MODELING AND PERFORMANCE ANALYSIS OF A HYBRID BIOGAS-PHOTOVOLTAIC SYSTEM

Analysis of the Electrical and Thermal System in Eichhof Center, Germany – A Case Study in Jordan

By,

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Outline

- Introduction
- Modeling of the Energy System in Eichhof Agricultural center
- Proposed Scenario
- Case study in Jordan
- Conclusions
- Recommendations for future work
Introduction
Introduction – Objectives

1. To realize the optimum scenario in which a mix of two kinds of renewable energy resources, one of which is an intermittent source and the second is a provider of base load.

2. To determine whether the studied system and the integration of biogas and PV can be implemented in different environmental conditions.
Introduction – Scope

1. Modeling the energy system of the Eichhof center through simulating the electrical energy and heat producers (biogas and PV) and the electrical and heat energy consumers.

2. Evaluating the performance of the system in Eichhof at the current situation and proposing an improved scenario that would bring the system closer to the goals stated previously.

3. Applying the simulation that is created for Eichhof on the system that is chosen in the MENA region.
Modeling of the Energy System in Eichhof Agricultural center
Modeling of Eichhof Agricultural center – The site

- Eichhof castle
- Residential premises
- Offices
- Workshops
- Stabling
- Classroom
- Laboratories
- Silage
- Biogas plant
- Micro gas Turbine
- Fermenter
- Manure storage
- PV system
Modeling of Eichhof Agricultural center – System
Modeling of Eichhof Agricultural center – Load
Modeling of Eichhof Agricultural center - Simulation

The simulation included three main parts:

1. Biogas process modelling

2. PV system modelling

3. System analysis and suggested future scenario modelling
Modeling of Eichhof Agricultural center – Biogas

<table>
<thead>
<tr>
<th>Calculated biogas (m³)</th>
<th>Actual biogas (m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>264,600</td>
<td>267,175</td>
</tr>
</tbody>
</table>
Modeling of Eichhof Agricultural center – PV

In

Out
Penetration level

Electricity: 101.1% in total

- PV: 34%
- Biogas: 66%

Heat: 17.86% in total
- Biogas: 18%
- Natural gas: 82%

141.7% for BG consumers
Correlation – electrical

Correlation coefficient = 0.0324
Modeling of Eichhof Agricultural center - Results

Correlation – thermal
Modeling of Eichhof Agricultural center - Results

Biogas availability

In total: 76.33%
Proposed Scenario
Proposed Scenario - Results

Substrate management
Proposed Scenario – Control Strategy

1. Load (L)
2. Difference: \( R = (PV - L) \)
   - If \( R > 0 \):
     - Yes: To battery
   - If \( R \leq 0 \):
     - No: Read inputs: CHP, T
     - Divide to two parts
     - \( R2 = \frac{R \times CHP}{(CHP + T)} \)
     - \( R1 = \frac{R \times T}{(CHP + T)} \)
     - Difference: \( F = (R2 - Q_f) \)
       - If \( F > 0 \):
         - Yes: \( F = 0 \)
       - If \( F \leq 0 \):
         - No: \( F = |F| \)
     - \( R2 = R2 + F \)
     - \( R1 = R1 - F \)
     - Send signal to CHP
     - Send signal to turbine
     - Fermenter heating requirements (\( Q_f \))
Proposed Scenario – Results

Residual load from PV
Proposed Scenario - Results

Correlation – electrical (biogas + PV)

Correlation coefficient = 0.9515
Proposed Scenario - Results

Correlation – electrical (plus battery)
Proposed Scenario - Results

Correlation – thermal (from biogas)
Proposed Scenario - Results

Biogas availability

In total: 98%
Case study in Jordan
The Hammoudeh dairy farm is located in Al-Khaldieh in the Al-Mafraq city.

<table>
<thead>
<tr>
<th>Longitude</th>
<th>36°17'22&quot;E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>32°9'58&quot;N</td>
</tr>
</tbody>
</table>

3000 dairy cows

Electrical consumption reaches 4,000,000 kWh per year
### Case study in Jordan – Available potential

#### Biogas properties

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amount</td>
<td>14600 m³/yr (40 m³/day)</td>
</tr>
<tr>
<td>Density</td>
<td>900 kg/m³</td>
</tr>
<tr>
<td>TS</td>
<td>15 %</td>
</tr>
<tr>
<td>VS</td>
<td>10.41%</td>
</tr>
<tr>
<td>V_f (minimum)</td>
<td>4800 m³</td>
</tr>
<tr>
<td>T_f</td>
<td>38 °C ± 2 °C</td>
</tr>
</tbody>
</table>

#### Potential for PV

![Graph showing potential for PV]
Case study in Jordan - Simulation
## Case study in Jordan - Results

### scenario one: more biogas

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily biogas production</td>
<td>1276.5</td>
<td>m³/day</td>
</tr>
<tr>
<td>Total biogas produced</td>
<td>4.659 \times 10^5</td>
<td>m³/year</td>
</tr>
<tr>
<td>Maximum turbine electrical power output</td>
<td>82</td>
<td>kW\textsubscript{el}</td>
</tr>
<tr>
<td>Maximum turbine thermal output</td>
<td>154</td>
<td>kW\textsubscript{th}</td>
</tr>
<tr>
<td>Maximum PV power output</td>
<td>109.7</td>
<td>kW</td>
</tr>
<tr>
<td>Peak of supply</td>
<td>188.4</td>
<td>kW</td>
</tr>
<tr>
<td>Total electrical energy production</td>
<td>905</td>
<td>MWh</td>
</tr>
<tr>
<td>Total thermal energy generation</td>
<td>1350</td>
<td>MWh</td>
</tr>
<tr>
<td>Penetration level of RE</td>
<td>22.64</td>
<td>%</td>
</tr>
<tr>
<td>Share of the minor source (in total)</td>
<td>35.09</td>
<td>%</td>
</tr>
</tbody>
</table>

### scenario two: more PV

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily biogas production</td>
<td>1276.5</td>
<td>m³/day</td>
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<tr>
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</tr>
<tr>
<td>Maximum turbine thermal output</td>
<td>154</td>
<td>kW\textsubscript{th}</td>
</tr>
<tr>
<td>Maximum PV power output</td>
<td>1645</td>
<td>kW</td>
</tr>
<tr>
<td>Peak of supply</td>
<td>1724</td>
<td>kW</td>
</tr>
<tr>
<td>Total electrical energy production</td>
<td>4.2</td>
<td>GWh</td>
</tr>
<tr>
<td>Total thermal energy generation</td>
<td>1350</td>
<td>MWh</td>
</tr>
<tr>
<td>Penetration level of RE</td>
<td>105</td>
<td>%</td>
</tr>
<tr>
<td>Share of the minor source (in total)</td>
<td>19</td>
<td>%</td>
</tr>
</tbody>
</table>

### PV power

![PV power graph]

**PV power:**

- **scenario one: more biogas**
- **scenario two: more PV**
# Case study in Jordan - Results

## Economical analysis

1 Jordanian Dinar (JD) = 1.07 Euro (€)

<table>
<thead>
<tr>
<th></th>
<th>1st scenario</th>
<th>2nd scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dominating renewable energy source</td>
<td>Biogas</td>
<td>PV</td>
</tr>
<tr>
<td>Share of the other source</td>
<td>35% PV</td>
<td>19% biogas</td>
</tr>
<tr>
<td>Penetration level of both sources</td>
<td>22.64%</td>
<td>105%</td>
</tr>
<tr>
<td>Total investment (€)</td>
<td>1,319,100</td>
<td>5,783,300</td>
</tr>
<tr>
<td>Total installed capacity (MW)</td>
<td>0.22</td>
<td>1.65</td>
</tr>
<tr>
<td>LCE (€/kWh)</td>
<td>0.195</td>
<td>0.146</td>
</tr>
</tbody>
</table>

Electricity price: 0.046 JD/kWh
Conclusions

• The hybrid biogas/PV system in Eichhof shows very high prospects with suitable control systems and biogas is able to provide a flexible supply based on demand. Together, PV and biogas are able to almost completely cover the load.

• In Jordan, three factors render the project feasible: a relatively high installed capacity, a high share of PV and a feed-in-tariff higher than 0.21 €/kWh.
Recommendation for future work

- More complex model for fermentation process modelling
- Develop and design the control strategy
- More detailed power study
Thank you for your attention