Small-scale biodiesel production economics: a case study focus on Crete Island

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A B S T R A C T

Remarkable research has been carried out in the past decade in the field of biofuels in general and, more specifically, in the feasibility of their production. A number of studies have been published that focus on the viability of the investments on biodiesel production plants from a technical–economic perspective. The common characteristic of these studies is that they refer to medium to large-scale production plants. The principal aim of this study is to investigate the viability of a small-scale biodiesel production plant investment in Greece determining the factors and figures that rule the economics of such a plant. Having in mind that a small-scale plant offers greater opportunities for rural development and decentralization as well as that rural development is a focal point in the Greek economy, the financial performance of a small-scale biodiesel plant in Crete Island is analysed in the present work. It is believed that the results obtained may prove very useful in determining the technical and financial characteristics and parameters of similar production facilities.

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1. Introduction

Transportation has been characterized as the sector holding major responsibility regarding the creation and variations of energy consumption and environmental emissions within the European Union (EU) borders (European Commission, 2001, 2006a). Energy consumption in the transportation sector accounted for 33% of the total final energy consumption in 2007 and it is almost fully dependent upon oil-derived products (98%). It also accounts for 67% of the EU final oil demand, being a key CO2 generator, responsible for 28% of the CO2 emissions in the EU (EC, 2010). The nearly complete dependence of this sector on oil products generates concerns on both: security of supply and climate change (European Commission, 2003a). These two concerns have given burst in the European Commission (EC) to encourage the development of alternative fuel technologies, based on the use of agricultural feedstock for the production of liquid biofuels (EC, 2006b,c). The EU Directive 2003/30/EC sets up the targets of biofuels on the EU transport fuel market setting the reference value to 5.75% of all gasoline and diesel used in transport by the end of 2010 (EC, 2003b; Kondili and Kaldellis, 2007). The main interest of the EU members has been focused on the production of biodiesel since 1992, largely in response to the positive signals from the EU institutions. Biodiesel continues to be the biofuel that EU prefers representing 78.5% of total biofuel production in EU for the year 2008 (Euroobserver, 2009).

In 2004 Greece submitted an extensive and complete 1st national report under the Directive 2003/30. This 1st report has estimated that 148,000 tonnes of biodiesel would be needed to fulfil the 5.75% target by the end of 2010 (HRMD, 2004a). Currently thirteen biodiesel plants with a total installed capacity of 700,000 tons/year operate in Greece (HRMEEC, 2009).

There is no doubt that biofuel production in Greece has significant opportunities; the main question for an investor is which is the scale of a production plant that would result in an optimal efficiency (Iliopoulos and Rozakis, 2009). The appropriate scale of a biofuel facility can be determined by the project goals and the company objectives (e.g. local energy provision vs. production exports). In general, large-scale (>50,000 tons annual capacity) plants are more globally competitive and export oriented while small-scale plants (up to 10,000 tons of annual capacity) offer greater opportunities for rural development. Costs of biofuel production are scale-dependent, with higher operating costs incurring in small-scale plants (CFC, 2007). On the other hand small-scale decentralized biofuel plants in remote rural areas may offer an alternative to high-priced diesel and serving local communities as will have lower capital investments and transport/distribution costs (Bernesson et al., 2004). Relative to the large-scale plants, small-scale plants offer social returns on public investments. Experience in Brazil, France, Germany and United States has shown that biofuel production facilities that are small...
and locally owned tend to bring about higher local revenues and lower social spending (EUBIA, 2010).

A remarkable research has been carried out in the past decade about biodiesel plants dealing with various aspects of biodiesel production. Raw materials selection – first or second generation, specific crops etc. – affects not only the financial performance of a plant, but also various other environmental assessments, production facilities design (Melamu and von Blottnitz, 2011; Mikulec et al., 2010). In parallel, many research works have been carried out concerning the conditions and development priorities of various countries (Krajnc et al., 2007; Martin et al., 2009; Pleanaji et al., 2009; Cavallet and Ortega, 2010; Schaffel and La Rovere, 2010; Iriarte et al., 2010). Biofuels supply chain has also been analysed and its characteristics have been revealed in recent research works (Papapostolou et al., 2008; Gold and Seuring, 2011). Certainly the environmental impacts of the biofuels in the whole life cycle have been a debate issue and have governed the research towards new materials. Many research works have been published in that issue (Pro et al., 2005; Kiwjaroun et al., 2009; Morais et al., 2010; Papapostolou et al., 2010). Also a number of studies have been published that investigate from a technical—economic point of view, the feasibility and the profitability of this type of investments (Basili, 1999; Canakci and Van Gerpen, 2001; Haas et al., 2006; Marchetti and Errazu, 2008; Gallagher, 2011). The common characteristic of these studies is that they refer to medium to large-scale production plants (Athanasiou et al., 2007a; Boukis et al., 2009b; Apostolakou et al., 2009).

The principal aim of this work is to investigate the viability of a small-scale biodiesel production plant investment in Greece (10,000 tons/year), located on a decentralized island area of Greece, with the plant capacity estimated to cover the specific diesel oil area needs.

To that effect the work analyses in detail all the factors and parameters that may be involved in the design and cost estimation of such a plant. The work is based on real cost data taken after communication with the corresponding biodiesel equipment retailers.

Certainly a lot of work has been carried out for medium to large-scale plants; however there is not much work for small-scale plants and it is believed that the present work may prove very useful in determining the technical and financial characteristics and parameters of similar production facilities.

In the previous works referring to medium scale plants usually 40,000–50,000 tons/year the Capital Investment has been based on fixed numbers given by the State, e.g. the capital investment cost for a new small biodiesel plant in Greece is given at 500€/ton of produced biodiesel.

2. The case study of Crete

Having in mind that a small-scale biodiesel plant offers greater opportunities for rural development and decentralization as well as that rural development is a focal point in the Greek economy, the case study of a small-scale biodiesel plant in Crete Island is examined.

Crete is the 13th Greek Region and the 5th largest island in the Mediterranean Sea with an area of 8335 km² and population that surpasses 600,000 residents (Giatrakos et al., 2009). According to recent official data in 2005, there were 148,039 vehicles using diesel in Crete (Trucks: 96,393; Busses: 1,617; Taxis: 2,155; Agricultural Vehicles: 47,874) with a total annual diesel demand of 127,500 tons (Zografakis, 2005). It has been estimated that the necessary biodiesel demand in Crete, in order to fulfil the Directive 2003/30 5.75% target by the end of 2010, would approach the amount of 10,000 tons on an annual basis.

Biomass can play an important and potentially synergistic role covering the Island’s energy needs. Biomass can both supply base load electrical power and be converted to liquid fuels for transportation (Vamvuka and Tsoutsos, 2002). In Crete Island and more specifically only in Heraklion prefecture there is enough available area that can be used for biodiesel energy crops (Athanasiou et al., 2007b). These crops could have enough annual yield that could supply the operation of a biodiesel production plant with a capacity of 10,000 ton/year (Boukis et al., 2009a). Finally it should be noted that until now in Crete Region there is not in operation any biodiesel production plant.

Considering these facts and figures, the authors believe that the installation of a small-scale biodiesel production plant with an installed capacity of 10,000 ton/year in Crete Island has good prospects to be a feasible and also rational option since biomass supply is available and the plant’s annual capacity can supply the current island diesel demand.

3. Examination of the project’s feasibility

In the case of a biodiesel production plant, the major target is the production of biodiesel at a reasonable and affordable cost (Papapostolou et al., 2008). Additionally a sensitivity and risk analysis is also usually performed in order to assess the profitability of the investment. However, these generic facts have to be quantified and specific figures that will help in making an investment decision, have to be referenced upon. The specific figures that are going to be used in this analysis are listed below:

- The project Internal Rate of Return (IRR) that in general must be higher than those offered by other similar investment alternatives.
- The Specific Investment Cost (SIC), i.e. an estimation of the capital needed to supply the required manufacturing and plant facilities, expressed as €/ton of biodiesel.
- The Biodiesel Production Cost (BPC), i.e. the sum of all plant operating costs, general expenses and the recovering of the capital investment, expressed as €/ton of biodiesel.

The economic parameters listed above are characterized as factors of great importance in determining the project’s viability. However, some generic quantification for these economic parameters can be given, based on the existing experience. These quantifications are listed below:

- The project’s IRR, referring to a new investment in an established market should be above somewhere in the range of 16–24%, for a time period of 20 years (Peters et al., 2004).
- The project’s SIC, referring to a small-scale biodiesel plant should be somewhere in the range of 370–610€/ton of biodiesel (IBF, 2002; HRMD, 2004b).
- The project’s BPC, referring to a small-scale biodiesel plant should be lower than the highest current biodiesel selling price in Greece which is reported to be 850€/ton of biodiesel (HRMEECC, 2010).

4. Technical and economic analysis of the project

4.1. Estimation of the specific investment cost (SIC)

In this study, the Capital Investment Cost (CIC) represents the capital necessary for the process equipment installation. Expenses for site preparation, piping, instruments, insulation, foundations and auxiliary facilities are typical examples of the costs that have...
been included. CIC also includes the capital required for the construction overhead and for all plant components that are not directly related to the process operation as field office and supervision expenses/home office expenses/engineering expenses/miscellaneous supervision costs/contractors fees and contingencies, land acquisition (Peters et al., 2004). In previous works the authors have presented a fully detailed process model used for the estimation of investment and operation costs for a biodiesel production plant (Skarlis and Kondili, 2008; Skarlis et al., 2008). The basic model parameters are analysed below, while no State subsidy is included in the current study (Kaldellis, 2002). According to this model, transesterification of vegetable oil with alkali based catalyst will be the selected technology since it is the most used technology worldwide (Rutz and Janssen, 2007). The production plant design is divided into three processing sections (Van Gerpen, 2005):

1. A transesterification section where the vegetable oil is subject to chemical transesterification in order to produce fatty acid methyl esters (biodiesel) and co-product glycerol.
2. A biodiesel purification section where the methyl esters are refined to meet the biodiesel specifications.
3. A glycerol recovery section.

The most crucial equipment items that are needed for the design of a biodiesel production plant can be divided in four process areas:

1. Working supply capacity process equipment (storage tanks).
2. Transesterification process equipment (reactors, centrifuge pumps).
3. Purification process equipment (washing columns, vacuum dryers, centrifuge pumps).
4. Glycerol recovery process equipment (centrifuge pumps, distillation columns).

A simplified block flow diagram of the plant is shown in Fig. 1. These four process areas create four different cost centres that represent the Total Equipment Cost (TEC). By supplying reliable and updated cost data based on Greek market prices for biodiesel process equipment, the TEC has been estimated (Skarlis and Kondili, 2008). The results from the input cost data are shown in Table 1. Other costs associated with equipment and land issues, have also been taken into account, see Table 2. These costs have been calculated as percentages of the TEC, found in international chemical plant design literature (Peters et al., 2004).

The analysis resulted in a CIC of 4,000,000€. This can be translated as a Specific Investment Cost (SIC) of 400€/ton per plant capacity. According to the operational program "Competitiveness" of the Greek Ministry of Development (HRMD, 2004b), the selected CIC for a production unit with a capacity of 10,000 tons biodiesel/year is 5,000,000€ (it considers as an SIC for small-scale plant, a value up to 500€/ton). In that program the CIC subsidy percentage for similar applications was 40%, however the current analysis does not take into account any State financial support. Therefore the SIC that has been estimated can be considered as a valid result. Furthermore this SIC value is consistent with other studies values that have been estimated to range from 370 to 610€/ton of biodiesel (IBFG, 2002). Concluding, the overall equipment cost (including piping and installation) constitutes a 52% of the CIC, see Fig. 2. The working supply capacity process is the biggest contributing cost centre, since it represents the 40% of the equipment cost, see Table 1.

4.2. Estimation of the biodiesel production cost

Once the capital investment of the project has been estimated, another important factor for the feasibility of the project, i.e. the total production cost, has to be determined. The total production cost for a biodiesel production plant, here defined as Biodiesel Production Cost, is the sum of all the costs of the plant’s operation, i.e. raw materials and utilities, labour, maintenance and operation, insurances, plant overheads, contingencies, costs of general

![Fig. 1. Flow sheet for the production of biodiesel from vegetable oil.](image-url)
expenses i.e. administrative, distribution and marketing expenses and costs of recovering the capital investment i.e. depreciation (Peters et al., 2004).

4.2.1. Raw materials and utilities cost

Biodiesel is the product obtained when a vegetable oil or an animal fat reacts chemically with an alcohol to produce fatty acid alkyl esters. A catalyst such as sodium or potassium hydroxide is required. Glycerol is produced as a co-product (Van Gerpen et al., 2004). The most common stoichiometric description of the reaction is:

\[ 1000 \text{ kg of oil} + 110 \text{ kg of methanol} \rightarrow 1000 \text{ kg of biodiesel} + 110 \text{ kg of glycerol} \]

Catalyst requirement is almost equal to 1.5% of the oil quantity. To finalise the analysis of the biodiesel production process, the description of the energy inputs for the transesterification process is required. In Table 3 the results of several works are presented, concentrated on the energy inputs required for the biodiesel production through the transesterification process. In this work, for each tonne of biodiesel produced an average electrical energy input of approximately 60 kWh/ton has been selected as an average and reasonable value. Besides, for each tonne of biodiesel produced an average thermal supply of approximately 440 kWhth/ton has been selected.

Water requirements of a biodiesel production plant include process water, steam water and cooling water. Modern biodiesel production plants should produce (by recycling and reuse) no more than 2 tonnes of waste water for each tonne of biodiesel produced (Saville, 2006). The utility requirements are determined from the material and energy balances of the process. The production Input and Output costs (I/O) for a biodiesel plant with an installed production capacity of 10,000 ton/year as well as the annual cost analysis of these inputs are presented in Table 4. The costs of raw material, utilities and by-products have been estimated based on domestic prices and specific references (IGA, 2009; Oleoline, 2007). The cost of the industrial oil in the Greek market has been varied between 400 and 810€/ton for the time period of 2000–2005 (Panoutsou et al., 2008). An average price of 600€/ton has been selected for our basic case study production cost. Any further effect of the vegetable oil purchase price in the biodiesel production cost will be considered in the sensitivity analysis.

4.2.2. Labour cost

The operating labour cost has been based on the estimation that the plant will be in operation 24 h/day, 330 days/year with a 25 day storage supply and will require almost 15 employees and an average cost per employee of 20,000€/year. As a result of these assumptions, the labour cost has been estimated as 300,000€/year.

4.2.3. Operation and maintenance cost

Annual maintenance costs according to the international chemical plant design literature are assumed to be 10% of the Total Equipment Cost, therefore this cost term has been estimated as 110,000€/year.

4.2.4. Property insurance cost

Insurance rates depend on the type of the process being carried out in the plant. Annual insurance cost, according to the international chemical plant design literature for a biodiesel unit, is assumed to be 5% of the Total Equipment Cost. Therefore, this term has been estimated as 50,000€/year.

4.2.5. Plant overhead costs

The expenditures required for routine plant services are included in the plant's overhead costs. According to the international chemical plant design literature, these are assumed to be approximately 50% of the Labour and M&amp;O cost; therefore the plant overhead costs have been estimated as 200,000€/year.

4.2.6. Contingencies

Operating costs estimates are subject to various uncertainties, especially in regard to strikes, natural disasters, price variations, production capacity and process uncertainties. In order to account for these uncertainties, a 15% overrun is assumed on the sum of all labour, M&amp;O cost and plant overhead costs; therefore this term has been estimated as 90,000€/year.

Table 2
Cost breakdown analysis of the major plant processes.

<table>
<thead>
<tr>
<th>Item</th>
<th>% of TEC</th>
<th>Cost (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Working supply capacity process</td>
<td>40%</td>
<td>440,000€</td>
</tr>
<tr>
<td>Transesterification process cost process</td>
<td>17%</td>
<td>190,000€</td>
</tr>
<tr>
<td>Purification process section process</td>
<td>13%</td>
<td>140,000€</td>
</tr>
<tr>
<td>Glycerol recovery section process</td>
<td>30%</td>
<td>330,000€</td>
</tr>
<tr>
<td>Total equipment cost (TEC)</td>
<td></td>
<td>1,100,000€</td>
</tr>
</tbody>
</table>

Table 3
Energy requirements for biodiesel production.

<table>
<thead>
<tr>
<th>Item</th>
<th>Electricity (kWhth/ton)</th>
<th>Heat (kWhth/ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Van Kasteren and Nisworo, 2007</td>
<td>40</td>
<td>90</td>
</tr>
<tr>
<td>Saville, 2006</td>
<td>60</td>
<td>440</td>
</tr>
<tr>
<td>Rooney et al., 2006</td>
<td>120</td>
<td>600</td>
</tr>
</tbody>
</table>
4.2.7. General expenses

In addition to the manufacturing costs, other general expenses are involved in the operations of a plant. These general expenses may be classified as administrative, distribution and marketing expenses. According to the international chemical plant design literature, these are assumed to be approximately 25% of the Labour and M&O cost, resulting in almost 100,000€/year.

4.2.8. Depreciation

The equipment, buildings and other material objects comprising a manufacturing plant require an initial investment that must be paid back. This is done by charging depreciation as an operation expense. The depreciation rate has been estimated at 250,000€/year during an operational period of 20 years.

The reason for taking a 20-years depreciation period is that the suggested plant will operate in a non-well regulated price market. Biodiesel selling price in Greece is determined by the Hellenic Republic Ministry of Energy Environment and Climate Change and Biodiesel selling price in Greece is determined by the Hellenic Republic Ministry of Energy Environment and Climate Change. Therefore the annual incomes of the plant has been estimated at 7,800,000€.

4.2.9. Biodiesel production cost

The biodiesel production cost (BPC) breakdown analysis of a small-scale biodiesel production plant with an installed running capacity of 10,000 tons/year is presented in Table 5.

The analysis resulted in an annual plant production cost of 7,800,000€, which can be translated as a BPC of 780€/ton. This value is consistent with the results of other analyses concerning the costs of biodiesel from vegetable oil feedstock (Panoutsou, 2005; Andres and Chacon, 2004). According to Table 4, the crucial parameter that affects the BPC is the oil feedstock cost (vegetable oil price). Raw materials and utilities costs constitute the greatest component of BPC (86%). The cost of vegetable oil feedstock is the largest contributing factor, itself constituting a 77% of the BPC, Fig. 3.

5. Viability of the project

5.1. Analysis of the project’s economics

Once the main economic parameters of the biodiesel plant, i.e. the Capital Investment Cost (CIC), the Specific Investment Cost (SIC) and the Biodiesel Production Cost (BPC) have been estimated, the viability of the project can be examined. The financial evaluation of the project has been performed using the Internal Rate of Return (IRR). The main financial figures and assumptions that were used in the project’s IRR calculations are listed below:

- A plant operation for 20 years with its full capacity being achieved in the first year of operation.
- The Capital Investment Cost of the plant has been estimated at 4,000,000€, therefore the Specific Investment Cost of the plant has been estimated at 400€/ton.
- The oil feedstock cost has been selected to be 600€/ton.
- The Biodiesel Production Cost of the plant has been estimated at 780€/ton, therefore the annual production costs has been estimated at 7,800,000€.
- The Biodiesel Selling Price has been selected to be 850€/ton, therefore the annual incomes of the plant has been estimated at 8,500,000€.
- Taxation rate at 25% of the gross profits.
- After the first year of operation, an annual increase of 5% on the Biodiesel Production Cost and Biodiesel Selling Price has been selected.

Based on the above financial figures and assumptions, the project’s IRR for a 20 year time period has been estimated to be 22%, a value which is consistent with the corresponding IRR (16–24%) values referring to a new investment in an established market, without any State subsidy.

5.2. Sensitivity analysis

The sensitivity of the project has been analysed based on the fact that the plant’s feedstock cost, i.e. the vegetable oil cost, is the most crucial cost item in Biodiesel Production Cost (BPC) representing 77% of the total cost and on the fact that the Capital Investment Cost (CIC) is a factor along with the BPC which basically determine the viability and profitability of the investment.

The project’s IRR is given in Fig. 4 as a function of vegetable oil cost, for three different values of CIC, i.e. the estimated CIC and two values referring to a new investment in an established market.
alternative CIC scenarios with value range of ±20%. Assuming an acceptable project IRR within the range of 16–24%, the importance of the vegetable oil cost on the project’s viability and profitability is clearly revealed. The critical oil feedstock price estimated at approximately 640€/ton, indicates that viable projects, in terms of IRR, may arise for a probable SIC range of ±20%. The main conclusion that can be drawn from the figure is that for lower CIC values, the project’s viability may be able to resist to higher oil feedstock price forcings.

Another important factor requiring further investigation is the annual operating time of the plant. Throughout this study it is assumed that the plant will operate for a time period of 20 years with its full capacity being achieved in the first year of operation and that it will operate at full capacity in the remaining years. However, in case that the plant’s annual running capacity is lower than the expected, i.e. lower than 100%, this might have serious effects on the project’s profitability or even viability, see Fig. 5. The figure indicates that only a 30% reduction in the annual running capacity of the plant will jeopardize the profitability of the investment (i.e. IRR value lower than 15%), while as it is rational an annual reduction beyond 60% will put at risk the viability of the investment.

A final comment that could be made concerning the biodiesel cost is based on the fact that biodiesel production in small scale is much more expensive than large-scale production. However, one should keep in mind that the present work focuses on an island from which the nearest oil refinery is in a distance of 7 h travel by ship. Diesel oil average pump price on the island according to of 22–12–2010 was 1660€/ton and currently (20–07–2011) has reached the price of 1910€/ton, which includes production costs, fuel taxation and pump station company profit. This price is more than double than the biodiesel production cost which is 780€/ton plus that is a tax exempted fuel. Therefore it is easy to understand that even with a future taxation on biodiesel there always will be a profit margin. Furthermore, the regional development and the social benefits from such an investment should always been taken into account when a decision needs to be taken.

6. Conclusions

In this study, the viability of a small-scale biodiesel plant (10,000 ton/year) in Crete Island has been investigated. From the figures presented here it seems that the investment of such a scale project in Crete Island is viable, having as basic advantages the low capital investment cost, i.e. 4,000,000€, and the low demand in oil feedstock, i.e. 10,000 ton/year. This can be covered by the local biomass production thus reducing any risk from sudden oil prices fluctuation. Note that during the entire analysis no State subsidy is considered. The analysis has shown that the two basic factors that affect and determine the economic viability of the investment are: a) the ensuring of the oil feedstock in acceptable prices, i.e. oil feedstock costs up to 640€/ton, and b) the ensuring of the biodiesel sales in the local market, i.e. figures indicate that by operating the plant at higher than 2/3 of its annual running capacity the plant profitability is guaranteed. Concluding, the investment is viable as long as the biodiesel selling price value is higher than the biodiesel production cost value which is 780€/ton.

The added value of this work is the detailed design and cost estimation of a small-scale plant, the development of the methodology and the steps that need to be followed, the quantification of all the terms being involved with real market data and, finally, the financial analysis of such a production facility.

In addition, independently of the feasibility of such a production plant, the estimations and the results of the present work may be used as a reference point for the analysis of other similar production facilities.

References


Glossary

BPC: biodiesel production cost
CIC: capital investment cost
EC: European Commission
EU: European Union
IRR: internal rate of return
I/O: inputs outputs
M&O: maintenance and operation
SIC: specific investment cost
TCC: total capital cost
TEC: total equipment cost