Assessment of Energy Production Options in Lieu of Orange Cultivation in Ribera Baixa (Valencia), Spain

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Abstract
The Comunitat Valenciana is the largest orange producing area in the European Union. During the past decade, orange cropping has been under severe economic stress arising from increasing competition from less-costly foreign imports. Consequently, farm-gate prices are depressed to the extent that it has effectively fallen to the same or below the cost of production. Orange groves are being abandoned in many instances. Preliminary assessment showed that conversion of orange grove in Ribera Baixa to produce energy does not appear to be a viable option. Electric power generation is not practicable in the absence of government feed-in tariff subvention. Photovoltaic power generation might however be practicable for self consumption under certain circumstances. Use of crude microalgal oil does not provide sufficient economic benefits to the prospective on-road end uses, in absence of any excise tax exemption. The production yield of crude moringa oil is far below that of crude microalgal oil to be of competitive interest.

Keywords
Biofuel; Economy; Energy; Oranges; Ribera Baixa; Valencia

Introduction
Orange (Citrus sinensis (L.) Osbeck), one of the most widely grown tree fruit crop in the World, is native to southern China (Morton, 1987). Cultivation of oranges in eastern coastal Spain began during the Islamic Era.

In the 1970s, there was a major rapid expansion of orange production in both Comunitat Valenciana and Andalusia. In 2010, Comunitat Valenciana produced ~1.51 million tonnes of sweet oranges, accounting for about 57% of the total orange production in Spain (IVE, 2012). Most of the oranges are grown in the province of Valencia. Orange is cropped in about 19% of the land area of Ribera Baixa, the highest among all the comarcas of the Comunitat Valenciana (GVA, 2010; IVE, 2012). The geographic location of Ribera Baixa is given in Figure 1. The land holdings in Ribera Baixa are highly fragmented (Wong and Navarro, 2013). The typical size of a single orange-grove holding is in the range of 0.2 to 1.0 hectare. It has been evident for many years that the net revenue from such small scale orange cropping does not provide sufficient living income for the land owner. Indeed many growers have alternative wage-paying off-farm employment. It may be noted that there are also significant number of farmers who combine rice cropping and orange cropping activities to achieve sufficient income for sustenance.

During the past few years, the orange cropping economy in Spain has been in significant decline. The underlying causes are well known: higher input costs, and long-term decrease in the price of fresh oranges imported into the vital EU markets from overseas. Both causes are difficult to resolve. Labour is and will continue to be a significant cost factor in the production of fresh oranges. And the labour cost in Spain is substantially higher than that in off-shore countries such as Brazil, Egypt, Morocco and South Africa. Freer trade with these producing countries into the EU is increasing irresponsibly year by year. Nevertheless, direct government subvention for
orange growers has been solicited actively during the past few years (Anon., 2011). In view of the continuing national budgetary problems and the lack of priority assigned to this agricultural sector under the EU’s Common Agricultural Policy, the outlook for offsetting financial support is dismal.

Up until about 2008, conversion of orange groves to housing estates has been a particularly attractive option for many farmers who wish to leave the business permanently. However, the economic crash since that time has halted this exit strategy abruptly.

A new strategy of agricultural production and distribution is needed to rectify this dismal economic situation (Wong and Navarro, 2014). This project was undertaken to determine if energy production in lieu of orange cropping might be a viable practical alternative for Ribera Baixa farm land.

**Methods**

Public-domain documents, including reports, statistics and journal publications were used for the present development and analysis of various energy-production scenarios for the remediation of the declining orange-cropping economy in Ribera Baixa.

On an as-required basis, USA cost data were adjusted to 2012 by using the Consumer Price Index calculator published by the US Bureau of Labor Statistics (http://www.bls.gov/data/inflation_calculator.htm). The US currency was converted to Euro using reference values published by the European Central Bank (ECB; http://sdw.ecb.europa.eu/) for the indicated time. Typically, US-dollar cost (or price) was first adjusted for inflation (or deflation), and then the inflation/deflation-adjusted value would be converted to Euros for the specified time period.

**Results and Discussion**

In view of the high incident solar radiation and generally warm climatic conditions available at the latitude of Ribera Baixa, it is logical to consider its deployment to produce portable energy. Figure 2 shows the candidate schemes evaluated. In particular, liquid fuel might be produced to offset the purchase of petro-diesel fuel for on-farm as well as off-farm uses.
**Power Generation**

During the past decade, Spain had an exceptional large expansion in power generation capacity based on renewables. This expansion was fuelled by generous government subsidies and readily available bank financing. As of December 31, 2013, about 30% of the installed power capacity was based on renewables, notably solar and wind (Red Eléctrica de España, 2014: 7). Since the start of the economic recession beginning in 2008, the Spanish government has terminated all subventions for the installation of new renewables power production (Morales and Sills, 2012). Moreover, it has cut previously-promised feed-in tariff subsidies successively to leave the investors of renewable power generation in increasingly serious financial difficulties. Although the operating cost of power production from renewables such as wind and solar is inherently low, the recurring significant cost of capital borrowing had to be continually financed. One of the consequences is the substantial steady rise in the price of (grid) power delivered to consumers to cover the financial shortfall. It is very plausible that grid power generators as well as the distribution network operator are also exploiting the present subvention turmoil for additional price increases. In order to quell the growing public discontent about steadily rising power cost in times of economic recession, the government has now intervened in the market in a reversal of its standing policy of energy-market liberalization (Anon., 2013a; Minder, 2013; Anon. 2014). This pre-tax price relief may be temporary as the government still needs higher tax revenue and lower financial subvention to re-balance the national finance. The evolving political-economic situation has a considerable impact on the ultimate viability of small-scale private power generation for sale to the national grid or to local users directly.

1) **Large-scale Electric Power**

In theory, orange cropland could be converted easily to produce electricity using the photovoltaic (PV) technology. Unlike concentrated solar power (including coupling to Stirling engines) technologies, there would be no need for cooling water. In the simplest configuration, there would be no storage of heat or electricity during no-sun periods. For this preliminary analysis, highly idealized conditions of PV power generation were used.

The annual revenue of a solar photovoltaic power generation option for Ribera Baixa was estimated as follows:

\[
R = P \times D \times E \times T
\]  
where \(R\) = revenue (€/ha per year), \(P\) = peak unit power (MW\textsubscript{p}/ha), \(D\) = maximum daylight time (hours/year), \(E\) = inverter efficiency (%) and \(T\) = wholesale tariff (€/MWh).

The simple payout time was calculated as follows:

\[
P = \frac{C}{R}
\]  
where \(C\) = capital cost of installation (€) and \(R\) = gross pre-tax revenue (€ per year). The assumptions used in these calculations are given in Table 1. The maximum net output per hectare was calculated to be 2,525 MWh for sale annually to the grid. This value could be considered to be highly idealized. In an evaluation of 26 fixed-tilt photovoltaic installations in the USA, the US Department of Energy (2012) has found the direct land use by annual electricity production to range from 400 to 1,250 MWh per hectare. It may be noted that most of the surveyed US installations are located in desert-like regions of southwestern United States. The production capacity of the Moura project in Portugal had cited 2,685 MWh generated per hectare of collector surface mounted on trackers (Acciona, 2008).

Under the highly idealized conditions used in the present estimation, the maximum gross pre-tax revenue would be €80,116 annually. At a capital cost of €3.642 million per hectare given in Table 1, the simple payback time is calculated to be about 45 years. It is evident that there is inadequate economy in the conversion of orange grove to produce electricity (for the grid) by photovoltaic means, in the absence of significant State subvention.

2) **Small-scale Electric Power**

Retail prices of PV panels and subsystems fell substantially during the year, due in part to the Spanish government’s termination of all subventions for new solar power production (Morales and Sills, 2012). The other factor causing lower retail prices was the entry of many low-cost PV hardware manufacturers into the EU market. In retrospect, the generous subvention provided by past Spanish governments had induced exuberant expansion of solar power generation. At present, PV panels (240 W/24 V) are retailing at about €200 per unit. And PV kits (5-kW\textsubscript{peak} power, including
panels wiring, controller, batteries and inverter) are available in the retail market at ~€ 7,900, exclusive of 21% VAT. The pre-tax cost such a kit would be about €1,580 per kW. According to the vendor (see http://www.kitsolar.com), the kit could provide sufficient for the need of a modern house with full complements of electrical appliances. Commentators and lobbyists have noted that the renewable energy sector can “help end the crisis with investment in self consumption” (Anon., 2013b). But in the pursuit of acquiring new tax revenue, the government has imposed an excise tax on PV electricity generated for in-home personal use in mid-2013 (Government of Spain, 2013). In view of this new tax, private PV-generated power has instantly become uneconomical, even for self consumption. In effect, the simple pay-out time for an average size house installed with simple PV-panels has now increased by 60% (Anon., 2013c). This regressive taxation policy has effectively deterred about 30% of the households with roofs for PV panel installations from supplying own pollution-free electricity. The same Real Decreto Ley 9/2013 also applies to any installation of PV panels in privately-owned orange orchards for the generation of power for own use. In essence, everyone is being taxed for using the Sun!

As shown in Figure 3, the pre-tax retail price of electricity for medium-size households has been rising rapidly since 2007. For comparison, in December, 2012, the cost of electricity at the household level in Ribera Baixa was €0.161 per kWh, exclusive of taxes and fees. The Instituto para la Diversificación y Ahorro de la Energía reported the average consumption of electricity of a detached medium-size house in the Mediterranean region (including Ribera Baixa) to be 8,363 kWh per year (IDAÉ, 2013). If the representative pre-tax price was €0.15 per kWh, the potential valuation of PV electricity to be generated (for a house located within an orange orchard) could be €1,254 annually. The simple payout time for the installation of the above-described PV system would thus be about 6 years, on a pre-tax basis.

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### TABLE 1: ASSUMPTIONS USED IN THE CALCULATION OF SOLAR PHOTOVOLTAIC POWER GENERATION UNDER HIGHLY IDEALIZED CONDITIONS

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Representative value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>P Power (peak) per unit surface area</td>
<td>0.71 MW₀ (peak, direct current) per hectare</td>
<td>In an evaluation of 26 fixed tilt photovoltaic installations in the USA, the US Department of Energy (2012) has found the direct land use by capacity to range from 0.23 to 0.71 MW per hectare. The Andosol solar photovoltaic power station near Guadix [37.2 °N, 3.1 °W], Andalucía reported 50 MW installed capacity from 51 hectares gross fixed-tilt collector surface (Solar Millennium, 2009).</td>
</tr>
<tr>
<td>D Daylight hours available at the specific location</td>
<td>2,821 hours net available</td>
<td>Total 4,445 daylight hours annually at Sueca (ASDC, 2012). Assumed 20 rainy days. Deduction of 2 hours after sunrise and 2 hours before sunset.</td>
</tr>
<tr>
<td>E Inverter efficiency</td>
<td>80%</td>
<td>Typical value for losses incurred in the converting of direct current to alternating current. Transformer efficiency is assumed to be 100%.</td>
</tr>
<tr>
<td>T Tariff at pre-tax wholesale level</td>
<td>€50 per MWh</td>
<td>Representative First Quarter, 2012 price (DG, 2012). Feed-in tariff in Spain will be cancelled as of December 31, 2012 (DG Energy, 2012).</td>
</tr>
<tr>
<td>C Cost of installation of photovoltaic power system</td>
<td>€3.642 million per hectare, without any thermal storage capacity (~ €5,130 per kW-peak, installed)</td>
<td>The US-EIA (2010) value was adjusted for inflation (1.06 multiplier) from 2010 to 2012, and then converted at US$1.2502 to €1.00 using ECB 3rd Quarter, 2012 reference exchange rate. The Andosol Project reported a capital cost of €6,000 per kW installed, including thermal storage and extensive infrastructure (Solar Millennium, 2009). €5,460 per kW with tracker system but without thermal storage, cited for the Moura solar photovoltaic power station, near Amareleja [38.2 °N, 7.2 °W], Portugal (Acciona, 2008).</td>
</tr>
</tbody>
</table>

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Basis: Annual household consumption: 2,500 to 5,000 kWh

FIG. 3 AVERAGE NATIONAL ELECTRICITY PRICES (WITHOUT TAXES) FOR MEDIUM-SIZE HOUSEHOLDS IN SPAIN AND THE EU

Without consideration of any standby power demand and/or possible export of a small amount
of surplus power to the grid, these preliminary calculations would suggest that the “power generation for self-consumption” scenario might be economically feasible.

If an “energy cooperative” of self consumers was to convert one hectare of “orange grove” for PV power generation, the potential pre-tax value of electricity generated would be as much as €3 million on the basis 710 kWpeak per hectare (from Table 1). The un-surprisingly high valuation would certainly tempt the “energy cooperative” to sell surplus power outside the farm gate, to exploit the apparent large pre-tax price differential between retail and wholesale electricity. It should be cautioned however that the apparently favourable economics is predicated on the assumption that there is no cost incurred for transmission and distribution to houses of self-consumers located virtually adjacent to the hypothetical PV power generation site. In practice, this scenario may not be practicable as many existing houses within orange groves are not fully occupied on a year round basis, and not sufficiently clustered to render shared PV production of electric power.

Table 2 Average Ratio of Network Price to Energy Price for Retail Electricity Delivered to Domestic Consumers

<table>
<thead>
<tr>
<th></th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spain</td>
<td>No data</td>
<td>0.39</td>
<td>0.39</td>
<td>0.82</td>
</tr>
<tr>
<td>EU-15</td>
<td>1.13</td>
<td>0.64</td>
<td>0.67</td>
<td>0.71</td>
</tr>
<tr>
<td>Sweden*</td>
<td>0.91</td>
<td>0.44</td>
<td>0.88</td>
<td>0.86</td>
</tr>
</tbody>
</table>

* inserted for comparison
Source: Adapted from EUROSTAT, 2012.

If surplus power generated was to be exported outside the farm gate of the “energy cooperative”, there would definitely be a substantial addition of network cost. Table 2 illustrates the magnitude of the network cost relative to the base (= wholesale) cost of electricity for Spain, Sweden and EU-15. With the addition of a network cost, the pre-tax price differential between retail and “wholesale + network” would narrow substantially for the planned power-export business of the “energy cooperative”.

Furthermore, unfettered reasonable fee-for-service access to existing transmission and distribution network may not be a certainty for the small electric power producer such as the hypothetical “energy cooperative”. Recent EC directives (e.g., Directive 2009/72/EC) have mandated the complete segregation of power transmission business from power generating companies to afford greater market competition. The small independent power producers still encounter the problem of unavailability of volume discount for network usage. The economic viability of prospective export of surplus power by the “energy cooperative” would thus be degraded further.

Biomass Oils

The conceptual plan is to produce crude triglyceride oil from microalgae or oil-bearing tree crops. The crude triglyceride oil would then be used directly in diesel engines with little or no engine modifications. Baquero et al. (2010) have reported successful experimental use of straight vegetable (triglyceride) oil in farm diesel engines. In this fashion, the costly refining of the crude triglyceride oil into approved EN590 diesel fuel or EN14591 ester diesel blending stock could be avoided.

As given in Table 3, the demand of diesel fuel for orange production is relatively small, at ~90 litres per hectare under orange cropping conditions which are similar to those of Ribera Baixa. In comparison, the demand for fuel (95% diesel + 5% gasoline) is given to be about 300 litres per hectare for rice cropping (Greer et al., 2012). For an orchard size of one hectare, the annual diesel fuel expense would be less than €100 for stand maintenance, if the farm-use diesel fuel was available for purchase at nominal €1.00 per litre (with excise tax exemption and reduced value-added tax). This small expenditure certainly does not justify any on-purpose production of liquid fuel for this purpose.

Table 3 Fossil Fuel Usage Reported for Orange Farms in Several Different Countries

<table>
<thead>
<tr>
<th>Location</th>
<th>Reference</th>
<th>Diesel fuel, litres/ha</th>
<th>Yield*, kg/ha</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antalya, Turkey</td>
<td>Ozkan et al., 2004</td>
<td>338</td>
<td>None cited; about 300 trees per ha</td>
<td>100% diesel; including tillage (land preparation) and delivery of irrigation water</td>
</tr>
<tr>
<td>Florida, USA</td>
<td>Pimentel, 2006</td>
<td>186</td>
<td>46,000 (field?)</td>
<td>50% vol. diesel + 50% vol. gasoline</td>
</tr>
<tr>
<td>Manzadaran, Iran</td>
<td>Namdari et al., 2011</td>
<td>300</td>
<td>32,500 (field?)</td>
<td>100% diesel; including tillage (land preparation) and delivery of irrigation water</td>
</tr>
<tr>
<td>San Joaquin Valley - South (California), USA</td>
<td>O’Connell et al., 2009</td>
<td>87</td>
<td>28,845 (field)</td>
<td>Diesel + gasoline; stand maintenance only.</td>
</tr>
</tbody>
</table>

* In the case of fresh oranges, packing-house yield is typically 80% of field yield.
However, production of biofuel for on-road uses might be economically more attractive, in view of continued rise in the base petroleum price globally.

1) Microalgal Oil

In view of the abundant amount of sunlight and warm ambient temperatures available annually, microalgal oil production could be an attractive candidate. As in the case of rice cropping in the same geographic region, it has been estimated that a production of 17,000 litres of crude microalgal oil (CMO) per hectare might be feasible (Wong et al., 2013). As given in Figure 4, the proposed processing scheme would result in no effective discharge of process effluents or solid wastes into the receiving environment.

In order to implement open-pond production of microalgae, a means to control the infiltration of water through the soil would be required. Moreover, an effective water management scheme would also need to be established to account for the high evaporation of water from the open pond during the hot summer months.

The scenario of producing CMO for on-road uses is examined in Table 4. The two principal assumptions used in this analysis are that a) CMO could be used directly in place of petro-diesel with minor engine modification to account lower calorific value, b) the cost ready-to-use CMO would be equivalent to the base pre-tax price of petro-diesel, and c) excise tax for on-road usage could not be avoided. The European Commission (2012) has specific rules and regulations governing the collection of minimum excise tax on fuel in all EU member states.

Depending on the final organizational structure of the production facility, it may be possible to avoid the payment of value-added tax (VAT). For example, each member of a “biofuel cooperative” could use its own-produced crude bio-oil, after isolation and filtration at a centralized processing facility. It could be argued that there was no transfer of ownership of any goods to cause any imposition of VAT.

![Diagram](https://example.com/diagram.png)  
**FIG. 4 CONCEPTUAL SCHEME TO PRODUCE CRUDE MICROALGAL OIL (CMO) IN RIBERA BAIXA**

![Graph](https://example.com/graph.png)  
**FIG. 5 EFFECT OF EXCISE TAX AND CMO PRODUCTION COST ON ANNUAL COST SAVINGS IN A MODEST-SIZE DIESEL VEHICLE USING 100% CMO**

At the anticipated yield of 17,000 litres CMO per year, conversion of ~330 m² of present orange grove would be sufficient to produce ~560 litres of CMO.
for the operation of a single model diesel vehicle (at 10,000 km usage per year) each year. But the annual saving that could be accrued from operating the model diesel vehicle would be €95. The level of saving could be realized only after expending considerable cost to convert the orange-producing land for self-production of CMO as petro-diesel substitute. Figure 5 shows the impact of excise tax and CMO production cost on the realizable saving in motor fuel cost. Note that the cost saving for the operation of a single diesel model car could reach ~€550 annually, if there was no excise tax on the CMO and if the CMO production was 25% of the base case. There is no practicable means to avoid paying the excise tax for on-road motor vehicles. It may be noted that all tax exemption for biofuel sold to the public will be terminated in Spain as of December 31, 2012. In view of continuing Spanish national budget crisis, there is essentially no prospect of any resumption of “biofuel subsidy” in Spain in the immediate future.

**TABLE 4 CRUDE MICROALGAL OIL (CMO) PRODUCTION OPTIONS**

<table>
<thead>
<tr>
<th>CMO production options</th>
<th>1-hectare individual orchard in Ribera Baixa</th>
<th>Ribera Baixa</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMO production</td>
<td>CMO-Zero</td>
<td>CMO-20</td>
</tr>
<tr>
<td>% land use</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>hectares</td>
<td>0</td>
<td>0.2</td>
</tr>
<tr>
<td>litres/year</td>
<td>0</td>
<td>3,400</td>
</tr>
<tr>
<td>GJ/year</td>
<td>0</td>
<td>119</td>
</tr>
<tr>
<td>Petro-diesel required (b)</td>
<td></td>
<td>87</td>
</tr>
<tr>
<td>litres/year</td>
<td>0</td>
<td>87</td>
</tr>
<tr>
<td>€/year (c)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>CMO surplus</td>
<td>GJ/year</td>
<td>0</td>
</tr>
<tr>
<td>litres/year</td>
<td>0</td>
<td>3,330</td>
</tr>
<tr>
<td>Private cars fuelled (d)</td>
<td>number/year</td>
<td>0</td>
</tr>
<tr>
<td>€ cost/car/year (e)</td>
<td>654</td>
<td>559</td>
</tr>
<tr>
<td>€ savings/car/year</td>
<td>---</td>
<td>95</td>
</tr>
<tr>
<td>Gross farm-gate revenue</td>
<td>€/year – oranges (f)</td>
<td>6250</td>
</tr>
<tr>
<td>€/year – CMO (g)</td>
<td>0</td>
<td>2560</td>
</tr>
<tr>
<td>€/year total</td>
<td>6250</td>
<td>7560</td>
</tr>
</tbody>
</table>

Notes:
(a) Total area of land used for orange cropping in Ribera Baixa in 2011 (GVA, 2011).
(b) for orange farming.
(c) market price at €1.00/litre for farming uses (Daniel Buguera, personal communications, 2012)
(d) adjusted for lower CMO calorific value
(e) Calculated pump price of petro-diesel at €1.298 per litre; Calculated pump price of CMO fuel = €1.100/litre (i.e., €0.769 per litre pre-tax base price + €0.331 per litre excise tax, without any VAT)
(f) Oranges: 25 tonnes/hectare x €250/tonne x hectares allocated for orange cropping
(g) CMO: 17,000 litres/ha x €0.769/litre (excluding excise tax) x hectares allocated for biofuel production

Assumptions:
- CMO can be used in conventional diesel engines with minor engine modifications (Wong et al., 2012).
- CMO productivity = 17,000 litres/ha/year (Wong et al., 2012)
- Fuel properties:
  - Calorific value: 42.3 MJ/kg petro-diesel; 38.0 MJ/kg CMO
  - Density: 0.833 kg/litre petro-diesel; 0.920 kg/litre CMO
- Reference automobile: KIA Rio – 2011 UK model 1.1 CRDi Manual (1.12-litre; 5-passerger) with lowest emission (viz., 85 g CO2 per km) of any internal-combustion motor vehicles sold in the UK. http://www.kia.co.uk/~media/specifications/rio_spec_sheet_updated.ashx
  - 3.50 litres petro-diesel/100 km urban; 123 MJ/100 km urban
  - 3.53 litres CMO/100 km urban at the same 123 MJ/100 km urban
  - Typical 14,000 km/year automobile usage
- Fuel pricing:
  - Farm use: €1.000/litre petro-diesel, including €0.07871/litre excise tax and 18.0% VAT (EC, 2012). The calculated base pre-tax petro-diesel price at pump = €0.769/litre
  - Road use: €1.298/litre petro-diesel at pump, calculated from base pre-tax price to include €0.331/litre excise tax and 18.0% VAT (EC, 2012).
The commitment of Spain to comply with the EU biofuel objectives by 2020 (EC, 2007) would be met by decree. In the absence of government subsidies, there may be no further expansion of production of biodiesel blending stock inside Spain. In the fulfillment of this EU-wide motor fuel composition requirements, biofuel blending stock could be imported perhaps more economically from other EU member states such as France and Germany. However, this negative economic projection could be mitigated substantially if the prevailing base-case pre-tax price of petrol-diesel rose significantly, due to real-term rapid increases in global crude petroleum prices.

2) Tree Oil Crops

Cultivation of jarak (Jatropha curcas L.) as an energy crop has been studied at several field trial locations in the Comunitat Valenciana by the Instituto Valenciano de Investigaciones agrarias in about 2007 (IVIA, 2008; IVIA, 2009). Jarak grows best under humid tropical conditions (DECD, 2005; Daniel, 2006). This IVIA research project appeared to have since abandoned, possibly because of the intractable problem of supplying large quantities of irrigation water for the mass production of a liquid biofuel product that has no direct Spanish government subvention in the market place (EC, 2012).

In contrast, moringa (Moringa oleifera Lam.) is highly valuable multi-purpose small tree found in tropical and subtropical regions of the World. All parts of the tree, viz., leaves, pods, roots, bark, stems and twigs have highly-nutritious alimentary uses (Hsu et al., 2006). Moringa is drought tolerant. Typically, it can be grown in areas with 250 to 1,500 mm rainfall annually (Radovich, 2011). Thus, with the annual precipitation in Ribera Baixa rainfall being about 500 mm, no irrigation would be required. The best mean annual temperature range is 25 to 35 °C (Palada and Chang, 2003). Established moringa trees can survive low temperature of 0 °C and high temperatures up to 48 °C (Price, 2007), for short periods. Moringa is a fast growing plant which is responsive to irrigation and fertilization. Foidl et al (2001) have reported that moringa shrub would grow typically to 1.5 to 2 metres before extensive branching starts. The corresponding diameter at breast-height would be 20 to 40 cm. Under intensive culture, green pods as well as leaves could be harvested 6 to 7 months after seeding (Schabel, 2003). Full productivity could be attained by the fourth year after seeding (Rajangam et al., 2001). The conceptual scheme to produce crude moringa oil is shown in Figure 6. Note that all solid wastes are managed gainfully.

The productivity of moringa oil is estimated to be in the range of 685 to 1,141 litres per hectare per year, on the basis of the following assumptions:

- Planting density = 400 trees/ha (Radovich, 2011, p.9)
- Productivity at maturity = 15,000 to 25,000 seed/tree/year (Foidl et al., 2001, Table 1)
- Seed weight = 300 milligrams/seed (Foidl et al., 2001, Table 1)
- Oil content of seed = 35% by weight (Rashid et al., 2008)
- Crude oil density = 0.920 kg/litre

It may be noted that Radovich (2011) has suggested a yield of only ~225 litres per hectare per year for “natural” cropping of moringa in Hawaii. If the maximum output of 1,141 litres per hectare per year was assumed, conversion of 1/2 of one hectare of orange grove would be sufficient for the operation of a single model diesel car. The annual demand of one motor vehicle would be ~500 litres of crude moringa oil per year.

![FIG. 6 CONCEPTUAL SCHEME TO PRODUCE CRUDE MORINGA OIL IN RIBERA BAIXA](image-url)
There is no reliable information available for moringa cropping in northern-latitude regions. The cropping of almonds in the Sacramento Valley (Connell et al., 2012) was used as the surrogate to estimate the possible production cost of moringa oil. The climatic conditions and farm labour cost structure of the Sacramento Valley (California) are largely similar to those of Ribera Baixa (Wong and Navarro, 2013). Harvesting of moringa pods would be made by mechanical shaking in a similar fashion as the harvesting of almonds from mature trees. In the transcription to the Ribera Baixa location, moringa cropping was assumed to be practicable without the use of fertilizers, pest control chemicals and irrigation water, and without any interest on operating capital.

At the highest probable yield of 1,141 litres per hectare per year cited above, and using the production cost for almonds, i.e., US$3,923 per hectare (Connell et al., 2012), the estimated 2012 production cost would be €2.75 per litre of crude moringa oil (at ECB reference currency exchange rate of €1.00 = US$1.2502 for 3rd Quarter, 2012). Note that the additional cost of expressing crude oil from the harvested moringa seeds has been omitted in the present calculation of production cost.

If the farm-gate price was €2.50 per litre of crude moringa oil after deducting nominal €0.25 per litre for in-farm cost of expressing harvested moringa seeds to produce ready-to-use crude oil, the maximum gross revenue would only be ~€2,853 per hectare annually. This figure can be compared to ~€13,000 per hectare for the CMO option, and ~€6,250 per hectare for the present orange cropping. Even in the best-case scenario, the conversion of land for the production of crude moringa oil for transportation uses would not be an attractive alternative to currently-practiced orange cropping in Ribera Baixa.

However, in view of the potential demand for a “natural” nitrogen fertilizer for proposed organic orange farming, there could be a business case for the implementation of moringa cropping, albeit on a small scale, among the orange groves. In this instance, moringa cropping could be undertaken solely to provide young foliage for the preparation of “green manure”.

Table 5 shows moringa leaves to have similar nitrogen (N) content as farm animal manures. With the exception of rice straw, olive oil mill wastes (mainly found in Andalusia or Catalunya), farm animal manures (from livestock rearing in Asturias) and fish meals (available largely from Galicia) are not readily available locally for composting in Ribera Baixa. Thus, cultivation of moringa specifically for leaf production appears to be an attractive proposition for boosting the nitrogen content of rice straw (Ayuntamiento de Valencia, 2004) for the local preparation of a natural fertilizer for organic tree cropping. Furthermore, microalgae solids might be available if a crude microalgal oil production project was realized separately in the Albufera rice cropping area of Ribera Baixa (Wong et al., 2013). The cost of “natural” nitrogenous fertilizer for organic cropping of oranges and tree nuts could thus be reduced substantially.

### Table 5 Comparative Nitrogen Content with Selected Natural Fertilizers

<table>
<thead>
<tr>
<th>Nitrogen Source</th>
<th>% Total N of Dry Matter</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moringa leaves</td>
<td>3 - 5</td>
<td>Foildi et al., 2001; Kakengi et al., 2007; MAG, 2010; Pérez et al., 2012</td>
</tr>
<tr>
<td>Rice straw</td>
<td>0.5 - 0.9</td>
<td>Juliano, 1985; Marimuthu et al., 2002; Goyal and Sindhu, 2011; El-Aksher et al., 2012</td>
</tr>
<tr>
<td>Olive oil mill wastes</td>
<td>0.8 - 1.6</td>
<td>Khatib et al., 2010; López Piñeiro et al., 2010.</td>
</tr>
<tr>
<td>Farm animal manure</td>
<td>2 - 5</td>
<td>Pratt and Castellanos, 1981; Khatib et al., 2010.</td>
</tr>
<tr>
<td>Fish meal</td>
<td>9 - 12</td>
<td>Sujeewa, 2000; Kakengi et al., 2007.</td>
</tr>
<tr>
<td>Microalgae</td>
<td>8 - 10</td>
<td>González López et al., 2010.</td>
</tr>
</tbody>
</table>

*Where applicable, N was calculated as “reported protein/6.25”.

### Perennial Energy Crops

Several perennial plants such as miscanthus (Miscanthus giganteus), switch grass (Panicum virgatum) and giant reed (Arundo donax L.) have been suggested as potential energy crops for the EU to meet the mandated long-term goal of reducing the emission of greenhouse gases. In particular, C₄ plants are recognized to be highly efficient in photosynthesis; they are tolerant to drought as well as high temperature conditions (Bower and Leegood, 1997). Nevertheless, intensive water and fertilization management were required to achieve maximal growth of both C₃ and C₄ energy crops (Angelini et al., 2005; Mantineo et al., 2009; Nassio Di Nasso et al., 2010; Dopazo et al., 2010). It is also instructive to note the caution given by Ericsson et al. (2009) that high profitability of energy crops (especially with generous government subvention) will lead to high land and production costs for food crops, especially in the cereal-grain producing regions of the EU.
Angelini et al. (2009) have reported an average yield of ~38 tonnes dry matter/hectare per year for giant reed and ~29 tonnes dry matter/ha per year for miscanthus in a 12-year field trial in central Italy (43.67 °N, 10.32 °E; 2 metres above sea level). In a separate shorter 5-year field trial in Sicily (37.38 °N, 14.35 °E; 550 metres above sea level), Mantineo et al. (2009) reported average yield of giant reed and miscanthus to be 33 tonnes/ha/year and 22 tonnes/ha/year, respectively. Interestingly, a C₄ plant (i.e., giant reed), afforded substantially higher average yield than a C₃ plant (i.e., miscanthus) in both independent Italian studies. Zhu et al. (2008) have estimated that continual rise in the average global temperature as a result of higher atmospheric CO₂ concentration would narrow the difference in solar energy conversion efficiency between C₃ and C₄ plants. Dopazo et al. (2010) have cited that short-term trials of several selected cultivars of miscanthus in Portugal under conditions of intense irrigation had provided practical yields of only 10 to 25 tonnes dry matter per hectare.

Sugar cane (Saccharum officinarum), a ubiquitous C₃ plant, has been grown routinely, but not as mass-scale monoculture, in southeastern Spain during medieval Islamic time. Triana et al. (2008) has reported the practicality of a new Cuban variety of sugar cane which could provide proportionally higher yield of fibrous biomass relative to the customary sugar juice. Exceptionally high yield of up to 80 tonnes per hectare has been reported for experimental cultivation under optimized conditions in Cuba (Alejandro Abril, personal communication, 2013). Using the methodology described by Weyer et al. (2010), the theoretical practicable biomass yield from phytosynthesis under tropical conditions was estimated to be 85 to 110 dry tonnes per hectare per year. As shown in Table 6, average incident solar radiation and temperature at Sueca are substantially lower than those in Matanzas (Cuba), for example. If the “80 tonnes per hectare” yield was transcribed into the prevailing Sueca meteorological conditions without consideration of other growth factors such as different rainfall pattern and soil structure, the expected annual yield would be decreased to between 20 to 60 tonnes per hectare, at about the same range of biomass yield as miscanthus or giant reed reported in above-cited Italian field trials.

The fundamental obstacle to the implementation of the “energy-cropping” approach is that the pattern of highly fragmented holdings in Ribera Baixa is not conducive to mass-scale field crop production. Even if the above issue could be overcome, there are no local end users, i.e., suitable solid-fuel thermal power generation facilities, to purchase the biomass produced by these energy crops. Transportation of compressed dried biomass, as a commodity, from Valencia to thermal power plants in northern EU countries is financially impractical. It may however be noted that many Dutch thermal power plants have been importing wood pellets from Canada as well as Eastern Europe for co-firing with coal for many years. The mandated strategic goal is to reduce the emission of greenhouse gases.

**Conclusions**

The problem of orange cropping in Ribera Baixa is persistent and difficult to solve in view of continued globalization of freer trade with competitive fresh oranges arriving into the EU market from low-wage producing countries. The solar-energy capture of selected approaches was evaluated without consideration of economics. Moreover, cultivation activities were assumed to be under optimal conditions in which cultivar selected, soil fertility, appropriate year round temperatures, water supply,

<table>
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<tr>
<th>TABLE 6 METEOROLOGICAL CONDITIONS FOR SUGAR-CANE CROPPING IN SUECA, SPAIN AND IN MATANZAS, CUBA</th>
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<tbody>
<tr>
<td>Basis: 1 year</td>
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<tr>
<td>(23.1 °N)</td>
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<tr>
<td>Average annual full-spectrum incident solar radiation, MJ/m² (a)</td>
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<tr>
<td>Maximum theoretical yield (b), dry matter, kg/ha</td>
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<tr>
<td>Calculated full-spectrum solar energy conversion efficiency, % (c)</td>
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<tr>
<td>Average daily temperature, °C (a)</td>
</tr>
<tr>
<td>Degree-days above 18 °C (a) minimum for biomass growth (d)</td>
</tr>
<tr>
<td>Maximum theoretical yield of dry matter, relative to “Matanzas”, %</td>
</tr>
<tr>
<td>Due to lower incident solar radiation</td>
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<td>Due to fewer degree-days available</td>
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</table>

(a) ASDC (2012) data
(b) Based on the calculation model of Weyer et al. (2010) for primary production.
(c) Cf. Zhu et al. (2008) had cited 4.6% and 6.0% full-spectrum solar energy conversion efficiency for C₃ plants and C₄ plants, respectively.
(d) Deerr (1921: 24-30) had commented >70 °F (21 °C) for adequate biomass growth and maturation.
etc. are available without limit. The production of energy, in the form of photovoltaic electricity or plant oil as diesel fuel substitute, does not appear to have sufficient economic advantages in lieu of present orange cropping. The production of photovoltaic electricity for self consumption might be practicable under certain circumstances. The hurdle is not technology, but government fiscal and regulatory policies.

**REFERENCES**


