The Potential for CO₂ Reduction of Energetically Used Landscape Conservation Materials and Green Waste in the County Marburg-Biedenkopf, Germany

A Thesis submitted to
the Faculty of Engineering Cairo University and Kassel University
in Partial Fulfillment of the Requirements for the Degree of
Master of Science
in
RENEWABLE ENERGY AND ENERGY EFFICIENCY
Order of Presentation

I. Introduction

II. Energetic use of biomass in Germany

III. Determination of green waste utilization

IV. Determination of the potentials of green waste

V. Development considerations

VI. Transferability of the concept to the Jamaican context.

VII. Conclusion

VIII. References
I. Introduction

- Definitions
  - Energetically used green waste: Extraction and conversion of the contained energy to useful forms such as heat and power.
  - Green waste and landscape conservation material (GWLCM): Leaf material, old bedding, wood and non-woody prunings, grass clippings, garden, park, hedge and verge waste, of a kind that is not particularly cultivated for the express use in energy conversion.
  - Not considered is: kitchen and food waste, tree stumps, tree roots, agricultural crop residue, forestry residue.
III. Significant sources of green waste and landscape conservation material

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I. Introduction

I.3 Problem Statement

The full potential of bio-waste material including GWLCM is mostly underutilized.
I. Introduction

I.4 Relevance

- Traditional methods of waste disposal are unsustainable
- Dwindling fuel quantities threaten energy security in countries around the world
- Risk of air, soil and ground water contamination, increased health risks to plant, animal and human health, ecosystem destruction, etc.
- Early initiatives provide smooth transition from traditional energy sources to alternate sources with little to no disruption to economies.
- Increased energy security
I. Introduction

I.5 Methodology

- Literature review
  - Legislation
  - Technology
  - Biomass trends
  - Power utilities
  - Waste management authorities
- Field visits
- Quantitative assessments of gathered data
I. Introduction

I.6 Constraints

- Language barrier in obtaining information directly related to Landkreis Marburg Biedenkopf (LMB)
- German-English translations needed

- Access to information regarding the Jamaican case study.
II. Energetic use of biomass in Germany

II.1 Contribution of Biomass in Germany?

- Approximately 71.7% of total renewables contribution
- Approximately 7.7% of overall final consumption

Heat and power production from biomass includes sewage and landfill gas and the biogenic fraction of waste.

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Final Energy Consumption Germany 2010

Source: Bioenergy in Germany: Facts and Figures 2012

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Supply from Renewables- Germany 2010

- Biomass (heat) 45%
- Biomass electricity 13%
- Biofuels 13%
- Wind power 14%
- Hydropower 7%
- Solar thermal 2%
- Geothermal 2%
- Photovoltaics 4%

Source: Bioenergy in Germany: Facts and Figures 2012

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II. Energetic use of biomass in Germany

II.2 Major conversion technologies for biomass currently used
II.3 Main technology used for treating green waste

Fluidized Bed Incinerator

Source: http://www.renewable-energy.uk.net/biogas/definition_digestor.htm
III. Determination of green waste utilization

III.1 Benefits

- Energetic benefits:
  - Power
  - Heat

- Material benefits:
  - Compost
  - Recycling plant nutrients
  - Products for improving soil functions
  - Carbon sequestration
<table>
<thead>
<tr>
<th>Rated Average Annual Capacity</th>
<th>Basic Tariff</th>
<th>Substance Tariff Class I</th>
<th>Substance Tariff Class II</th>
<th>Gas Processing Bonus (Section 27(^c)(2))</th>
<th>Bio-waste Fermentation Installations (^5) (Section 27(^a))</th>
<th>Small Manure Installations (Section 27(^b))</th>
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<tbody>
<tr>
<td>[kW(_{e})]</td>
<td>[ct/kWh]</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(\leq 75) (^4)</td>
<td>14.3</td>
<td>6</td>
<td>8</td>
<td>(\leq 700) standard cubic meter (scm)/h: 3</td>
<td>16</td>
<td>256)</td>
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<tr>
<td>(\leq 150)</td>
<td></td>
<td></td>
<td></td>
<td>(\leq 1,000) scm/h: 2 (\leq 1,400) scm/h: 1</td>
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<td>(\leq 500)</td>
<td>12.3</td>
<td></td>
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</tr>
<tr>
<td>(\leq 750)</td>
<td>11</td>
<td>5</td>
<td>8 / 6 (^4)</td>
<td></td>
<td>14</td>
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<tr>
<td>(\leq 5,000)</td>
<td>11</td>
<td>4</td>
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<tr>
<td>(\leq 20,000)</td>
<td>6</td>
<td>-</td>
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</table>

Source: Tariffs, degression and sample calculations pursuant to the new Renewable Energy Sources Act (Erneuerbare-Energien- Gesetz - EEG) of 4 August 2011 ('EEG 2012')
III. Determination of green waste utilization

- III.3 Challenges to utilization:
  - Low energy content
  - Inconsistent supply based on growing season
  - Conversion technology not optimized for substrates
  - Logistics
IV. Determination of the potentials of green waste

IV.1 Carbon Dioxide Emissions Saving Development (CdESD) Tool

- Based on Handbook of Electric Power Calculations & Dr. A. Kaupp “5 Steps to tons of CO$_2$ mitigated”
- Phyllis database Research Center of the Netherlands (ENC)
- Creates various scenarios of biomass substrates and fossil fuels
- Supports decision making
- User friendly
- Flexible
IV.2 Sample of formulas used in model

- Cost of fuel $/MJ = ($cost/tonne)/[(1000 kg/tonne)(heating value MJ/kg)]

- Total heat input to boiler = (fuel kg/h)(fuel heating value MJ/kg) = MJ/h

- Net generating-unit power output (kW) = output from generator kW - electric loads of plant auxiliaries kW

- Net Heat Rate of the Generating Unit (MJ/kWh) = (Total heat input to boiler MJ/h)/(Net power output of generating unit kW)
IV.3 Sample of carbon emissions formulas

- Maximum Carbon Emission (kg) = Fuel carbon content (%) * 3.6667
- Total Residue (kg) = Ash content / [1 - remaining carbon fraction (%)]
- Remaining Carbon (kg) = Remaining Carbon fraction * Total residue
- Actual Carbon emissions (kg) = Max. Carbon emissions – Remaining Carbon

The factor 3.6667 is derived from the stoichiometric equation that 1 kg mol of Carbon weighs 12 kg and generates 1 kg mol of CO2 weighing 44 kg (1 atom Carbon - 12 g/mol 2 atoms Oxygen - 32 g/mol)
IV.4 Cycles assumed in model

Rankine Cycle

Organic Rankine Cycle

### Scenario Data Input

#### Scenario Name
- **Base Case**
- **Green Waste**
- **Higher Heating Value**
  - **High**
  - **Average**
  - **Low**

#### Key Model Assumptions
- Conventional power plant, no carbon capture
- Only selected waste stream is combusted, no co-combustion
- All the water is in its liquid state at the end of combustion
- High end of the fuel higher heating value range
- Average of the fuel higher heating value range
- Low end of the fuel higher heating value range

#### Load Profile
- **Annual Power Demand**
  - Power demand for Marburg-Bienenkopf: 25000 kW
- **Peak Load Power Demand**
  - Maximum load required of system: 24500 kW
- **Average Power Load**
  - Load exceeded 100% of the time. Approx 27-33% of peak

#### Base Case
- **Select Reference Fossil Fuel**
- **Select Higher Heating Value**

#### Generating Unit
- **Unit/Plant Rating**
  - 1.0 MW
- **Unit Lifetime**
  - 50 yr
- **Availability Factor**
  - Online Hours: 80% %
- **Internal Plant Power Requirements**
  - Plant auxiliaries including boiler: 15.00% %
- **Fuel Price per unit quantity**
  - $/tonne: 80 e/m
- **Heat input to System**
  - Assumption value: 8000000 MJ/h
- **Plant Efficiency**
  - Industry efficiency standard: 38-47% %
  - Industry standard 60-75% thermal conversion: 39.0% %

#### Economics of Plant
- **Total installation Capital Costs**
  - $4,500,000.00
- **Annual Levelized Fixed Charge Rate**
  - Including return, depreciation, taxes, insurance approx 15-20%, 5% lower for publicly owned plants: 10% %
  - Assume 0.83% of total installation capital: 3.75E+04 $/yr

#### Green Waste Comparison
- **Select Waste Stream**
- **Select Higher Heating Value**

#### Generating Unit
- **Unit/Plant Rating**
  - 1.0 MW
- **Unit Lifetime**
  - 50 yr
- **Availability Factor**
  - Online Hours: 80% %
- **Internal Plant Power Requirements**
  - Plant auxiliaries including boiler: 15.00% %
- **Yearly Available Quantity**
  - Available green waste: 8000000 kg/yr
- **Fuel Price per unit quantity**
  - $/tonne: 80 e/m
- **Plant Efficiency**
  - Industry efficiency standard: 20-25% %
  - Industry standard 60-75% thermal conversion: 20.0% %

#### Economics of Plant
- **Total installation Capital Costs**
  - $7,500,000.00
- **Annual Levelized Fixed Charge Rate**
  - approx 15-20%, 5% lower for publicly owned plants: 10% %
- **Total Annual Fixed Operation and Maintenance Costs**
  - $62500
V. Determination of the potentials of green waste

V.2 Scenario LMB Coal vs Grass/Plant Composite

Based on 2MW power plants

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Scenario LMB Comparison - Emissions per Ton Fuel

<table>
<thead>
<tr>
<th>Tonne CO₂</th>
<th>Coal</th>
<th>Composit G/P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>5573.025</td>
<td>5358.553</td>
</tr>
<tr>
<td>Average</td>
<td>5687.077</td>
<td>5690.593</td>
</tr>
<tr>
<td>High</td>
<td>5499.821</td>
<td>5698.715</td>
</tr>
</tbody>
</table>

Legend:
- Base Case
- Green Waste
Scenario LMB: Heating Value Comparison
(MJ/kg)

- **Coal**
  - Low: 25.05
  - Average: 31.733
  - High: 37.044

- **Composit G/P**
  - Low: 16.357
  - Average: 19.509
  - High: 21.962
Scenario Comparison- Energy Potential

Energy Content per tonne Fuel

- Base Case
- Green Waste

Actual Energy Yield

- Base Case
- Green Waste

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Top Level Results Scenario: Coal, High vs Plant/Grass Composite, High

- 1 tonne fossil fuel =
  - 3438.146 kWh = 3.138 tonnes CO2 emitted

- 1 tonne green fuel =
  - 1132.416 kWh = 3.969 tonnes CO2 emitted
Potential Energy Recovery from Waste Digestion

![Bar chart showing total potential energy yield (kWh) and actual yield (kWhth) for various waste materials.](chart.png)

- Wildflower growth
- Silphium perfoliatum
- Poultry manure
- Landscape management
- Clover
- Legume mix
- Lupines
- Lucerne grass
- Horse dung
- Phacelia
- Cow dung
- Liquid cow manure
- Sheep dung, goat dung
- Pig dung
- Liquid pig manure
- Straw
- Winter beet

**Legend:**
- **Actual Yield (kWhth)**
- **Total Potential Energy Yield (kWh)**
Scenario Jamaica, Cost Comparison: Own & Operate Plant
Oil = U$480/tonne, Green Waste = U$100/tonne

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Average</th>
<th>High</th>
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</thead>
<tbody>
<tr>
<td>Oil</td>
<td>3590.404557</td>
<td>2115.228515</td>
<td>1938.509183</td>
</tr>
<tr>
<td>Compost G/P</td>
<td>1882.304274</td>
<td>1660.202881</td>
<td>1531.468547</td>
</tr>
</tbody>
</table>
V. Development considerations

- Logistics
  - Collection
  - Sorting & distribution
- Supply availability
- Incentives
- Energy content
- Magnitude of scale
- Future price of material
- Available technology
VI. Transferability of the concept to the Jamaican context.

- Good potential
- Early stages in renewable energy and waste management sectors
- Plans for upgrading facilities
- Guiding documents being drafted
- Incentives
- Political will
- Not ready for this type of energy use
VII. Conclusion

- Good potential for CO₂ emissions reduction
- Best used in summer and growing seasons
- Best used by waste management sector
- Early investors may benefit
- Loses economic edge with increased green fuel price
Thank you for your attention

For further information contact:
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Email: renee.britton@gmail.com

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VIII. References

- **Bioenergy in Germany: Facts and Figures January 2012** Federal Ministry of Food, Agriculture and Consumer Protection publisher Fachagentur Nachwachsende Rohstoffe e.V. (FNR) OT Gülzow · Hofplatz 1 · 18276 Gülzow-Prüzen · Germany


- **Methane Digesters for Fuel Gas and Fertilizer with Complete Instructions For Two Working Models** by L. John Fry


- Discussion image https://ctools.umich.edu/access/content/user/angelaas/Public%20Portfolio%20Files/clipart_of_15186_sm_2.jpg
