Feasibility of biomass heating system in Middle East Technical University, Northern Cyprus Campus

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Feasibility of biomass heating system in Middle East Technical University, Northern Cyprus Campus

Samuel Asumadu-Sarkodie* and Phebe Asantewaa Owusu

Abstract: Global interest in using biomass feedstock to produce heat and power is increasing. In this study, RETScreen modelling software was used to investigate the feasibility of biomass heating system in Middle East Technical University, Northern Cyprus Campus. Weiss Kessel Multicratboiler system with 2 MW capacity using rice straw biomass as fuel and 10 units of RBI® CB0500 boilers with 144 kW capacity using natural gas as fuel were selected for the proposed biomass heating system. The total cost of the biomass heating project is US$ 786,390. The project has a pre-tax and after tax internal rate of return (IRR) of 122.70%, simple payback period of 2.54 years, a net present value of US$ 3,357,138.29, an annual lifecycle savings of US$ 262,617.91, a benefit-cost ratio of 21.83, an electricity cost of $0/kWh and a GHG reduction cost of −204.66 $/tCO2. The annual GHG emission reduction is 1,283.2 tCO2, which is equivalent to 118 hectares of forest absorbing carbon. The development and adoption of this renewable energy technology will save costs on buying conventional type of heating system and result in a large technical and economic potential for reducing greenhouse gas emissions which will satisfy the sustainable development goals.

Subjects: Bio Energy; Clean Technologies; Energy & Fuels; Environmental; Novel Technologies; Renewable Energy; Renewable Energy; Traditional Industries – Clean & Green Advancements

Keywords: biomass heating; renewable energy; sustainable development; RETScreen; GHG emissions; Northern Cyprus
1. Introduction

Biomass is ubiquitous and readily available source of energy. The discovery of energy released from wood through fire over one million years BC transformed humanity and civilization (Strezov & Evans, 2014). Accessibility to modern energy services comprises household access to minimum level of electricity; access to safer and more sustainable cooking and heating fuels and stoves; access that enables productive economic activities; and access for public services (International Energy Agency, 2014). The industrial revolution (combustion used to fulfil the basic human needs like: cooking, heating and protection) brought about change of living conditions and technology, and by mid-nineteenth century, technological advancements introduced power stations and the internal combustion engine, requiring a major shift in fuel sources as energy demand increased (Rosillo-Calle, 2012; Strezov & Evans, 2014). The use of biomass decreased and lost its role as the primary source of energy as fossil fuel energy generation gained popularity (Strezov & Evans, 2014). Now, the dominance of fossil fuel-based energy generation in today's increasingly energy-intensive society brings a lot of challenges associated with greenhouse gas emissions (GHGs) (Kabata-Pendias, 2010; Strezov & Evans, 2014): atmospheric pollutants (SO₂, NOₓ, particles, traces of metals), water pollution from coal, management of fly ash waste and depletion of fossil fuels. The depletion of fossil fuel and its uneven geographical distribution is drawing fears of energy insecurity, which is a reflection of political instabilities (Cherp et al., 2012; Johansson, 2013; Luft, 2009; Strezov & Evans, 2014). The Intergovernmental Panel on Climate Change (IPCC) report titled: “Climate change 2007: the physical science basis, summary for policy makers”, stated that continued GHG emissions from fossil fuels will lead to a temperature increase of between 1.4 and 5.8°C, over the period from 1990 to 2100 (Change, 2007). Falkowski (2000) argues that, understanding the consequences of the aforementioned activities in the coming years is critical for formulating economic, energy, technology, trade and security policies that will affect civilization for generations to come. As a result of this, renewable energy sources like biomass is gaining new global attention, in terms of energy research and development to unearth its advantages to address the growing challenges in energy generation and utilization (Biswas & Kunzru, 2008; Li & Suzuki, 2009; Ng, Lam, Ng, Kamal, & Lim, 2012; Pasini et al., 2011; Tock, Lai, Lee, Tan, & Bhatia, 2010). Global interest in using biomass feedstock to produce heat, power, liquid fuel and chemicals is increasing (Spellman, 2011). Biomass ranks fourth among the sources of energy in the world, which represents about 14% of the world’s final energy consumption, higher than coal (12%) and comparable with gas (15%) and electricity (14%) (Demirbas, 2005; Saidur, Abdelaziz, Demirbas, Hossain, & Mekhilef, 2011). Approximately 40% of the world’s population relies on traditional bioenergy for their energy needs, accounting for 9% of global energy use and 55% of global wood harvest (Masera, Drigo, Bailis, Ghilardi, & Ruiz-Mercado, 2015). Biomass is the main source of energy in many developing countries, which are mostly non-commercial (Demirbas, 2005; International Energy Agency, 2014; Saidur et al., 2011). Biomass is one of the sources of renewable energy derived from plants through photosynthesis. During photosynthesis, plants combine carbon dioxide and water to form carbohydrates, which constitute the building blocks of biomass (Baskar, Baskar, & Dhillon, 2012). The solar energy that drives the process of photosynthesis is stored in chemical bonds of the carbohydrates and other molecules in the biomass. Biomass is a renewable resource that can be used to generate energy on demand, if it is cultivated and harvested in a manner that allows further growth without depleting nutrients and water resources, with little net additional contribution to global GHGs (Baskar et al., 2012; Hall, Rosillo-Calle, & de Groot, 1992). According to McKendry (2002), “burning new biomass contributes no new carbon dioxide to the atmosphere, as replanting harvested biomass ensures that CO₂ is absorbed and returned for a cycle of new growth”. McKendry (2002) defines biomass as any renewable material sourced from a biological origin, which includes anthropogenically modified materials (by-products, products, residues and waste from agriculture, industry and the municipality). The key sources of biomass are: forest residue, whole forest, agricultural residues and crops grown on purpose (Shahrukh et al., 2015).

There are a few literatures on biomass heating systems nonetheless, Li and Wang (2014) investigated the challenges in smart low-temperature district heating development using a holistic approach that measures the reduced system design margin and improve operation of decentralized
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Heat generations. Lund et al. (2014) investigated on the fourth-generation district heating integrating smart thermal grids into future sustainable energy systems. Their study indicated that the fourth-generation district heating involves meeting the challenges of more efficient buildings as well as the operation of smart energy systems. Noussan, Cerino Abdin, Poggio, and Roberto (2014) investigated on the biomass-fired combined heat and power, and heat storage system simulations in existing district heating systems. Torchio (2015) did a comparison of district heating combined heating and power and distributed generation combined heating and power with energy, environmental and economic criteria for Northern Italy. Their study indicated that district heating shows the best values for primary energy savings. Vallios, Tsoutsos, and Papadakis (2009) presented a methodology of the design of biomass district heating systems taking into consideration the optimum design of building structure and urban settlement around the plant. Their study concluded that biomass district heating system model constitutes a favourable and flexible system which responds to all energy requirement in small urban settlements. Wissner (2014) examined the possibility of regulating district heating systems and the difficulties associated with practical implementation using the example of the German district heating market. They concluded that the vast number of district heating generating systems under the European CO₂ trading scheme are economically promising. Ancona, Bianchi, Branchini, and Melino (2014) investigated and analysed the district heating network design using a software based on the Todini–Pilati algorithm generalized by the use of Darcy–Weisbach equation. Their study introduced a district heating network that eliminated combustion systems at final users of thermal energy thereby reducing pollutants and thermal emissions in the study area.

Our study is in line with Stolarski, Krzyżaniak, Warminiśki, and Śnieg (2013) who investigated the energy, economic and environmental assessment of heating a family house with biomass. The average consumption of their proposed system ranged from 6.00 to 7.13 t/year at a heat production cost ranging from 713 to 785 €/year. Their study is capable of reducing GHGs from 17.4 to 34.3 t of carbon dioxide equivalent. Nonetheless, their study was limited to a family house which may not be a true representation of the population. Against this backdrop, we present herein, the feasibility of installing a biomass heating system in Middle East Technical University, Northern Cyprus Campus using the RETScreen modelling software by National Resource Canada. An advantage of using RETScreen software is that it facilitates a project evaluation process for decision-making.

2. Materials and method

RETScreen modelling software by National Resource Canada was used to analyse and assess the energy production, energy production cost and savings, GHG reduction, life cycle costs, operation and maintenance cost and financial feasibility of the biomass heating system. Figure 1 shows the biomass heating energy model flowchart. For brevity, not all the equations are outlined since it is already available in RETScreen® International. However, in RETScreen Biomass Heating Project Model, the following mathematical equations are followed (RETScreen® International, xxxx):

\[ DD_i = \sum_{k=1}^{N_i} (T_{set} - T_{ax}) \]  

(1)

where monthly degree-days is denoted by DD, \( N_i \) is number of days, set-temperature is denoted as \( T_{set} \) and average daily temperature denoted by \( T_{ax} \).

\[ dd_i = \frac{DD_i}{N_i} + dd_{DHW} \]  

(2)

where \( dd_i \) is the monthly degree-days per day.

The total peak load \( P_j \) for the \( j \)th cluster of buildings is therefore expressed as:

\[ P_j = P_{Ni}A_j \]  

(3)
The alternative fuel consumption is calculated as:

$$M_{AFC} = \frac{Q}{\eta_{hs,se} C_f}$$  \hspace{1cm} (4)

where $M_{AFC}$ is the alternative fuel consumption, $\eta_{hs,se}$ is the heating system seasonal efficiency, $C_f$ is the calorific value for the selected fuel type and $Q$ is the energy demand of the building or cluster of buildings.

The total heating load carried in a pipe in the main distribution line, $P_{pipe}$, can be calculated as:

$$P_{pipe} = \rho V C_p \Delta T_{s-r}$$  \hspace{1cm} (5)

where $\rho$ is the density of water, $V$ is the volumetric flow of water, $C_p$ its specific heat (78°C, 4,195 J/(kg°C)) and $\Delta T_{s-r}$ is the differential temperature between supply and return.

2.1. Proposed biomass heating system

Agricultural biomass namely rice straw bale was selected as a fuel (baseload) for the biomass system. Figure 2 shows the agricultural biomass pathway for heating energy model. Each biomass fuel has a unique characteristic, production amounts per acre, different collection procedure, processing,
storage and combustion dynamics (Agricultural Utilization Research Institute, xxxx). The rice straw feedstock for the biomass heating system will require a bale grinder/slicer for processing, a fork lift/crane as a handling equipment and a barn/shed for storage. The cost of this fuel ranges from $18 (Delivand, Barz, & Gheewala, 2011) to $80 (Agricultural Utilization Research Institute, xxxx) per tonne depending on the location and quality. Rice cultivation is one of the economic activities in Turkey and Northern Cyprus therefore rice straws are enormous and easily available; however, since agricultural biomass sometimes have high levels of alkali in them, fouling issues normally occurs in some biomass boilers (Corp, xxxx). Nonetheless, Weiss Kessel® Multicratboiler biomass system is an exception. Weiss Kessel Multicratboiler system with 2 MW capacity was selected for the proposed biomass heating system. The selection was made because of its multi-purpose function (cyclone, nozzle grate, cyclone burner and push grate furnaces) designed for both dry and wet forms of forest residue, whole forest and agricultural residues. In addition, it has automatic control and regulation system designed for automatic operation, fuel discharging system with infeed and metering systems, the furnace, the boiler and the flue gas cleaning plant until the chimney (WEISS Kessel, 2014).

Natural gas was selected as the fuel for the peak load heating system due to its low cost and its high-reserve discovery in the shore of Northern Cyprus (Coşin, xxxx). The boiler (Model: CB0500) for the system is manufactured by RBI® with a capacity of 144 kW, 98% efficiency, inlet temperature of between 16 and 60°C and a flow rate between 2,322 and 12,609 l/h. The fully modulating firing
system of RBI® CB0500 continuously varies the energy input to exactly match the heating load without over-firing and wasting fuel providing extremely high part-load efficiencies, this is why this model was selected (RBI, xxxx).

Modelling and simulation of the biomass heating project was performed for three dormitories with two blocks each on Middle East Technical University, Northern Cyprus Campus. The buildings (three dorms with two blocks each) have four floors with a total floor area of about 27,000 m² which accommodates approximately 1,800 students. The total peak heating load for all the dormitories is assumed to be 3,375 kW. Figure 3 shows the proposed case system load characteristics graph. Winter season occurs between November and May in Guzelyurt, Northern Cyprus, corresponding to the increasing heating demand as depicted in Figure 3. The baseload system (primary/main system) can meet the heating demands throughout the year without the peak load system (secondary/reserve system). However, during winter months and coldest days as depicted in Figure 3, the

![Figure 3. Proposed case system load characteristics graph.](image)

**Table 1. Specifications of the biomass heating system**

| Item                  | Parameter                        |
|-----------------------|----------------------------------|
| Baseload Biomass      |                                  |
| Fuel type             | Rice straw                       |
| Fuel rate             | 30 S/t                           |
| Biomass system capacity | 2,000 kW                         |
| Heating delivered     | 4,768 MWh                        |
| Manufacturer          | Weiss Kessel®                    |
| Model                 | Multicratboiler                  |
| Number of units       | 1                                |
| Seasonal efficiency   | 80%                              |
| Boiler type           | Hot water                        |
| Fuel required         | 9.0 GJ/h                         |
| Peak load             | Natural gas                      |
| Technology            | Boiler                           |
| Fuel rate             | 0.45 S/m³                       |
| Capacity              | 1,440 kW                         |
| Heat delivered        | 196.6 MWh                        |
| Manufacturer          | RBI®                             |
| Model                 | CB0500                           |
| Number of units       | 10                               |
| Seasonal efficiency   | 80%                              |
baseload system cannot meet the heating demand without the peak load system. Table 1 shows the specifications of the biomass heating system employed in the study.

### 2.2. Financial analysis

The RETScreen Clean Energy Project Analysis modelling software is capable of performing financial analysis based on financial parameters like; project lifetime, inflation rate, debt interest rate, energy cost, GHG credit, energy cost escalation rate, etc. In Table 2, a summary of financial input parameters used for cost analysis is given. The cost analysis contains a listing of estimated initial and annual cost for biomass heating project. Unless otherwise stated, all the financial input parameters are referred from Minnesota Biomass Heating Feasibility Guide (Agricultural Utilization Research Institute, xxxx).

### 2.3. Greenhouse gas reduction analysis

According to the IPCC, the annual GHGs can be reduced through technological advancement which requires actions like: adopting energy-efficient technologies and practices, increased fuel switching towards lower carbon fuels, combined heat and power systems, greater reliance on renewable energy sources, etc. (Intergovernmental Panel on Climate Change [IPCC], xxxx). The RETScreen Clean Energy Project Analysis modelling software is capable of performing greenhouse gas reduction analysis based on the energy model of the project. Based on global warming potential of GHG by IPCC 2007, 25 tonnes of CO$_2$ are equivalent to 1 tonne of CH$_4$ and 298 tonnes of CO$_2$ are equivalent to 1 tonne of N$_2$O (RETScreen, xxxxa). Therefore, the emission factor for CO$_2$ is 49.4 kg/GJ; CH$_4$ is 0.0036 kg/GJ, N$_2$O is 0.0009 kg/GJ and GHG is 0.179 tCO$_2$/MWh which corresponds to GHG emission of 1,367.1 tCO$_2$ and a fuel consumption of 7,638 MWh.

The base load heating system of the proposed biomass heating system has the emission factor for CO$_2$ as 0 kg/GJ; CH$_4$ as 0.0299 kg/GJ, N$_2$O as 0.0037 kg/GJ and GHG as 0.007 tCO$_2$/MWh which corresponds to GHG emission of 39.9 tCO$_2$ and a fuel consumption of 5,960 MWh.

### Table 2. A summary of financial input parameters and assumptions for cost analysis

| Item                                | Value          |
|-------------------------------------|----------------|
| Initial costs                       |                |
| Baseload biomass system             | US $260/kW     |
| Peak load biomass system            | US $50/kW      |
| Feasibility study                   | US $5,000      |
| Development                         | US $7,000      |
| Engineering                         | US $10,000     |
| Miscellaneous/contingency fund      | 5%             |
| Annual costs                        |                |
| Parts and labour cost               | US $10,000     |
| Miscellaneous/contingency fund      | 5%             |
| Financial parameters                |                |
| Debt ratio                          | 75%            |
| Debt interest rate                  | 6%             |
| Debt term                           | 10 years       |
| Fuel cost escalation rate           | 2%             |
| Discount rate                       | 6%             |
| Inflation rate                      | 2%             |
| Project lifetime                    | 25 years       |
The peak load heating system of the proposed biomass heating system has the emission factor for CO₂ as 49.4 kg/GJ; CH₄ as 0.0036 kg/GJ, N₂O as 0.0009 kg/GJ and GHG as 0.179 tCO₂/MWh which corresponds to GHG emission of 44 tCO₂ and a fuel consumption of 246 MWh.

3. Results and discussion

In the base case heating system, heating is done using a plant operating on natural gas while the proposed biomass heating system operates on rice straw biomass for the baseload heating system using Weiss Kessel® Multicratboiler and natural gas for the peak load heating system using RBI® CB0500 boiler which serves as a secondary backup during winter months and coldest days. Table 3 shows the summary of the proposed case system. The proposed base load heating system consumes 1,829 tonnes of rice straw in a Weiss Kessel® Multicratboiler operating at a capacity of 2,000 kW to produce 4,768 MWh of energy for heating purposes while the proposed peak load heating system consumes 23,602 m³ of natural gas in 10 units of RBI® CB0500 boiler operating at a capacity of 144 kW each to produce a total of 197 MWh of energy for heating purposes.

The cost of the project and its savings are critical to its success and investment. The total cost of the biomass heating project for Middle East Technical University, Northern Cyprus campus is US$ 786,390; initial cost is US$ 644,700 which includes feasibility study, development, engineering, the cost of the heating systems and the balance of the system and miscellaneous; the annual costs and debt payment is US$ 141,690 including: operations and maintenance, fuel cost of the proposed case and debt payments for 10 years; and an annual savings and income of US$ 330,040 as a result of avoiding fuel cost in the base case heating system. Table 4 shows the summary of the costs and savings of the proposed project.

Table 5 shows the summary of the financial viability of the proposed project. The first and second row in Table 5 shows the pre-tax and after tax internal rate of return (IRR) of the proposed project. The IRR represents the true interest of the biomass heating system project over its 25 years’ lifetime without discount rate assumption (RETScreen, xxxxb). The pre-tax and after tax IRR has the same value of 122.70% as the return on the investment in the biomass heating project.

The third row in Table 5 shows the simple payback period of the proposed project. The simple payback period (Thevenard, Leng, & Martel, 2000), which is the number of years required for the initial cost of the biomass heating project to be paid for out of the savings is 2.54 years.

The fourth row in Table 5 shows the equity payback period of the proposed project. The equity period (Thevenard et al., 2000), which is the time required to recover the equity investment out of pre-tax cash flows reflecting inflation (2%) and debt payments (US$ 65,696) is 0.83 year.

The fifth row in Table 5 shows the net present value (NPV) of the proposed project. The NPV is the sum of all the costs and benefits which is adjusted according to when they occur in the project (Thevenard et al., 2000). The NPV of the project is US$ 3,357,138.29; since the NPV for the biomass heating project is positive, the project is financially attractive at a discount rate of 6%.

The sixth row in Table 5 shows the annual lifecycle savings of the proposed project. The annual lifecycle savings is US$ 262,617.91, which represents the positive savings irrespective of inflation rate, interest rate and taxes.
The seventh row in Table 5 shows the benefit–cost ratio of the proposed project. The benefit–cost ratio of the biomass heating project is 21.83, which shows a positive value greater than 1 giving a signal that the benefits of the proposed project outweighs its cost.

The eighth row in Table 5 shows the energy production cost of the proposed project. The cost of electricity is $0/kWh.

The ninth and the last row in Table 5 shows the greenhouse gas (GHG) reduction cost of the proposed project. The GHG reduction cost of the project is −204.66 $/tCO₂, which means the value of energy saved through greenhouse gas reduction is greater than the capital, operating and maintenance costs (IPCC, xxxx).

Figure 4 shows the cumulative cash flow of the proposed project. It is obvious that the cumulative cash flow is directly proportional to the duration of the biomass heating project, which reassures investors that their profit is secured and in case of unforeseen circumstances, they can still meet their financial obligations at the shortest possible time (Schmidt, 2014).

The proposed biomass heating project has a GHG of 83.9 tCO₂ compared to the based case GHG emission of 1,367.1 tCO₂. The annual GHG emission reduction is 1,283.2 tCO₂, which is equivalent to 118 hectares of forest absorbing carbon.

### Table 4. A summary of costs and savings/income of the proposed project

| Initial costs                      | Unit | Value   |
|-----------------------------------|------|---------|
| Feasibility study                 |      | $5,000  |
| Development                        |      | $7,000  |
| Engineering                        |      | $10,000 |
| Heating system                     |      | $592,000|
| Balance of system & misc           |      | $30,700 |
| Total initial costs                |      | $644,700|
| Annual costs and debt payments     |      |         |
| O&M                               |      | $10,500 |
| Fuel cost–proposed case            |      | $65,494 |
| Debt payments–10 yrs               |      | $65,696 |
| Total annual costs                 |      | $141,690|
| Annual savings and income          |      |         |
| Fuel cost–base case                |      | $330,040|
| Total annual savings and income    |      | $330,040|

### Table 5. A summary of the financial viability of the proposed project

| Financial viability                  | Unit | Value   |
|--------------------------------------|------|---------|
| Pre-tax IRR-equity                   | %    | 122.70  |
| After-tax IRR-equity                 | %    | 122.70  |
| Simple payback                       | yr   | 2.54    |
| Equity payback                       | yr   | 0.83    |
| Net Present Value (NPV)              | $    | 3,357,138.29 |
| Annual life cycle savings            | $/yr | 262,617.91 |
| Benefit–cost (B–C) ratio             |      | 21.83   |
| Energy production cost               | $/MWh| 0       |
| GHG reduction cost                   | $/tCO₂| -204.66 |
3.1. Validation of RETScreen biomass heating system

The load duration curve generated by Project Analysis modelling software designed by Natural Resources Canada has been validated with a computer model by Ingvar Larsson at FVB District Energy Consultants in Sweden. Larsson’s model (DD-IL) was developed using extensive and reliable record from a closely monitored District heating systems at Uppsala (Sweden) and St. Paul, Minnesota (USA). The RETScreen Clean Energy Project Analysis model was tested against Larsson’s model (DD-IL) with data from four different cities (Edmonton, Alberta (Canada), Toronto, Ontario (Canada), St. Paul, Minnesota (USA) and Uppsala (Sweden)) which showed an accurate and precise output. Figure 5 shows the output of RETScreen model validation against Larsson’s model (DD-IL).

4. Conclusions

Global interest in using biomass feedstock to produce heat, power, liquid fuel and chemicals is increasing. In this study, RETScreen Clean Energy Project Analysis modelling software designed by Natural Resources Canada was used to investigate the feasibility of biomass heating system in Middle East Technical University, Northern Cyprus Campus. RETScreen modelling software is capable
of analysing and assessing the energy production, energy production cost and savings, GHG reduction, life cycle costs, operation and maintenance cost and financial feasibility of the biomass heating system. Weiss Kessel Multicratboiler system with 2 MW capacity using rice straw biomass as fuel and 10 units of RBI® CB0500 boilers with 144 kW capacity using natural gas as fuel were selected for the proposed biomass heating system. A summary of findings from the study are as follows:

- The total peak heating load for three (two blocks each) dormitories is assume to be 3,375 kW.
- The proposed base load heating system consumes 1,829 tonnes of rice straw in a Weiss Kessel® Multicratboiler operating at a capacity of 2,000 kW to produce 4,768 MWh of energy for heating purposes.
- The proposed peak load heating system consumes 23,602 m³ of natural gas in 10 units of RBI® CB0500 boiler operating at a capacity of 144 kW each to produce a total of 197 MWh of energy for heating purposes.
- The total cost of the biomass heating project for Middle East Technical University, Northern Cyprus campus is US$ 786,390.
- The initial cost of the biomass heating project is US$ 644,700 which includes feasibility study, development, engineering, the cost of the heating systems and the balance of the system and miscellaneous.
- The annual costs and debt payment is US$ 141,690 including: operations and maintenance, fuel cost of the proposed case and debt payments for 10 years.
- The biomass heating system has an annual savings and income of US$ 330,040 as a result of avoiding fuel cost in the base case heating system.
- The project has a pre-tax and after tax IRR of 122.70%, simple payback period of 2.54 years, equity payback period of 0.83 year, a NPV of US$ 3,357,138.29, an annual lifecycle savings of US$ 262,617.91, a benefit–cost ratio of 21.83, a cost of electricity of $0/kWh, and a GHG reduction cost of −204.66 $/tCO₂.
- The annual GHG emission reduction is 1,283.2 tCO₂, which is equivalent to 118 hectares of forest absorbing carbon.

Biomass heating system is economically feasible in Middle East Technical University, Northern Cyprus Campus. The development and adoption of this renewable energy technology will save costs on buying conventional type of heating system and result in a large technical and economic potential for reducing GHGs which will satisfy the sustainable development goals. Future work should focus on reducing biomass production cost while increasing efficiency.

**Nomenclature**

**Symbols**

- \( T_{\text{set}} \): set temperature
- \( \text{DD} \): monthly degree-days
- \( N \): number of days in a month
- \( Q \): annual energy demand
- \( T_{\text{avg}} \): average daily temperature
- \( Q_h \): demand corresponding to space heating
- \( Q_{\text{DHW}} \): portion of demand corresponding to domestic hot water
- \( D_{\text{DHW}} \): domestic hot water demand
- \( d \): fraction of the annual total demand
- \( C_i \): cumulative duration coefficient
- \( D_i \): fractions of peak load
- \( F_0 \): empirical monthly factor
$T_{des}$ design temperature
$G_i$ load duration coefficient
$H_i$ normalize coefficient
$E_{fm}$ equivalent full load hours
$P$ total peak load
$A_i$ total heated area
$M_{AFC}$ alternative fuel consumption
$C_f$ calorific value
$Q_{PLUS}$ peak load heating system
$NHV$ as-fired calorific value
$MCWB$ moisture content on a wet basis of biomass (%)
$W_{water}$ weight of water
$W_{drywood}$ weight of dry biomass
$HHV$ higher heating value (MJ/kg)
$P_{pipe}$ total heating load carried in a pipe
$C_p$ specific heat (78°C, 4,195 J/(kg°C))
$\Delta T_{s-r}$ differential temperature between supply and return

Subscript
$i$ month
$k'$ secondary pipe network
$k$ Pipe oversizing factor
$j$ cluster of buildings
$hs, se$ heating system seasonal
$bio$ biomass

Greek letters
$\eta$ efficiency
$\rho$ density

Abbreviation
WHR Waste heat recovery

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