Nordjylland Power Station: Carbon Footprint Study of Biomass Fueled CHP Station

Yingying Zheng
Stephanie Owyang
Yini Xu
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ABSTRACT

Denmark has a long term sustainability goal of being independent of fossil fuels by 2050. Aalborg Municipality recently acquired the Nordjylland Power Station, a coal – fired plant, and the Municipality would like to replace coal with a renewable source. The main purpose of this study is to assess the environmental performances of straw or wood pellet as a fuel alternative for district heat production for the Nordjylland Combined Heat and Power (CHP) Station. In this study, an environmental impact study was conducted to compare two different biomass types: straw and wood chips with coal, which the power plant is currently using. The results indicates that for producing 1 MJ of heat from the power plant, the CO2-eq from coal is 111.28 g CO2-eq/MJ, from straw is 22.73 g CO2-eq/MJ and from wood pellets is 85.66 g CO2-eq/MJ. The results indict that biomass is a carbon-neutral energy resource and will help the power station become less reliant on coal.
INTRODUCTION

Aalborg Municipality recently purchased the Nordjylland Power Station, a combined heat and power (CHP) plant where the primary fuel source is coal. It is located along the north bank of the Limfjord in Vodskov, Denmark and about 17 km northeast of Aalborg where over 200,000 people reside. According to the Municipality, the station provides Aalborg with 56% of its district heating and is used as a reserve for the town’s electricity.

The station consists of two operational units commissioned in 1977 and 1998 respectively. Unit 3 uses an ultra-supercritical boiler (USC) whose main fuel source is bituminous coal, imported from other countries. The boiler is a once-through tower with double reheat and is cooled by the seawater from the fjord. The hot water supply temperature for district heating is 40-50°C which is quite low for most CHP stations. Currently, the station consumes 223 t/h at full load which yields a maximum district heat capacity of 462 MJ/s and gross electricity capacity of 717 MW.

The European Union’s climate and energy package states its goals to reduce its greenhouse gas emissions by 20% in comparison to its emissions in 1990, increase the amount of renewable energy consumption by 20%, and increase the amount of renewable energy forms in the transportation sector by 10% by 2020. In order to meet these objectives, Denmark must increase their energy consumption to 30% by 2020. Supplementing the EU targets, the Danish National Allocation Plan states the country has set a goal to be 100% carbon-neutral and independent of fossil fuels by 2050. An incremental step is to phase out the use of coal in Denmark by 2030.

Aalborg Municipality plans to make its first investments towards using 100% renewable energy in early 2016 in order to meet the national environmental requirements. This paper will compare the use of straw and wood pellets in the case the power plant converts to a biomass CHP in terms of CO2 emissions, and maximum capacity by conducting a life cycle assessment screening and compare the results to the power station's current production using coal.

LITERATURE REVIEW

Life Cycle Assessments (LCA) is a common technique for assessing the potential environmental aspects involved in the production process of a service. The Judl paper did an in-depth LCA on using wheat straw as a fuel source for district heat production in Denmark. This study was carried out between February and June of 2013. It outlined a very detailed structure of an LCA including a scenario development, life cycle inventory and a comparison to using natural gas and wood pellets. This study was done in a span of four months, so many figures such as regrowing straw are taken from other papers. Some of the references used are from as early as 1999 involving straw production technologies and land use effects. Allen did a similar study analyzing carbon balance in wood pellet manufacturing covering both combustion and regeneration.

METHODOLOGY

Using the emissions information from the power plant, this study will compare it with the potential emissions for straw and wood chips. These emissions are calculated by doing an environmental impact study based on the LCA process for straw and wood pellet/wood chip combination. This assessment consists of four components:
1. Goal and Scope

The goal of this study is to assess the environmental consequences of using wheat straw and wood pellets for district heat production in a CHP power at Denmark.

2. System Boundary Definition and Functional Unit

Figure 1: System Boundary of LCA process

The system boundary presented in Figure 1 illustrates the energy conversion process of the selected biomass (straw or wood pellet), to support the main objective of this study. The system boundary is comprised of key processes, starting from the removal of the biomass, collection and pre-processing (including field transportation and chopping), delivery to CHP storage site, energy production (heat) plus marginal electricity substitution (as a co-product of the system). Slag from burning of straw is found to be 54kg/ton in dry base (Nielsen 2004) and the slag has fertilizer value in the form of P2O5 and K2O. Those nutrient values of slag return to farmland are assumed as ‘avoided product’ which brings a negative contribution to carbon emissions. Transportation distance of slag is assumed to be zero in this study. The functional unit for the LCA is 1 MJ of heat produced from the system.

Key Assumptions:

- Transportation distance is constant for both biomass sources.
- Unlimited biomass
- 100% combustion of Carbon

3. Life Cycle Impact Assessment
As a first step a survey of the potential biomass substrates for direct combustion for heat production. In this study Straw is assumed to have a moisture content of 15% and at this moisture content, straw has a lower heating value (LHV) of 14 GJ/ton at this moisture content. Wood pellets are assumed to have a moisture content of 10% and a LHV of 17.5 GJ/ton (Parajuli 2014). Based on the LHV, 1 ton of straw will produce 827.05 kwh of electricity and 7100 MJ of heat and 1 ton of wood pellets will produce 1094.625 kwh of electricity and 9310 MJ of heat.

4. Interpretation

Finally, summarize and verify the calculate results. These results will be compared to other LCA studies and a conclusion will be discussed based on the findings. After conducting both assessments, the emissions from each source of biomass and the amount of energy each can supply per ton of biomass will be compared.

RESULTS

1. Coal: Baseline Values

Acquisition: Since bituminous coal is found near the Earth's surface, the most common extraction method is open cast, or strip mining. This involves the use of heavy machinery such as draglines, power shovels, wheel excavators, conveyors and large trucks. Other emissions contributors to the excavation process are explosives to break through the surface.

Combustion: Coal is transported from storage to silos where the coal is crushed into a fine dust. A mixture or air and coal is blown into the burner where combustion occurs in the boiler furnace at 1600-1800°C.

<table>
<thead>
<tr>
<th>Process</th>
<th>Amount</th>
<th>CO2 emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g CO2-eq/kwh</td>
<td>g CO2-eq/MJ heat</td>
</tr>
<tr>
<td></td>
<td>min</td>
<td>max</td>
</tr>
<tr>
<td>Coal acquisition</td>
<td>176</td>
<td>289</td>
</tr>
<tr>
<td>Coal combustion</td>
<td>790</td>
<td>1017</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: CO2 Emissions due to coal

Comparing the values in Table 1 to another source, the CO2-eq value is about 111.28 g CO2-eq/MJ (Parajuli 2014). Bituminous coal has a lower heating value (LHV) between 27-30 GJ/ton.

2. Straw

Straw Acquisition: Impacts of straw removal are primarily associated with the perspective, including reduction in the soil fertility and nitrate leaching. It is also found that, if straw has to be removed from the field fuel propose, an equivalent amount of fertilizers should be added (Parajuli 2014).

Composition of straw (85% DM): C (47.3%), N (0.6%), P (0.09%), K (1.5%)
Straw Cultivation:

Soil C sequestration = 1 ton*0.85*47.3%*9.7% = 38.99 kg C = 143 kg CO2-eq

CO2 from avoiding decay = 1 ton*0.85*47.3*44/12 = 1474 kg CO2

CO2 from avoiding decay - Soil C sequestration = 143 - 1474 = -1331 kg CO2-eq/ton

Pre-treatment: In order for the straw to be used in the supercritical boiler, it must be organized into a manageable size for the boiler. This process includes grouping the straw into bales and handling the bales into a machine that feeds the boiler.

Boiling/Combustion Process: The combustion of biomass results in the emission of carbon dioxide, sulfur dioxide and nitrogen oxides. However, since biomass binds carbon dioxide, the carbon dioxide is not considered to contribute to global warming. As the biomass binds carbon dioxide by photosynthesis during its growth, fuel production gives rise to fossil carbon dioxide emissions of various types. The emissions occur primarily during the transportation and processing phases, but also from forestry or agriculture, depending on the origin of the fuel.

Other outputs: Slag is assumed to be reused as fertilizer because of its nutrient value, and ash is supposed to be disposed in landfill sites because of the presence of heavy metals.

<table>
<thead>
<tr>
<th>Process</th>
<th>Amount</th>
<th>Unit</th>
<th>Comments/Remarks</th>
<th>g CO2-eq/MJ heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw cultivation</td>
<td></td>
<td></td>
<td></td>
<td>10.61</td>
</tr>
<tr>
<td>Straw acquisition</td>
<td>-1331 kg CO2 eq/ton</td>
<td></td>
<td></td>
<td>-159.21</td>
</tr>
<tr>
<td>Straw pretreatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baling and Handling</td>
<td>61 MJ</td>
<td>Diesel: 85 g CO2 eq./MJ</td>
<td></td>
<td>0.62</td>
</tr>
<tr>
<td>Chopping</td>
<td>6.46 MJ</td>
<td>Diesel: 85 g CO2 eq./MJ</td>
<td></td>
<td>0.07</td>
</tr>
<tr>
<td>Straw transportation</td>
<td>170 tkm</td>
<td>0.85 * 200 km: 130 g CO2 eq./km</td>
<td></td>
<td>2.64</td>
</tr>
<tr>
<td>Straw combustion</td>
<td>1474 kg CO2 eq/ton</td>
<td></td>
<td></td>
<td>176.32</td>
</tr>
<tr>
<td>Slag back to the field</td>
<td></td>
<td></td>
<td></td>
<td>-0.04</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>20.39</td>
</tr>
</tbody>
</table>

Table 2: LCA of Straw

3. Wood Chips

Wood acquisition: Forest wood residue and/or agricultural woody residue is often used. A potential source of these raw materials is importing from Latvia which is 845 km away from Denmark.

Wood pre-treatment: Trees are cut into logs on site and transported to a preparation site by using trucks. In the preparation site, the barks will be removed first for some other usage (as energy fuel for pre-treatment). After, the wood will be dried to reduce its moisture content for easier combustion in the CHP.
Boiling/Combustion Process: The wood chips are fed into the boiler and incinerated boiling water and producing steam for district heating. The emission from combustion is calculated based on the carbon content in the wood.

<table>
<thead>
<tr>
<th>Process</th>
<th>Amount</th>
<th>Unit</th>
<th>Comments/Remarks</th>
<th>g CO2-eq/MJ heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood pellets acquisition</td>
<td>-1299.27</td>
<td>kg CO2 eq/ton</td>
<td></td>
<td>-138.07</td>
</tr>
<tr>
<td>Wood pellets pretreatment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drying</td>
<td>3215</td>
<td>MJ</td>
<td>Diesel: 85 g CO2 eq./MJ</td>
<td>29.04</td>
</tr>
<tr>
<td>Chopping</td>
<td>6.46</td>
<td>MJ</td>
<td>Diesel: 85 g CO2 eq./MJ</td>
<td>0.03</td>
</tr>
<tr>
<td>Wood transportation</td>
<td>861</td>
<td>tkm</td>
<td>0.85 * 200km: 130 g CO2 eq./km</td>
<td>11.89</td>
</tr>
<tr>
<td>Wood pellets combustion</td>
<td></td>
<td></td>
<td></td>
<td>175.35</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>78.24</td>
</tr>
</tbody>
</table>

Table 3: LCA of Wood Pellet

4. Summary

Figure 2 (below) shows the comparison between the three fuel sources. Both straw and wood chips produce less CO2 emissions than coal.

Figure 2: CO2 Emissions Summary
Biomass acts as a storable, renewable energy source that is important in conjunction with the fluctuating renewable energy technologies such as solar panel, wind power, and wave energy. A straw-fired CHP plant producing both heat and electricity is a carbon-neutral process, which will help Denmark to reach its goal by 2050. Straw-fired CHP plant will take a big part of Denmark's future energy mix. However, due to limited availability of biomass resource and increasing number of biomass-fired CHP plants, the cost of running a biomass CHP plant will be increasing.

Our results show that both biomass sources produce less carbon emissions than coal, however, their heating value is about half the value of coal. A majority of the carbon emissions from the biomass sources are from combustion and cultivation stages. In the combustion stage, CO2 is immediately released into the atmosphere as a byproduct. Since straw has a lower energy content, the thermal energy production is much smaller than wood pellets. Therefore, straw is a more favorable source in terms of carbon emissions.

Straw has a shorter harvesting period than wood pellets, and therefore will be able to be replaced at a faster rate. It can also be grown locally in Denmark, which will decrease transportation costs and emissions.
Comparing our CO2 emissions results with the Vattenfall’s Life Cycle Assessment paper, the distribution between operation, transportation and infrastructure are very similar. The CO2 due to combustion is between 80-90%, and according to Vattenfall, it is 80%. However, according to the Vattenfall studies, wood chips produce less carbon emissions than straw. This variation can be due to the differences in transportation cost. Since we assumed we would be getting our straw locally, and importing our wood chips, the difference in transportation costs are very different.

The Nordjylland Power Station currently uses 118 t/h of coal in Unit 3. If the power plant were to use 100% of either straw or wood chips, they would use 236 t/h and 189 t/h respectively. However, most CHP stations do not use only one type of biomass. The Avedore power station currently uses only 6% straw. The Herning power plant, a 100% biomass station, also uses a mix of wood chips and wood pellets, which is a 7:3 ratio.

Difficulty converting coal to biomass (challenges):

- Economic

  Equipment cost. Because biomass needs more storage space, more money has be spend on silo construction.

  Transportation cost: The energy content of coal is almost doubles the energy content of straw, which means the transportation cost will be higher for biomass fired CHP.

  Competition for biomass between other power stations

- Environmental

  Burning biomass emits certain amounts of air pollution and the power plant has to meet biomass CHP emissions regulation

Uncertainties/Limitations:

- Transportation: Accurate model is needed to model carbon footprint of transportation section.

- Slag back into the field (transportation back to the field)

- Availability of biomass, geographically and seasonally
REFERENCES


*DOE’s "Sector-Specific Issues and Reporting Methodologies Supporting the General Guidelines for the Voluntary Reporting of Greenhouse Gases under Sections 1605(b) of the Energy Policy Act of 1992"


APPENDIX

Table A: Straw Baseline Values

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference flow (wheat Straw)</td>
<td>1</td>
<td>ton</td>
</tr>
<tr>
<td>LHV of Straw</td>
<td>14</td>
<td>GJ/ton</td>
</tr>
<tr>
<td>Moisture Content of Straw</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Electrical Efficiency</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Electricity production</td>
<td>827.05</td>
<td>kwh</td>
</tr>
<tr>
<td>Input Electricity</td>
<td>110</td>
<td>kwh</td>
</tr>
<tr>
<td>Net electricity output</td>
<td>717.05</td>
<td>kwh</td>
</tr>
<tr>
<td>Heat production</td>
<td>7140</td>
<td>MJ</td>
</tr>
<tr>
<td>Input Heat</td>
<td>40</td>
<td>MJ</td>
</tr>
<tr>
<td>Net heat output</td>
<td>7100</td>
<td>MJ</td>
</tr>
</tbody>
</table>

Table B: Wood Pellet Baseline Value

<table>
<thead>
<tr>
<th></th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference flow (wood pellets)</td>
<td>1</td>
<td>ton</td>
</tr>
<tr>
<td>LHV of Wood</td>
<td>17.5</td>
<td>GJ/ton</td>
</tr>
<tr>
<td>Moisture Content of wood</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>Electrical Efficiency</td>
<td>0.25</td>
<td></td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>Electricity production</td>
<td>1094.625</td>
<td>kwh</td>
</tr>
<tr>
<td>Input Electricity</td>
<td>110</td>
<td>kwh</td>
</tr>
<tr>
<td>Net electricity output</td>
<td>984.625</td>
<td>kwh</td>
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<tr>
<td>Heat production</td>
<td>9450</td>
<td>MJ</td>
</tr>
<tr>
<td>Input Heat</td>
<td>40</td>
<td>MJ</td>
</tr>
<tr>
<td>Net heat output</td>
<td>9410</td>
<td>MJ</td>
</tr>
</tbody>
</table>