Evaluation and design of a solar-biomass hybrid dryer. A case study for Murcia Spain

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Spin-off Workshop

Prepared by: José Párraga
Supervised by: Dr. Rafael Jiménez Castañeda
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  - Location, product & clients
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  - Biomass
  - Drying process
  - Drier components

- Case study: Methodology
  - Drying curves
  - Energy & water requirements
  - Selection of drier components
  - Simulation
  - Economic analysis

- Results and conclusions
Purposes & Objectives

POST – HARVEST LOSSES (30-50%)
* Poor handling facilities
* Processing technologies
* Lack of infrastructure

POLLUTION
* Greenhouse emission reduction
* Replacement of fossil fuel by RE sources

* Optimize solar-biomass drying system
* Faster drying process
* Reducing wastage
* Adding value to farms
Market potential for dehydrated products

- Fruit snacks are among the best performing products in sweet and savory snacks in Europe
- EU - largest importer of dehydrated fruits
- Worldwide - projected value gains > 5%
- Asia - projected value gains > 13%
- Latin America – Up to 20%

Source: Euromonitor
Design of Solar-Biomass Dryer for Broccoli in Murcia Region (Spain)

Location: Province of Murcia, Southeast of Spain

High average annual solar radiation - 1850 KWh/m²

High number of agricultural cooperatives

Potential clients: Agricultural cooperatives
* FECOAM
* Agromediterranea Hortofruticola

Fruit and vegetable leader companies
20,000 ha of production
Experience in production & processing goods

Type of vegetable: Broccoli
Popular vegetable - High glucosinolates content:
- Stop cancer
- Protect DNA from oxidative damage by toxins

High market demand (375,000 tns) – 75% in Murcia
High market price, between 1.5 and 2 € per 50 grams of dried product

http://www.foodsfromspain.com/
Solar drying

• Removal of water content:
  ✓ Provide Latent heat evaporation
  ✓ Extraction of water vapour from the products
• Effective alternative to traditional sun drying methods
• The most common method for dehydration of food

Major drawback:
it can only be used during the daytime.

http://nepalsolar.com/products.php
Biomass as Energy Source for Heat

- Spain: 32 pellets plants - 150,000 tn
- Huge potential: market for olive stones
- 2013: 8 million tons olives (15% pellets)
- De-stoning olives before oil extraction
- Special design combustion boilers

Source: www.dondeviajar.net
Solar – Biomass Hybrid Drying

Advantages compared to solar energy systems:
- Continuous year-round operation
- 60-80% reduction in drying time
- Improves the financial viability

Examples of Real Life Applications
- Solar-Biomass Hybrid Cabinet Dryer, Thailand, Commercial; Asian Institute of Technology (AIT), Thailand
- Solar-Biomass Hybrid Cabinet Dryer, Nepal, Research Centre for Applied Science (RECAST),
- FD-50 Solar-Biomass Hybrid Cabinet Dryer, Philippines, Research of Solar Laboratory at UPD/UPLB

Drying process (I)

Heat Transfers: Conduction, convection & radiation

3 main steps: * Pre drying processing * Drying treatment * Post-drying treatment.

Main factors: Temperature / airflow / velocity of drying air / relative humidity / material size

Phase I:
• Heat up the material till the drying temperature is achieved
• The product surface is saturated with vapor
• Lasting till there is enough water in the product surface

Phase II:
• Decrease in the rate period as the surface is not vapor saturated
• Moisture diffusion controlled by the internal liquid movement

Phase III:
• Falling rate drying
• Moisture flow from the interior to the surface decreases
• Lasting till an equilibrium is achieved (drying stop)

Key factor: Drying rate increases with Temperature, reducing drying time

Source: (Bellesiottis et al, 2011)
Drying process:

- Transfer of heat to ensure the products get the latent heat of vaporization
- Extraction of water vapor from the goods
- Air velocity of 0.1 m/s - adequate for drying most food products.
Solar-Biomass Drier Components

Solar flat collectors

- Absorbs the incoming solar radiation
- Convert it into heat
- Transfers the heat to a fluid
- Oriented and sloped properly

- Absorbing plate (aluminum, cooper, steel)
- Fluid
- Top transparent cover
- Edge and back insulation
- Enclosure that forms a casing.

Conversion factor & Heat loss coefficient

https://newenergyportal.wordpress.com/category/solar-energy/
Solar-Biomass Drier Components

**Biomass boiler**

- Integrated with the solar drier system
- More reliable and economical system
- Solar collectors as the main heating system
- Biomass boiler as the heating backup.

- Use of different types of biomass
- Special design for olive stones
- Reduce the costs for generating heat

http://www.ergomalternative.com/
Solar-Biomass Drier Components

Air treatment unit (ATU)

- Equipment designed to meet the demand for installations with special air requirement
- Automatically regulate temperature & moisture
- Removal of excess moisture: Moisture separator unit (condensed water drained off)
- Hot & Cold sections: to heat / cold the input air with the use of heat exchanger batteries
- Fan to circulate the air to the drying chamber
- Input data: Mass flow / water T/ Moisture & T (air)
- Output: Batteries, blower, condenser, compressor

Source: www.scielo.br
Solar-Biomass Drier Components

Drying chamber

- Commercial units to dry up products:
  (fruits, vegetables, fish, meat, plants)
- ATU - provide the hot air
- Control Temp. & humidity by ATU

http://www.termoplin.rs/gallery_dryers_fruits_vegetables.html
To design the proper drying process:
- Initial drying conditions
- Drying curves
- Optimum moisture removal rate
- Drying time

Most dry vegetables: Moist. content < 20%

To optimize the drying process the right amount of moisture removal is necessary

Special aim: to retain initial GLs content

Maldonado (2003): T=60ºC & WC=15%
Low GLs degradation rate

Similar conclusion (Mrkic et al. 2010)

Target: Drying with 60ºC till 15% WC
Drier Requirements For The Process: Drying Time

(Maldonado et al 2003) research

➤ Drying curves at several dry bulb temperature (60, 70 and 80ºC) were constructed.

➤ The moisture in fresh broccoli was 92.11%.

➤ When the drying temperature is higher, the moisture decrease in the solid is greater.

➤ Most suitable constant-rate zones at 60 ºC

➤ Conclusion: The equilibrium humidity level was reached after three hours of drying at 60ºC.

(Deanna 1992) research – similar results (2.5 hrs)
Energy Requirements For The Process: Heat Transfer

- Determination of the amount of heat required to dry up broccoli

Assumptions:
- 90.7% as initial moisture content
- 15% as final moisture content
- 890.5 gr of moisture removed per kg
- $C_p$ of 4.01 kJ/kg°C, as specific heat capacity
- Initial temperature of the broccoli = 25°C
- Drying temperature = 60°C for 3 hours.

Latent heat evaporation (water) = 2257 KJ/kg

Heat energy required for each kg of broccoli:

$$\text{Heat required} = (60 - 25)\degree C \cdot 4.01 \frac{KJ}{kg \degree C} + 0.8905 \text{ kg} \cdot 2,257 \frac{KJ}{kg} = 1,957 \frac{KJ}{kg}$$

For 400 kg broccoli:

$$Q = 400 \text{ kg} \cdot 1,957 \frac{KJ}{kg} = 782,890 \text{ KJ} = 782,890 / (3 \cdot 3600 \text{ sc}) = 72.5 \text{ KW}$$

Masic flow:

$$m = \frac{Q}{H_{outflow} - H_{Initial}} \frac{(W)}{(KJ/kg)} = \frac{72500}{88 - 55} = 2.19 \frac{kg}{sc}$$
The initial and final conditions of the air and water in the ATU:
Water: Input temperature: 80°C, output temperature: 50°C
Approximate ATU losses: 20% (supplier info)
Input water (T= 80°C) = \( 21525 \) liters per day

<table>
<thead>
<tr>
<th>Hot water requirements</th>
<th>Unit</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air heat required</td>
<td>KW</td>
<td>72.5</td>
</tr>
<tr>
<td>Air heat required</td>
<td>KW/d</td>
<td>580</td>
</tr>
<tr>
<td>Air heat required</td>
<td>KJ/d</td>
<td>2088000.0</td>
</tr>
<tr>
<td>Losses in ATU - 20%</td>
<td>KJ/d</td>
<td>2505600.0</td>
</tr>
<tr>
<td>Water temperature input</td>
<td>°C</td>
<td>80</td>
</tr>
<tr>
<td>Water temperature output</td>
<td>°C</td>
<td>50</td>
</tr>
<tr>
<td>Fluid specific heat, glicol 20%</td>
<td>KJ/kg</td>
<td>3,88</td>
</tr>
<tr>
<td>Flow</td>
<td>l/d</td>
<td>21525.8</td>
</tr>
<tr>
<td>Pipe diameter (&quot; )</td>
<td>Inches</td>
<td>1 1/4&quot; / 1 1/4&quot;</td>
</tr>
<tr>
<td>Fluid velocity</td>
<td>m/s</td>
<td>2.4</td>
</tr>
</tbody>
</table>
Case Study
Equipment

Solar Flat Plate collector

- Viessman Vitosol 200 F
- Highly efficient sol-titanium coated cooper absorber, with effective insulation
- Awarded with the rating "Very Good" by "Stiftung Warentest"

http://www.viessmann.es/
**Case Study**

**Equipment**

**Biomass boiler**

- Hergom Oliva 100
- Local biomass (olive stones) or particles grain size < 40 mm
- Maximum boiler output 100 kW.
- Power automatically regulated: Potentiometers/pump control system/thermostats
- Two types of smoke flow: Direct & tangential to the walls of the combustion chamber
- High performance (up to 90% energy efficiency)
- Automatic feeding system – able to work for long periods of time
- Ashes removed in an easy way

1. Fuel feeding system.
2. Combustion chamber.
3. Secondary air flow.
4. Smoke passing area.
5. Secondary smoke passing area.
6. Third smoke passing area.
7. Smoke exit
8. Smoke extractor.
9. Water flow
10. Water flow return.
11. Cleaning system
12. Thermal insulation
13. Ceramic fiber insulation
14. Dash recovery system
15. Dash chamber
16. Ventilator for combustion air

http://www.hergomalternative.com/
**Air treatment unit (ATU)**

- **Model:** System Air – Danvent DV20
- **Automatically control T & moisture**
- **Adjustable air inflow & outflow sections**
- **Filter sections**
- **Heat & cold batteries**
- **Fan**

- **Units built in modules**
- **Assembled on site**
- **Software to determine ATU components**

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**Case Study**

http://www.archiexpo.com/

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**Resumen de la unidad no. 1, Danvent DV20**

<table>
<thead>
<tr>
<th>Tamaño unidad impulsión</th>
<th>20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ancho unidad impulsión (mm)</td>
<td>1270</td>
</tr>
<tr>
<td>Peso (kg)</td>
<td>361</td>
</tr>
</tbody>
</table>

**Impulsión**

| Caudal (1.205 kg/m3) | 4922.00 m3/h |
| Velocidad del aire (por unidad) | 2.08 m/s |
| Presión externa (P.E.D) | 100 Pa |
| Filtro de bolsa | F7 |
| Velocidad del ventilador | 2351 RPM |
| Motor | 1.50 kW |
| Tensión | 3x400 V |
| Voltaje, Intensidad, calculada | 3.30 A |

**SFP, filtros limpios incl. variador de frecuencia:** 0.72 kW/(m3/s)

**SFP, filtros limpios excl variador de frecuencia:** 0.68 kW/(m3/s)

**Batería de Calor:** 57.66 kW - Aire 25.0/60.0°C - Agua 80/65°C - 28.7 kPa - 0.97 l/s

**Diámetro conexión tubería 1 1/4” / 1 1/4”**

**Eurovent energy efficiency class**: <E

<table>
<thead>
<tr>
<th>Nivel potencia sonora</th>
<th>63</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1k</th>
<th>2k</th>
<th>4k</th>
<th>8k</th>
<th>Hz</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aire de impulación</td>
<td>70</td>
<td>71</td>
<td>79</td>
<td>74</td>
<td>72</td>
<td>64</td>
<td>59</td>
<td>55</td>
<td>dB</td>
<td>76</td>
</tr>
<tr>
<td>Aire exterior</td>
<td>72</td>
<td>71</td>
<td>78</td>
<td>75</td>
<td>68</td>
<td>67</td>
<td>66</td>
<td>66</td>
<td>dB</td>
<td>76</td>
</tr>
<tr>
<td>Ruido radiado</td>
<td>63</td>
<td>61</td>
<td>57</td>
<td>49</td>
<td>41</td>
<td>39</td>
<td>37</td>
<td>36</td>
<td>dB</td>
<td>52</td>
</tr>
</tbody>
</table>
Case Study
Equipment

Drying chamber

• Model: Progress Inzenjering VTS 3000
• Maximum capacity of 3000 kg/day
• Designed rate of 400 kg every 3 hours
• Metal with double walls and heat insulated
• Goods placed on plates within a carriage
• Loading manually or mechanically.

<table>
<thead>
<tr>
<th>Chamber type</th>
<th>Row material capacity based on</th>
<th>Work surface</th>
<th>Heating body power</th>
<th>Installed power</th>
<th>No. of carriages</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>plum</td>
<td>mushrooms</td>
<td>camomile</td>
<td>m²</td>
<td>kW</td>
</tr>
<tr>
<td>VTS-2000</td>
<td>2000</td>
<td>1600</td>
<td>1500</td>
<td>110</td>
<td>100</td>
</tr>
<tr>
<td>VTS-3000</td>
<td>3000</td>
<td>2400</td>
<td>1500</td>
<td>160</td>
<td>150</td>
</tr>
<tr>
<td>VTS-4000</td>
<td>4000</td>
<td>3200</td>
<td>2000</td>
<td>210</td>
<td>200</td>
</tr>
</tbody>
</table>

http://www.progres-cacak.rs/Voce_e.html
Case Study
Equipment

Storage tank

- Supplier: Viessman
- Thermal reservoir
- Heat added by the biomass boiler, solar system
- Steady supply of hot water to the UTA
- Equipped with temperature sensors to be connected to a control system that regulate the boiler operation

http://www.viessmann.ca/en/District_Heating/Products/dhw/Storage_Tanks.html
Case Study

Equipment

Heat dissipater

Model: Ferroli AE F10 – Up to 10 Panels
AE F20 - Up to 20 Panels
AE F30 - Up to 30 Panels

Dissipates the excess of heat produced
Particularly for the summer season

Required data:
- The external air temperature
- The temperature of the fluid
- Percentage of glycol
- Capacity that needs to be dissipated

Determine the optimum number of collectors required for the design of the project
To assess the thermal performance of the solar system
Input data: Geographical and climatological characteristics, climate zone,
global solar radiation (MJ/m²), horizontal radiation (KJ/m²/d)
latitude (°/min.), altitude (m), average relative humidity (%),
max & Min. water temperature (°C), average ambient temperature (°C)
collector characteristics, collector surface (m²)
Consumption characteristics, energy needs and reference temperature (80°C)

Results of annual simulation
(System with 10 flat solar collectors)

• Installed collector power: 17.7 kW
• Installed solar surface area (gross): 25.2 m²
• Irradiation (collectors): 45 MWh, 1,805 kWh/m²
• Energy delivered: 15 MWh, 590 kWh/m²

Results also presented with efficiency data, energy balance, solar fraction, fuel savings, CO2 emissions, wood pellet savings.
The following table shows the costs for a solar dryer with 10 collectors system + boiler.

<table>
<thead>
<tr>
<th>Collector costs</th>
<th>Model / size</th>
<th>Unit price (€)</th>
<th>Units</th>
<th>Cost (€)</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supplier: Viessman</td>
<td>Vitosol 200F</td>
<td>776</td>
<td>10</td>
<td>7760</td>
<td>(I)</td>
</tr>
<tr>
<td>Storage tank costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier: Viessman (I)</td>
<td>1300</td>
<td>4500</td>
<td>1</td>
<td>4500</td>
<td>(II)</td>
</tr>
<tr>
<td>Supplier: Viessman (I)</td>
<td>2550</td>
<td>6000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier: Viessman (I)</td>
<td>3800</td>
<td>7500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass boiler</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(III)</td>
</tr>
<tr>
<td>Supplier: Hergom</td>
<td>Hergom Oliva 100</td>
<td>20931</td>
<td>1</td>
<td>20931</td>
<td></td>
</tr>
<tr>
<td>Air treatment Unit</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(IV)</td>
</tr>
<tr>
<td>Supplier: Systemair</td>
<td>Danvent DV20</td>
<td>4610</td>
<td>1</td>
<td>4610</td>
<td></td>
</tr>
<tr>
<td>Drier Chamber</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(V)</td>
</tr>
<tr>
<td>Supplier: Progres Inzenjering</td>
<td>VTS-3000</td>
<td>7500</td>
<td>1</td>
<td>7500</td>
<td>(VI)</td>
</tr>
<tr>
<td>Heat exchanger</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supplier: Ferroli</td>
<td>AE-F 10</td>
<td>765</td>
<td>1</td>
<td>765</td>
<td>(VII)</td>
</tr>
<tr>
<td>Supplier: Ferroli</td>
<td>AE-F 20</td>
<td>1015</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipework &amp; components</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pipes, supports, valves,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>insulation,</td>
<td>150</td>
<td>10</td>
<td>1500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Labour</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(VI)</td>
</tr>
<tr>
<td>Installation works Coll.</td>
<td>600</td>
<td>10</td>
<td>6000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total costs 53566

References:
(I) Viessman pricelist (www.comercialgoher.es/Tarifa%5C Energia Solar%5CViessmann.pdf)
(III) Tarifas Hergom 2012 (www.ferroli.es/tarifas/2012/cafeaccion
(IV) See ATU quote in appendix 4
(V) Supplier: "PROGRES INŽENJERING", price estimated according to similar drier chambers in the market.
(VI) Supplier: "Technisolar" (www.technisolar.es), price estimated according to supplier information
(VII) http://www.ferroli.es/tarifas/2012/cafeaccion
## Operation & Maintenance Costs

Operation and maintenance costs for the drier system with 10 collectors + boiler

**Labor costs**

<table>
<thead>
<tr>
<th>Nº of people</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salary for drier operator &amp; preparatory labour (€/month)</td>
<td>1500</td>
</tr>
<tr>
<td>Total labor costs (€/year)</td>
<td>36000</td>
</tr>
</tbody>
</table>

**Operating costs**

| Maintenance, 15% equipment cost (€) | 8035 |
| Total costs (€/year) | 51077 |

**Capital costs**

| Equipment cost (€) | 53566 |
| Interest rate (%) | 10 |
| Period of years | 15 |
| Total capital cost (€/year) | 7043 |
Energy costs for dryer system with 10 collectors + boiler

<table>
<thead>
<tr>
<th>Energy Costs</th>
<th>10 Collectors system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pellets consumed by the boiler</td>
<td></td>
</tr>
<tr>
<td>Annual power required (MWh)</td>
<td>57,6</td>
</tr>
<tr>
<td>Calorific value (KWh/kg)</td>
<td>5</td>
</tr>
<tr>
<td>Boiler working hours (h)</td>
<td>8,00</td>
</tr>
<tr>
<td>Pellets required per year (kg)</td>
<td>33297</td>
</tr>
<tr>
<td>Unit price pellets, olive stones (€/kg)</td>
<td>0,12</td>
</tr>
<tr>
<td>Daily cost (€)</td>
<td>16,82</td>
</tr>
<tr>
<td>Montly cost (€)</td>
<td>369,97</td>
</tr>
<tr>
<td>Yearly cost (€)</td>
<td>4439,64</td>
</tr>
<tr>
<td>Total (€/year)</td>
<td>4,439,64</td>
</tr>
</tbody>
</table>

(II) Supplier: Calor-eco (http://www.calor-eco.es/lista-de-precios.html)

(III) Electricity consumption of the ATU is 3.8 kW/hr. See appendix 4, quote from Systemair

(IV) The price of the KWh in Spain is currently 0,185 €/kWh

(http://www.minetur.gob.es/energia/electricidad/Tarifas/Tarifas2008/Paginas/precios.aspx)
**Case Study**

**Economic Analysis**

**Product Costs & Revenues**

Product costs and revenues for dryer system with 10 collectors + boiler

<table>
<thead>
<tr>
<th>DRY BROCCOLI PRODUCTION REVENUE</th>
<th>Unit</th>
<th>Quantity</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drying</td>
<td>%</td>
<td>15,00</td>
<td></td>
</tr>
<tr>
<td>Fresh broccoli per load</td>
<td>kg</td>
<td>400,00</td>
<td></td>
</tr>
<tr>
<td>Broccoli production per load</td>
<td>hr</td>
<td>60,00</td>
<td></td>
</tr>
<tr>
<td>Drying duration period</td>
<td>hr</td>
<td>3,00</td>
<td></td>
</tr>
<tr>
<td>Load &amp; reload duration</td>
<td>hr</td>
<td>0,03</td>
<td></td>
</tr>
<tr>
<td>Preheating duration</td>
<td>hr</td>
<td>0,25</td>
<td></td>
</tr>
<tr>
<td>Duration per load</td>
<td>hr</td>
<td>3,28</td>
<td></td>
</tr>
<tr>
<td>Loads per day</td>
<td>u.</td>
<td>2,44</td>
<td></td>
</tr>
<tr>
<td>Average market price (dry broccoli),</td>
<td>€/kg</td>
<td>11,50 (I)</td>
<td></td>
</tr>
<tr>
<td>Daily revenue</td>
<td>€</td>
<td>1681,2</td>
<td></td>
</tr>
<tr>
<td>Montly revenue</td>
<td>€</td>
<td>36426,4</td>
<td></td>
</tr>
<tr>
<td>Total revenue per year</td>
<td>€</td>
<td>437116,75</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
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<th>FRESH BROCCOLI COST</th>
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<tbody>
<tr>
<td>Quantity</td>
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<tr>
<td>Quantity</td>
<td>kg/y</td>
<td>253401,0</td>
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<tr>
<td>Price</td>
<td>€/kg</td>
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<tr>
<td>Purchase costs per year</td>
<td>€</td>
<td>195118,78</td>
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</table>

(I) Based in the two main Spanish suppliers:
(www.biolandia.es/alimentos/362-polvo-de-brocoli-deshidratado.html)
(www.cartagenaecologica.com/brocoli-ecologico-deshidratado-murcia-ecologica-venta-online?search=brocoli)
(II) See appendix 8
(www.dpz.es/diputacion/areas/presidencia/z4e_observatorio/producto.php?pr=5)
## Case Study Economic Analysis

### Cash Flow

**Cash Flow for dryer system with 10 collectors + boiler**

<table>
<thead>
<tr>
<th>Ref. Year</th>
<th>Year</th>
<th>Initial costs (No boiler)</th>
<th>Biomas boiler</th>
<th>Operatio n costs</th>
<th>Labour</th>
<th>Capital costs</th>
<th>Energy</th>
<th>Fresh Product Cost</th>
<th>Pretreatment &amp; cutting</th>
<th>Milling &amp; Packaging</th>
<th>Total costs</th>
<th>Total income from dry products</th>
<th>Cash flow</th>
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<td>621359</td>
<td>576766</td>
<td>-44592</td>
<td></td>
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</tbody>
</table>

Discount Rate: 10%

- **O&M (Δ)**: 2.41%
- **Labour Cost (Δ)**: 2.41%
- **Dry product price (Δ)**: 2%
- **Energy Cost (Δ)**: 7.96%
- **Fresh Product (Δ)**: 2%

**NPV**: 352,321.8

**IRR**: 164%

**NPV Benefits**: 405,887.8

**NPV Invest.**: 53,566.0

**Annual Paym.**: 53,363.6

**Payback per.**: 1.0

Source: Guideline VDI-Standard: VDI 2067
RESULTS ON ANNUAL SIMULATION FOR 10, 20, 30 AND NONE FLAT SOLAR COLLECTORS WITH THE USE OF ONE BIOMASS BOILER (8 hr/d)

| Number of collector | Area (m²) | Collector Power installed (KW) | Irradiation on to collector surface (MWh) | Irradiation on to collector surface (KWh/m²) | Power delivered by collector (KWh/m²) | Power delivered by collector (KW) | Energy from auxiliary heating (KW) | Wood pellets savings (Kg) | Solar fraction (%) | System efficiency (%) | NPV (€) | IRR (%) | NPV Benefit (€) | NPV Investment (€) | Annual payment (€) | Payback period (years) |
|---------------------|-----------|---------------------------------|--------------------------------------------|---------------------------------------------|-------------------------------------|----------------------------------|---------------------------------|----------------------------|-------------------|---------------------|----------------------|---------|---------|-----------------|-------------------|----------------|---------------------|
| 10                  | 23        | 17,64                           | 45,51                                       | 1805,7                                      | 14,87                               | 590,18                           | 57,6                            | 3456,9                     | 11,3%             | 31,2%               | 352.322              | 164     | 405.888 | 53.566          | 53.364            | 1,0              |                     |
| 20                  | 50,4      | 35,28                           | 91,01                                       | 1805,7                                      | 28,07                               | 557                              | 44,4                            | 6625,2                     | 20,2%             | 30,0%               | 306.018              | 117     | 376.594 | 70.576          | 49.512            | 1,4              |                     |
| 30                  | 75,6      | 52,92                           | 136,51                                      | 1805,7                                      | 38,4                                | 507,93                           | 34,1                            | 9333,6                     | 27,5%             | 28,1%               | 255.290              | 87      | 343.391 | 88.101          | 45.147            | 2,0              |                     |
| -                   | -         | -                               | -                                           | -                                          | -                                   | -                                | -                               | 72,5                       | -                 | -                   | 376.435              | 201     | 421.476 | 45.041          | 55.413            | 0,8              |                     |
Case Study Considerations

Environmental Impact

- Reduction of GHE
- Sustainable utilization of energy resources

Environmental Impact

### Case Study

#### Pellets requirements 10 Collectors system

<table>
<thead>
<tr>
<th>Pellet power supplied (MWh)</th>
<th>14,9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler annual power supplied (MWh)</td>
<td>57,6</td>
</tr>
<tr>
<td>Pellet calorific value (KWh/kg)</td>
<td>4,7</td>
</tr>
<tr>
<td>Pellets required per year (kg)</td>
<td>3164</td>
</tr>
<tr>
<td>Unit price pellets, olive stones (€/kg)</td>
<td>0,12</td>
</tr>
</tbody>
</table>

**Pellets yearly cost (€)**: 379,66

**Petrol saving**

- Petrol required per year (lt): 6928
- Unit price petrol (€/lt): 1,107
- Petrol daily cost (€): 29,05
- Petrol monthly cost (€): 639,09
- Petrol yearly cost (€): 7669,14

**Petrol yearly savings (€)**: 7.669,14

**Electricity saving**

- Unit price (€/KWh): 0,124
- Daily cost (€): 34,05
- Monthly cost (€): 749,17
- Yearly cost (€): 8990,00

**Electricity yearly savings (€)**: 8.990,00

**Renewal energy generated per year (MWh/y)**: 50,3

**Fossil fuel savings**

- Petrol calorific value (KWh/kg): 11,5
- Petrol required per year (lt): 4803,3
- CO2 generated per petrol (kg/l): 2,63

**Total CO2 savings (kg)**: 12632,7

---

(I) Review of pelletizing technology, combustion technology systems 2012-European Commission (EIE programme)

(II) Supplier: Calor-eco (http://www.calor-eco.es/lista-de-precios.html)

(III) Official price in Spain on 31-11-2013 (http://www.dieselgasolina.com/)

(IV) The price of the KWh in Spain is currently 0,185 Euros/kWh (http://www.minetur.gob.es/energia/electricidad/Tarifas/Tarifas2008/Paginas/precios.aspx)
Conclusions

- Viable project according (demand dried products vs costs)
- Drier with just biomass boiler has lower payback period
- Drying process is further optimized
- Suitable for big farmer associations & small farmer groups
- Increase economic development of many rural areas
- Vital to preserve agricultural surplus products

http://www.termoplin.rs/gallery_dryers_fruits_vegetables.html
## Case Study Considerations

### Economic Viability & Environmental Impact

#### Benefits:
- Enabling continuous drying
- Enhancing quality of dried fruits
- Reducing post-harvest lost
- Opportunity to process & store

#### Economic Viability:
- Fast Paid-Back
- Increase value
- Generation of rural employment

#### Environmental Impact:
- Reduction of GHE
- Sustainable utilization of energy resources

<table>
<thead>
<tr>
<th>Pellets requirements</th>
<th>10 Collectors system</th>
<th>Ref.</th>
</tr>
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<tbody>
<tr>
<td>Solar power supplied (MWh)</td>
<td>14,9</td>
<td>(I)</td>
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<tr>
<td>Boiler annual power supplied (MWh)</td>
<td>57,6</td>
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<tr>
<td>Pellet calorific value (KWh/kg)</td>
<td>4,7</td>
<td>(I)</td>
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<tr>
<td>Pellets required per year (kg)</td>
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<td></td>
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<tr>
<td>Unit price pellets, olive stones (€/kg)</td>
<td>0,12</td>
<td>(II)</td>
</tr>
<tr>
<td><strong>Pellets yearly cost (€)</strong></td>
<td>379,66</td>
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<tr>
<td><strong>Petrol yearly cost (€)</strong></td>
<td>7669,14</td>
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<td><strong>Petrol yearly savings (€)</strong></td>
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<tr>
<td><strong>Electricity yearly savings (€)</strong></td>
<td>8990,00</td>
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### Calculation Details:

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<td>Pellets yearly cost</td>
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<td><strong>Petrol yearly cost</strong></td>
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<td><strong>Petrol yearly savings</strong></td>
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<td><strong>Electricity yearly savings</strong></td>
<td>8990,00 €</td>
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**Renewal energy generated per year (MWh/y):** 50,3 Ref.  
**Fossil fuel savings:**  
- Pellet calorific value (KWh/kg): 11,5 (I)  
- Pellet required per year (lt): 4803,3  
- CO2 generated per petrol (kg/l): 2,63 (II)  
**Total CO2 savings (kg):** 12632,7