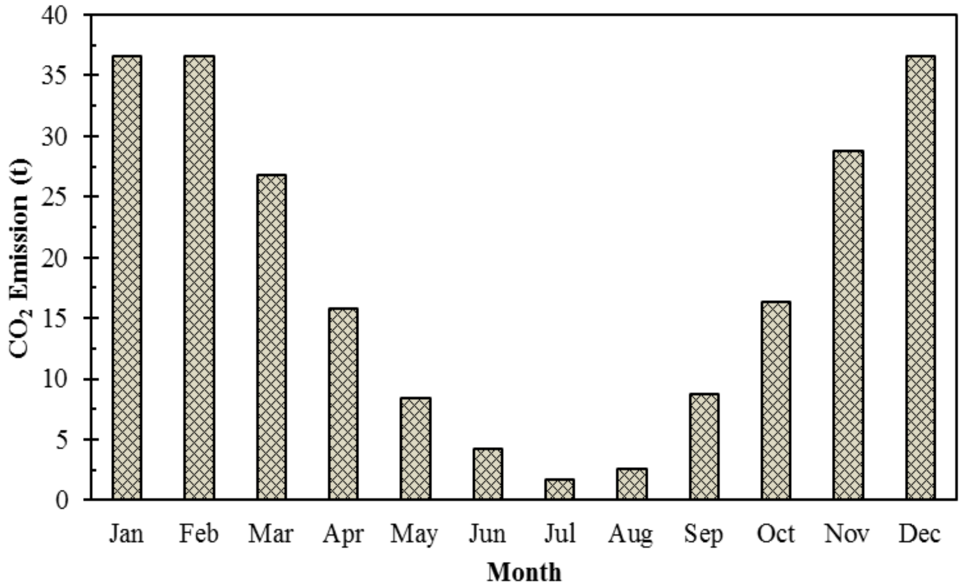
During 25 years of performance of the GSHP, some environmental impacts result. The amount of emitted CO_2 is considered here as an indicator of the GSHP environmental impact, as a primary system for DE. The Ontario electricity generation mix is made up of various resources (coal, natural gas, wind, nuclear, hydro, and others), and the CO_2 emission is dependent on the mixture. CO_2 emission from electricity generation in Ontario has been reported, as 242 MWh/month [36].

Figure 6. GSHP Cost breakdown



The monthly distribution of the emitted CO_2 by a GSHP as the primary system in DE is depicted in Figure 7. By assuming the electricity mix in Ontario remains fixed over the next 25 years, the GSHP emissions of CO_2 is found to be 10,314.65 t over its life. Note in Figure 7 that in January, February, and December, the GSHP operates at its maximum capacity of 1,100 kW and the rest of the heating load is covered by an auxiliary system. Consequently, the maximum CO_2 emissions occur in months of January, February and December.

Figure 7. Typical monthly CO2 emission by the GSHP (only heating operation)



5. Results and Discussion

DE systems have the flexibility to accommodate various energy suppliers. The focus of this study is on comparing two common energy resources: solar and geothermal. To have a consistent comparison, the technologies are sized for an identical DE system. The economic and environmental aspects are individually analyzed.

5.1. Economic Appraisal

The energy resource technologies can be financially compared in a consistent manner because they are linked to an identical DE system. Assuming a 25-year lifetime for each technology, annual costs are estimated and presented over the life of each energy technology, providing useful insights for financial analysts and managers.

The revenue of the DE system from selling heat is considered the same for both technologies. Thus, this amount is not mentioned in any cost estimation, since adding or subtracting a constant number to the total cost has no effect on the final comparison.

The annual costs of the two technologies for the proposed DE system are demonstrated in Figures 2 and 5, which show that the costs of both technologies decrease after 10 years, when the loan on the initial investment is paid off. It can also be seen that the solar technology has the highest initial investment. Solar energy after paying off the loan, it has the lowest cost for the next 15 years.

Not only is the distribution cost significant in decision-making, but also the overall cost of the two technologies for the proposed DE system is important. Comparing overall cost for solar energy ($4,100,000) and geothermal ($7,000,000) reveals solar technology is less expensive.

In order to make the final decision, other financial factors, such as the annual costs and project circumstances, must be reflected in the above prioritization.

Similarly, the cost breakdown of each energy supplier for the DE system in Figures 3 and 6 reveals that the solar collectors have the highest loan payment and lowest I&M cost, and that the GSHP has the highest cost of I&M and electricity. Depending on the economics of the community and finance availability of the project, these details are important. For example if there is budget limitation for implementing a DE system, the option of the technology with the lowest initial investment is prudent. If the capital is available for launching the DE system, but there is inadequate funding during the operation of the DE system, then the energy option with the lowest operational cost may be more advantageous.

5.2. Environmental Appraisal

The environmental feature of the DE system is one of the key parameters in the decision-making process for choosing an energy supplier. Figure 7 illustrates CO_2 emissions during one typical year for GSHP operation while solar energy has no emission during the operational period. Thus, solar energy is the more advantageous energy option environmentally.

The environmental aspect of industrial projects attracts much attention. Sometimes the environmental impact is the main factor for decision making. The benefits of improving environmental characteristics include protecting the environment, receiving government tax incentives and reducing carbon taxes (if applicable), satisfying industry standards and governmental regulations, and demonstrating new models for similar industries.

6. Conclusions

A methodology for analysing solar energy and GSHPs from the viewpoint of economic aspects and CO_2 emission has been presented. The fuel cost is a key component of the annual cost and the overall cost of the DE system. The carbon tax and cost can be affected by the type of fuel.

A community-based DE system was considered as a case study. First, a characteristic heat load of the proposed DE system was developed, and then the two energy options for the DE system were compared in a consistent manner. The energy sources were solar thermal and geothermal. The systems were sized for both energy options, and the CO_2 emission and economic characteristics of each were analyzed. The results indicate that:

- Solar thermal is the most advantageous energy technology for the DE system because it has less CO_2 emission during operation.
- Solar thermal technology, as the main energy supplier for the DE system, incurs the highest loan payment and the lowest fuel cost and I&M (insurance & maintenance) costs.

Acknowledgement

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Nomenclature

i	Monthly interest rate (%)
IR	Inflation rate (%)
M	Monthly payment (capital recovery) ($)
N	Number of monthly payments

n	Number of years
P	Principal ($)
Y_0	Present value ($)
Y_n	Future value (of money) in year n ($)

Conflict of Interest

The authors declare no conflict of interest.

References and Notes

1. M. Marinova, C. Beaudry, A. Taoussi, M. Trépanier and J. Paris, "Economic assessment of rural district heating by bio-steam supplied by a paper mill in Canada," *Bulletin of Science, Technology & Society* **2008** vol. 28, pp. 159-173.
2. B. Rezaie and M.A. Rosen, "District heating and cooling: Review of technology and potential enhancements," *Appl. Energy* **2012** vol. 93, pp. 2-10.
3. A. Poredoš and A. Kitanovski, "Exergy loss as a basis for the price of thermal energy," *Energy Conversion and Management* **2002** vol. 43, pp. 2163-2173.
4. M. Rosen and I. Dincer, "Exergy–cost–energy–mass analysis of thermal systems and processes," *Energy Conversion and Management* **2003**, vol. 44, pp. 1633-1651.
5. K. Çomaklı, B. Yüksel and Ö. Çomaklı, "Evaluation of energy and exergy losses in district heating network," *Appl. Therm. Eng.* **2004** vol. 24, pp. 1009-1017.
6. C. Reidhav and S. Werner, "Profitability of sparse district heating," *Appl. Energy* **2008**, vol. 85, pp. 867-877.
7. I. Vallios, T. Tsoutsos and G. Papadakis, "Design of biomass district heating systems," *Biomass Bioenergy* **2009** vol. 33, pp. 659-678.
8. Y. Wu and M.A. Rosen, "Assessing and optimizing the economic and environmental impacts of cogeneration/district energy systems using an energy equilibrium model," *Appl. Energy* **1999**, vol. 62, pp. 141-154.
9. V. Curti, M.R. von Spakovsky and D. Favrat, "An environomic approach for the modeling and optimization of a district heating network based on centralized and decentralized heat pumps, cogeneration and/or gas furnace. Part I: Methodology," *International Journal of Thermal Sciences* **2000** vol. 39, pp. 721-730.
10. P.J. Agrell and P. Bogetoft, "Economic and environmental efficiency of district heating plants," *Energy Policy* **2005** vol. 33, pp. 1351-1362.
11. D. Henning, S. Amiri and K. Holmgren, "Modelling and optimisation of electricity, steam and district heating production for a local Swedish utility," *Eur. J. Oper. Res.* **2006** vol. 175, pp. 1224-1247.
12. J.S. Nijjar, "Analysis and design of a district energy system," Master of Science Dissertation, Dalhousie University, **2006** Halifax, Nova Scotia, Canada.
13. G. Genon, M.F. Torchio, A. Poggio and M. Poggio, "Energy and environmental assessment of small district heating systems: Global and local effects in two case-studies," Energy Conversion and Management **2009** vol. 50, pp. 522-529.

14. H. Zhai, Y. Dai, J. Wu and R. Wang, "Energy and exergy analyses on a novel hybrid solar heating, cooling and power generation system for remote areas," *Appl. Energy* **2009** vol. 86, pp. 1395-1404.
15. M.F. Torchio, G. Genon, A. Poggio and M. Poggio, "Merging of energy and environmental analyses for district heating systems," *Energy* **2009** vol. 34, pp. 220-227.
16. K. Difs, E. Wetterlund, L. Trygg and M. Söderström, "Biomass gasification opportunities in a district heating system," *Biomass Bioenergy* **2010** vol. 34, pp. 637-651.
17. E. Wetterlund and M. Söderström, "Biomass gasification in district heating systems–The effect of economic energy policies," *Appl. Energy* **2010** vol. 87, pp. 2914-2922.
18. Y. Genchi, Y. Kikegawa and A. Inaba, "CO_2 payback–time assessment of a regional-scale heating and cooling system using a ground source heat–pump in a high energy–consumption area in Tokyo," *Appl. Energy* **2002** vol. 71, pp. 147-160.
19. K. Holmgren and A. Gebremedhin, "Modelling a district heating system: introduction of waste incineration, policy instruments and co-operation with an industry," *Energy Policy* **2004** vol. 32, pp. 1807-1817.
20. O. Eriksson, M. Carlsson Reich, B. Frostell, A. Björklund, G. Assefa, J.O. Sundqvist, J. Granath, A. Baky and L. Thyselius, "Municipal solid waste management from a systems perspective," *J. Clean. Prod.* **2005**, vol. 13, pp. 241-252.
21. A.N. Ajah, A.C. Patil, P.M. Herder and J. Grievink, "Integrated conceptual design of a robust and reliable waste-heat district heating system," *Appl. Therm. Eng*. **2007**, vol. 27, pp. 1158-1164.
22. T. Fruergaard, T.H. Christensen and T. Astrup, "Energy recovery from waste incineration: Assessing the importance of district heating networks," *Waste Manage.* **2010** vol. 30, pp. 1264-1272.
23. F. Sun, L. Fu, S. Zhang and J. Sun, "New waste heat district heating system with combined heat and power based on absorption heat exchange cycle in China," *Appl. Therm. Eng.,* **2011**.
24. H. Lund, B. Möller, B.V. Mathiesen and A. Dyrelund, "The role of district heating in future renewable energy systems," *Energy* **2010**, vol. 35, pp. 1381-1390.
25. P.A. Østergaard and H. Lund, "A renewable energy system in Frederikshavn using low-temperature geothermal energy for district heating," *Appl. Energy* **2011**, vol. 88, pp. 479-487.
26. J.T. Houghton, Y. Ding, D.J. Griggs, M. Noguer, P.J. Van der Linden, X. Dai, K. Maskell and C.A. Johnson, " Climate change 2001: The scientific basis. Contribution of working group I to the third assessment report of the intergovernmental panel on climate change," Cambridge University Press **2001**Cambridge, UK.
27. M. Fraser and E.M. Jewkes, *Engineering Economics*, **2013** Toronto, Canada: Pearson.
28. *ASHRAE Handbook - Heating, Ventilating, and Air-Conditioning Applications*, **2007** American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc..
29. Kalwa Biogenics, "Camrose County Office Complex Biomass Heat Conversion, Biomass Energy System Heat Load and System Size Evaluation," **2009** Kalwa Biogenics Inc..
30. Canadian Association of Petroleum Producers, "Natural Gas," **2012**. Accessed April 10, 2013, http://www.capp.ca/canadaindustry/naturalgas/pages/default.aspx
31. L.D.D. Harvey, *A handbook on low-energy buildings and district-energy systems: fundamentals, techniques and examples*, Earthscan, **2006**.

32. T. Schmidt, D. Mangold and H. Müller-Steinhagen, "Central solar heating plants with seasonal storage in Germany," *Solar Energy* **2004** vol. 76, pp. 165-174.
33. Ontario Energy Board, "Electricity Prices," **2012**. Accessed August 17, 2012, http://www.ontarioenergyboard.ca/OEB/Consumers/Electricity/Electricity+Prices
34. Ontario Ministry of Finance, "Solar Energy Systems Rebate Program," 2012. Accessed August 10, 2012, http://www.fin.gov.on.ca/en/refund/sesr/