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Techno-Economic Analysis of Power Production by Using Waste Biomass Gasification

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Abstract

Energy recovery from waste biomass can have significant impacts on the most pressing development challenges of rural poverty and environmental damages. In this paper, a techno-economic analysis is carried out for electricity generation by using timber and wood waste (T & WW) gasification in Iceland. Different expenses were considered, like capital, installation, engineering, operation and maintenance costs and the interest rate of the investment. Regarding to revenues, they come from of the electricity sale and the fee paid by the Icelandic municipalities for waste collection and disposal. The economic feasibility was conducted based on the economic indicators of net present value (NPV) and discounted payback period (DPP), bringing together three different subgroups based on gasifier capacities, subgroup a: 50 kW, subgroup b: 100 kW and subgroup c: 200 kW. The results show that total cost increases as the implemented power is increased. This indicator varies from 1228.6 k€ for subgroups a to 1334.7 k€ for subgroups b and 1479.5 k€ for subgroups c. It is worth mentioning that NPV is positive for three subgroups and it grows as gasifier scale is extended. NPV is about 122 k€ (111,020 $), 1824 k€ (1,659,840 $) and 4392 k€ (3,996,720 $) for subgroups a, b and c, respectively. Moreover, DPP has an inversely proportional to the installed capacity. It is around 5.5 years (subgroups a), 9.5 months (subgroups b) and 6 months (subgroups c). The obtained results confirm that using small scale waste biomass gasification integrated with power generation could be techno-economically feasible for remote area in Iceland.

Keywords

Waste Biomass Gasification, Techno-Economic Analysis, Power Production, Waste to Energy

1. Introduction

The rapid development of global economy, increasing population and living standards has been posing great pressure on energy resources and the environment. There is an urgency to use local renewable energies to promote local development and also reduce carbon emission. Waste biomass is an abundant and renewable energy that creates low net CO_2 emission. It is also the only suitable and primary energy resource that can provide transportation fuels [1] [2] [3]. Biomass gasification is an attractive option that is getting huge attention for conversion of different feedstocks to energy. In the gasification, a partial oxidation at elevated temperature (600˚C - 1700˚C) is happened that converts organic components to a Synthesis Gas (syngas), consisting mainly of CO, H_2, CH_4, tars, inorganic impurities and particulates [4] [5].

Beneficially, waste biomass gasification can be applied for small/medium scales that lead to dramatic reduction of some pollutants emission as furans, dioxins, and NOx and the possibility of the utilization of the syngas in high efficiency thermal devices like internal combustion engine and gas turbines [6]. Hence, waste biomass gasification can be installed as a reliable energy supply technology for places which are far from the central energy networks and require district heat and power systems [7] [8] [9].

In this paper, we will explore the potential of timber and wood waste (T & WW) gasification for energy production in small communities in Iceland, (T & WW is the most existing biomass feedstock in this country). In this way, a techno-economic analysis of T & WW gasification facilities integrated with electricity generation unit will be directed for three subgroups with different gasifier installed power, 1): 50 kW, 2): 100 kW and 3): 200 kW to propose a sustainable waste to power system adapted with conditions in Iceland.

2. Material and Methods

2.1. Process Description

Figure 1 shows the studied system in this paper. T & WW is the significant resource entering to the system, liquid fuel and electricity are also the accessory inputs. The proximate and elemental analyses of T & WW are shown in Table 1.

T & WW is transferred from the waste fields to pre-processing part that is next to gasification and electricity generation unit. Diesel fuel is used in trucks

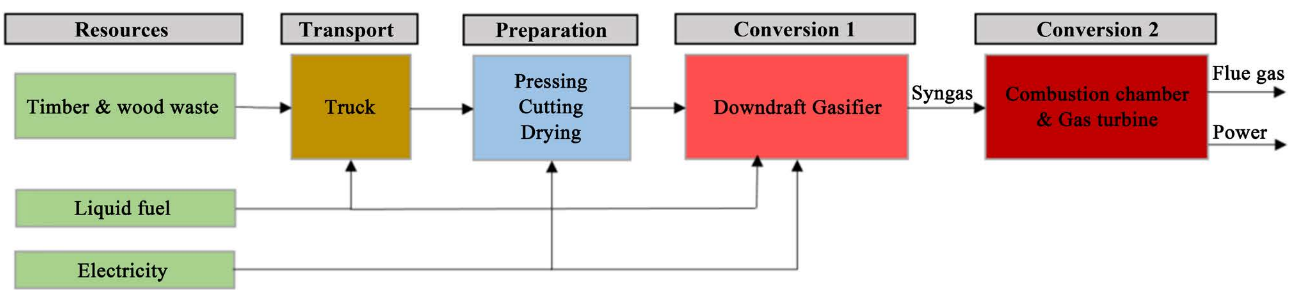

Figure 1. System boundaries, technologies, energy and material streams.

Table 1. Ultimate and proximate analysis of T & WW [10].

Parameters	Value (%)
Proximate analysis (wt%)	
Moisture	5.01
Volatile matter (VM)	93.06
Fixed carbon (FC)	6.38
Ash	0.56
Ultimate analysis (wt%-dry basis)	
C	56.8
H	7.28
N	0.18
Cl	0.82
S	0.07
O	34.29

for transportation and electricity is applied for driving force and heat generation over the process. The electricity production in Iceland is derived from geothermal and hydropower that makes Iceland's main source of clean energy. The gasification process consists of drying, pyrolysis, combustion and gasification [11]. In this work the down draft reactors are considered that operate at atmospheric pressure, to gasify T & WW and air is used as the gasification agent, resulting in CO_2 and H_2O, which subsequently undergo reduction upon contact with the char produced from pyrolysis. Reduction yields combustible gases as H_2, CO, and CH_4 through a series of reactions [5] [12]. Then the produced syngas enters a combustion chamber followed by a gas turbine. The combination of these two modules represents the behavior of a combustion engine where the reaction with air occurs [13] [14]. The inputs values and key assumptions used in this work are based on our waste biomass gasification simulation model developed by ASPEN Plus [8] and the main values of the downdraft gasifiers characteristics, operational parameters and the flue gas composition are relied on our previous work [15].

2.2. Techno-Economic Assessment

In the economic assessment, all prices are expressed in K€ (kilo-euro) and the interest rate is 8%. A computer program has been developed to investigate economically for three subgroups of 50 kW, 100 kW and 200 kW of gasifier installed power. The model is able to evaluate the cash flow analysis, total cost, Net Present Value (NPV) and Discounted Payback Period (DPP). A project is an economically attractive while it has the lowest DPP and the NPV higher than zero. NPV is calculated based on Equation (1) [16]:

$$NPV = \sum_{n=1}^{t} \frac{CF_n}{(1+r)^n} - C_c \tag{1}$$

where CF_n is the annual cash flow, being the difference between Revenues (R)

and Expenditures (E), Operation and Maintenance Costs ($C_{O\&M}$), r is the discount rate, C_c is the total capital costs of investment and t is the lifetime of the investment (15 years). DPP is calculated according to Equation (2):

$$DPP = \frac{LN\left(\dfrac{1}{1-\dfrac{C_c \times r}{CF}}\right)}{LN(1+r)} \tag{2}$$

The periodic cash flow, with all the revenues and expenditures, is calculated by considering the incomes from the generated electricity, and the credits for the Waste Treatment Bill (WTB) [6]. The expenditures also include the C_c and $C_{O\&M}$. C_c is divided into three categories: hardware price (C_g), installation cost (25% of C_g) and engineering costs, the engineering costs includes engineering and design (13% of C_g), purchasing & construction (14% of C_g), fuel handling/preparation (9% of C_g) and electrical/balance of plant (6% of C_g) [17] [18]. C_g is the price of gasifier system overally on the basis of various capacities. In this work, we extracted gasifier prices from various companies [19] [20]. C_g was considered 73.6 k€, 105.5 k€ and 147.5 k€ for 50 kW, 100 kW and 200 kW, respectively.

The whole yearly $C_{O\&M}$ can be determined by the sum of the costs for the maintenance cost (2% of C_c), insurance and tax (2% of C_c), waste disposal (15% of C_c), electricity cost, liquid fuel cost and personnel cost. Electricity costs are calculated based on electricity consumers and liquid fuel costs are estimated for fuel consumers with 7000 hr/year of plant availability [17] [18]. The unitary cost of electrical and fuel energies supplied in Iceland are equal to 0.03 $/kWh and 1.08 $/lit (0.91 €/$ as conversion rate) [3]. Personnel cost includes annual labour, cost. A total of two employees were assumed for plant operation management (1 person/shift and 2 shifts/day), with a yearly cost of 60,000 €/year per person in Iceland.

In relation to revenues, the selling price of electricity to normal households and small businesses in Iceland is about 124.69 $/MWh [21]. Hence, the sale price of the generated electricity based on waste gasification was considered at 109.89 $/MWh (100 €/MWh) in our work. Moreover, The Icelandic municipalities pay a fee (WTB) by weight, to the private companies, for the collection and disposal the MSW in sanitary landfills. The WTB for collection and disposal of the MSW varies from 90 - 170 €/ton through over Iceland. In this work, a mean value of 130 €/ton is used.

3. Results

Figure 2 shows the relation between the installed power and the amount of T & WW that is fed to the system for treatment and power production. Clearly, as the installed power grows, input biomass also increases. The requested waste biomass varies from 132.1 kg/hr for the first subgroup to 309.5 kg/hr for the second one and 575.3 kg/hr for the third subgroup.

The total cost of the generation plant for each subgroup is shown in **Figure 3**. The total cost increases as the installed power grows, it is about 1228.6 k€ (Subgroup a), 1334.7 k€ (Subgroup b) and 1479.5 k€ (Subgroup c). In addition, **Figure 4** depicts the percentage shares of hardware, installation, engineering and annual

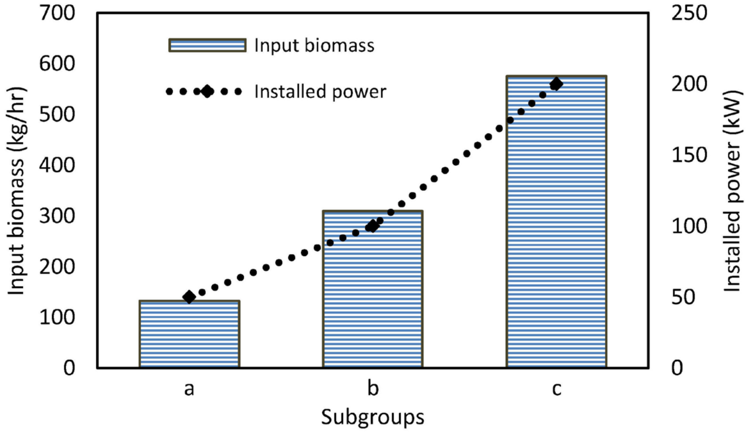

Figure 2. Input T & WW and installed power for subgroups.

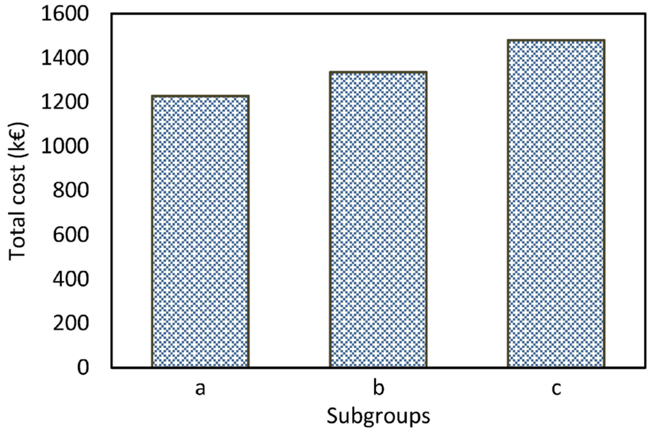

Figure 3. Total costs for different subgroups.

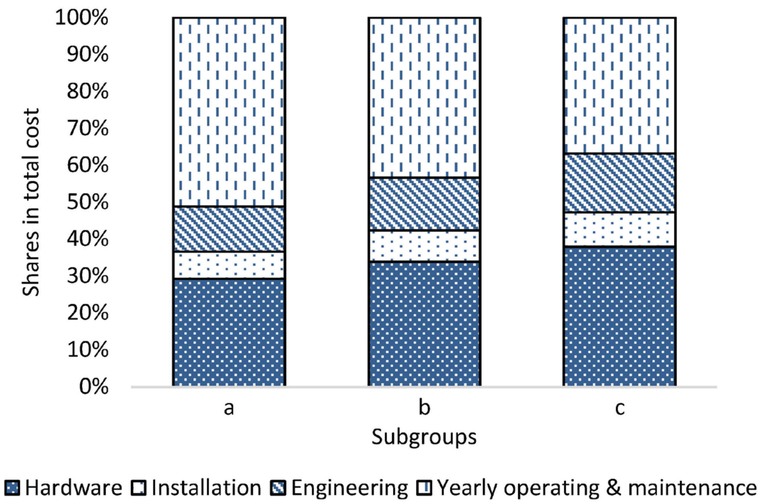

Figure 4. Percentage shares of total cost.

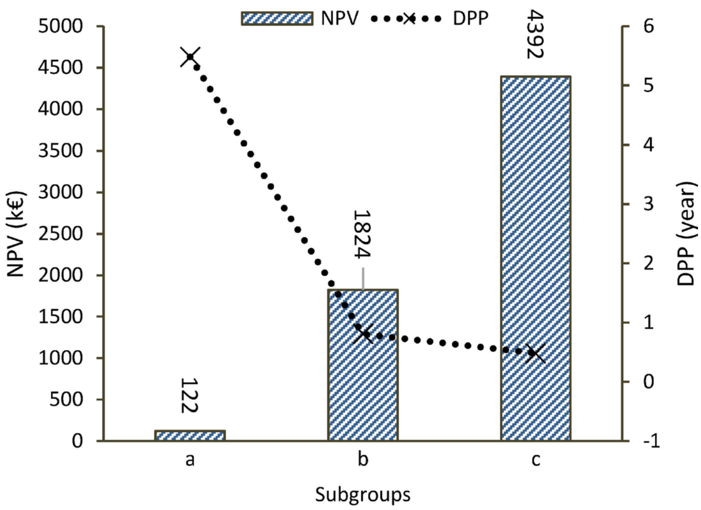

Figure 5. NPV and DPP for different subgroups.

O & M costs in total cost. The yearly O & M costs occupies more than 55% of total cost for the first subgroup, it has also the dominant statue among different kinds of costs for subgroups b (43%). However, the highest share is related to gasification system price for subgroups c.

The economic assessments, based on the indexes of NPV and DPP for three subgroups, are shown in **Figure 5**. It is worth mentioning that NPV is positive for three subgroups and it grows as gasifier scale is extended. NPV is about 122 k€, 1824 k€ and 4392 k€ for subgroups a, b and c, respectively. Moreover, DPP shows the gasification plant in this context is very feasible for Iceland. It has an inversely proportional to the installed capacity. It is around 5.5 years (subgroups a), 9.5 months (subgroups b) and 6 months (subgroups c).

4. Conclusion

In this work, techno-economic of power production plant that utilized syngas from a timber and wood waste gasification process in Iceland was investigated. The technical assessment focused mainly on input waste, and installed power. The economic assessment was conducted relied on the economic indicators of total cost, revenues, NPV and DPP, for three subgroups with different gasifier installed power, 1): 50 kW, 2): 100 kW and 3): 200 kW. The results show that total cost increases as the implemented power is increased. This indicator varies from 1228.6 k€ for subgroups a to 1334.7 k€ for subgroups b and 1479.5 k€ for subgroups c. It should be emphasized that NPV is positive for three subgroups and it grows as gasifier scale is extended. The NPV in subgroup c, is averagely 58% and 97% higher than subgroups b and a, respectively. NPV is about 122 k€, 1824 k€ and 4392 k€ for subgroups a, b and c, respectively. Moreover, DPP has an inversely proportional to the installed capacity. It is around 5.5 years (subgroups a), 9.5 months (subgroups b) and 6 months (subgroups c). Finally, the obtained results confirm that using small scale waste biomass gasification integrated with power generation could be techno-economically feasible for remote area in Iceland.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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