A Techno-Economic Feasibility Assessment on Small-Scale Forest Biomass Gasification at a Regional Level

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Abstract

In recent years public and political awareness to environmental issues and energetic aspects have led to the development of alternative energy resources. The
use of woody biomass from forest management presents a renewable, low-carbon feedstock which can implement alternative sources for energy production. For example, biomass gasification is a prominent conversion route for producing a renewable clean feedstock used for power generation. In 2012, the "burden-sharing" Decree 28/2012 of the Italian Ministry of Economic Development introduced regional targets for Friuli Venezia Giulia region with an increase of 257 ktoe produced from renewable energy equal to 12.7% of the regional consumption. The present work was focused on overall mountain area of this region in the North-East of Italy. The study showed technical and economic aspects of forest combined heat and power (CHP) biomass system with two different types of gasification plants: (i) gasification with combustion engine and (ii) gasification with a Stirling engine. The technical and economic characteristics of small-scale gasification technology was determined using the methodology of Net Present Value (NPV) in order to identify the best technological solution for the construction of a gas plant in a company that processes timber:

From the technical point of view the gasification plant with Stirling engines is a more reliable energy system which is not subjected to strains due to the use of synthesized gas during its normal activity. However, the investment costs are significantly higher (€ 7,429/kWe) when compared to the costs necessary for a gasifier with internal combustion engine (€ 4,040/kWe). The techno-economic feasibility assessment has shown no substantial difference in the remuneration time for both type of gasification plant being in the range of 4-5 year period.

Additional studies are necessary to elucidate both technical and economic aspects and to suggest which type of technology is more suitable on small-scale forest biomass gasification at a regional level.

**Keywords:** forest, wood biomass, gasification, economic analysis

### 1 Introduction

Forests play a key role in the overall socio-economic development providing different material, environmental or occupational benefits and for that reason increasing resources should be dedicated to forest sustainable management and conservation. One potentially valuable by-product from conventional forestry systems which produce wood for constructions and pulp or paper is biomass for energy [Richardson, 2007]. Today biomass provides about 10% of the global energy supply, amounting to around 14 PWh per year, of which the main part (over 80%) originates from wood or shrubs, in form of trees, branches and residues [Chum, 2011; IEA, 2011]. Woody biomass is regarded as a “CO₂ neutral” solid fuel and a promising alternative to decreasing resources of fossil fuels [Zhou, 2006]. Biomass gasification is a prominent conversion route for producing a renewable clean feedstock used for power generation [Wongchanapai, 2012]. Furthermore, use of biomass in district energy creates jobs and promotes social and economic development in local communities [Openshaw, 2010; Yagi, 2011].
In 2011 the energy consumption in Italy was of 168 Mtoe (million tons of oil equivalent), where all renewable energy resources, including hydropower and biomass, accounted for 20.2 Mtoe (about 12%) [Eurostat, 2013]. At the moment, no published data exist on the relative contribution of biomass alone, but some recent estimation report a total potential contribution of 24-30 Mtoe (about 13.6%) [ITABIA, 2008]. The use of agro-forestry biomass can contribute to increased use of renewable sources for energy production considering the latest directives of the European Union (EU) Energy and Environment Policy that established a new framework for renewable sources (Directive EC 28/2009; European Commission, 2009).

The Italian Energy Action Plan of 2010 set a target of at least 17% of total energy generated from renewable sources by 2020 [European Commission, 2009]. In 2012, the "burden-sharing" Decree 28/2012 of the Italian Ministry of Economic Development introduced regional obligations to ensure the accomplishment of national 2020 targets. Regional targets for Friuli Venezia Giulia region are particularly demanding for renewable energy, with a projected increase of 257 tonnes of oil equivalent (12.7% of the regional consumption): +138% in 2020 relative to 2005 [Ministry of Economic Development, 2012].

In relation to targets set both on national and regional level, the quantitative analyses of strategies for utilizing woody biomass energy sources should be performed both evaluating the potential resources of bioenergy in different regions (e.g. forest-rich or with agricultural-land surplus) and identifying the woody biomass demand within forestry industries, and other possible territorial complications. In Friuli Venezia Giulia region the presence of highly discontinuous agricultural activities and issues related to mountain regions make somewhat difficult the exploitation of biomass for the simultaneous production of electricity and heat (cogeneration). This problem is in part related to the use of established technologies that have high power (> 1 MW) requiring significant amounts of biomass (i.e. steam turbines or Organic Rankine Cycle) and it is in part related to the lack of utilities with continuous use of heat throughout the year.

In north Italy is active a constant research of new technologies to make highly applicable small to medium size plants (100-250 kWe) for biomass utilization and more efficient energy conversion. Two different technologies may be usually applied for biomass power generation: (i) gasification with internal combustion engine and (ii) gasification with a Stirling engine. In this way agro-forestry companies could diversify their income rendering it more stable by taking advantages of state incentives for electricity production from biomass. In specific, state incentives and municipal support are higher if the electricity production derives entirely from forestry and agricultural by-products [Ministry of Economic Development, 2012]. These technologies for energy generation allow also the production of biochar, a form of charcoal produced through pyrolysis of carbon-rich biomass. When this material is applied to agricultural lands it increases soil water and nutrient retention as well as enhances its fertility while sequestering carbon [Laird, 2008; Lehmann et al., 2007].

This study was focused on the mountain area of Friuli Venezia Giulia region...
Daniele Dell’Antonia et al.

(North-East Italy). We showed technical and economic aspects of CHP biomass system with a small-scale gasification equipment. The biomass fuel considered in this evaluation was represented by residues of wood processing and wood chips from forest management procedures. The objective of this research was to find out the economic feasibility of CHP system on small-scale level in mountain areas in Italy comparing two different technologies for biomass power generation.

2 Materials and methods

2.1 Study site

The study area is located in the Friuli Venezia Giulia region (North-East Italy) and has a total surface area of 785,648 ha. According to the data of the National Forests Inventory, the regional forests cover an area of 357,224 ha with an average wood withdrawal of 170,000 m$^3$ which is the 5% of raw material requirements in woodworking industries [INFC, 2012]. The regional supply of raw material is dependent on import from foreign countries with a yearly amount of 3,000,000 m$^3$ year distributed as follows: 70% panels (wood pulp), 11% chair industry; 10% furniture; 2% floors and windows and 7% for energy or other uses [Wood Services, 2010].

2.2 Gasification plants

The feasibility study has considered two different types of gasification plants in order to identify the best technological solution for the construction of a gas plant in a company that processes timber (Table 1).

In the first case study was identified a system with nominal power output of 140 kWe formed as follows:
- an updraft gasifier which produces fuel gas from wood chips: in this way it is possible to avoid the use of filtering systems and use biomass with higher moisture content;
- four heat generators for gas burning process (to note: direct contact with the heads of Stirling engines);
- four Stirling engines with electric power unit of 35 kWe each;
- a heat accumulator that acts as a thermal stabilizer and allows the accumulation of hot water.

The functioning of the system is fully automatized; biomass is loaded from inside the reactor and subjected to high temperature with a limited oxygen supply which allows the gasification of introduced materials. The syngas is extracted in the upper part of the reactor and used to move Stirling engines. Besides electricity this engine produces also heat used for warming of water contained within the accumulator.

The second case study has a system with a nominal electric power of 250 kWe and is formed of:
• a downdraft gasifier system with electrostatic filtering system of the syngas;
• a dryer for biomass moisture reduction localized in the inlet of the reactor that uses the heat of the internal combustion engine;
• two sets of diesel engines with nominal power unit of 125 kWe.

In this system the syngas product is extracted at the bottom of the reactor and passed through a series of scrubbers and electrostatic filters that allow the removal of impurities. Consequently, the gas is injected with a small amount of diesel fuel inside the combustion chamber of an internal combustion engine at the end of the piston compression phase. The amount of added diesel fuel allows the ignition of the mixture and starting the engine.

<table>
<thead>
<tr>
<th>Energy</th>
<th>Gasifier with internal combustion engine</th>
<th>Gasifier with Stirling engine</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Power generation efficiency (%)</td>
<td>Power (kW)</td>
</tr>
<tr>
<td></td>
<td>Power generation efficiency (%)</td>
<td>Power (kW)</td>
</tr>
<tr>
<td>Electricity</td>
<td>24</td>
<td>250</td>
</tr>
<tr>
<td>Thermal energy</td>
<td>45</td>
<td>480</td>
</tr>
<tr>
<td>Dispersions</td>
<td>31</td>
<td>295</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>1,025</td>
</tr>
</tbody>
</table>

(1) 7,000 hours/year of energy plant activity.

Table 1 – Technical characteristics of gasification plants.

2.3 A techno-economic feasibility assessment

Through the analysis of data on the thermal and electrical power efficiency of the plant and overall activity hours (7,000 hours/year) it was possible to estimate the total amount of produced energy by the gasifiers. Total electricity produced in this way was directly transferred and used by the electrical network, while the remaining thermal component could be used to meet the energy needs of the company.

In the case of combined gasifier with internal combustion engine part of the produced heat is used to dry the introduced biomass (10-15 % final humidity content). On the contrary, for the system with Stirling engine there are no particular requirements in relation to the humidity of applied fuel and all heat can be re-used in the company for other purposes. In our feasibility assessment was also evaluated the possibility of equipping sawmill with a dryer to allow the re-use of thermal energy. In this way, a part of company's products could be dried directly in situ thus avoiding and reducing the costs associated with use of third-party companies for drying processes.

The technical and economic aspects of small-scale gasification technology was determined using the methodology of Net Present Value (NPV). Profits from
the sale of produced electricity have been calculated considering the base rate of the Ministry of Economic Development in 2012, for the production of electricity from renewable sources (229 €/MWh) added with the incentive for use of heat (40 €/MWh). The used thermal energy has been accounted as non-retrieved costs for the drying of panels by third-party companies (30 €/t). After determining cost and profit items it was calculated the expected cash flow for a 20-year investment period during which remains valid the price for sale of electricity. In addition, profits from electricity sale are not affected by inflation while remaining incomes are subjected to these variations. For a more detailed analysis these incomes, subjected to inflation, were calculated for each year in the whole considered period. The calculated values were presented as incomes less costs deferred in time using an interest rate equal to average of inflation adjustments indexes for the period 1992-2012 (2.7%) [ISTAT, 2014]; using the following function:

\[ CF = I_e - [I_t \cdot (1 + i)^t] - [C \cdot (1 + i)^t] \]  

(1)

Where:
- CF, in €, is the annual cash flow;
- Ie, in €, is the incomes from the sale of electricity energy;
- It, in €, is the incomes from the re-use of thermal energy;
- C, in €, is the cost for the management of the plants;
- i, in %, is the interest equal to average of inflation;
- t, is the time of the cash flow.

Afterwards, we calculated the cash flows, discounted to present value using an interest rate equal to 4% and was determined the net present value (NPV) of the two selected types of plants as follows:

\[ \sum_{t=0}^{n} \frac{CF}{(1+r)^t} \]  

(2)

Where:
- CF, in €, is the annual cash flow;
- r, in %, is the discount rate;
- t, is the time of the cash flow;
- n, is the year of the investment period.

3 Results

The first phase of the economic analysis was focused on the evaluation of individual costs and incomes related to purchase and management of small-scale gasification plants. The total investment cost for purchase and installation of the gasification plant with four Stirling engines was equal to 1,040 M €, while the cost of the gasification plant with internal combustion engines was of 1,010 M € (Table 2).
Techno-economic feasibility assessment

<table>
<thead>
<tr>
<th>Plant</th>
<th>Gasifier with internal combustion engine</th>
<th>Gasifier with Stirling engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier</td>
<td>875,000</td>
<td>850,000</td>
</tr>
<tr>
<td>Dryer</td>
<td>55,000</td>
<td>110,000</td>
</tr>
<tr>
<td>Wood chipper</td>
<td>40,000</td>
<td>40,000</td>
</tr>
<tr>
<td>Connection to electrical network</td>
<td>10,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Expenditures for civil engineering works</td>
<td>30,000</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1,010,000</strong></td>
<td><strong>1,040,000</strong></td>
</tr>
</tbody>
</table>

| Gasifier costs (€/kWe)       | 4,040                                    | 7,429                         |

Table 2 – Investment costs for the construction of gasification plants and associated dryers.

In Table 3 are presented economic accounts relative to costs and incomes of the annual management of gasification plants. Maintenance costs and necessary employment for the plant with Stirling engines account for an annual charge of € 31,900, compared to the gasifier with internal combustion engines where the planned expenses are € 86,580. The relevant difference is due to the high demanding maintenance of internal combustion engine powered with syngas. Due to this issue it is considered the cost of 45 €/MWh produced for full-service maintenance provided by the company which constructs gasification plants with internal combustion engine.

In Table 4, based on the availability of by-products (1100 tons/year) we calculated the amount and the cost of necessary biomass for the operation of gasifiers (40 % humidity): 829 tons/ year and 1,817 tons/year for the plant with the Stirling engine and for the plant with internal combustion engine, respectively. In relation to the re-use of thermal energy process of gasification plants, it is possible to dry a total of 1,600 t/year of plates (13% of the processed products) for systems with Stirling engine and about 700 tons/year of plates (6% of processed products) for gasifiers with internal combustion engine.

<table>
<thead>
<tr>
<th>Gasifier</th>
<th>Incomes (€/year)</th>
<th>Costs (€/year)</th>
<th>Profit (€/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Electricity</td>
<td>Thermal energy</td>
<td>Total</td>
</tr>
<tr>
<td>Gasifier with internal combustion engine</td>
<td>470,750</td>
<td>21,000</td>
<td>491,750</td>
</tr>
<tr>
<td>Gasifier with Stirling engine</td>
<td>263,620</td>
<td>48,000</td>
<td>311,620</td>
</tr>
</tbody>
</table>

Table 3 – Profits and annual costs for the management of gasification plants.
Table 4 – Costs of used biomass for each gasification plant.

At the end of the techno-economic feasibility assessment we concluded that the remuneration and compensation time for the gasification plant with four Stirling engines is of 5 years, after which the NPV starts to have a positive value up to the amount of approximately 1.5 M €. For gasification plants with internal combustion engines the recovery time is equal to 4 years and the NPV value after 20 years results in the range of 1.9 M €.

In case of no re-use of thermal energy the investment would be reimbursed after 7 and 13 years for the plant with internal combustion engine and the one with Stirling engines, respectively. This economic situation is caused by a decrease in profits; the incomes due to the drying of wood panels were not accounted and also due to a lower price of marketed electricity (Figure 1).

4 Conclusions

From the technical point of view the gasification plant with Stirling engines is a more reliable energy system which is not subjected to strains due to the use of syngas during its normal activity. On the other hand, the internal combustion engine is significantly affected by the quality of applied fuel and all uncertainties associated with revision times of these engines are still elevated. Moreover, the re-use of thermal energy for drying processes of the plates could implement the energy efficiency of the simultaneous production of electricity and heat in small-scale plants, compared to the large cogeneration system where most part of heat is dissipated.
The analysis presented in this study could indicate that the investment costs in both analyzed cases are extremely expensive for single companies. The investment cost related to installed power units is greater in case of gasification plant with four Stirling engines (€ 7,429/kWe) than that of gasifier with internal combustion engine (€ 4,040/kWe). The economic analysis of the NPV demonstrated that the installation of gasification plants with internal combustion engine allows reimbursement of investment costs in shorter time compared to gasifier with a Stirling engine. Nevertheless, the use of biomass gasification plants for production of energy could reduce emission of carbon dioxide into the atmosphere and implement carbon sequestration by distributing produced biochar on agricultural land. Many issues must still be explored in terms of techno-economic feasibility, local energy production policies and incentives based on renewable sources as well as development of technologies that improve efficiency of energy systems and the reduction of possible environmental impact.

References


Techno-economic feasibility assessment


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