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Integrated Renewable Energy Solutions for Aquaculture Processing—Enerfish

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Abstract: The European Union Framework Programme 7[1] Enerfish project aims to demonstrate a new poly-generation application with renewable energy sources for the fishery industry in Vietnam. The fish processing plant under consideration can be made by energy self-sufficient when all fish waste oil is processed into biodiesel and further converted to electricity and heat (for cooling) in a CHP (combined heat and power) unit. The purpose of the present paper is to discuss the profitability of such plants in southeast Asia. The economic model shows that electricity production is, due to the low electricity tariff, uneconomical (except during electricity blackout), even if cogeneration heat can be utilized. This prompt a design of the plant whereby the necessary heat for the biodiesel process is taken from the waste heat produced by the compressors of a CO_2 cooling system. According to the calculations and assumptions of the present study, the profitability of biodiesel production from fish cleaning wastes in Vietnam depends strongly on the market prices for fish waste and fish oil. Different business case scenarios are described.

Key words: Biodiesel, cogeneration, energy efficiency, energy from waste, environmental economics, distributed power generation, food technology, waste heat.

1. Introduction

The present study deals with the promotion of a poly-generation process (electricity, heat, cooling) where fish wastes are converted into fish oil [1] which in its turn is processed into biodiesel by transesterification [2-4]. Combustion of the biodiesel in a high efficiency CHP (combined heat and power) unit produces energy (electricity and heat) [5, 6]. Here, an economic study is carried out for a demonstration project called "Enerfish" (www.enerfish.eu), where such an integrated renewable energy solution is being erected in a fish-processing plant in Vietnam. The plant is located in a large aquaculture farm where 120 tons of catfish are processed every day and therefore a large amount of fish waste is available (approximately 80 tons per day) [7].

Most of the world production from aquaculture comes from Asia and this growth is likely to continue [8]. China represents two third of the world's aquaculture production, but in the past decade, southeast Asia has developed a major export-led industry (Vietnam being the third aquaculture producer), focusing on prawns and catfish: products are processed before export, taking advantage of lower labour costs, but creating significant volumes of waste, often rich in oils and fat.

Today, the main uses of fish waste are the production of fishmeal and fish oil [1, 9] mainly for aquaculture

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and farmed animals. Two sectors are competitors: the human food industry which needs omega-3 fatty acids (fish oil) [10] and the pharmaceutical industry which generates high-added value products from fish waste. This puts pressure on the availability and thus the market prices of fish waste and fish oil which are possible feedstocks for biodiesel production.

Over the last five years, fish oil prices have shown extreme variations, the main drivers for these variations are a stable production with a growing demand, a production mainly in the hands of two countries (Peru and Chile) which depends not only the El Niño oscillation but also on the fat content of the catches and at last, the increasing fish oil demand for human food production, fish farming in Europe and from the pharmaceutical industries.

The present study focuses on possible markets in southeast Asia for Enerfish-like processes. Such markets should mainly be driven by the availability of fish waste and the need for biodiesel, i.e., the market conditions under which can be produced. Demand in diesel varies enormously for the different ASEAN (Association of Southeast Asian Nations) countries. There is no clear political framework equivalent to the RED (renewable energy directive) [11] in the EU27, even though some countries have set clear objectives in the promotion of biodiesel blends (Bn), mainly to encourage indigenous supplies such as palm oil.

2. Business Models

The Enerfish process is well suited for fish processing units where there is a sufficient daily amount of waste to produce biodiesel. Fig. 1 puts forward a schematic chart of the Enerfish process with the main raw materials, by-products and outputs. This scheme suggests at least five different business models. The different business models are given by the vertical dotted arrows.

BAU (business as usual): this is the business as usual scenario where fish waste is sold to the market.

Fish-oil: the company only invests in a fish-oil processor and sells fish oil to the market.

Biodiesel_a: the company invests in both a fish-oil processor and a biodiesel processor and sells the biodiesel to the market (as well as the main by-product, i.e., glycerine).

CHP: this is the "Biodiesel_a" business model with a supplementary investment in a CHP (combined heat and power) unit which produces electricity and heat. Electricity and heat can be sold to the market (to the grid for electricity and to a local heat network if any) and/or can be used to produce energy for the Enerfish process unit. If the production of biodiesel is sufficient, the surplus (part which is not used for combustion in the CHP unit) can be sold to the market.

Biodiesel_b: the company only invests in the biodiesel processor, i.e., it sells its waste to a fish-oil processor and buys back fish oil. Biodiesel and glycerine are sold to the market.

One of the main features of the Enerfish project is poly-generation: a cooling/freezing cascade based on CO_2 has been installed. This investment is accounted

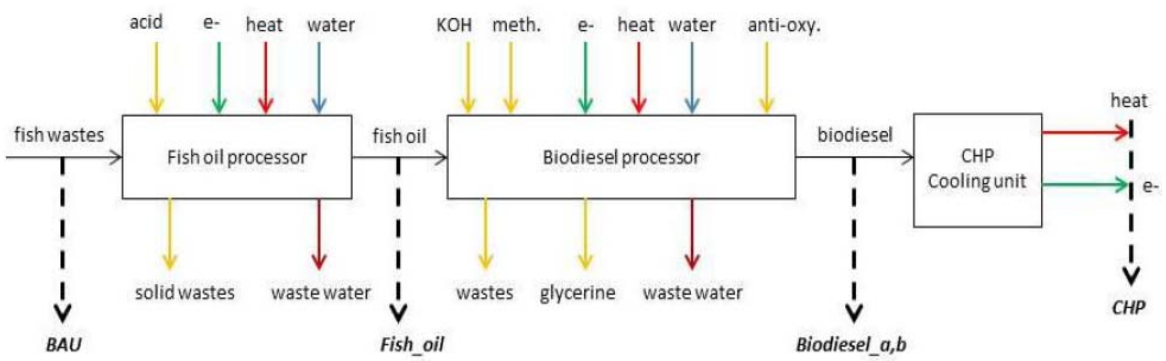

Fig. 1 Schematic view of the Enerfish process. Dotted arrows: business models. Acid: formic acid; e-: electricity; KOH: potassium hydroxide; meth.: methanol; anti-oxy.: anti-oxidant.

for in a variant of the "CHP" business model where part of the produced electricity is used in the compressors of the cooling/freezing unit.

A profitability analysis has been carried out for the Enerfish unit under operating conditions, i.e., mass flow rates and enthalpies, which are taken from the preliminary work performed in Refs. [1, 2]. All prices and cash flows for these variables are computed in Euros, i.e., the risks inherent to fluctuations in currencies are not directly accounted for.

The profitability of the different business models is investigated in terms of NPV (net present value), which is the sum of all discounted cash flows, including investments, during the economic period which is under investigation. This analysis is performed without accounting for taxation (EBITA (earnings before interest, tax and amortization)) so that the outcomes of the calculations are independent from the financial strategy of the company or its taxation scheme. If a business model is found to be profitable with this preliminary analysis, a financial (taxes) framework, which depends on the business model, the country, etc., should be applied for further investigations.

The analysis is performed as for a regular investment project, with an initial investment, that generates positive (earnings) and negative (costs) cash flows during n years of operation. All cash flows are expressed in constant currency, i.e., free from any inflation which is supposed to be constant. These cash flows are discounted with a WACC (weighted average cost of capital) and their sum gives the net present value of the project. The profitability index of the project, PI, i.e., the ratio $PI = NPV/I$, yields a measure of the discounted benefits per invested unit of currency (I is the total investment).

In the case of unevenly distributed cash flows in time (l represents the cash flow index, for example, cash flows related to the purchase of formic acid for the fish-oil processor and k is the time index, i.e., year "k"), people resort to the "economic equivalent cash flow" that gives the same result in terms of NPV,

$$CF_{l,e}.Fa(r,n,t_l) = \sum_{k=1}^{n} CF_{l,k}\frac{(1+t_l)^k}{(1+r)^k}$$

and the net present value of a project that can be calculated as (si is the total subsidy in % of the total investment I) :

$$NPV = -(1-si)I + \sum_l CF_{l,e}.Fa_l(r,n,t_l) + VR/(1+r)^n$$

where the discount factor is calculated not only as a function of the duration of the project, n, and the WACC, r, but also as a function of a drift term, t_l, which can represent for example, the variation of prices of raw materials or electricity and so on associated with cash flow CF_l. The discount factor is given by the following formula:

$$Fa_l(r,n,t_l) = (1+t_l)\left[1-\left(\frac{1+r}{1+t_l}\right)^{-n}\right]/(r-t_l)$$

VR is the sum of all residual values. The $CF_{l,k}$ terms are computed as the product of the variable (mass flow rate, energy flow) by its market price.

3. Results

In the computations, the authors assumed market prices (in Vietnam) of fish waste at 244 Euros/ton, of fish oil at 680 Euros/ton and of biodiesel at 687 Euros/litre. These numerical values differ from the ones taken in Refs. [7, 12], especially fish waste, i.e., 100 Euros/ton instead of 244 Euros/ton.

Table 1 shows the different cash flows associated with each component of the Enerfish process computed from the data provided by one of the Vietnamese partners (ECC (Energy Conservation Center of Ho Chi Minh City)) and the main economic variables are displayed in Table 2. Table 2 puts forward the economic variables that have been chosen as a preliminary computation (inflation, equity, debt, investment and OM (operating and maintenance) costs, etc.). Table 2 shows that there are no OM costs for the fish oil and diesel oil processors as well as for the auxiliaries. No data was available and therefore it has been assumed that the cash flow generated by these costs do not influence too much the results. The sum of the cash flows displayed in Table 1 represents the total cash flow per day that

Table 1 Daily cash flows for the CHP business.

Fish oil processor	€/d	Diesel oil processor + tank	€/d	CHP/Diesel unit	€/d
Fish cleaning wastes	-19,764	Fish oil	-11,560	Gas oil	0
Acid	-1,100	Potassium hydroxide	-1,040	Bio diesel	-1,099
Fish oil wastes	5,040	Methanol	-750	Electricity	298
Fish oil	11,560	Water	0	Heat	163
Electricity	-30	Electricity	-3	Op. & maint.	-175
Heat	-80	Heat	-12	Total	-813
Operation & maintenance	-	Biodiesel	8,931		
		Glycerine	400		
		Residues	0		
		Anti-oxidant	-240		
		Operation & maintenance	-		
Total	-4,374	Total	-4,274	Total	-813

Table 2 Economic variables for the computation of the NPV of the business models.

Economic variables: cost of capital, duration of project, recovery factor, etc.			
i	Inflation rate	0.02	
d_y	Number of processing days/year	300	days/year
n	Economic duration of the project	10	y
r_inv	Investors' interest rate	0.1	
x_inv	Investors' share	0.2	
r_loan	Bank loan	0.06	
x_loan	Bank's share	0.8	
Investment costs	-	-	-
I_fop	Fish oil processor	400,000	€
I_Dop	Diesel oil processor	450,000	€
I_CHP	Diesel/CHP unit	220,000	€
I_aux	Auxiliaries, control system, etc.	100,000	€
si	Subsidies (% of total)	0	
OM (operation and maintenance) and refurbishment costs			-
vc_CHP	CHP unit	1.84	€/MWh

could be expected from the "CHP" business model. Obviously no profitability can be expected. These cash flows show that the important economic variables are the market prices of the fish cleaning wastes, fish oil, and biodiesel. The market prices of electricity and heat are important for the cash flows generated by the CHP unit, but they are not first order terms for the overall cash flow values. Daily cash flow associated with the numerical values can be found in Ref. [13].

If a value of 100 Euros/ton is taken for the fish waste, as presented in Ref. [12], the cash flow for the fish-oil processor becomes positive (7,290 Euros/day) and the overall cash flow as well. Profitability can be expected from the CHP business model with a lower price for fish cleaning wastes (profitability is generated by the fish-oil processor).

With the numerical values of Table 2 and Ref. [12], (i.e., a fish cleaning waste price of 100 Euros/ton), the profitability of the project is extremely high, i.e., a PI of 3.37 is reached after 10 years. For the lifespan of the CHP unit, an average value of 10 years has been taken. Note that in the case of a minimum lifespan of five years for the CHP unit, the PI would still be 2.68. As a matter of fact, under these assumptions (100 Euros/ton for the fish waste), the project is so profitable that one could invest in the cooling/freezing system as well (720,000 Euros in investment and 5.5 MWh of daily electricity consumption) and obtain a PI of 2.28. In such a case, the PBT (pay back time) would be 2.6 years.

4. Sensitivity Analysis and Discussion

4.1 CHP Business Model

As seen in the previous section, for the CHP business model, profitability mainly depends on the price of fish cleaning wastes and to some extent on the price of biodiesel. The cash flows in Table 1 clearly show that it is more profitable to sell the biodiesel directly to the market than to produce electricity. That is why, the number of hours at full load, for the CHP, has been set to 6.3 hours/day, i.e., it corresponds to an energy production (electricity and heat) which covers the needs of the Enerfish process.

Fig. 2 displays the NPV as a function of the fish cleaning waste price in two different cases: with a cooling unit and a five year lifespan for the CHP unit and without a cooling unit and a ten year lifespan for the CHP unit. Economic duration of project: ten years. In both cases, the price of the fish cleaning wastes must be below 120 Euros/ton in order to reach profitability (120.7 for the former case and 116.6 for the latter case). The supplementary investment costs for the cooling system (50% more) and the CHP unit (double investment) do not make a difference. As a matter of fact, if the fish cleaning wastes were to be bought at the market price (244 Euros/ton), a price for biodiesel of at least 1,500 Euros/ton would be necessary in order to reach profitability.

4.2 Fish Oil Business Model

In such a business model, an economic duration of 15 years is taken as it corresponds roughly to the lifespan of the equipment. In such a case, a maximum price of 188 Euros/ton can give profitability (it is the value which yields a zero NPV after 15 years).

For a market price of 244 Euros/ton for the fish waste, the minimum price value of fish oil which gives profitability is 948 Euros/ton. Therefore, under current market conditions, such an investment could be profitable, i.e., fish oil is currently traded in international markets at 1,500 US$/ton which is approximately 1,100 Euros/ton. However, Fig. 3 shows that such price levels are not likely to hold for a period of 15 years since they are correlated to crude oil price. One could argue that crude oil is going to keep its high prices, but such an assumption can be risky for the Enerfish investor.

4.3 Biodiesel_a Business Model

Table 1 shows that this scenario is rather similar to the CHP one since the cash flows generated by the production of heat and electricity are much smaller than those generated by selling biodiesel to the market.

The limit values are roughly the same as in the CHP business model. A market price of 133 Euros/ton for the fish waste is the maximum value for profitability for an unchanged price of biodiesel. If the price of biodiesel is the variable and the price of fish cleaning

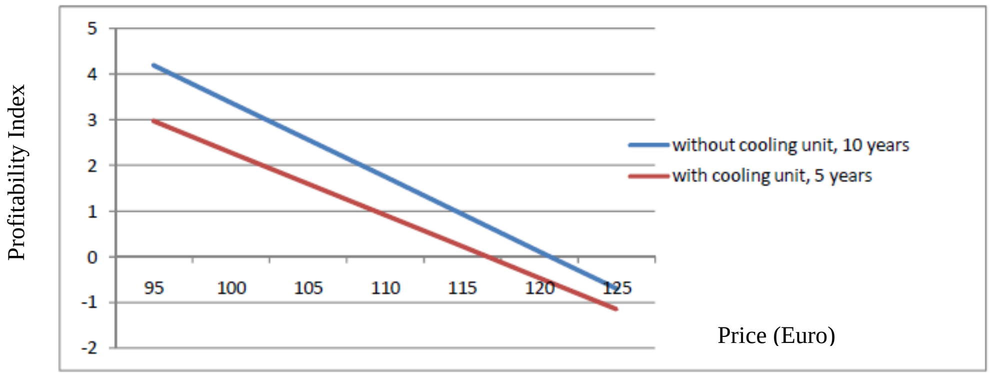

Fig. 2 CHP business model. Profitability index PI as function of the fish cleaning waste price in Euros in two different cases: with a cooling unit and a five year lifespan for the CHP unit and without a cooling unit and a ten year lifespan for the CHP unit. Economic duration of the project: ten years.

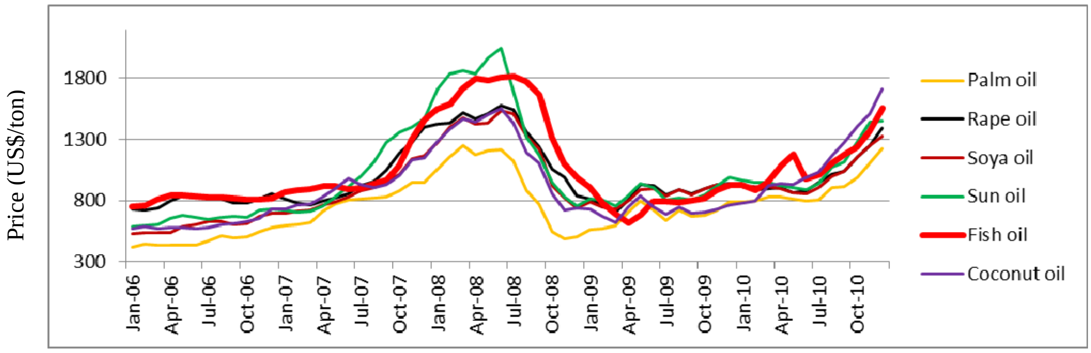

Fig. 3 Market prices for palm, rape, soya, sunflower, coconut and fish oils from January 2006 to December 2010 [3, 14].

wastes is set at 244 Euros/ton, biodiesel must be sold at 1,377 Euros/ton to reach a zero NPV.

4.4 Biodiesel_b Business Model

Again, in the case of selling fish waste to a processor and buying back fish oil, the price of biodiesel or fish oil must reach values that are far from current market values in order to reach profitability.

5. Preliminary Findings

A market study [13] has been performed for a biodiesel based poly-generation process (electricity, heat, cooling) where fish wastes are used to produce fish oil, which is transformed into biodiesel. The process under investigation is built upon the Enerfish demonstration project in Vietnam where every day an aquaculture farm and its fish processing plant produce 80 tonnes of catfish waste.

The study shows in a first part that aquaculture farms are the main niche market for this technology; aquaculture has a very high efficiency in terms of waste processing since there are almost no losses. Waste processing can be performed on site, thus avoiding logistics and GHG (greenhouse gas) emissions generated by the transport. The main markets for aquaculture will be in Asia, with China representing already today two thirds of the world's aquaculture production; Europe is a rather small market, aquaculture is mainly focused on cultured salmonids (salmon and trout).

There is no specific demand today for fish waste or fish oil to produce biodiesel. The main uses of fish waste are the production of fishmeal and fish oil (which is a by-product of fishmeal production) largely for diets for aquaculture and farmed animals. Two sectors have increased their pressure on fish oil supply: the human food industry which needs omega 3 fatty acids (fish oil) and the pharmaceutical industry which generates high-added value products from fish waste.

The market prices of these two commodities (fish wastes and fish oil) exhibit large variations. Economic modeling shows that under current market conditions, profitability can only be expected for the production of fish oil (and value added proteins) from fish waste. Enerfish-like processes are likely to remain technical solutions for niche markets where fish waste are not valorized and/or where there is no organized supply of fuels. This might be the case of remote territories such as islands or regions in developing countries.

6. Conclusions

Economic modeling shows that under current market conditions, where prices of fish waste and fish oil are historically high, there is no obvious profitability for Enerfish-like processes or any business model derived from it, i.e., production of fish oil from fish waste, or production of biodiesel from fish oil or both [15].

The quantities of fish waste needed to produce significant amount of biodiesel show that Enerfish-like processes are likely to remain technical solutions for niche markets where fish waste are not valorized and/or where there is no organized supply of fuels. This might be the case in remote island territories such as the Shetlands (UK).

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