

Life cycle cost analysis: an evaluation of renewable heating systems in Turkey

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Abstract

This paper presents a comparison of the LCC of five heating systems in four climate zones in Turkey. While being a country with huge renewable energy potential, Turkey's energy demand is met to a great extent by imported energy sources which constitute a substantial economic burden for Turkey. In this study, we analyzed the most common heating technologies, namely geothermal district heating systems (GDHS), natural gas-fired boilers, pellet-fired boilers, ground coupled heat pumps (GCHP) and coal-fired boiler technologies in terms of various criteria including life cycle cost (LCC), accessibility, initial investment cost, technical infrastructure, resource cost and annual heat cost. This study is vital to determine the shortcomings and strengths of the renewable heating (REH) technologies, both economically and technologically against non-REH technologies. The outcomes of the study may eventually assist home owners, property developers and policy makers in taking informed decisions in case of new construction or renovation, or proposing new policy mechanisms to promote the REH technologies. This study revealed that, due to the high labor intensity, inadequate supply chain of energy sources and structural constraints; REH technologies are not cost competitive against non-REH technologies in Turkey. Turkey is expected to revisit its medium-term energy policy to ensure wide application of REH technologies, introduce encouraging support mechanisms, and prioritize REH technologies on the basis of Turkey's resource mix and policy goals. If appropriate policies are in place and obstacles are eliminated, the potential of renewable energy can be exploited and market expansion of REH technologies can be realized.

Keywords: Renewable energy, Life cycle cost analysis, Heating, Biomass, Greenhouse, Resource economics

1. INTRODUCTION

In Turkey, the potential of renewable energy for both heating and cooling systems remains mostly untapped. Turkey's energy production meets only 27% of its aggregated primary energy demand. Turkey is heavily dependent on imported energy, which leads to budget deficits of both private and public households. As of 2012, Turkey has spent 60 billion US dollars on energy bills which constitutes 60% of current deficit of Turkey (Aydin, Temmuz, 2011; Berkun *et al.*, 2005). With an annual growth rate of 1.7%, Turkey's population is expected to increase from 76 million in 2013 to 83.4 million in 2022 (Balat, 2010). As a result of growing population and expanding economy, Turkey's total final energy consumption is projected to rise 5.9% annually between 2011 and 2020 (Evrendilek and Ertekin, 2003). On the other hand, Turkey has a huge potential of different domestic renewable resources which should be tapped. Technologies related with renewable energy for heating (REH) are considered economically beneficial for Turkey by opening new markets and creating job opportunities. Moreover, the country's GHG emissions would be reduced with the increased use of REH technologies.

In 2009, the heating demand in households in Turkey amounted to 913.9 PJ, which is 74% of the overall heating demand of 1.235 PJ. In recent years, heating sources have diversified with an increased use of natural gas. As natural gas consumption has increased, the share of domestic and imported coal has decreased (Bank, 2010). Efficient energy use is considered to be a solution in addressing fossil fuel depletion, energy security, and global warming (Wang *et al.*, 2009). In Turkey, the interest in alternative or renewable energy sources for greenhouse heating is currently high, owing to the large heating loads and the relatively high price of fossil fuels.

Despite the fact that Turkey's geographical position offers a significant potential for renewable energy sources, Turkey's energy demand is met to a great extent by imported energy sources which constitutes a substantial economic burden for Turkey. As Figure 1 illustrates, the households, services and agriculture sector consume almost 50% of the country's final energy.

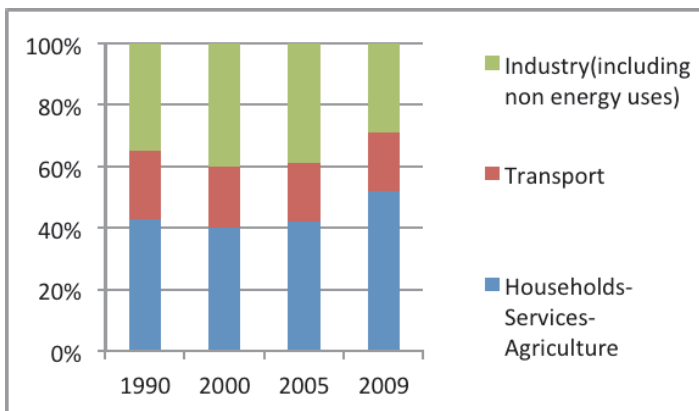


Figure 1. Distribution of final energy consumption by sector in Turkey (Sözen, 2009).

In Turkey, renewable energy collectively provides 9.5% of the primary energy demand which is composed of mainly combustible renewable and wastes (4.5%), hydropower (4%) and other renewable energy sources (1.5%) (Erdogdu, 2008). There are various obstacles which hinder the widening of the REH technologies in Turkey. Utilization of non-renewable energy sources for the heating purposes is increasing. In order to deal with this challenge, comprehensive research is vital to determine the shortcomings of the REH technologies, both economically and technologically and present a comparison of the available REH and non-REH technologies in terms of their life cycle costs and assist home owners, property developers and policy makers in taking informed decisions at the time of new construction or renovation, or in proposing new policy mechanisms to promote REH technologies.

There are various studies that deal with the heating energy consumption of households and the utilization of REH technologies in Turkey. For instance, (Utlu and Hepbasli, 2005) analysis of energy and exergy use of the Turkish residential sector. (Uygunoglu and Kecebas, 2011) conducted an LCC analysis for energy-saving of construction materials. (Murat, 2009) compared the life cycle cost of heat pumps and natural gas “combi” boilers without considering the other heating technologies and other climate zones. (Esiyok, 2007) investigated the energy consumption and thermal performance of typical residential building in different climate zones in Turkey, without conducting a LCC analysis for REH technologies. However, none of existing studies are comprehensive enough to cover and compare all four climate zones and the most common heating systems in Turkey.

2. OBJECTIVES

As mentioned, Turkey’s energy production meets only 27% of its aggregated primary energy demand and (REH) are considered beneficial for Turkey both economically and environmentally. Increasing the share of REH technologies is associated with numerous tasks such as identifying available renewable energy sources and assessing the achievable renewable energy potentials, cost analysis of existing heating technologies and proposing best suitable policies to make the renewable energy technologies more attractive. In the current condition, more and more people are keen to use non-REH technologies for the heating purposes. At this stage, there is a need for a comprehensive analysis of most common heating technologies in Turkey in order to understand the current status quo, strength and shortcomings of different heating technologies against each other. In this context, the first aim of this paper is to explore renewable energy sources utilized to meet heating demand. The second main aim of this research is to conduct a life cycle cost (LCC) analysis for existing heating technologies in Turkey. In the light of outputs of LCC analysis, this paper will also analyze the current employed technologies, expected developments and propose strategies to widen application of renewable heating technologies. The first section of the paper will highlight sources of renewable heat and provide estimates on sources of renewable energy available in Turkey. After this, this paper will deal with the renewable heating technologies and their potential in Turkey. After exploring the most used heating technologies, a comprehensive LCC analysis will be conducted. In order to carry out the LCC analysis, each heating technology will be analyzed in terms of

availability of energy feedstock, cost of energy feedstock, main equipment costs, and market conditions. Lastly, the results of LCC analysis will be evaluated and some recommendations will be highlighted.

3. CURRENT STATUS OF HEATING ENERGY SOURCES AND HEATING APPLIANCES IN TURKEY

3.1. Biomass

In Turkey, biomass has significant potential which is mostly untapped. Economically feasible biomass energy potential is composed of mainly agricultural residues, farming wastes, forestry, wood processing residues and municipal wastes (Toklu *et al.*, 2010). Firewood is the most common biomass source in rural regions. According to the IAE figures, in 2008 total biomass consumption was 5.0 Mtoe which constitutes only 30% of total economically recoverable biomass energy potential (IEA, 2010). The aggregated recoverable biomass potential of Turkey is estimated to be about 16.9 Mtoe (Gokcol *et al.*, 2009). Table 1 illustrates the potential of different types of biomass energy sources.

Table 1. Annual Recoverable Biomass Energy Potential in Turkey (Gokcol et al., 2009).

Type of Biomass	Energy Potential (Mtoe)
Animal Wastes	2.3
Dry agricultural residue	4.5
Firewood	4.1
Forestry and wood processing residues	4.3
Moist agricultural residue	0.2
Municipality wastes and human extra	1.3
Total	16,9

Mtoe: million tons of oil equivalent

In terms of forest and wood potential; natural forest areas, forest residues consisting of thin branches, bark and stumps constitutes a substantial biomass resources. According to the estimates of the General Directorate of Forestry, the potential of forest residues are varying between 5-7 million tons annually which are mostly not processed and left in the forests as a result of the lack of necessary technologies and infrastructural deficiencies. Additionally, wood processing residues also constitute another important source of biomass energy in Turkey. According to Table 1, half of the biomass content of a typical saw log becomes residue at a primary sawmill (Turker

et al., 1999). These kind of secondary forest products are processed in many regions as wood shavings fiberboards, animal bedding etc. Although secondary forest residues are very suitable raw materials for the wood pellet production, utilization of pellet for heating purposes is almost non-existent in Turkey. Fortunately, The Turkish Forest Directorate has recently initiated a plan to explore the potential of forest residues, between 5-7 million tons annually, and facilitate the production and utilization of wood pellets in Turkey. When it comes to agricultural biomass potential, according to the statistical figures, agricultural activities in Turkey is mainly comprised of industrial plants used to produce for instance edible oils from olives, sun flower, cotton seeds, etc. The aggregated agricultural area in Turkey is about 26.350 million ha, of which 38.4% is sown area, 44.1% forest, 10% fallow land, and 7.1% fruit and vegetables areas (Kar and Tekeli, 2008). The industrial processing activities of agricultural goods produce significant amounts of agricultural residues.

Unfortunately, a large amount of straw is currently disposed of in the field by burning, and sometimes by ploughing (Balat, 2005). The hazelnut shell and hazelnut tree pruning constitute an important source of biomass energy, with the annual amount of 453,150 tons and 1,742,389 tons respectively (Haciseferoğullari *et al.*, 2003). Fruit residues and tree pruning also represent substantial biomass energy potential. Aggregated agricultural and fruit residues annually amount to 16 million tons and the energy equivalent of these residues corresponds to about 21.3 Mtoe.

3.2. Geothermal energy

After biomass, Geothermal energy constitutes the second biggest source of heat from renewable energy in Turkey. Turkey's technical potential corresponds to 31.5 GWth. According to the reports of Mineral Research and Exploration General Directorate of Turkey (MTA), there are nearly 300 geothermal resource areas and about 1,500 hot and mineralized natural springs and wells existing in Turkey (Serpen *et al.*, 2010). In accordance with the ongoing formal procedure, MTA explores and assesses geothermal prospects and publishes the geothermal resource inventory in Turkey (Türkiye Jeotermal Kaynakları Envanteri) which also includes geothermal maps, temperatures for each location that has been explored by the MTA. At the second stage, the MTA organizes a tender for certain licensed geothermal fields. The data provided by MTA highlights three main geothermal regions, namely western, central and eastern Turkey geothermal regions which appear to be suitable for geothermal power development. The same MTA report highlights that the highest density of geothermal resources occurs in several provinces of western Turkey. The west ern regions of Turkey pose greater potential than elsewhere in terms of geothermal resources, which is consistent with the current focus of activities.

4. HOUSEHOLD HEATING APPLIANCES IN TURKEY

In the rural areas in Turkey, traditional biomass including agricultural waste, wood fuel and animal dung is the most common source of domestic heating. Fire wood stoves and ovens are quite widespread in the rural regions and used for cooking and heating purposes. On the other hand, the share of biomass consumption in the urban regions is decreasing sharply since other types of modern heating technologies are

becoming more convenient compared to the traditional use of biomass in Turkey. Particularly in recent years, Turkish government has provided access to gas for all households in city centers and urban regions and natural gas has gaining more and more acceptance in urban regions since it is considered inexpensive, clean, safe and a versatile kind of energy source. Natural gas is used both for water and indoor heating.

Table 2. Distribution of Natural Gas Connection Subscription in Turkey.

Subscription Type	Subscription Number
Individual Households	4,716,013
Number of Households with Apartment Building Central Heating System	899,388
Industrial and Others	1,004,033
Total	6,619,434
Number of Apartment Buildings with Central Heating	89,502

As of 2011, 21% of the total imported natural gas, 8.7 billion m³ was used in the households for domestic heating. Table 2 shows the amount of natural gas subscribers in 2007. It is estimated that the number of natural gas subscribers will be increasing in the near future. Considering the current tables, natural gas is the most common source of residential heating in urban regions.

4.1. Pellet-fired boilers

Due to some structural and economic constraints, pellet boilers are not widely used in Turkey. However, the number of households using pellet boilers is increasing. For the time being, there is no concrete data on the amount of pellet boilers sold in Turkey. There is a growing number of national and international pellet stove producers who have recently started to market their own pellet boiler brands more intensively, such as DAIWA of Aral Makina or Zibro Pellet. According to these market players, more and more Turkish people are becoming interested in pellet boilers and are keen to purchase pellet stoves in case that pellet systems become cost competitive against other type of energy sources in Turkey. Currently, there are mainly two types of pellet stoves on the market: pellet stoves for private households which are utilized only for heating and central heating pellet boilers for buildings which provide both heat and warm water.

On the other hand, wood pellet prices are not stable and affected by the cost of transport and availability of the raw materials since there are currently only few pellet production facilities in Turkey.

4.2. Geothermal

Compared with other energy sources, geothermal energy is regarded as a more cost competitive heating alternative in areas with a geothermal energy supply. In Turkey, geothermal energy is mostly used through district heating systems for households and commercial buildings. Depending on several factors such as the quality of the geothermal resource, financial capacity of the respective license holders etc., there are several types of geothermal heating systems ranging from low cost, simple systems to complex facilities that have been installed in Turkey. The simple geothermal heating systems are taking clean geothermal fluid obtained from a respective surface manifestation map surface manifestation and piping it through non-insulated steel pipes. With the help of a heat exchanger, the fluid flows through radiators and heats the building. These kind of simple systems would not require deep wells, pumps or a heat exchanger and do not include chemical inhibitors. Such simple, low cost systems are installed in some local buildings, mosques and schools (Mertoglu *et al.*, 2007). Spa facilities are mainly consisting of well and piping systems. They use geothermal fluid directly, or mix it with clean cooling water, and are thus less complex and less costly.

4.3. Heat pumps

Although heat pump systems are one of the most attractive methods both heating and cooling, the applications of heat pumps are very limited in Turkey. High initial investment costs and fluctuating electricity prices are seen as the main reasons of the very low application degree of heat pumps. According to the estimation of some heat pump market players, as of 2011, the amount of heat pump installments has reached 10,000 which includes 700 residential applications and more than 9000 commercial and agricultural applications in shopping malls, hotels, office buildings and plants (FINDIK, 2011). On the other hand, more and more shopping malls are keen to establish heat pump systems in order to reduce heating and cooling bills. Geothermal heat pump applications in Metro Meydan M1 Shopping Center with a capacity of 3500 kW cooling and 1200 kW heating is the biggest heat pump application so far in Turkey. As of 2011, there were a few companies who have started producing heat pump mechanisms. However, because of the high application costs, a lack of service personnel and insufficient financial support for such products, the heat pump market is developing very slowly in Turkey.

In Turkey, two types of heat pumps are mainly used: air-source heat pumps and ground-source heat pumps (GSHPs), also known as geothermal heat pumps (GHPs) (Acikkalp and Aras). Due to the high electricity prices and inconvenient geographical conditions in many regions, GSHP systems are seen more convenient than air source heat pump systems. Installment cost of ground source heat pump systems for a 150 qm² house with annual heat load of 11,400 kWh is expected to be around 5517 €. The cost includes all equipment and installation cost units. According to the estimation, the heat cost of GSHP is around 2.4 /cent for each 1000 kcal.

5. COST ANALYSIS OF RENEWABLE HEATING TECHNOLOGIES IN TURKEY

With the aid of the life cycle cost (LCC) analysis methodology, this study evaluates five heating technologies in four different climate zones in Turkey. The heating technologies studied are; 1) Geothermal district heating systems (GDHS) 2) Natural Gas-fired boilers, 3) Pellet boilers, 4) Coal-fired boilers and 5) Ground coupled heat pumps (GCHP). The study is vital to determine the shortcomings and strengths of the REH technologies, both economically and technologically and present a comparison of the available REH and non-REH technologies terms of their life cycle costs. The outcomes of the study may eventually assist home owners, property developers and policy makers in taking informed decisions at the time of new construction or renovation, or in proposing new policy mechanisms to promote the REH technologies.

In the context of the study, a hypothetical case study is developed. According to the hypothetical case study, the sample residence is a two-story family house with a floor area of 150 m² designed for four people and five alternative heating systems are compared in terms of the LCC analysis over a life of 25 years. Since the design and performance of the heating systems depends largely on the regional climate, the systems are studied for the same house at four locations having different climatic conditions.

5.1. Life cycle cost analysis

Life-cycle costing (LCC) is seen as an economic method to estimate the net present value of all relevant cost units throughout the study period, including construction costs, maintenance, repair and replacement costs, energy costs, and residual values (Fuller and Petersen, 1995; Kneifel, 2010). The LCC methodology is widely used for comparing various energy technologies in terms of duration, maintenance and cost of energy sources. The investment cost model for different heating technologies is developed with three cost categories as follows:

$$IC = C_{ic} + C_{in} + C_{co}$$

Where;

IC = Investment Cost

C_{ic} = Initial cost, purchase price of main equipment (boiler, stove, etc.)

C_{in} = Installation cost, labour cost, auxiliary equipment cost, etc.

C_{co} = Commissioning or subscription cost

The present value method is used to calculate the energy cost during the whole operating phase. The core part of LCC analysis is the present value calculations which is utilized to compare cash flows at different times intervals (Ong *et al.*, 2012). The LCC considers the initial cost of the HVAC systems and the annual cost of energy, used for heating (Yang *et al.*, 2008). The cost for maintenance, retrofitting, and demolition is not included. The annual operating energy use is assumed to be constant over the lifetime of the house.

The LCC in the form of present value model for this study can be formulated as

follows;

$$LCC = IC + \sum_{i=0}^n \frac{EC_i}{(1+r)^i}$$

Where EC annual energy feedstock is cost and r is discount rate. Annual energy consumption is calculated with the help of the formula below;

where is the amount of heating energy source, [kcal], is the annual heat load [kWh], is the coefficient of performance of Heating System, $N_{E,G,I}$ is the efficiency of generation source type-i [%], 860 is conversion factor [kcal/kWh]. Overall cost of energy consumption is calculated by multiplying respective energy unit price and annual consumption of energy source for the heating.

5.2. Assumptions

The LCC analysis involves the most common heating systems in Turkey, namely geothermal heating systems, natural gas boilers, pellet boilers, coal boilers and ground source heat pumps.

Table 3. Heating energy demands for each region according to TS 825 for lowest and highest A/V rate.

	For A/V ≤ 0.2 (kWh/m ²)	For A/V ≥ 1.05 (kWh/m ²)	Annual Average Heat Loss ¹ (kWh)
1. Region	27	66	6,975
2. Region	48	104	11,400
3. Region	64	121	13,875
4. Region	104	175	20,925

¹Average Annual Heat Loss is calculated for a 150 qm² house in each region.

Gathering all relevant data for this study was a substantial challenge since the study requires current technology and feed stock prices to be received from the market players. Some of the contacted companies were reluctant to share information about the heating technologies and related costs. Therefore, the input data for the study have been generated from various sources including market players, related government bodies, civic associations, technology experts, scientific journals and researchers. Heating energy loads for different climate zones are obtained from official statistics published by the Energy and Natural Resources Ministry. Annual average heat loss of different types of buildings are calculated with the methodology described in the respected Turkish standard TS-825 which considers the data such as thermal transmittance “U” values (for walls, floors, windows, glazing and ground floor) for

each region, and the maximum heating demand values according to regions (Esiyok, 2007). In our study, the annual heat load for each region is calculated by taking the average of the maximum and minimum heat load in each region for different type buildings, as seen in the Table 3.

The sample residence is a two-story family house with a floor area of 150 m² designed for four people. The lifetime of heating equipment is set to be 25 years and discount rate is assumed to be 2.5 %. It is also assumed that the residents do not take loans or any form of credit and finance the costs of the heating equipment from their private investment.

6. RESULTS AND DISCUSSIONS

Five types of heating systems, namely geothermal district heating systems (GDHS), natural gas-fired boilers, pellet boilers, and coal-fired boilers and ground coupled heat pumps (GCHP) were evaluated in terms of C_{ic} (initial cost), C_{in} (installation cost, labour cost, auxiliary equipment cost, etc.), C_{co} (commissioning or subscription cost) and C_{op} (operating cost, annual energy feedstock cost). In the first part of the study, unit energy cost has been calculated taking into consideration the calorific intensity, unit price and fuel efficiency (Table 4).

Table 4: Calorific Intensity, fuel efficiency and unit price of common energy sources in Turkey

Type of Energy Source	Calorific Intensity	Unit Price	Fuel Efficiency (%)
Geothermal	-	0,025 €/ 1000 kCal	-
Natural Gas	9,155kCal/m ³	0,37 €/m ³	% 90
Pellet	4,500kCal/kg	207 €/ton	% 85
Coal	6000kCal/kg	172 €/ton	% 85

In order to analyze the existing heating systems in Turkey, the unit price of different energy sources which are the most commonly used energy sources in Turkey, have been calculated.

In the second part of the study, taking into account the unit energy cost, annual heat load, boiler efficiency, and discount rate, LCC analysis has been carried out with an aim to estimate the net present value of all relevant cost units throughout the study period of 25 years. LCC calculation is made for each heating technology for four different climate zones since Turkey is divided into four different climate zones with a varying annual household heat load.

As shown in Tables 5, 6, 7 and 8, primary energy consumption of the sample household varies according to the climate zone which results in a different annual heat cost for each REH and non-REH technology. The study revealed that climate zone plays a substantial role in the LCC of heating technologies.

In spite of the fact that the LCC analysis only evaluates the investment cost and annual heat cost of the heat productions systems, there are some other considerations in Turkey which have substantial effect on determining the appropriate heating system for households. Locations, type of building, accessibility of the energy resource are among the most important factors to determine the type of heating system. Detailed comparison and evaluation of each heating technology from various aspects are made in the respective sections.

6.1. Geothermal district heating systems

Compared with other heating technologies, the annual heating cost of GDHS seems to be a most competitive alternative after the GCHP system. However, when the LCC of the heating technologies are considered, GDHS with LCC cost for 25 year is the most competitive heating technology in all climate zones in Turkey. The heat bill is calculated based on the monthly heat utilization with a rate of 2.5 ¢/cent for each 1000 kcal. As the Tables illustrate, LCC of GDHSs is considerably lower than other heating sources and other energy systems are not in a position to compete with geothermal energy in terms of initial investment and annual heating cost. Given the limited geothermal energy resources and limited number of cities supplied with geothermal heat, the price advantage of GDHS over other heating energy technologies applies only to the regions with an adequate geothermal energy resource and supply network. Additional to monthly geothermal heat costs, the households are required to pay a subscription fee of about 1,100 € for a 150 qm² household in advance.

6.2. Natural gas-fired boilers

As seen in the Tables 5, 6, 7 and 8, in terms of the LCC of heating technologies, natural gas-fired boiler systems are 3rd most convenient heating system in climate zone one and 4th most convenient heating system in other climate zones. After pellet-fired boilers, natural gas-fired boiler systems are the most energy consuming heating technology. Despite that, natural gas-fired heating appliances are the most widespread heating technology in Turkey in all climate zones. One of the main advantages of natural gas-fired boilers against other heating appliances is the utilization of natural gas for the cooking purposes as well. Natural gas is used both for heating, domestic hot water and cooking. Additional to that, the initial investment cost of 1551.7 € is lower than the initial investment cost of other technologies which may also increase the convenience of natural gas systems. As of 2011, there were 5,300,000 natural gas “combi” systems (combining heating and hot water) in the individual households. Natural-gas fired boilers are perceived as the clean and easy to maintain systems. A broad supply network of natural gas, a mature natural gas appliances market and a low initial investment cost against other heating technologies are the main drivers of the widespread employment of natural gas-fired boiler systems.

6.3. Ground coupled heat pumps (gchp).

Given the investment cost of 5517 €, GCHP systems are the most expensive to install. However, if the annual heat cost are considered, GCHP systems are the least expensive to operate and maintain in all four climate zones. Particularly in the case of climate zone three and four where the annual heat load is bigger than climate zone one and two, GCHP's annual heat cost is relatively less than other heating appliances, with the tables 144.4 €, 236 €, 287.9 € and 434 € for the first, second, third and fourth climate zones respectively. As seen in the Table 5, 6, 7 and 8, GCHP has one of the least LCC among the other four heating appliances. On the other hand, the application of GCHP systems in Turkey is very limited. A number of studies are carried out to analyze cost effectiveness of heat pump systems in various regions in Turkey, such as (Bakirci, 2010; Hepbasli, 2007; Kaygusuz, 1999; Kaygusuz, 2000). Almost all of existing studies indicate that because of high initial investment cost, the application of heat pump systems remain very few (Bakirci, 2010). As a result of these facts, heat pump systems today do not represent a cost competitive alternative to other sources of heating in Turkey. Inadequate awareness represents also a big hindrance against the proliferation of the GCHP technologies in Turkey. Particularly new types of renewable heating technologies are not widely known in Turkey. It can be concluded from the outputs of the study that the GCHP today is not cost competitive against other heating systems and may not be attractive enough unless local authorities provide subsidies to heat pump systems.

Table 5. LCC Analysis of heating technologies for the 1st Climate Zone in Turkey.

	Geothermal District Heating	Gas-Fired Boilers	Pellet Boilers	Ground Coupled Heat Pumps (GCHP)	Coal Fired Boilers
Boiler Efficiency	-	84%	90%	80%	
Annual Heat Cost for the 1.Region	150 €	322.7 €	360.3 €	144.4 € ²	253.4 €
Discount Rate	2.5%	2.5%	2.5%	2.5%	2.5%
Investment Cost ¹	1,896.5 €	1552 €	2241 €	5517 €	2069 €
LIFE CYCLE COST (LCC)	3918.9 €	5903.8 €	7100 €	7465 €	5486.5 €

Table 6. LCC Analysis of heating technologies for the 2nd Climate Zone in Turkey.

	Geothermal District Heating	Gas-Fired Boilers	Pellet Boilers	Ground Coupled Heat Pumps (GCHP)	Coal Fired Boilers
Boiler Efficiency	-	84%	90%	80%	
Annual Heat Cost for the 2.Region	245 €	527.5 €	587.5	236.5 € ²	414 €
Discount Rate	2.5%	2.5%	2.5%	2.5%	2.5%
Investment Cost¹	1896.5 €	1551.7 €	2241 €	5517 €	2069 €
LIFE CYCLE COST (LCC)	5202 €	8864.8 €	10164 €	8706.8 €	7653 €

Table 7. LCC Analysis of heating technologies for the 3th Climate Zone in Turkey.

	Geothermal District Heating	Gas-Fired Boilers	Pellet Boilers	Ground Coupled Heat Pumps (GCHP)	Coal Fired Boilers
Boiler Efficiency	-	84 %	90 %	80 %	
Annual Heat Cost for the 3.Region	298 €	641.7 €	716.8 €	287.9 € ²	504 €
Discount Rate	2.5%	2.5%	2.5%	2.5%	2.5%
Investment Cost¹	1896.5 €	1551.7 €	2241 €	5517.2 €	2069 €
LIFE CYCLE COST (LCC)	5918 €	10204.8 €	11907 €	9399.6 €	8866.8 €

Table 8. LCC Analysis of heating technologies for the 4th Climate Zone in Turkey.

	Geothermal District Heating	Gas-Fired Boilers	Pellet-Fired Boilers	Ground Coupled Heat Pump (GCHP)	Coal-Fired Boilers
Boiler Efficiency	-	84%	90%	80%	
Annual Heat Cost for the 4.Region	450.2 €	968.2 €	1081.3 €	434 € ²	760.3 €
Discount Rate	2.5%	2.5%	2.5%	2.5%	2.5%
Investment Cost¹	1896.5 €	1551.7 €	2241 €	5517 €	2069 €
LIFE CYCLE COST	7964.4 €	14,604.8 €	16,822 €	11,371 €	12,321.7 €

¹Investment cost comprises installation cost, labour cost, auxiliary equipment cost etc.²The cost of electricity utilized by the Heat Pump for the heat generation.

6.4. Pellet-fired boilers

When it comes to pellet-fired boilers, the annual heat cost is the highest among others. High annual heat cost of pellet systems is attributed to high final consumer price of the pellet. Parallel to the annual heat cost, pellet-fired boiler has the highest LCC among other heating technologies as a result of the high investment cost and resource price. The price of wood pellets is highly affected by the cost of transport and availability of raw materials, since there are currently only a few pellet production facilities in Turkey. Therefore, the price difference in Adana where there are some pellet producers and in Izmir (west of Turkey), the price difference is ranging between 40 to 70 %. In terms of pellet heating systems, the price of biomass fuel plays a significant role in the assessment of the system's feasibility. The price of pellet material is varying depending on the distance to production areas and the quality of the pellet. Therefore, the application of pellet systems would be reasonable when the location of the pellet boiler is close to site of its production which would decrease the high transportation costs and eliminate supply difficulties.

In terms of labor intensity, pellet heating systems which require proper maintenance and removal of ash content of solid fuels regularly are not competitive when compared to the comfort of natural gas-fired boilers, GDHS and GCHP systems.

Theoretically, in rural areas without a natural gas supply, GCHP systems or pellet boilers would be an alternative to wood stoves which do not provide domestic hot water. Particularly in rural areas, as a relatively cheaper and easily accessible sort of renewable energy source, biomass in the form of pellets could be a common renewable energy source in the future. To achieve that, it is considered essential to have a biomass producing, processing and distributing industry that is able to supply biomass products (such as logwood, wood-chips, wood- or straw-pellets, agricultural residues etc.) to customers reliably, durably and in a timely manner. As 99 % of all the forests in Turkey are owned by the state, the growth of this strategy for the development of wooden-biomass-supply is dependent on the General Directorate of Forestry of Turkey and the Ministry of Environment and Forestry (MoEF). This strategy shall take the best and most practical bioenergy production strategies of other countries into account.

6.5. Coal-fired boilers

Additional to the natural gas-fired boiler systems, another most common non-REH technology in Turkey is the coal-fired boiler. In terms of initial investment cost, coal-fired boilers are superior to pellet-fired boilers and GCHP systems. When it comes to the LCC of heating technologies, coal-fired boilers are the second most competitive heating technology in climate zones one, two and three. However, in climate zone four, coal-fired boilers are third most competitive heating technology after GDHS and GCHP systems. In all climate zones except climate zone four, coal-fired boiler systems seem to be the more economical heating technology against available renewable heating technologies. Widespread utilization of coal-fired boiler systems is attributed to the relative low cost and high accessibility of coal and coal technologies. On the other hand, for the regions without a natural gas supply, coal-fired boiler systems are seen as the second best heating technology option.

6.6. Barriers hindering proliferation of renewable heating technologies and some suggestions

There are numerous barriers which prevent the proliferation of REH technologies in Turkey. First and foremost, currently available Turkish laws and regulations do not address explicitly heating and cooling with renewable energy resources. Turkey does not have specific legislation or legislative framework concerning solar thermal and biomass energy for heating and cooling purposes. Although in the energy strategy paper Turkey has set the goal to increase the share of renewable energy, current financial support for renewable energy production is not considered sufficient to trigger the necessary investments. By offering a feed-in tariff, the focus of financial mechanisms is electricity production. Currently, there is no similar tariff for heat production in Turkey. Supportive measures, such as tax exemptions, reduced interest rates for heat production from renewable energy sources are very limited (Ates, 2013).

Scientific and technical barriers also constitute a significant bottleneck for stalling large-scale adoption of REH technologies. Currently, there is a lack of appropriate service sectors and necessary studies in terms of improving and installing REH technologies in Turkey.

Inadequate awareness also represents a big hindrance against the implementation of the REH technologies in Turkey. Particularly new types of renewable heating technologies, such as pellet boilers and heat pump systems are not widely known in Turkey.

Economic barriers are considered as one of the main barriers to a broader use of REH technologies. Economic barriers include costs of technologies, difficulties in obtaining financing as well as fluctuating energy prices. For many REH technologies, high initial investment cost associated with building the necessary infrastructure is regarded as the main barrier for wider application of these technologies. However, the currently available supportive mechanisms for REH technologies are not sufficient to overcome this problem. Particularly for private households, without receiving an incentive, initial financing of REH technologies is hard to realize. Due to a lack in technical capacity to evaluate heating appliance projects, banks categorize those kinds of projects as risky. Thus, private banks in Turkey are not keen to provide credit or financial support for REH investment projects. Providing financing producers / vendors / installers for this sort of technology with specifically designated conditions to pass the financing on to their clients could be an alternative way of overcoming financial barriers.

In terms of technical barriers, each heating technology has its own problems. However, problems such as a lack of experienced technicians, insufficient network of auxiliary equipment can be generalized for all REH technologies. The current absence of widely spread specific training for REH technologies makes installation and engineering companies reluctant to suggest this technology to their clients as well.

7. CONCLUSION

In this paper, we have analyzed the life cycle cost of 5 different heating technologies in Turkey. As being a country with huge renewable energy potential, Turkey's energy demand is met to a great extent by imported energy sources which constitute a

substantial economic burden for Turkey. By investigating the most common heating technologies in Turkey, we were able to understand the current status quo and the strengths and shortcomings of renewable heating technologies against non-renewable heating technologies. According to the LCC analysis, the competitiveness of the heating technology is dependent to the annual heat load and consequently to the climate zones. The study revealed that, REH technologies are not cost competitive against non-REH technologies in Turkey. For instance, due to the high labor intensity, inadequate supply chain of energy source and structural constrains, pellet-fired boiler systems have the highest LCC among other heating technologies in all four climate zones. Price of biomass fuel plays a significant role in the assessment of the system's feasibility. The price of pellet material varies depending on distance to the production areas and the quality of the pellet. The study also explored that, natural gas-fired boiler systems are the 3rd most convenient heating system in the climate zone one and 4th most convenient heating system in other climate zones. After pellet-fired boilers, natural gas-fired boiler systems are the most energy consuming heating technology. Despite that, natural gas-fired heating appliances are the most widespread heating technology in Turkey, in all climate zones. One of the main advantages of natural gas-fired boiler against other heating appliances is the utilization of natural gas for cooking purposes as well. When it comes to the GDHS, this study revealed that the GDHS is the most competitive heating technology in all climate zones in Turkey. Given the limited geothermal energy resources and limited number of cities supplied with geothermal heat, the price advantage of GDHS over other heating energy technologies applies only to the regions with an adequate geothermal energy resource and supply network.

This analysis has proved that, if appropriate policies are in place and obstacles are eliminated, the big potential of renewable energy can be exploited and market expansion of REH technologies can be realized. Turkey is expected to revisit its medium-term energy policy to ensure wide spread application of REH technologies and introduce encouraging support mechanisms, and to prioritize REH technologies on the basis of Turkey's resource mix, policy goals, Rand D activities and international collaborations efforts.

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