ENERFISH

Integrated Renewable Energy Solutions for Seafood Processing Stations

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Executive Summary

The present market study deals with the promotion of a poly-generation process (electricity, heat, cooling) where fish wastes are converted into fish oil which in its turn is processed to biodiesel. Combustion of the biodiesel in a high efficiency CHP unit produces energy (electricity and heat). The study is part of a demonstration project, “Enerfish”, 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 tonnes of catfish are processed every day and therefore a large amount of fish waste is available.

Most of the production from aquaculture comes from Asia and this growth is likely to continue. China represents two third of the world’s aquaculture production, but in the past decade Southeast Asia has developed a major export-led industry, 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 fats. European countries play a significant role in the supply of cultured salmons and are expanding production of other species such as blue fin tuna and sea bass, as catches from the wild fall. However it remains probable that the main market for such processes based on biodiesel production will be in Asia, either in large farms where fish wastes are available or in places where there is a local niche market.

The main uses of fish wastes are the production of fishmeal and fish oil mainly for aquaculture and farmed animals. Two sectors are competitors: the human food industry which needs omega 3 fatty acids (fish oil) and the pharmaceutical industry which generates high-added value products from fish wastes. This puts pressure on the availability and thus the market prices of fish wastes and fish oil which are 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 the EU and in South-East Asia for Enerfish-like processes. Such markets are mainly driven by the availability of fish wastes and the need for biodiesel, i.e. the market conditions under which it can be produced. EU biodiesel markets are rather heterogeneous: they depend mainly on public policies and to some extent on the availability of raw materials, existing production means and distribution channels. EU biodiesel producers have been severely affected by heavily subsidised imported biodiesel mainly from the US and Argentina.

Demand in diesel varies enormously for the different ASEAN countries. There is no clear political framework as the RED directive in the EU27 even though some countries have set clear objectives in the promotion of blends (B*n*). As in Europe, the biodiesel industry in Thailand and the Philippines for instance, has suffered from the price variations in feedstocks (palm and coconut oils). Other countries have shown interest in biodiesel produced from jatropha due to its high oil content and its ability to grow in poor soils.

Economic modelling shows that under current market conditions, where prices of fish waste and fish oil are quite 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 wastes, or production of biodiesel from fish oil or both.

The quantities of fish wastes needed to produce significant amount of biodiesel show that Enerfish-like processes are likely to remain technical solutions for niche markets where fish wastes are not valorised and/or where there is no organised supply of fuels. This might be the case of remote territories such as islands.

Contents

1 Overview

Climate change issues have become one of the main drivers of the so-called green economy mainly as a consequence of voluntary policies in many developed countries. In Europe, for instance, the main objectives of the energy policy of the European Commission (EC) are to reduce greenhouse gases (GHG) emissions, increase energy efficiency and promote renewable energies.

In the EU 27, energy (electricity) production and transports represent a significant and growing part of the GHG emissions and as a consequence, the EC has decided to promote, among others, the use of biofuels in road transports. The development of biofuels in the EU aims to partially replace diesel and gasoline in order to meet the commitments on climate change, to ensure a sustainable security of supply, and to promote renewable energies. However, biofuels cannot be seen today as a mean to replace all fossil fuels: only biofuels whose cultivation complies with minimum sustainability standards shall be considered in the future.

Road transport, in particular, is responsible for 85% of GHG emissions from the transport sector in the EU 27; the transport sector is in addition 98% dependent on oil. Because of their similar properties to those of conventional fuel, biodiesel and bioethanol are now the most promising alternatives in the short term.

Biodiesel can also be used in stationary applications, i.e. CHP units, in order to produce energy and heat. This application is in line with the present project where the aim is to design and test an integrated renewable energy solution for a fish-processing plant in Vietnam. The technical implementation is based on a high-efficiency CHP unit using biodiesel produced onsite from fish wastes.

This type of application is not foreseen as an alternative to classical energy production means but rather as a complementary solution in niche markets where fish wastes (animal fat) are available and can be processed into diesel oil. The present study aims at showing, firstly, that there exists market applications for such technologies and secondly, that these applications can be profitable under specific market conditions.

2 Introduction to Enerfish project and aims of market survey

The overarching goal of the Enerfish project is to design and test an integrated renewable energy solution for a fish-processing plant in Vietnam. The technical implementation is based on a high-efficiency CHP unit using biodiesel produced onsite from fish wastes. A cooling/freezing unit, based on CO_2, completes the system. The main features of the project are therefore energy efficiency and low greenhouse gases (GHG) emissions.

- Using local energy production offers a potential gain in efficiency. In the Enerfish project, the local production of biodiesel could be sufficient to make the whole plant self-sustained. Poly-generation can be used to produce electricity, heat, steam, hot water and cooling/freezing energy. The remaining energy, electricity for instance, can be sold to the network.
- Apart from efficiency improvement, one advantage of the project is to limit onsite GHG emissions by producing biodiesel from the fish-processing wastes and by promoting a cooling/freezing cascade based on CO_2. Carbon dioxide is non-toxic and it has a global warming potential (GWP) which is much lower than that of the refrigerants currently used in the refrigeration industry.

This choice of erecting the demonstration plant in Vietnam is mainly two-fold: market and fish quality. Today, south-east Asia is the main aquaculture producer in the world, i.e. 6 out of the 10 world’s top aquaculture countries are located in this region [1]. Vietnam is one of the main players: its production has increased by 17% per year since 2004 to reach nearly 1.65 million tonnes a year in 2006, which makes it the third producer in the world in terms of quantity (51.7 million tonnes in the world in 2006). Asia (without China) represents 23% whereas China alone stands for 67% of the world’s aquaculture production [1]. As far as fish quality is concerned, Pangasius (catfish), one the main species used for aquaculture in Vietnam, has a high fat content in its waste stream (22% in mass) and it is therefore well-suited for biodiesel production (high yield).

The value chains, the species, the size of the vessels, the processing infrastructures, etc., of the different fish industries in the world are quite different [1]. Therefore it will not be straightforward to replicate the demonstration poly-generation plant at any fish-processing site in the world, i.e. a market survey is necessary to answer the following questions, as specified in the Enerfish description of work (DoW):

- What is the market potential in EU-27/South-East Asia?
- What are the fast track options that will help reach the early adopters?
- What is the critical complementary funding necessary to reach these early adopters?
- What are the remaining barriers that still prevent the adoption of the technology in the key countries to be addressed?

Answers to these questions will be provided not only in market terms but also in technical and economic terms, e.g. by systematically estimating the NPV (net present value) of the projects.

Before going through the figures of the different markets in Europe and South-East Asia, it is necessary to understand the background to fisheries and aquaculture markets in these regions and the value chains and material flows of the fish processing industry. This is the purpose of the two next sections. Then, the report is organized as follows: in section 5, an analysis of the main raw material market (fish oil) is given since the availability, the other uses and the price of this commodity will influence the technical and economic feasibility of Enerfish-like projects. The core of the market analysis is presented in sections 6 and 7: an analysis of biodiesel markets in south-east Asia and Europe is put forward in section 6 and, in section 7, the market potential for the Enerfish technology is discussed. Then, based on DCF (discounted cash flow) analyses, the economics of the different options are given (section 8). Recommended actions to encourage an early adoption of the technology (section 9) are presented before concluding (section 10).

3 Background to fisheries and aquaculture markets in Europe/SE Asia

The present section aims at answering the following questions: what is the overall fishery production (capture in the oceans and/or inland waters, and aquaculture)? What is the situation of fishers, fish farmers and the fishing fleet? What is the state of fishery resources? This preliminary analysis is going to give some major trends on the location and the specificities of the main regional markets in the world.

3.1 - Overview of the world production

The world production from fisheries and aquaculture was about 144 million tonnes in 2006: 110 million tonnes were used for human consumption, cf. Table 3.1. The total capture figures have remained the same over the last five years (2002 to 2006), with fluctuations mainly due to oceanographic conditions determined by the El Niño Southern Oscillation in the Southeast Pacific (catches of anchoveta). Aquaculture has grown steadily, and it is the driving factor for the increase in production during the period of observation. Aquaculture represented more than one third of the total world production in 2006; this figure was 1% in the beginning of the 50s and about 4% in 1970. Therefore, it is likely that aquaculture will overtake capture fisheries as a source of food fish.

Table 3.1: world fisheries and aquaculture production and utilization (million tonnes), source [1].

		2002	2003	2004	2005	2006
Inland	Capture	8.7	9	8.9	9.7	10.1
	Aquaculture	24	25.5	27.8	29.6	31.6
	Total	32.7	34.4	36.7	39.3	41.7
Marine	Capture	84.5	81.5	85.7	84.5	81.9
	Aquaculture	16.4	17.2	18.1	18.9	20.1
	Total	100.9	98.7	103.8	103.4	102
Total capture		93.2	90.5	94.6	94.2	92.0
Total aquaculture		40.4	42.7	45.9	48.5	51.7
Total world fisheries		133.6	133.2	140.5	142.7	143.6
Utilization	Human consumption	100.7	103.4	104.5	107.1	110.4
	Non-food uses	32.9	29.8	36.0	35.6	33.3

According to the FAO [1, 2] more than 50% of all monitored fish stocks are now fully exploited, with no room for further expansion of fishing quantities. Over a quarter are overexploited, depleted, or slowly recovering. The remaining fish stocks are underexploited or moderately exploited. This suggests that capture production has reached a maximum close to its highest sustainable limit and it should not grow in the future.

China is the largest producer in the world with roughly 51 million tonnes (34 and 17 million tonnes from aquaculture and capture fisheries, respectively), that is roughly 55 % of the Asian production, cf. Table 3.2. Peru and the United States are the other main producers in the capture sector (7 and 4.9 million tonnes respectively). In the aquaculture sector, not surprisingly, the other top producers are countries from Asia, i.e. India and Vietnam with productions close to 3.1 and 1.65 million tonnes in 2006.

Table 3.2: fishery production per fisher and per fish farmer in 2006 (source [1]).

Regions	Production[1]		Fishers and fish farmers		Production/person
	(tonnes)	(%)	(Number)	(%)	(tonnes/year)
Africa	7 684 068	5.3	3 637 316	8.4	2.1
Asia	94 300 307	65.6	37 337 594	85.8	2.5
Europe	15 552 606	10.8	725 498	1.7	21.4
North America	6 778 441	4.7	344 071	0.8	19.7
Latin America	17 832 018	12.4	1 401 764	3.2	12.7
Oceania	1 393 129	1.0	55 457	0.1	25.1
Total	**143 647 650**	**100**	**43 501 700**	**100**	**3.3**

1: capture + aquaculture

Fisheries and aquaculture farms employ directly more than 43 million people in the world, cf. Table 3.2. The Chinese fishers and fish farmers represent 8.1 and 4.5 million employees respectively (32% of Asia). According to the FAO, most of the fishers and fish farmers in the world are small-scale, artisanal businesses operating on coastal and inland fishery resources. This is clearly seen in Table 3.2: the European production per fisher and fish farmers is nearly ten times higher than in China. Current fleet-size reduction programmes, especially in China, aim at reducing overfishing and therefore the total number of employees in developing countries should decrease in the coming years.

The world's fishing fleet consists of small vessels (90% are less than 12 metres long) powered by engines – often fuelled by diesel; the estimated number is 2.1 million of which approximately 70% are located in Asia.

Asia represents 65 % of the world's production, but the producing companies (capture and aquaculture) are rather small. Most of the production from aquaculture comes from Asia and this growth is expected to continue. China represents two third of the world's aquaculture production.

One can therefore anticipate that one of the main markets for the Enerfish process is going to be Asia, for two main reasons: the region has by far the highest potential in terms of quantities and aquaculture is developing rapidly. It is likely that most applications of the process will take place where there are wastes on site so that logistics is not a problem. Aquaculture farms should be one of the main targets if the market study shows that most of them are integrated, i.e. fish processing is done on site.

3.2 - Capture

As mentioned before, the total world capture production has remained the same over the last years of observation with fluctuations mainly due to environmental factors. However, this static trend does not show variations of quantities in different regions of the world for different species.

Table 3.3: top-ten countries in marine and inland capture fisheries production (left). Middle: principal marine fishing areas. Right: top-ten species in marine capture production. Unit: million tonnes. Year: 2006. Source: [1].

Countries*		Fishing areas**		Species**	
China	17.1	North-West Pacific	21.6	Anchoveta	7.0
Peru	7.0	Southeast Pacific	12.0	Alaska pollock	2.9
USA	4.9	Western Central Pacific	11.2	Skipjack tuna	2.5
Indonesia	4.8	Northeast Atlantic	9.1	Atlantic herring	2.2
Japan	4.2	Eastern Indian Ocean	5.8	Blue whiting	2.0
Chile	4.2	Western Indian Ocean	4.5	Chub mackerel	2.0
India	3.9	Eastern Central Atlantic	3.3	Chilean jack mackerel	1.8
Russia	3.3	Northeast Pacific	3.1	Japanese anchovy	1.7
Thailand	2.8	Southwest Atlantic	2.4	Largehead hairtail	1.6
Philippines	2.3	Northwest Atlantic	2.2	Yellowfin tuna	1.1

* Marine + inland capture.
** Marine capture only.

The first-hand value of the capture fisheries in the world is estimated at 91.2 billion US$, that is roughly 1 $/kg, cf. Table 3.1. China is by far the leading producer in the world, cf. Table 3.3 and this production has remained rather stable over the last years. In 2006, Chile dropped down to 6th place (4th place in 2005) due to the anchoveta catch decrease and the Philippines replaced Norway in tenth position. Asia has 6 countries among the top ten producers and, in addition, positions 12 to 15 are occupied by other Asian countries, i.e. Myanmar, Vietnam, the Republic of Korea and Bangladesh.

Table 3.3 shows that the main marine fishing areas are in the Pacific Ocean: production has increased in these areas as well as in the Indian Ocean whereas it has decreased in the Atlantic regions (-25% in the Northeast Atlantic regions the last ten years). Variations in catches in the different regions and countries are mainly due to natural events and economic development.

The top-ten species in marine capture have been the same for some years. They represent roughly 30% of the world's total marine production. They consist of five small pelagic species (anchoveta, Atlantic herring, chub and Chilean jack mackerels and Japanese anchovy), two tunas (skipjack and yellowfin) and two-low value gadiformes (Alaska pollock and blue whiting). Most of these species are marketed in processed forms except for Peruvian anchovetas which are processed into fish meals and fish oils. The "Largehead hairtail", which ranks ninth in the top-ten species in marine capture, is mainly caught by China (90% of the total).

As far as inland catches are concerned (10 million tonnes out of 92 million tonnes of total capture in the world), the FAO [1] reports that the reliability of these statistics is rather questionable. This production is dominated by developing countries: 67% in Asia and 25% in Africa (Europe represents only 3.5% of which 60% comes from Russia). China represents 25% of the total. The captured species are rather diverse: the two main one, in quantity, are cyprinids (carps, barbels, etc.) - 0.73 million tonnes per year - and cichlids (tilapias, etc.) - 0.72 million tonnes per year-.

In the top-fifteen countries having marine and inland capture fisheries, 10 are from Asia. The only European country, Norway, ranks 11. The capture production is rather stable; inland production has increased but the statistics are not reliable.

These statistics (section 3.2) confirm the preliminary analysis: Asia is the main market in terms of volumes. Norway seems to be the only European country (outside the EU 27) which plays a significant role.

3.3 - Aquaculture

The estimated first-hand value of the aquaculture production in the world is estimated at 78.8 billion US$, that is roughly 1.5 $/kg, cf. Table 3.1. It is the fastest growing animal food-producing sector: it supplied the world with 0.7 kg per capita in 1970, and close to 8 kg per capita in 2006. The Asia-Pacific region represents 89% of the production in terms of quantity (77% in value), this dominance is due to China, i.e. 67% in quantity, cf. Table 3.4a. The sector has been growing steadily since 1970, approximately 8.7% per year worldwide.

Table 3.4: top-ten aquaculture producers (a). Major species in world aquaculture (b). Production is in million tonnes. Quantities, growth and value are in % of the total.

(a)

Countries	Production	Growth*
China	34.5	6
India	3.1	5.7
Vietnam	1.65	17.6
Thailand	1.4	4.9
Indonesia	1.3	11.2
Bangladesh	0.89	-1.25
Chile	0.80	9.8
Japan	0.73	-2.8
Norway	0.71	5.5
Philippines	0.62	10.3

* annual growth (2004-2006).

(b)

Species	quantity	value	Growth**
Freshwater fishes	54	37	9
Molluscs	27	15	7.5
Crustaceans	9	23	18
Diadromous fishes	6	15	7
Marine fishes	3	8	10.5
Other aquatic animals	1	2	-

* annual growth (1970-2006)

Table 3.4a shows that this growth is unevenly distributed; some countries like Vietnam and Indonesia are developing extremely fast whereas for others, the production is decreasing, Japan for example. Norway is the only European player in the top-ten.

According to the FAO, most of the aquaculture production comes from inland waters (61% in quantity and 53 % by value), the rest being mostly the marine environment. The inland production takes place mainly in freshwaters (95%). In 2006, more than half of the world aquaculture production came from freshwater finfish (27.8 million tonnes worth US$29.5 billion), the second largest share being molluscs (14.1 million tonnes worth US$11.9 billion), cf. Table 3.4b. One can note the high value of crustaceans (US$ 17.95 billion for 4.5 million tonnes).

China produces 77% of all carps (cyprinids) and 82% of global supply of oysters (ostreids) (these figures are 98% and 95% for Asia, with 88% of shrimps and prawns - panaeids-). In Europe, Norway is the world leading producer of cultured salmons (salmonids) with 33% of total world production (Chile is second with 31%). Other European producers supply 19% of the other salmonids.

The main market for aquaculture is in Asia, especially China. European countries play a significant role in the supply of cultured salmons (52% of the word production, most of it being in Norway, 33%).

As mentioned in section 3.1, the activity of marine fisheries is not sustainable. Even though the FAO reports that the proportion of overexploited, depleted or recovering stocks has remained relatively stable since 1970, most of the stocks of the top-ten species (which account for about 30% of the world marine fisheries production in quantity) are fully exploited or overexploited. One can therefore anticipate that future markets for the Enerfish process, and more especially growth potentials, will be related to aquaculture businesses where fish processing is done on site.

3.4 - Fish utilization and fish processing

Figure 3.1 displays the utilization of world fisheries production with a focus on processed fish.

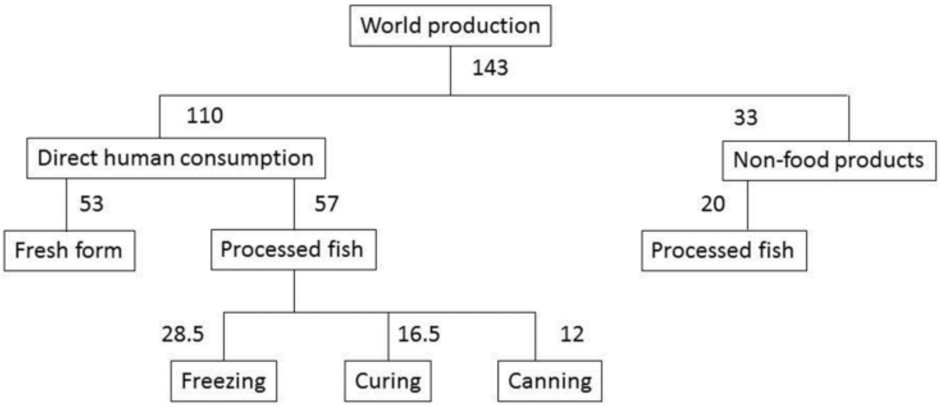

Figure 3.1: utilization of world fisheries production (focus on processed fish). Curing refers to preservation and flavoring processes by smoking and by the addition of a combination of salt, sugar and either nitrate or nitrite. Source [1].

In 2006, 77% (110 million tonnes) of the world production was used for direct human consumption; most of the rest was dedicated to the production of fishmeal (a high-protein animal feed supplement made by cooking, pressing, drying, and grinding fish[1]) and fish oil, which is mostly a byproduct of fish meal production, cf. [D2].

A significant part of the fish used for direct human consumption is still distributed in live and fresh form. However, due to long term shifts in consumer preferences, more and more fish is marketed as high-value processed products, cf. figure 3.1 (processed fish is frozen, cured or canned). This trend has resulted in technological innovations in refrigeration, ice-making, food-packaging and fish-processing equipment even though most on the fish processing in developing country is handmade.

There is a clear trend worldwide towards increased fish processing. This trend has resulted in the need for sophisticated production equipment and methods and is therefore capital intensive. As a consequence, one can observe in the fish processing business the growth of international distribution channels controlled by large retailers.

In addition, due to the still relatively large fraction of labour in the production price of processed fish, most fish coming from developed countries (e.g. Europe and North America) is sent to Asia (mainly China, India and Vietnam) for filleting and packaging and then re-imported. A similar trend is observed at the European level where smoked and marinated products are processed in Central and Eastern Europe.

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[1] Fish meal can also be used as fertilizer.

At the same time, there is a trend of integration both in aquaculture and capture. Many processors, especially in Asia rely on their own fleet of fishing vessel (capture) or on their aquaculture farms. In Europe, such integrated plants exist for large producers of salmon but they are facing competition from low-cost processors in developing country.

Trends imply that most demand for Enerfish process might be at large integrated plants rather than small. Due to long term shifts in consumer preferences, more and more fish is marketed as high-value processed products and therefore more fish wastes will be generated.

3.5 - Conclusions

The following preliminary conclusions can be drawn:

- Most of the production from aquaculture comes from Asia and this growth is expected to continue. China represents two third of the world’s aquaculture production. Consequently, the main market for aquaculture is in Asia, especially China. European countries play a significant role in the supply of cultured salmons (52% of the word production, most of it being in Norway, 33%).
- More and more added value products imply processing and therefore an increase of fish wastes. Most of the market for fish processing is in low labour countries, i.e. South East Asia and Eastern Europe at a minor scale.
- Fish wastes are mainly used to make fish meals and fish oil. Fishmeal has a single application whereas fish oil, which is the basic raw material to make biodiesel in the Enerfish process, has many applications.

In the next section, attention will be focussed on the possible applications of fish wastes and more especially fish oil. In section 5, a market analysis of fish oil will be performed.

4 From fish wastes to biodiesel: value chain and material flows

Nowadays, due to increased competition in the fish processing sector, there is a clear trend towards the reduction of fish wastes and/or the maximization of the value of the material available to it. Disposal of fish wastes on land and/or at sea is decreasing: in Europe, it is more and more regulated, mainly due to environmental concerns in waste management. The EU landfill directive requires that member states reduce the quantities of biodegradable wastes being disposed of to landfill to 35% of the 1990 levels by 2020. In addition to that, fish waste disposal requires permitting, licensing and it generates costs such as landfill tax, in most EU countries.

The amount of generated fish wastes during processing depends on many factors: the processing technique, the fish type, the local regulations, the market, etc. For example, when it is directly performed at sea, the gutting operation (guts, liver and other viscera) generates, in mass, approximately 16% of the total weight of the fish.

Fish wastes are mainly produced in shore-based processing facilities. After processing, the remainder of the fish generally consists of head, viscera, frames, lugs, flaps and skin (if skinless fillets are produced). The edible portion of the different fish species varies between 35% for catfish to 53% for herring, of the total fish weight [3]. The respective generated wastes, out of the total fish mass, are therefore 65% for catfish and 47% for herring (this is in line with the ratio of the Enerfish process, i.e. for 120 t/day of pangasius -catfish-, 80 t/day of fish wastes are generated, that is roughly 67%). In the UK for example, and on average, 43% of the fisheries resources is used for human consumption; the remainder of the fish (fish wastes) consists of on-shore processing wastes (35%), waste at sea (5%) and discard at sea (17%). In such a case, one can see the overwhelming advantage of aquaculture in terms of efficiency of wastes processing since there is no disposal and all the remaining can be processed. In addition, fish wastes are produced on the spot and there is therefore no logistics involved in the process which can generate extra costs, risks and above all environmental impacts mainly due to the GHG emissions generated by the transports.

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 emissions generated by the transports.

4.1 - Fish meal and fish oil

The major outlet for fish wastes is fishmeal and fish oil production. Both fishmeal and fish oil are produced by the same process [4, 5]. The raw materials used for production are not only fish wastes but most of the time fish caught for the sole purpose of fishmeal production (for example by Chile, Peru[2], Norway, Denmark[3], etc.). As mentioned in section 2, since the mid-1990s, the proportion of fish used for direct human consumption has grown. This tendency has come about as more fish is used as food and less for producing fishmeal and fish oil. As a result trimmings, i.e. fish wastes, now constitute around 25% of the raw material for fishmeal production. Small pelagics, in particular anchoveta, are the main groups of species used, and the production of fishmeal and fish oil is strongly linked to the catches of these species. The other feed grade fish caught for fishmeal production (e.g. mackerel, menhaden, capelin and sand eel) are mainly small oily short-lived, fast-growing fish with little or no demand for human consumption [5].

Fishmeal is processed by cooking, pressing, drying and milling fresh raw fish and/or food fish trimmings; fish oil is a by-product of the process obtained during the pressing step (it is usually refined). The processes are described thoroughly in [4] and also in the project deliverables, i.e. [D2] and [D3].

A typical content of fishmeal is as follows: 60% to 72% protein, 10% to 20% ash, and 5% to 12% fat. The fat content of fishmeal is rather high and above all contains the health promoting omega-3 (very long chain polyunsaturated fatty acids EPA and DHA[4]).

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[2] Fish oil produced from anchoveta catches.

[3] http://www.999.dk/

[4] Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA).

The energy content of fishmeal as well as the presence of essential nutrients such as well-balanced amino-acids, essential fatty acids, makes fishmeal an indispensable ingredient in diets of most aquaculture species and many land-farm animals, i.e. the main uses for fishmeal are fish farming and feed for pets, cattle, poultry, etc., cf. Figure 4.1. Products from farmed animals fed high omega-3 fishmeal are functional foods which benefit human health (meat, milk and egg).

Fish meal is mainly sold as three different products:

- high quality, usually for trout farms or marine species in rather small-scale aquaculture units,
- fairly averaged quality, which has a lower protein content, mainly for pigs and poultry,
- low temperature meal, for salmon and piglet production.

Fish meal is diluted in diets. The inclusion rate is much lower for farmed-animals than for aquaculture. The typical inclusion rate for farm animal diets is 1 to 5%, whereas it can reach 30% (together with 20% fish oil) for farmed salmon diets.

Fish oil is also mainly used in feed for fish farming along with fishmeal because it is close to the natural feed of the fish in the wild. Fish oil is also used in human food and human health supplements (sometimes called "nutraceuticals") due to its content in omega-3 fatty acids[5], cf. Figure 4.1.

Fish wastes are mainly used to produce fishmeal and fish oil. The main outlet of fishmeal and fish oil is diets for farmed fish and land-farm animals. Fish oil is also used for humans due to its high omega-3 content.

Waste water is a by-product of the fishmeal production. Waste water can be used to make biogas and fertilisers, cf. [D12].

4.2 - Other non-nutritional uses

There are many other applications of fish wastes, which could compete, in the long run, with the fishmeal and fish oil production.

Fish skin can be used as a source of gelatin. This specific application has attracted interest mainly after bovine spongiform encephalopathy (BSE). Fish skin is also a source of leather (clothing, shoes, handbags, wallets, belts, etc.). Larger fish, such as shark, salmon, ling, cod, hagfish, tilapia, etc., are well suited to leather production.

The main non-nutritional uses of fish wastes[6] are encountered in the pharmaceutical industry:

- shark cartilage, ovaries, brain, skin and stomach are used in many preparations and reduced in powder, creams and capsules,
- fish collagen[7] is used in the pharmaceutical industry because it has advantages over bovine collagen,
- many pigments can be extracted from crustacean wastes (carotenoids, astaxanthins, etc.),
- anticancer molecules have been discovered following research on marine sponges, bryozoans and cnidarians. For reasons of sustainability, these molecules are not extracted from marine organisms but are chemically synthesized (aquaculture of some sponge species is currently under investigation),

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[5] Omega-3 fatty acids are part of a healthy diet that helps lower risk of heart disease. Increased intake of EPA has beneficial effects on coronary heart disease, high blood pressure, and inflammatory disorders, such as rheumatoid arthritis. Most people in the Western world do not get enough omega-3 fatty acids in their diet.

[6] Here, fish wastes include also wastes from shellfish, etc.

[7] It is a protein extracted from fish that is mainly used as a cosmetic aid to decrease the appearance of wrinkles (collagen represents up to 30% of the protein in human bodies).

- chitin and chitosan, molecules obtained from shrimp and crab shells, can be used to clot blood, in bandages, etc.[8],
- etc.

Calcium carbonate for industrial use can be obtained from mussel shells. Oyster shells are used in some countries as a raw material in the construction of buildings and for the production of quicklime (calcium oxide).

Non-nutritional uses of fish wastes are numerous. The applications in the pharmaceutical industry will probably generate high added-value products which could compete with other applications such as fishmeal and fish oil for the access to raw materials.

4.3 - From fish oil to biodiesel

Fish oil can be used to produce biodiesel; it is the application under investigation in the present report. A detailed description of the process has been given in [D2]. Deliverable 2 puts forward a description of the process of producing fish oil and biodiesel from fish wastes; the management of by-products and waste streams generated in the process is also given. This information is not displayed here. It will however be used in chapter 8 where a complete mass and heat balance of the process is performed in order to find possible business models where such a production can be profitable.

The main use of fish wastes is the production of fishmeal and fish oil mainly for aquaculture and farmed animals. Two sectors are competitors: the human food industry which needs omega 3 fatty acids (fish oil) and the pharmaceutical industry which generates high-added value products from fish wastes. This will probably put pressure on the availability and thus the market prices of fish wastes and fish oil.

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[8] These molecules can also be used in agrochemicals, water treatments, cosmetics and toiletries, food and beverages. Chitosan has recently been heavily marketed as a weight loss and cholesterol lowering diet supplement.

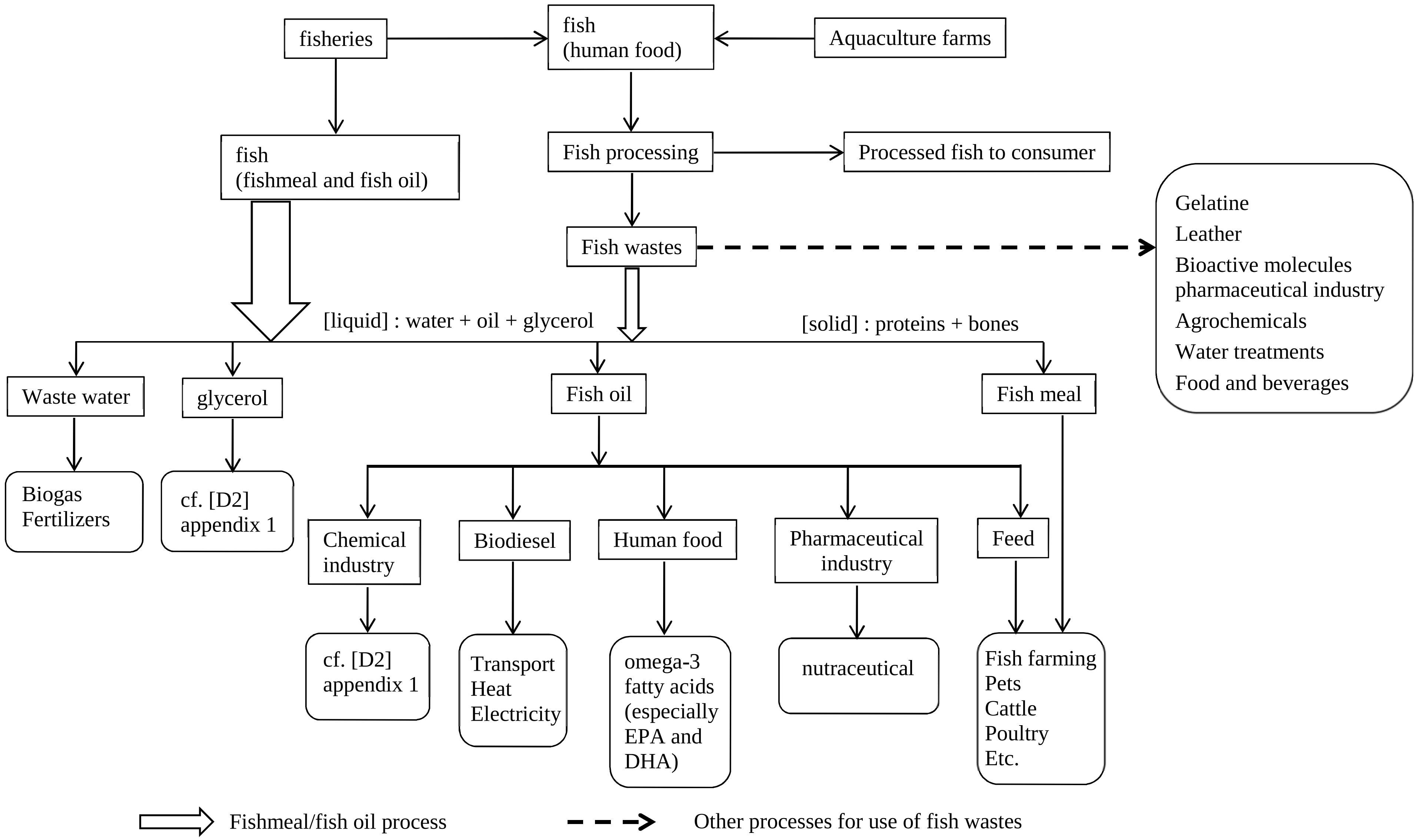

Figure 4.1: value chain of fishmeal and fish oil processing and by-products. Fish wastes have many applications, the main ones being fishmeal and fish oil. Fish wastes are also used in other industries.

5 Background to global fish oil markets

In the preceding sections, it has been shown that fish is not only used for direct human consumption but also in the production of fishmeal and fish oil. Figure 3.1 shows that roughly 25% of the world fish production is used for non-food products, the main part being converted into fishmeal and fish oil. There exists a correlation between fishmeal and fish oil markets since both products are obtained from the same process. In the following, the main market facts for fishmeal and fish oil will be given, together with an analysis of the price signals for these two commodities. An investigation of the main price drivers is also put forward at the end of the chapter.

5.1 - Main markets facts

There are about 400 fishmeal plants in the world producing roughly 5 million tonnes fishmeal and 1 million tonne fish oil every year. They are produced from 22 million tonnes of raw material, i.e. whole wastes (16.5 million tonnes) and trimmings (5.5 million tonnes), the main by-product being waste water, i.e. 16 million tonnes [6]. 88% of the fish oil production and 50% of the fishmeal production are used in aquaculture. 76% of the fish oil use in aquaculture is for salmon and trout diets (figures from 2008, [6]). The volumes of whole fish used in fishmeal production have decreased steadily, whereas the volume of trimmings has increased. This trend has been explained in section 3.4: due to long term shifts in consumer preferences, more and more fish is marketed as high-value processed products, resulting in an increased amount of fish wastes in the world.

As mentioned in section 4, the part of trimmings is approximately 25%, i.e. 5.5 million tons. This figure is a worldwide average. However, it should be pointed out that in some European countries it is already much higher. As a matter of fact, it is nearly 100% in Germany, Italy, Spain and France. This figure is much lower in Denmark (10%) and Sweden (25%) where there is an industrial production of fishmeal with dedicated fish catches [2, 6].

Table 5.1 displays the top 9 fishmeal producers in the world. Peru, Chile and Thailand are by far the main producers. Peru and Chile, which represent together over 40% of the world production, rely mainly on anchoveta catches for their production.

Table 5.1: top 9 fishmeal producers in thousand tonnes. Source: [6].

	2002	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Peru	1,941	1,251	1,983	2,019	1,378	1,407	1,396
Chile	839	664	933	794	759	770	673
Thailand	387	397	403	410	461	428	468
USA	337	318	353	268	232	251	212
Japan	225	230	295	230	219	200	202
Denmark	311	246	259	213	209	166	161
China	460	420	400	305	297	204	141
Iceland	304	279	204	188	144	152	140
Norway	241	212	215	154	169	172	135
Total	**5,045**	**4,017**	**5,045**	**4,581**	**3,868**	**3,750**	**3,528**
Total world	6,202	5,402	6,274	5,826	5,143	4,970	4,818
% total	0.81	0.74	0.80	0.79	0.75	0.75	0.73

During the last decade, fishmeal production has been rather stable, fluctuating between 5 million and 7 million tonnes depending mainly on catch levels of anchovy in South America but also on precautionary quotas related to the sustainability of the production [7].

The demand for fishmeal has increased rapidly, especially in some of the emerging aquaculture countries in Asia. China is the single largest user of fishmeal. In 2004 (last available figures), it used approximately 1.6 million tonnes, with 1.2 million tonnes imported and the remainder (0.4 million tonnes) coming from domestic production, cf. Table 5.1. Of this total amount, about 75% was used for aquaculture production. It is estimated that the Asia-Pacific aquaculture sector used about 2.4 million tonnes of fishmeal in 2004, which was half of the world production. Other countries producing large amount of fishmeal such as Japan and Norway are net importers (approximately 0.1 million tonnes).

Overall, the EU 27 is also a major market player: in 2008, it produced roughly 0.33 million tonnes of fishmeal but imported over 1 million tonnes.

The growing aquaculture activity in South-East Asia is probably going to be one of the main drivers for the exports of fishmeal. China continues to be the main market for Peruvian fishmeal, with about half of Peruvian fishmeal exports going to this market [8]. In a relatively new development, Vietnam is now strongly represented as an importer of fishmeal from Peru.

Table 5.2 puts forward the top 9 producers of fish oil. As for the data presented above for the top 9 producers, the world production of fish oil has remained rather stable the last years (around 1 million tonnes). Global aquaculture production has continued to grow while usage of fishmeal and fish oil has been rather static: alternatives (e.g. soy meal and rapeseed oil) can be used in partial replacement and increasing nutritional knowledge allows more replacement to take place particularly on more established species.

One can already anticipate that the prices of these two commodities (fishmeal and fish oil) are going to increase since global aquaculture production continues to grow (cf. section 3) while the production of fishmeal and fish oil is almost constant.

Not surprisingly, the main fishmeal producers are also the main fish oil producers. Peru and Chile represent more than 40% of the total.

Table 5.2 : top 9 fish oil producers in thousand tonnes. Source: [6].

year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Peru	221	205	352	287	286	337	275
Chile	146	130	138	145	155	187	167
USA	96	80	81	75	65	75	86
Iceland	70	104	49	63	54	51	72
Japan	64	61	68	67	68	60	62
Denmark	86	71	68	93	67	57	55
Norway	72	52	37	30	40	44	37
Mexico	8	9	12	13	26	21	35
Morocco	20	29	25	31	31	20	29
Total	**783**	**741**	**830**	**804**	**792**	**852**	**818**

Fish oil and fish meal production has been rather constant during the last years whereas aquaculture production has increased. The prices for fish oil should therefore increase in the coming years. South-East Asia and more especially China are going to be the main importers of these commodities.

5.2 - Fishmeal and fish oil prices

Figure 5.1 displays the market prices of fishmeal, fish oil and soya oil for the five last year, i.e. from January 2006 to January 2011.

A significant reduction in anchovy catches in Peru in 2006 led to sharply higher fishmeal prices in that year (up to 1300 US$ per tonne), but prices were rather stable in the course of 2007. In early 2008, fishmeal prices moved upwards again, and remained rather high, in view of high vegetable meal prices (alternatives to fishmeal such as soy meal for example). Already in the 2006-2008 period, the large share of fishmeal consumed by the aquaculture industry, estimated at 60 per cent, with strong demand particularly in China was a strong factor for the price increases (at the same time, the poultry industry drastically reduced its fishmeal use but the quantities were not sufficient to significantly influence the market) [1].

During the first quarter of 2009, fishmeal production in Peru was below the previous year's figures [8]. In addition, in May 2009, experts from US and Australian weather forecasts institutes predicted a strong possibility of an El Niño year. This, together with the exhausted Peruvian quota of catches and a strong demand from China, lead to sharply higher fishmeal prices in that year (China purchased more than 50% of the world production in 2009).

2010 was also an El Niño year, but a rather mild one. In addition, the catch of Peruvian anchovies remained low and the demand from China was high. This explains that prices reached historical values, above 1700 US$ per tonne (from January 2002 to December 2005, the fishmeal prices stayed between 600 and 900 US$ per tonne). In 2010, Vietnam also became strongly represented as a fishmeal importer due the development of its aquaculture (mainly the shrimp industry).

Overall, fishmeal prices show strong variations: this might be the consequence of financial speculation on this commodity since the main drivers of the market are well identified and some of them can be estimated in advance (weather forecasts for the temperature of the waters in the Pacific Ocean where anchoveta catches take place).

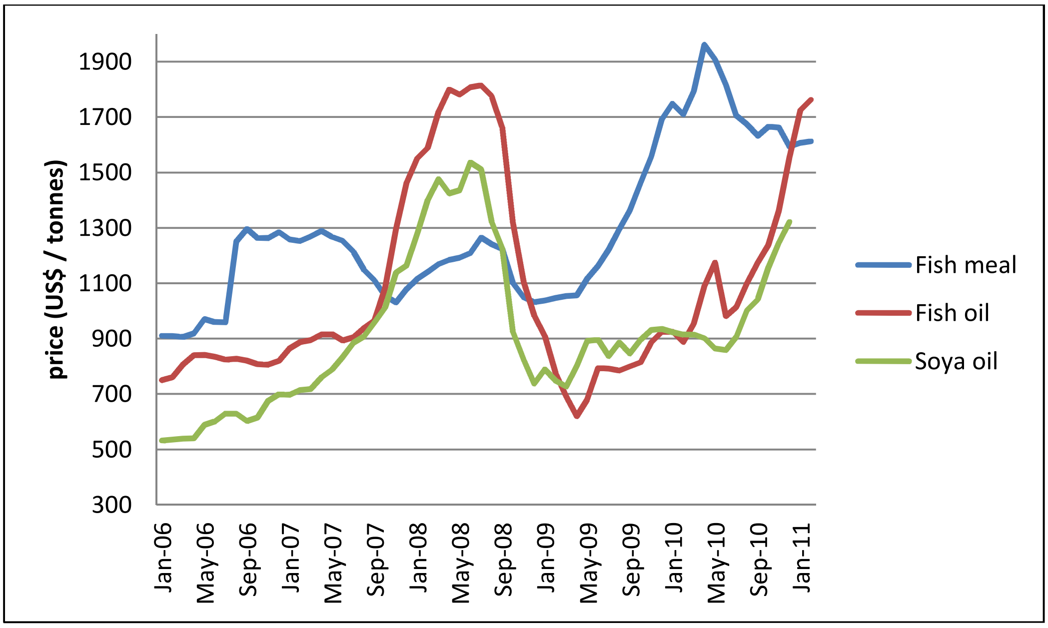

Figure 5.1: market prices for fishmeal, fish oil and soya oil from January 2006 to January 2011. Market price is in US$ per tonne. Source: [9].

Prices for fishmeal are mainly driven by the Peruvian and Chilean production and the Chinese demand. The Peruvian and Chilean production are functions of the El Niño Southern Oscillation in the South East Pacific and the new system of quotas. The availability of alternatives (soy meal for example) is also a price driver.

In early 2008, fish-oil prices reached an all-time record of US$ 1700/tonne, compared with US$ 915/tonne one year earlier (the prices varied steadily between 600 US$/tonne at the beginning of 2002 and 1000 US$/tonne at the end of 2007). It was estimated that demand for fish oil for direct human use was boosting prices (it was explained is section 4 that there is an increasing demand of fish oil in human food production but also in the pharmaceutical industry). However, for fish oil, the role of aquaculture is even greater than for fishmeal, with close to 85 per cent of the production consumed by the sector, and with salmonids responsible for more than 55 per cent of the sector's share. Not surprisingly Belgium, Norway, Denmark, Chile and Canada were the main importers for salmonids farming (these five countries accounted for over 72% of the Peruvian fish oil exports) [8].

In 2009, total fish oil production by the five main exporting countries (Peru, Chile, Iceland, Norway and Denmark) was 530,000 tonnes, a decline of 100,000 tonnes compared to 2008. Fish-oil prices reached US$950/tonne in March 2010, which was 50 per cent higher than a year earlier. In addition, due to extremely low soybean supply, soybean oil prices (an alternative to fish oil, which explains why both market prices are well correlated) exceeded those of fish oil for the first time in many years, cf. Figure 5.1.

Fish oil output declined in the first half of 2009. Some 365,000 tonnes were produced by the main fish oil exporting countries, representing 20,000 tonnes less than in the same period in 2008. The greatest decline was reported by Chile, while all other major fish oil producers reported relatively stable output. Fish oil prices usually mirror the trend in fuel prices, and rose in the second quarter of the year (this correlation with fuel prices is explained by the increasing share of fuel costs in the total fishing costs).

In 2010, the Chilean production of fish oil was damaged by the earthquake at the beginning of February. At the beginning of the year, Peruvian catches were higher than those in the corresponding period of 2009 but unfortunately the oil yield was quite low which resulted in a poor oil production [8]. This, in combination with a demand for human applications, caused a severe increase of fish oil prices which reached again 1700 US$ tonne at the end of 2010.

It should also be pointed out that during 2009, the largest sponsored exercise to examine whether fish oil and Vitamin D, or a combination of both, could help prevent heart disease, cancer and a range of other illnesses, was initiated. This trial which is conducted at the Harvard-affiliated Brigham and Women's Hospital in Boston is backed by various American health organisations. The study is going to last for five years. If it produces positive results, it could lead to massively increased consumption of fish oil worldwide and therefore an increased volatility in fish oil prices.

The main drivers for fish oil prices are the demand for the aquaculture industry and the fish oil production of Peru and Chile. Not only the El Niño oscillation has a strong influence on production, but also the fat content of the catches. The demand for human food production and from the pharmaceutical industries, still representing about 10% of the demand, seems to become an important factor in the extreme variations of the prices.

5.3 - Fish oil for human food and pharmaceutical applications

As it has been explained in section 4, fish oil is also used in human food and human health supplements (nutraceutical) due to its content in omega-3 fatty acids, and also in non-nutritional uses in the pharmaceutical industry. As a matter of fact, the use of fish wastes for extraction of bioactive molecules will probably generate high added-value products which could compete with fishmeal and fish oil production for the access to raw materials. In the present section, the influence of these growing demands for fish oil is further analysed (we recall that over 85% of the fish oil production still goes to aquaculture).

The presence of EPA and DHA in fish oil, i.e. so-called omega-3 fatty acids, have resulted in an increasing interest from other industries, i.e. human food and human health supplements [10]. Thus, the omega-3 demand and consumption has had an impact on fish oil prices and quantities available cf. section 5.2. As a matter of fact, one can observe in the United-States that, while demand for usual vitamins and dietary supplements slowed its pace, the sales of some supplement categories have increased with double-digit percentages. This is the case of fish oil concentrate sales which grew by 25% in 2010 according to data provided by Spins [9] [13]. Other market research firms such as Frost & Sullivan[10] for instance, estimate a compound annual growth rate from 2008 to 2013 of 10 percent [11]. The main consumers of omega-3 ingredients are North America (26,948 tonnes/year), followed by Asia (21,145), EU (13,596) for a total of 71,452 tonnes/year (estimates from Frost & Sullivan).

It is probable that most of this rise comes from (self-) treatment using supplements due to the lack of health insurance covering and more generally the prices of medical bills in some developed countries. Increase in consumer knowledge on the benefits of omega-3 is the main driver for its growth since medical studies have shown that many deaths are caused by diets deficient in omega-3. According to Euromonitor[11], recommended daily intake levels for long-chain omega-3s could soon be established by official and government institutions. Even though one can observe in different countries increasingly favorable regulatory environment towards omega-3s, the real benefits of omega-3 fatty acids on human health still seems to be questionable [12].

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[9] http://www.spins.com/
[10] http://www.frost.com/
[11] http://www.euromonitor.com/

The rather new need of fish wastes for extraction of bioactive molecules might also influence the price of fish oil since these coming high added-value products could compete with fishmeal and fish oil production for the access to raw materials. However, as matter stands, it seems that the fish types concerned by these applications are not the ones whose wastes could help produce fish oil. In addition, many bioactive molecules for cancer treatment have been discovered following research on marine sponges, bryozoans and cnidarians. For reasons of sustainability, these molecules are not extracted from marine organisms but are chemically synthesized. Aquaculture of some sponge species is currently under investigation.

5.4 - Conclusions

The main drivers of the fish oil market price have been identified. Over the last five years, fish oil prices have shown extreme variations, i.e. from January 2006 to February 2011 prices went from to 950 US$/tonnes in January 2006 to 1800 US$/tonnes in April 2008 and down again to 650 US$/tonnes in May 2009. They reached 1763 US$/tonnes in February 2011.

The main drivers for these variations are:

- A stable production with a growing demand: fish oil and fish meal production has been rather constant during the last years whereas aquaculture production has increased. South-East Asia and more especially China are going to be the main importers of these commodities.
- 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.
- The increasing fish oil demand for human food production and from the pharmaceutical industries.

The relative complexity of the fish oil markets has caught the attention of researchers involved in the field of natural resource modeling and some attempts have been made to model the dynamics of fish oil prices [14].

6 Background to European and SE Asian biodiesel markets

The purpose of the present chapter is not to give a full overview of biodiesel markets but merely to grasp the main facts of these markets in order to have some understanding of the possible price dynamics of biodiesel in the near future. These market signals will be used, together with the fish oil ones, in chapter 8 to perform the profitability analysis of the different business models.

In the present chapter, by biodiesel, it is of course meant first generation[12] biodiesel; it is an ester mainly produced from vegetable oil obtained classically by simple pressing of oilseeds, such as rapeseeds, sunflower, soybeans, etc. It can also be obtained from cooking oil and animal fat (Enerfish process).

The EU 27 is the major producer of biodiesel in the world. In 2009, biodiesel production in the EU 27 reached 10,187 Ml (million litres), which was approximately 57% of the world production (17,929 Ml). Germany and France are the main producers ahead of the United States (2,060 Ml), cf. Figure 6.1. The production of biodiesel in Asian countries (Thailand, China, Korea, India, Malaysia, Philippines, Indonesia, etc.) in 2009 is estimated at about 2,000 Ml [15], which is still a small amount compared to Europe. Overall, the production of biodiesel worldwide in 2009 has increased by 11% with respect to 2008.

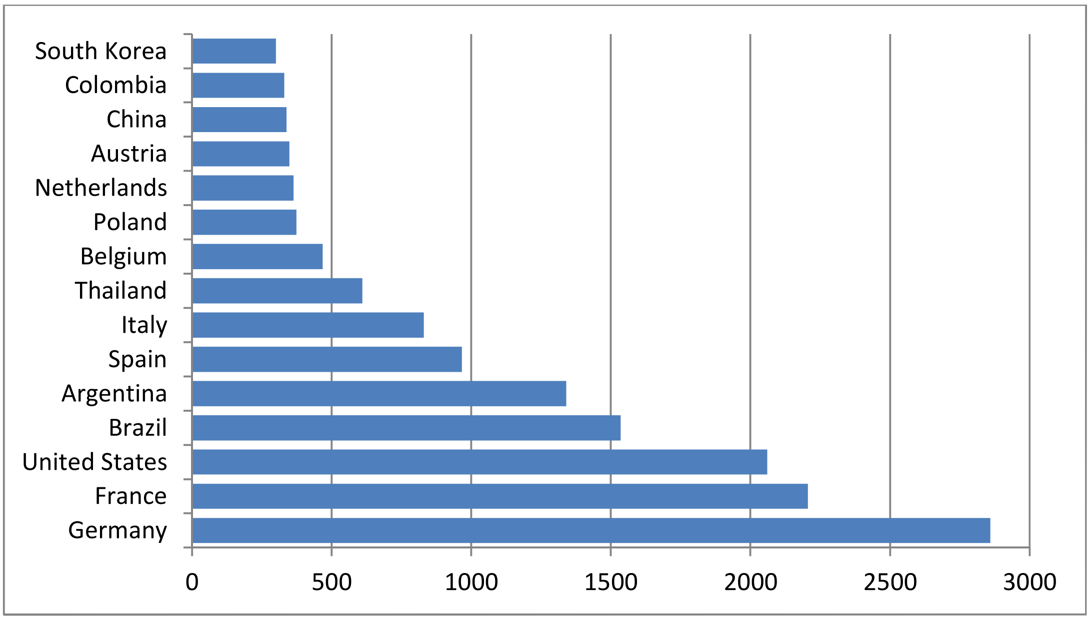

Figure 6.1: biodiesel production in 2009 for the top 15 producers in the world. Quantities are given in million litres[13]. Source: [15, 16].

The main issue related to the production of first generation biofuels is the availability of resources. Producing large amount of biofuels (biodiesel) requires a lot of agricultural land and the issues of competition with food and sustainable agricultural practice are inevitable, not to mention life cycle analysis studies (environmental impact studies) which show results that are still under debate [16, 17].

The annual biodiesel yield is 1150 l/ha [15]. This implies that the agricultural land that should be dedicated to biodiesel production in order to reach the EU 27 total of 2009 should be of the order of magnitude of 10 million hectares that is roughly twice the surface area of Switzerland. This is why alternative ways to produce biodiesel are investigated, i.e. production from lignocellulosic biomass (second generation biodiesel) with much higher surface area yields.

A similar basic computation could be made with fish oil, i.e. how much fish oil would be required to produce 10 billion litres of biodiesel? With the Enerfish ratios[14], it would require 13 million tonnes fish oil (here we

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[12] Biodiesel can also be obtained from syngas. This type of biofuels, often referred to as "synfuels", is today limited to pilot scale applications, or even research and development activities. It will probably take several years before it can play a significant role on the biodiesel market.

[13] For conversion in toe (tonne of oil equivalent) or t (tonne), one can use for biodiesel: 0.792 toe/m^3, 0.892 toe/t (lower calorific value: 33 MJ/l, 37.2 MJ/kg) [15]. According to the RED (Renewable Energies Directive, 2009/28/EC), cf. section 6.2, these values should be: 0.7882 toe/m3 and 0.8837 toe/t (lower calorific value: 33 MJ/l, 37 MJ/kg) with 1 toe = 41.868 GJ.

assume a density of 1 kg/l for the sake of simplification), 62 million tonnes fish wastes and 92 million tonnes of catfish (this is roughly the same amount, in tonnes, as the total fish world capture in 2006, cf. section 3.1). These figures show that the production of biodiesel from fish oil cannot be considered as an alternative or a complement to actual or future production means. Instead, production of biodiesel from fish oil is probably going to be, if profitable, a niche market for large fish processing units where fish wastes can be used to generate energy (electricity and/or heat) and/or as a fuel for the companies' vehicles.

Biodiesel production from fish oil cannot be an alternative or a complement to actual or future production means. The Enerfish process is probably going to be a niche market for large fish processing units if competing applications from other uses of fish wastes or fish oil are not more profitable.

As a matter of fact, there is no economic viability for biofuels except perhaps in Brazil (bioethanol). In all other countries, like in the United States, most EU member states and some Asian countries, there are subsidies from the respective governments. The production cost of biofuels (in the order of 0.75-0.90 €/l in the EU) is still substantially higher than that of conventional fuel (i.e. about 0.50-0.55 €/l for diesel and 0.40-0.45 €/l for gasoline) [15]. It is still a fragmented market since most countries have different taxation schemes and policies, see e.g. section 6.1 for the EU 27.

Overall, biofuels economics are strongly exposed to variations in oil (competitor) and bio-feedstock prices (raw materials). Up to now, the spikes in crude oil prices have not allowed biofuels to become competitive with fossil fuels. The growing needs of the biofuel industries have also put some pressure on the prices of commodities from which biofuels are produced. Figure 6.2 shows that the biofuel markets are exposed to variations in crude-oil and bio-feedstock prices.

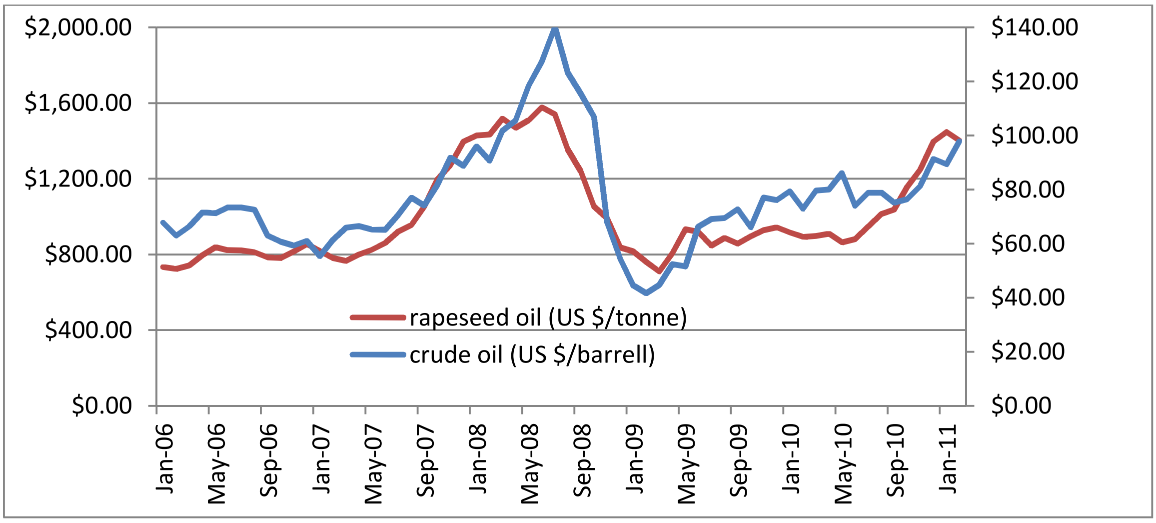

Figure 6.2: correlation between rapeseed oil prices (US$/tonne) and crude oil prices (US$/barrel) from January 2006 to February 2011. Source: [9, 18].

The fundamentals of commercial deployment for biofuels (biodiesel) remain the same: it still depends on appropriate regulatory frameworks and associated subsidies.

6.1 - Biodiesel markets in the EU 27

One of the main objectives of the energy policy of the European Commission (EC) is to reduce its GHG emission. Since GHG emissions from transports represent a significant and growing part of the EU 27's GHG emissions, the EC has decided to promote the use of biofuels in road transports.

This has been done through several directives and initiatives at the EC level [15, 19].

- Directive 2003/30/EC and the Biomass Action Plan. The directive mainly set targets for promotion of the use of biofuels or other renewable fuels for transport, i.e. 5.75% of all gasoline and diesel for

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[14] Per day, 120 tonnes of processed cat fish give 81 tonnes of fish wastes from which 17 tonnes fish oil are extracted. This yields 13 tonnes of biodiesel with the Preseco technology.

transport purposes placed on the EU markets by 31st December 2010 (reference values for these targets are given on the basis of energy content). In 2006, the Biomass Action Plan set out further objectives of biofuels introduction in transports, i.e. 5.75% in 2010, and 10% in 2020. The plan also addressed the issue of amending the biofuels directive 2003/30/EC so that only biofuels whose cultivation complied with minimum sustainability standards could count towards the EC's targets.

- Also in 2003, the Council directive 2003/96/EC authorized member states to apply total or partial exemptions or reductions in the level of taxation to, among others, biofuels (as defined in directive 2003/30/EC) with the aim of reducing distortions of competition between mineral oils and other energy products.
- In 2007, the member states agreed to proceed with the EC energy package and impose a 10% biofuel content in vehicle fuels by 2020. One year later, in 2008, the EC put forward a new plan called "energy-climate package" which proposed to set new rules to promote renewable energies (biofuels among others) and new environmental quality standards for biofuels. It was adopted at the end of the year. The legislative acts more specifically concerned with biofuels were the two 2009 directive, i.e. the Renewable Energy Directive (RED) and the Fuel Quality Directive (FQD).
- The European Industrial Bioenergy Initiative EIBI in the frame of the SET-Plan[15].
- The RED (2009/28/EC) establishes national renewable energy targets that result in an overall binding target of a 20% share of renewable energy sources in energy consumption in 2020 and a binding 10% minimum target for renewable fuels in transport to be achieved by each member state. It also encourages the development of better types of renewable energy (by setting sustainability standards for biofuels for example).
- The FQD directive has been adopted in order to improve air quality and reduce GHG emissions through environmental standards for fuel. The directive also facilitates the more widespread blending of biofuels into petrol and diesel and set ambitious sustainability criteria for biofuels in order to avoid negative consequences. The directive also incorporates the same environmental and social sustainability criteria for biofuels as in the RED.

This legislative framework has sent clear signals to the biofuel industries. As a consequence, the production growth has been rather high these last years, cf. Figure 6.3, i.e. 16.6% in 2009, 35% in 2008, etc. This however stands far below what EU biodiesel producers could achieve in a more favorable environment, that is the production capacity is still very high in comparison to the production, cf. Figure 6.3. In 2009, production has slightly decreased in some countries but overall it has increased due to important production expansions that have been realized for instance in Spain, which is now the third largest EU biodiesel producer, behind Germany and France [20].

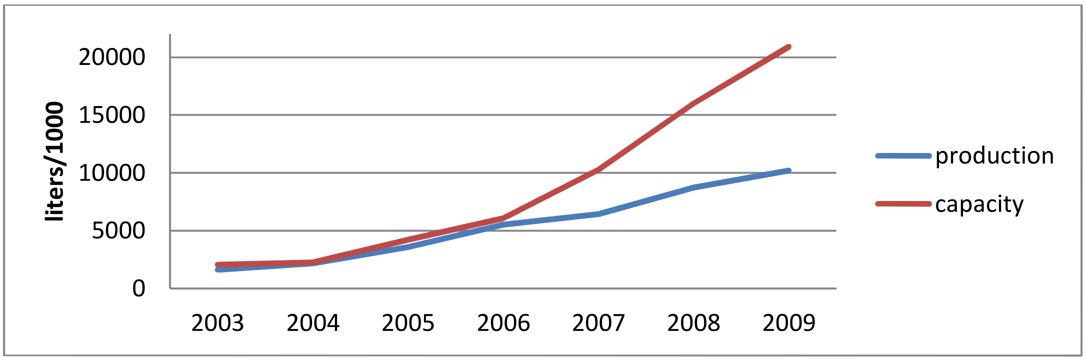

Figure 6.3: production and capacity for biodiesel in the EU 27. Source: [15].

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[15] The European Strategic Energy Technology Plan, SET-Plan, was adopted by the Energy Council of Ministers in February 2008 as a basis for the energy technology policy for Europe, which aims at the wide-scale application of low carbon technologies. One of the main tools for the implementation of the SET-Plan is the European Industrial Initiatives (EIBI: European Industrial Bioenergy Initiative).

As mentioned at the beginning of the chapter, the EU 27 is by far the leading biodiesel producing region worldwide (in 2009, 57% of the world production and 75% of biofuels produced in Europe). The European biodiesel production capacity is greater than 20,000 million liters with 245 dedicated facilities. This strong industrial basis is the result of considerable investments in biodiesel production planned already before 2007 in reliance of the ambitious objectives for biofuels consumption given by EU authorities.

According to [16], the reduced capacity utilization is mainly twofold: the massive imports of biodiesel coming from the United States and Argentina. Heavily subsidized biodiesel from the US, referred to as "B99", has been sold in the EU, even at a lower price than the raw material (soybean oil). The European Biodiesel Board has addressed this problem with the EC but there are still some concerns on the real efficiency of the measures that were taken [20]. Argentina also exported nearly 1,000 million liters of biodiesel to the EU. These imports are mainly driven by an artificial mechanism of differential export taxes, i.e. the export tax on crude soybean oil is much higher than that of biodiesel.

According to [20], the current technologies should be able to provide a significant part of the EU 2020 targets but it will probably not be sufficient: it is necessary to enlarge the feedstock basis and increase conversion efficiency, cf. second generation biofuels.

6.1.1 - Overview of EU biodiesel markets

National biodiesel markets are essentially driven by a combination of four factors: the size of the overall fuels and diesel markets, the fuel distribution market, government incentives for biofuels (or legislation mandating its use), availability of biodiesel supplies. Realistically, small scale biodiesel production from fish oils is only likely to influence the final category, although it may, of course be influenced by the other three.

Europe has traditionally led the world in mineral diesel demand, when expressed as a percentage of total road fuel demand. Much of this is due to historical factors, with technical development of diesel engines being based in Europe. To some extent, use in cars reflects the local dominant manufacturers; France has had a high incidence initially due to Peugeot-Citroen’s adoption of the fuel, with Germany also having widespread use in larger cars. In Britain and Italy, British Leyland and FIAT were later adopters of the fuel, and held back the wider market. National mineral oil taxation regimes also affected demand; France in particular always taxed diesel at a lower rate, initially assuming that it was likely to be used by commercial rather than private vehicles; higher tax in Britain held back demand. However it was not until August 2010 that more than half of British cars sold were diesel powered, reflecting a narrowing of the traditional price gap between petrol and diesel.

The fuel distribution market has to some extent followed the car market. As late as 1985 only 43% of British filling stations sold diesel as well as petrol, although just 5 years later this had risen to 76% and by 2000 almost 95%. Inevitably a higher proportion of stations in France or Germany sold the fuel. This pattern has to some extent been followed in biodiesel, with France and Germany leading the way. In France, this was to some extent supported by the Government encouraging national champions such as Elf (now part of Total) in the 1990s to sell biodiesel blends, as a way of providing assured outlets for farmers growing rapeseed as they diversified away from other crops to avoid set-aside under the Common Agricultural Policy. In Germany and Austria the move to biodiesel was more bottom-up, with agricultural co-operatives grouped under the Raiffeisen banner making the early running. As well as supplying farmers, these co-ops supplied farm fuels and operated public filling stations in rural areas (generally under the Raiffeisen name, but using BayWa in Bavaria and Genol in Austria). This created a closed loop for the product; the relatively large number of independent German petrol stations also allowed surplus biodiesel to be distributed readily in the market. In contrast, most other Western European countries were dominated by a handful of large international oil companies, and without Government pressure were less inclined to introduce biofuels blends. The one exception was Sweden, another market where co-ops (albeit from the consumer side) had historically had a strong market position.

The renewable fuels directive set a blanket target of 5.75% renewable fuels for 2020. Individual Member States interpreted this in different ways, with some adopting different targets, but others confirming the EU-wide figures. So while Italy and Britain aimed for just 2.5% or 3.6% by 2010, citing structural difficulties in reaching a higher target; Germany went for a split target favouring biodiesel (6.17% biodiesel to 3.6% bioethanol) and France set the highest target of 7%. Data suggests that although Germany was in line to exceed the target initially, in the event changes to the tax regime meant that almost no EU member States achieved their planned figures.

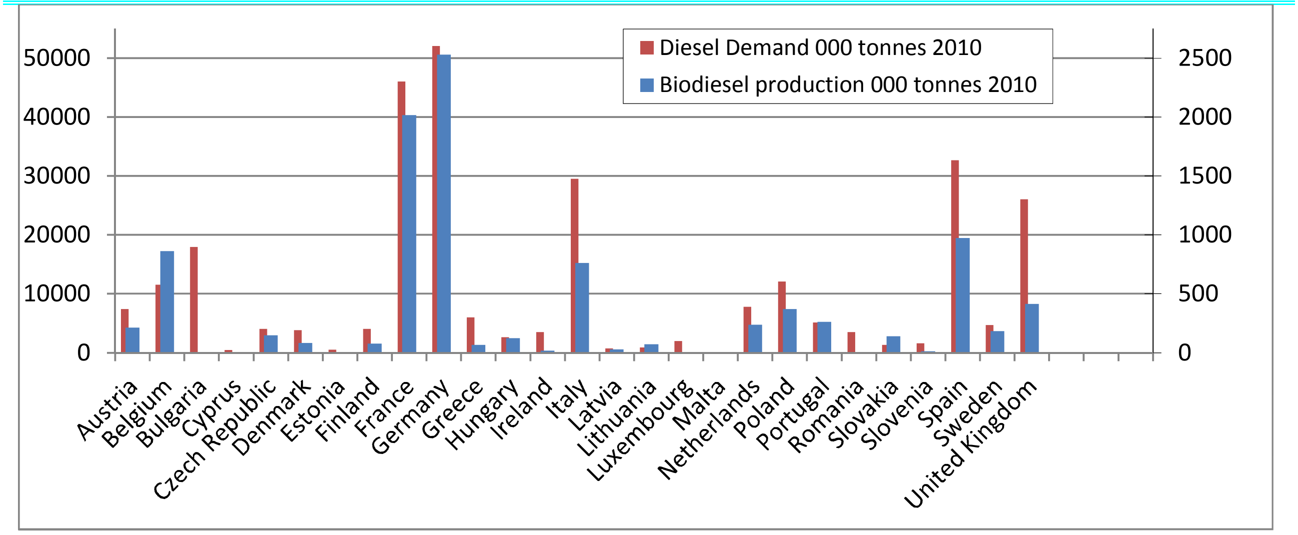


Figure 6.4: total diesel demand and biodiesel production in thousand tonnes in 2010 (left vertical axis for diesel, right vertical axis for biodiesel) in the EU 27 countries (data from IEA and Euromonitor).

Figure 6.4 shows the total diesel demand by country against local biodiesel production for 2010. The dominance of France and Germany in both categories is clear, but other notable data includes the high demand for diesel in Bulgaria and the relatively high production of biodiesel in Belgium. The latter may not be that surprising given the Antwerp region's traditional importance in oil products, although it is notable that Belgian production is 3.6 times that of the Netherlands, which has – if anything – an even greater role in oil refining. This data is slightly misleading in one respect, in that it matches total demand for the fuel to local production, and countries that have suffered from low cost imports, such as Britain, Germany and Italy, are likely to show lower production figures than biodiesel demand figures, which are harder to come by.

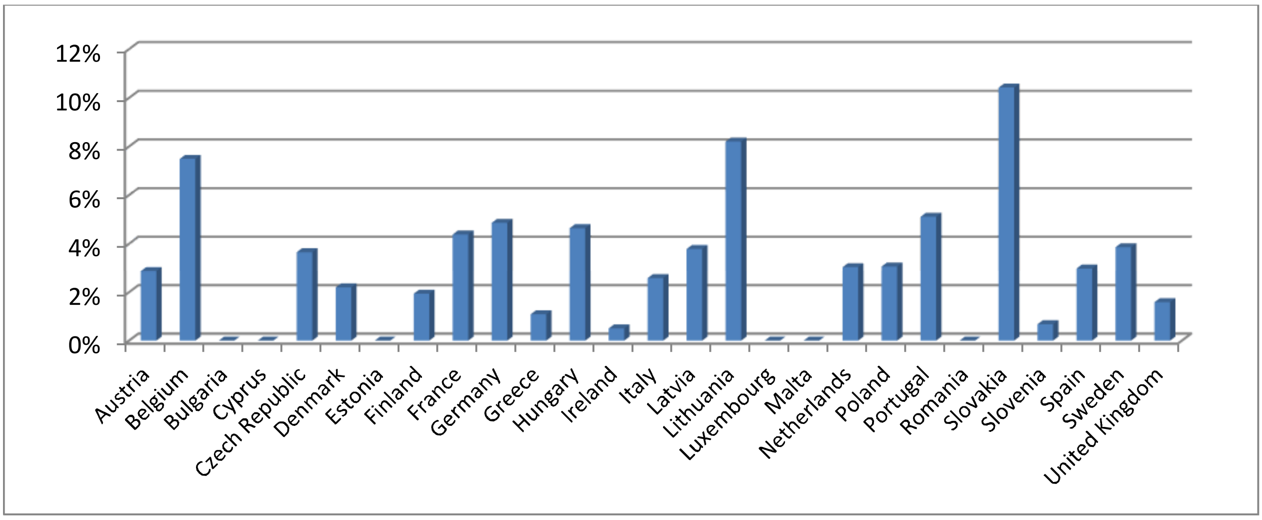


Figure 6.5: percentage of total diesel met by local biodiesel production in 2010 (data from IEA and Euromonitor).

Figure 6.5 displays the same data as in Figure 6.4, but expressed in percentage terms: only three countries (Belgium, Lithuania and Slovakia) have exceeded the EU 5.75% target, and these are all due in part to exports to neighbours with lower production – averaging Latvia, Lithuania and Estonia would possibly be more realistic. It is also worth observing that some countries yet to have any production and so may prove potentially fertile ground for smaller scale plants such as the Enerfish process – including the two Mediterranean islands of Cyprus and Malta. Luxembourg is, as ever with energy statistics, an exception, with low road fuel taxation creating high demand met entirely by imports from neighbouring countries. However data can be very uncertain. The European Biodiesel Board, a trade association, publishes alternative data, including capacity. It has yet to release its 2010 figures, but 2009 data shows extremely low levels of capacity utilisation, cf. Figure 6.6. This data is coherent with the data displayed in Figure 6.3.

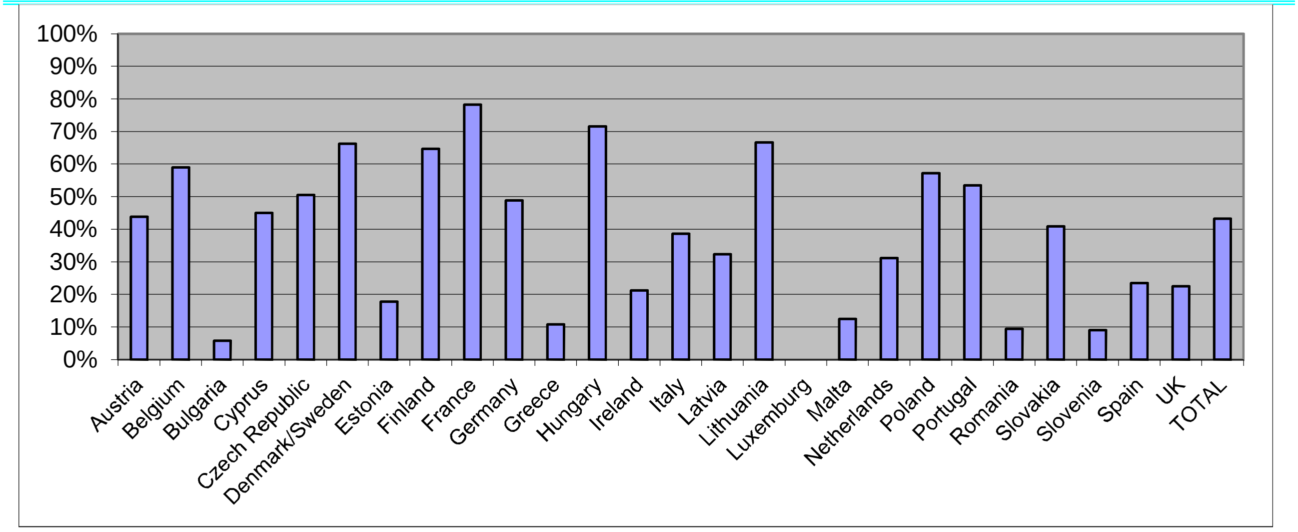


Figure 6.6: percentage of production of biodiesel versus capacity in the EU. Source: [20].

Some of the low figures may be due to new capacity coming on line within the year, but mostly the poor figures are due to competition from cheaper imports and a tendency of the market to have overbuilt capacity in the 2004-2007 period in the expectation that demand would rocket in order to meet EU targets. Among the major countries, both Spain and the UK reported utilisation rates below 25%.

Poor utilisation has inevitably led to bankruptcies within the industry and plants being closed or mothballed. Following on from a very difficult 2009, the European Biodiesel Board reported capacity reductions in 8 member states, led by Slovakia with a 37% drop, and Austria with a 21% fall. In absolute terms, though, Germany reported the largest fall, losing production capacity of 267,000 tonnes a year.

6.1.2 - Biodiesel Blends

European biodiesel is subject to the EN14214:2008 standard for FAME (fatty acid monoalkyl esters derived from biologically produced oils or fats including vegetable oils and animal fats including fish oils). Essentially this sets forth a series of limits covering areas such as cetane number (a minimum of 51), density and viscosity, as well as the acceptable testing methods for each parameter. There are also prescribed maximum limits for impurities such as sulphur, glycerine, (poly)glycerides, iodine, phosphorus and sodium. Some of these are likely to be of greater concern when dealing with fats and fish oils than with vegetable origin FAME. Biodiesel produced for static, off-road applications (cf. e.g. a CHP unit) may not need to comply fully with EN14214:2008 dependent on the actual engine in which it is being used, but should generally meet the limits for non-combustible impurities.

Biodiesel is rarely sold undiluted, but as a blend with mineral diesel indicated by B*n*, where *n* represents the percentage of biodiesel in the blend. In Europe, most biodiesel is sold as a weak blend of typically 5% biodiesel known as B5 as this can be used without modification in almost all vehicles, and with no breach of engine manufacturers' warranties. Consequently it can be used to replace purely mineral diesel at filling stations. The European standard for diesel (EN590) currently permits up to 7% FAME within regular diesel. In North America, in contrast, biodiesel is mainly being marketed as a specialist fuel in a B20 (20% blend) and the American Society for Testing and Materials (ASTM) has focused on developing standards for that blend with major US automotive manufacturers.

Some cars – notably those from within the Volkswagen group – are able to accept pure biodiesel (B100). This is not generally sold commercially through filling stations but at specialist outlets, or is generated by enthusiasts using micro-biodiesel production units (some will also use pure filtered vegetable oil.)

Internationally traded biodiesel can be sold in other blends. As noted above, B99 was exported from the US to Europe to take account of domestic American tax incentives, and latterly B19 has also been available for similar reasons. As both are likely to be blended down to B5 or B7, the exact mix is not especially important as long as it is consistently available.

6.1.3 - Preliminary conclusions

EU biodiesel markets are rather heterogeneous: they depend mainly on policies and to some extent on the availability of raw materials, existing production means and distribution channels. Most EU 27 countries have not met their 2010 target even though most of them have the production capacity to do so. EU biodiesel producers have been severely affected by heavily subsidised imported biodiesel mainly from the US and Argentina.

6.2 - Biodiesel markets in SE-Asia

Biodiesel markets in South East Asia are more diverse than in Europe, reflecting three main factors: greater disparity in national income, division between energy rich and energy poor countries and a lack of a regional driver equivalent to the RED in Europe.

The wealthier, larger countries in SE Asia have all sought to introduce biodiesel, with Thailand making most of the running, cf. Figure 6.7. However outside Thailand, Malaysia, Indonesia and the Philippines there has been relatively little large scale introduction of the fuel. Although it may appear surprising that Singapore, as the region’s richest state has more or less shunned the fuel, it should be borne in mind that all fuel has to be imported into the island state (mineral or bio-derived) and that as the centre of the regional oil refining industry, Singapore could arguably have most to lose from local or small-scale production of biodiesel.

Thailand and the Philippines are both lacking in fossil fuels, and so have the most to gain potentially from biofuels. Not unsurprisingly, Thailand has made the running, and in the mid-2000s unveiled ambitious plans to grow fuel crops both domestically (in some cases on land formerly given over to rice or rubber production as rice prices fell) and through acquiring oil palm plantations in neighbouring countries.

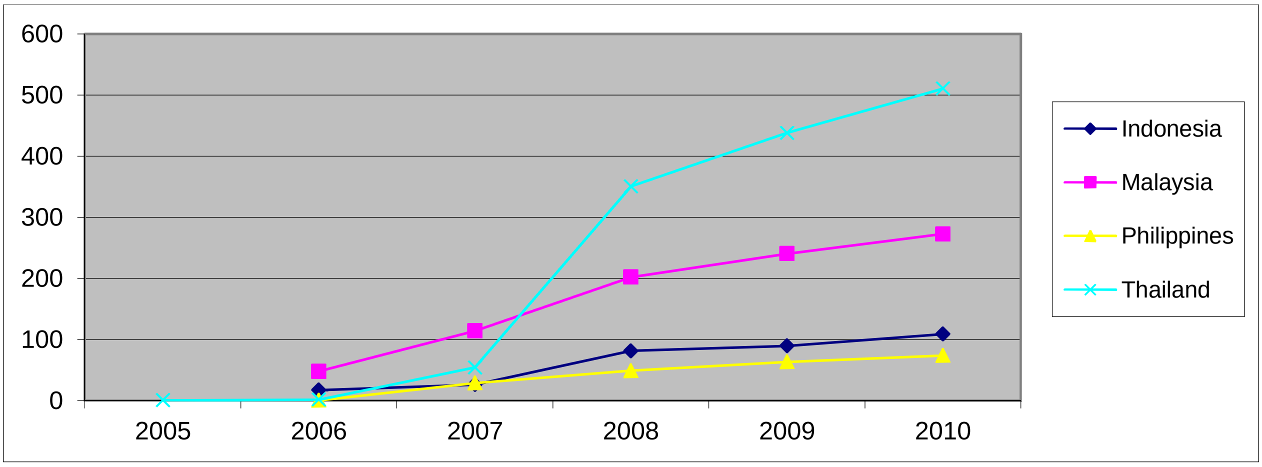


Figure 6.7: ASEAN (Association of Southeast Asian Nations) production of biodiesel in million tonnes oil equivalent (mtoe). Conversion in million tonnes or in billion litres can be obtained with the formulas displayed in footnote 13, cf. chapter 6. Source: International Energy Agency (IEA).

Thailand’s campaign to introduce biodiesel began in earnest in 2005, but initial production was insignificant. Limited sales were made by companies such as Bangchak, which has historically had links to the agricultural sector, but high-speed diesel remained wholly mineral oil based until February 2008, when B2 (2% biodiesel) was mandated. Simultaneously, tax breaks though an oil fund fee were given to B5, leading to a typical retail price differential of up to 2 baht (approx. 4.5 euro cents) a litre, but by May 2010 this had dropped back to 0.8 baht, equivalent to just over 4% of the typical pump price. Sales of B5 rose from 23% of the market in 2008 to 45% in 2009, but slipped back in 2010 as world prices fell and the price differential between regular B2 and B5 narrowed.

As well as fostering demand, the Thai Government encouraged supply with low interest loans to promote palm oil plantations, principally in former rubber strongholds in Northeast Thailand. These were supported by schemes to improve the yield. Production and planting targets were not met, with little more than half the annual 80,000 extra hectares planned for palm oil actually being planted in each of the three years from 2008 to 2010, leading to greater incentives for new plantations outside the Northeast. This may create openings for non-traditional biodiesel sources such as fish oil, but the Thai Government’s scale is very much larger than elsewhere, with an expected requirement of around 900,000 tonnes crude palm oil per annum from 2011 onwards. Recognising that this is imposing an almost impossible burden on the industry, in December 2010 the Thai Government delayed the national rollout of B5, but has confirmed its intention to move basic high speed diesel from B2 to B3 during 2011.

It should be stressed that Thailand’s problems arise from a shortage of supply of crude palm oil or other suitable biodiesel feedstock (such as stearin, even though it produces a slightly lower grade of biodiesel and is itself a by-product of refining palm oil for food products), not of processing capacity; the fourteen major plants had a capacity (2009) of almost 6 million litres per day, but only processed just under 1.5 million litres per day on average in late 2009. Inevitably most biodiesel producers are suffering losses, despite production being closely balanced to demand. Plants associated with the big marketers (especially PTT and Bangchak) are likely to be better positioned to survive the current crisis.

Malaysia is the second largest producer and user of biodiesel, cf. Figure 6.8. It too has reached around 3% of demand being met from biodiesel in 2010, and has benefitted from the greater area of the country given over to palm oil production as well as lower overall diesel demand (although this has risen from around half to just over 60% of Thailand’s level of consumption over the past 5 years).

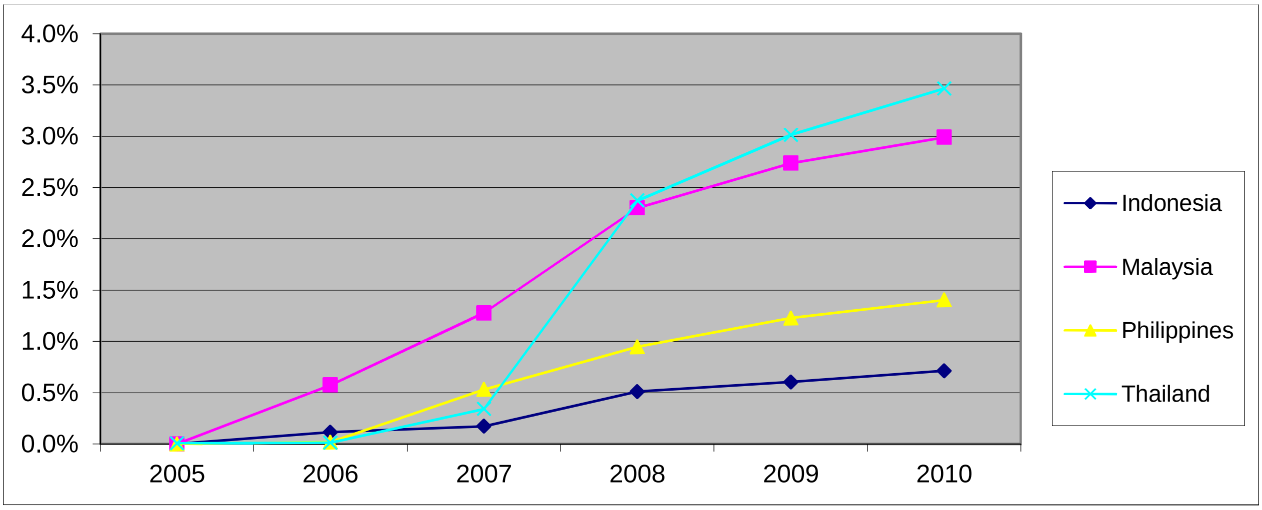


Figure 6.8: ASEAN percentage diesel demand from locally produced biodiesel. Source: IEA.

Figure 6.8 shows that the proportion of biodiesel used in the Philippines and Indonesia is much lower at around 1.5% and 1% respectively, but has also started to grow significantly since 2006. Indonesia remains the only of these countries where fuel distribution remains in the hands of a state-controlled monopoly (Pertamina) and so can potentially be more directly controlled by Government policy.

In the Philippines the Biofuels Law mandated an increase of the biodiesel blend from 1% to 2% in February 2009. In compliance, Petron and other major fuel retailers started blending 2% Coconut Methyl Ester (CME) in all diesel sold in the country starting February 6. Recently there has been a surge in interest in biodiesel produced from jatropha, building on its reputation for being able to be grown on marginal land, as the country has less surplus land that could be lost to food production. Jatropha can produce the feedstock for one to three tons of bio-diesel per hectare. B5 is also reported as having been available from February 2009, but only in limited quantities. It is possibly fair to say that the main biofuels focus has been on blending bioethanol into petrol.

Vietnam is the third largest ASEAN market for diesel and one of the most rapidly growing: demand has risen by over 25% since 2005 when it surpassed the Philippines for the first time. Distribution is in a complex monopoly of mainly state controlled firms, with one – Petrolimex – controlling over half the market. Until recently wholly dependent on imported oil products, it could have been expected to be fertile ground for biodiesel, but national policy seems to have been more focused on developing a domestic mineral oil refining industry. Nonetheless from 2010, under the plan on biofuel development to 2015 with a vision to 2025, Vietnam aims to produce 1.8 million tons of ethanol and vegetable oils for use as fuel annually, meeting 5 percent of domestic petrol and diesel demand in the next 15 years. As in the Philippines, interest has centred on jatropha due to its high oil content.

Experimental plantations of jatropha bushes, which grow in poor soils and have a life cycle of 30 years, are being established. For example, the Dong Xanh JSC is planting 30,000 hectares of jatropha in seven central provinces to supply its plant in Quang Nam. Despite this, it seems unlikely that B5 will be widely available before 2016. Cambodia is also looking at jatropha-based biodiesel, but on a smaller scale.

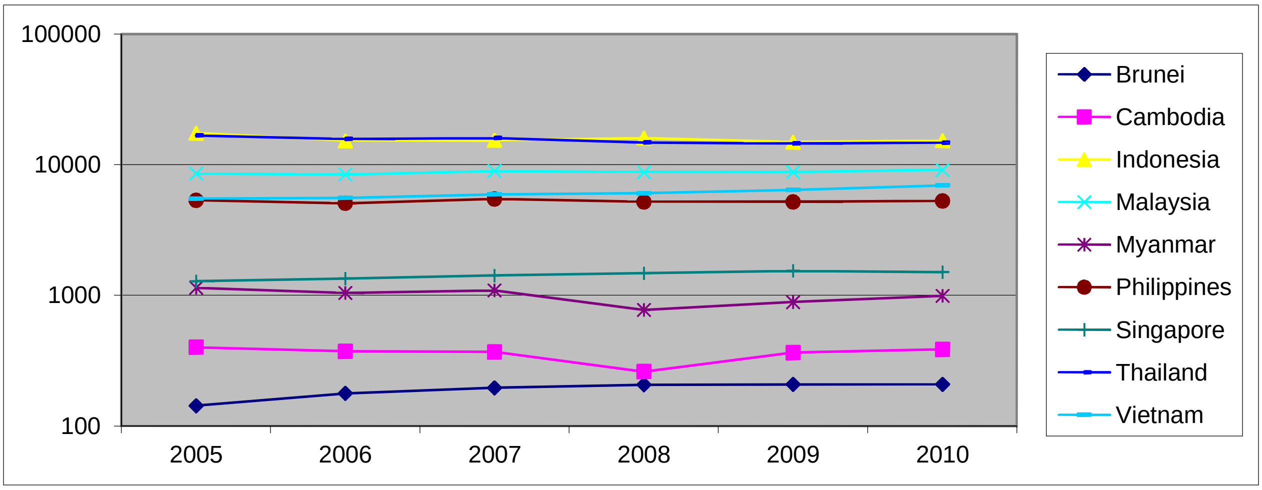


Figure 6.9: total ASEAN diesel demand in thousand tonnes (000t - log scale). Source: IEA.

Figure 6.9 displays the total ASEAN diesel demand. As can be seen from the fact that chart has to be drawn on a log scale, demand between ASEAN countries varies enormously. Demand is rising fastest in Brunei, but this remains a tiny total market (and given oil's importance to the local economy, biodiesel is unlikely to be seen as an imperative). Demand in Cambodia and Myanmar appears to fluctuate rather more than in other, more robust, economies and may offer opportunities for Enerfish type plants, especially Cambodia where there is a significant Mekong fishery.

As mentioned at the beginning of this chapter, the Enerfish process cannot be seen as a mean to produce biodiesel (blends) as such scales. For Vietnam, 5% of biodiesel in the overall diesel consumption would mean approximately a production of 500,000 tonnes biodiesel per year. According to the ratios discussed at the beginning of the chapter, i.e. 1 tonne biodiesel/ha/year or roughly 10 tonnes cat fish for 1 tonne of biodiesel, this production would require 500,000 ha of land or 5 million tonnes catfish. The former is 8% of Vietnam's arable land and the latter is more than twice the aquaculture production of Vietnam. Therefore, as mentioned earlier, the Enerfish process is interesting in large plants where fish wastes are available and can be processed on the spot for local use (energy or fuel for transport).

Demand in diesel varies enormously for the different ASEAN countries. There is no clear political framework as the RED directive in the EU27 even though some countries have set clear objectives in the promotion of blends (B*n*). As in Europe, the biodiesel industry in Thailand and the Philippines for instance, has suffered from the price variations in feedstocks (palm and coconut oils). Other countries have shown interest in biodiesel produced from jatropha due to its high oil content and its ability to grow in poor soils.

7 Market Potential in Europe/SE Asia

It is clear from the preceding sections that the potential is not homogeneous, either globally or regionally. Indeed, there is some evidence that even within a single country, opportunities for development of Enerfish-type plants may vary with local factors and one specific instance of this is considered in section 7.3 below. However it is clear that to be viable, three main factors have to be favourable for any given location:

1. there must be a demand for the end product (biodiesel),
2. raw material (fish oil or waste) has to be available,
3. the economics need to be right.

In general, if there is any demand at all for biodiesel, it is likely to swamp fish oil availability, so it makes sense to consider the potential in the order above (starting with demand, rather than supply). The final point on economics can be sub-divided further to take into account:

i) the value of the raw material when sold for alternative purposes,
ii) the price of competing raw materials,
iii) the price of the processed product – biodiesel – including any subsidies or mandated requirements for use.

These factors can be viewed hierarchically to help determine the market potential.

7.1 - SE Asia: market potential in Vietnam and ASEAN

7.1.1 - Demand for Product

Section 6.2 has looked at ASEAN demand for biodiesel. Currently there is clear demand in four major markets – Thailand, Malaysia, the Philippines and Indonesia, with demand in the near future in Vietnam. There may be smaller scale opportunities in Cambodia. Data on Laos and Myanmar is hard to come by, but if there is further liberalisation in Myanmar it is reasonable to assume that a demand for locally produced biodiesel may arise. (Currently all road fuels are in short supply, but this has more to do with foreign exchange constraints.) It appears unlikely that there will be significant demand for biodiesel in either Singapore or Brunei in the foreseeable future.

Vietnam, as the host for the Enerfish pilot, should be most promising, but the market for biodiesel as a road fuel looks confused in the short term. A technical standard is in place (TCVN 7717:2007), based on the ASTM and EN standards, with broadly comparable limits set. Distribution appears to be more of an issue, with PetroVietnam responsible for the production side but none of the distributors are currently handling the product. (Bioethanol has a similar split and Petrolimex, the main downstream distributor, is not currently selling it, although some of its smaller competitors are). However this is likely to change by 2015, which would at least allow time for a number of clone Enerfish plants to be constructed.

The next section will only look at the six countries with potential demand.

7.1.2 - Availability of Raw Materials – Fish Oil and Fatty Wastes

All six countries have a significant fishing industry. Indonesia, the Philippines and Thailand are in the top ten countries in the world for capturing wild sea fish; the same three plus Vietnam are in the top ten for aquaculture. Malaysia also has a large fisheries industry. Cambodia has a strong wild fisheries industry, especially of *Osteichthyes* species, which are generally oily fish, but its aquaculture appears currently to be underdeveloped, with annual production only around 34,000 tonnes.

In each country therefore, there is a clear potential to develop biodiesel from fish industry, if the economics is right.

7.1.3 - Economic Considerations

Having considered a demand and potential resource availability, the next question is about whether that potential resource will be siphoned off to other end products. Here, the data is less clear, but in Vietnam, at least, there seems to be clear evidence that other end uses – notably the pharmaceutical industry – will pay sufficiently high prices as to render fish-based biodiesel uneconomic, cf. chapter 4. Currently, (March 2011) the following are typical prices: 7200 VND/kg (at the fish processing plant, 0.244 Euro/kg) for fish waste, 20000 VND/kg (0.678 Euro/kg) for fish oil and 18000 VND/litre (0.61 Euro/litre) for biodiesel.

Diesel is subsidised in Vietnam, with a current retail price of around 21,000-21,500 (0.71 Euro/litre) so prices do not fully reflect world market prices, and even at a crude oil price of over US$100 per barrel. As its use is not mandated, there is no premium attached to biodiesel at present. Vietnam also seems to suffer from its location, in that China – with a huge demand for all manner of raw materials – seems to exert a pull on its resources, including fish oil and by-products.

Elsewhere diesel is similarly priced in the Philippines (around 45 PHP/litre, or 0.75 Euro/litre) and costs 29.99 baht/litre in Thailand (0.70 Euro/litre) including a 5.1 baht subsidy from the oil fund. (There are nonetheless a number of taxes included in the retail price.) Where available in Thailand, B5 is priced at a very slight discount to the standard high speed diesel price. With continuing high crude prices, these subsidies may not be long lived; for example Indonesia has announced plans to phase out fuel subsidies completely by 2014.

The competing raw materials vary significantly in price. Crude Palm Oil (CPO) is openly traded in Malaysia and so a market price is easy to determine; currently at around 3325 ringgit/tonne (US$1100 or Euro 780) it is very similar to refined retail price of diesel, and somewhat higher than the Vietnamese fish oil price indicated. CPO also tends to track global oil prices, despite high demand from the food industry. CPO stearin is typically about 2-3% cheaper. Coconut Oil – which is only used to any extent for biodiesel in the Philippines – is considerably more expensive with a typical price of US$1800-1900, almost double that of Argentine soy bean oil, for example. Jatropha is less widely traded, but unlike fish oil its price closely tracks that of diesel as it has few alternate uses developed.

Section 8 looks in more detail at the financial benefits through economic modelling.

7.2 - Market potential in Europe

7.2.1 - Demand for Product

As shown in section 6.1, European demand for biodiesel is much more homogenous, as most countries had a target (admittedly, missed) of 5.75% of total diesel consumption. Although most countries are continuing to import large amounts of biodiesel, there is considerable underutilised production capacity across the continent. Most plants are set up to process oils of vegetal origin, including raw palm oil, soy oil, oilseed rape and sunflower, and it is unlikely that they would be able to switch to fish oil.

This may create a potential for smaller scale fish oil conversion along the lines of the Enerfish facility in areas of low to medium biodiesel demand, where there are no existing biodiesel plants. However, if it is only used to meet nationally mandated limits, it is unlikely that such a small scale facility will be economic; attention should be focused on applications where either a higher than standard biodiesel blend is acceptable (including B100), or where supply constraints have created market imperfections for the standard mandated fuel.

7.2.2 - Availability of Raw Materials – Fish Oil and Fatty Wastes

If demand (and the price for road diesel) is a constraining factor in Asia, then supply is the greater problem in Europe. Although Denmark and the UK are significant producers of fish oil from within the EU (and Iceland and Norway from outside), the region remains a net importer with most fish oil being used directly as feed for the large salmon farming industry.

7.2.3 - Economic Considerations

Traded fish oil always sells at a premium to crude oil. There is a reasonable correlation between the two, with the crude price effectively providing a floor below which fish oil seems unwilling to fall. As noted in section 5.1 fish oil has its own spikes, driven by intermittent supply squeezes (e.g. from El Niño) and double substitutions (so that high crude prices can draw more soya oil into fuel, raising all edible oil prices), cf. Figure 7.1.

European diesel prices are generally significantly higher than those in ASEAN, due to fuel being seen as a source of tax, rather than requiring subsidy. However this only benefits biodiesel if it benefits from a preferential rate of tax. Although this was quite widespread in the early years, when Governments were actively trying to develop a biodiesel industry, these are beginning to be withdrawn, as regulation (and the

EU 5.75% biofuels target) mandates use of biodiesel. In other words, biodiesel has now moved to being a pure commodity market with no user driven premium; instead diesel blenders are simply looking for the lowest cost sources of biodiesel that are compatible with any sustainability requirements. Biodiesel derived from fish oil will only be attractive if it costs no more than from bulk vegetal oil sources.

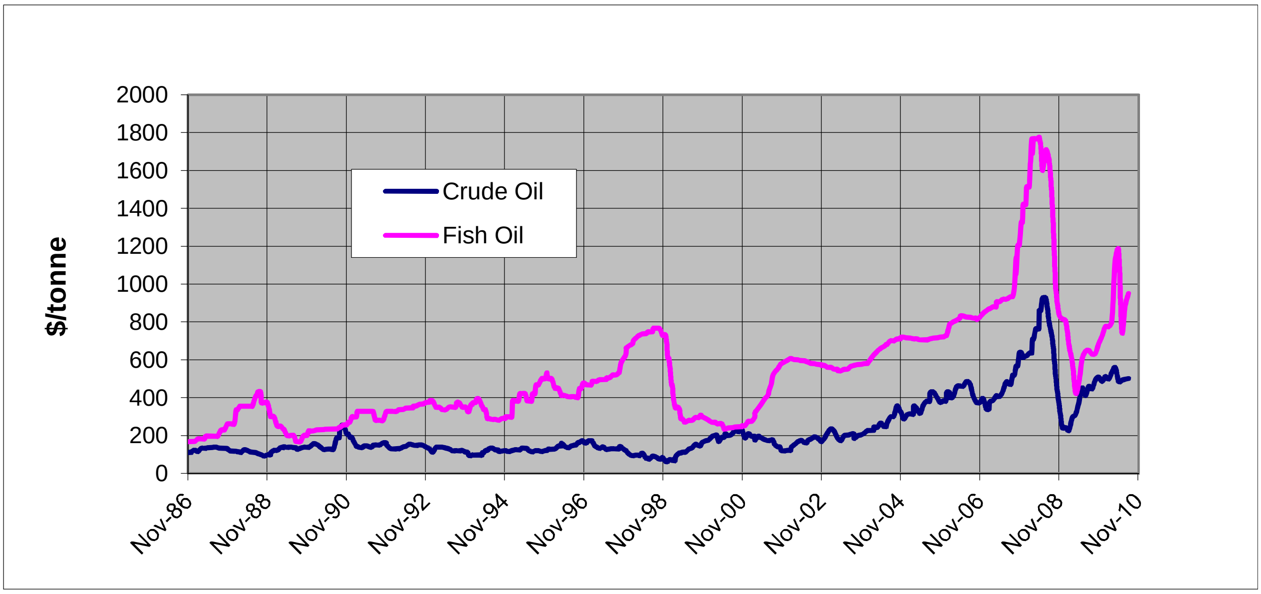


Figure 7.1: fish oil versus crude oil prices.

7.3- Islands

As noted in the introduction to section 7, the potential is not equal, and there may be some areas where special circumstances apply. Anecdotally, without having much firm data to go on, it would appear that an opportunity may arise on certain smaller islands, which lack alternative biodiesel processing plants, and where there is an existing fishing industry. However if only a standard nationally mandated biodiesel blend is being used for road fuels, it would make no economic sense to specially import pure mineral diesel from the mainland and blend it with local fish biodiesel. The fish diesel would have to added to the standard ex-refinery product available (which may already be B5) and boosted to B10 or B20, most likely for use in fishing boats or generator sets.

This has the added benefit of linking local production to demand, and most islands have a high relative demand for diesel for the fishing industry itself, avoiding some of the issues referred to in section 6.3 with the use of unauthorised biodiesel in road vehicles. Diesel for use in boats may of course be taxed at a quite different rate from road diesel; in the UK the former is known as "red" diesel due to the use of a dye to make it immediately distinguishable from diesel on which full road fuel duty has been paid.

Within the EU this may apply to Malta where there is only 5 million tonnes of existing production capacity, and a small but growing fish farming industry (principally around tuna). It may also work in some of the outlying islands of the UK (Shetland, possibly Orkney or Western Isles), Denmark (Faeroes), Spain or Portugal where there is generally no local biodiesel capacity. It is less likely to be applicable to nearer inshore islands or larger units, such as the Balearics or Cyprus.

Outlying islands also have higher fuel prices due to higher distribution costs and low levels of competition. For example several of the Scottish Northern and Western Isles have a de facto monopoly supplier through National Benzole, a subsidiary of Valero (formerly Chevron/Texaco). The downside to this is that some of these areas – in the UK context, the Shetlands, again – are also significant importers of fish oil for their fish farming industry.

In Southeast Asia, some of the same considerations may apply in the Philippines and Indonesia, although the latter of course has a downstream monopoly. Diesel demand in this region is also more likely to be for generation, with less resilient grid electricity supplies, creating a further local demand away from road or boat fuels. However, higher mixes of biodiesel should also be avoided in warm climates where fuel is likely to be stored for considerable periods of time before use, such as backup generators, owing to the risk of bacterial growth.

8 Summary financial benefits based on various assumptions

The purpose of the following section is to set up a computational model of the NPV (Net Present Value) of a given project starting from a process which has already been optimized from a technical and economic standpoint, cf. [D1].

8.1 - Possible business models

In the preceding chapters, it has been shown that the Enerfish process is well suited for fish processing units where there is a sufficient daily amount of wastes to produce biodiesel. Figure 8.1 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.

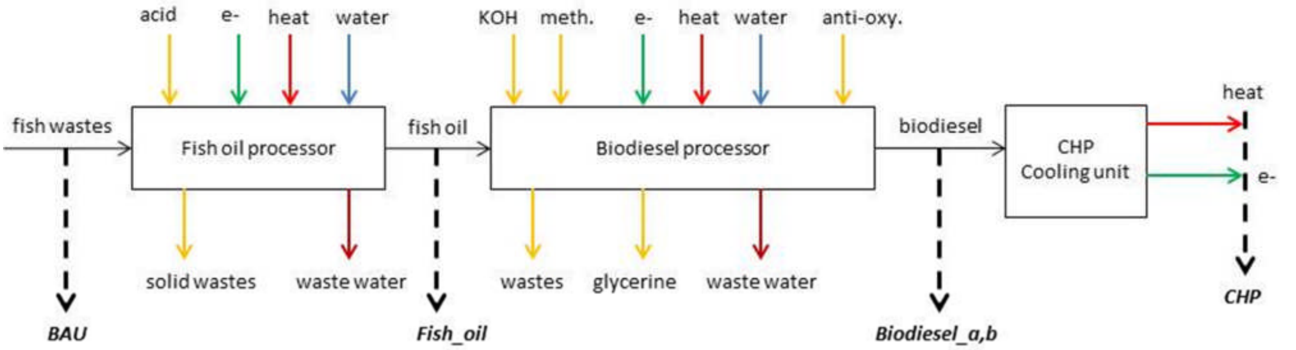


Figure 8.1: schematic view of the Enerfish process. Dotted arrows: business models. Acid: formic acid, e-: electricity, KOH: potassium hydroxide, meth.: methanol, anti-oxy: anti-oxidant.

The different business models are given by the vertical dotted arrows.

- BAU: this is the business as usual scenario where fish wastes are 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 wastes 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 is being installed. This investment will be accounted 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.

The profitability analysis is going to be carried out for the Enerfish unit under operating conditions, i.e. mass flow rates and enthalpies, which will be taken from the preliminary work performed in [D1]. All prices and cash flows for these variables will be computed in Euros, i.e. the risks inherent to fluctuations in currencies will not be directly accounted for. This risk will be considered, if needed, in the computation of the WACC, cf. section 8.1. Extension of the computations to a similar European case could then be performed by changing the numerical values of the relevant parameters (prices, costs, etc.) and operating parameters if sufficient information is available.

8.1 - DCF methodology

The profitability of the different business models will be investigated in terms of NPV, which is the sum of all discounted cash flows, including investments, during the economic period which is under investigation. This analysis will be performed without accounting for taxation (EBITA) 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 will be performed as for a regular investment project, with an initial investment, I, that generates positive (earnings) and negative (costs) cash flows during n years of operation. All cash flows will be expressed in constant currency, i.e. free from any inflation which is supposed to be constant. These cash flows are then discounted with a weighted average cost of capital (WACC) and their sum will give the net present value of the project. The profitability index of the project, PI, i.e. the ratio PI = NPV/I, will give a measure of the discounted benefits par invested unit of currency.

Table 8.1 gives the basic variables needed to set up the main equations of the algorithm. This is a preliminary list which can be updated as we move forward and present the different cash flows associated with each component of the Enerfish process.

Table 8.1: basic variables for the calculation of the NPV (Net Present Value) of an “Enerfish” business model.

Economic duration of project	n	year
Bank loan share (% of total investment, I)	x_{loan}	%
Equity share (% of total investment, I)	x_{equi}	%
Bank loan interest rate	r_{loan}	%
Equity rate of return	r_{equi}	%
Weighted Average Cost of Capital (WACC)	r	%
Inflation (constant)	i	%
Drift factor for cash flow CF_l	t_l	%
Total subsidy (% of total investment, I)	si	%
Total investment	I	€
Residual value	VR	€
Cash flow	CF_l	€
Discount factor for cash flow CF_l	Fa_l	
Net Present Value (NPV)	NPV	€
Profit Index (PI)	PI	-

The weighted average cost of capital (WACC) is computed as a function of the respective shares of bank loans and equity, i.e.

$$(1+i).r = \left(x_{loan}.r_{loan} + x_{equi}.r_{equi}\right) - i.$$

In the case of unevenly distributed cash flows in time (*l* represent 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”), we resort to the “economic equivalent cash flow” that gives the same result in terms of NPV,

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

($CF_l = CF_{l,e} = CF_{l,k}$ if the cash flows are constant in time), where the discount factor is expressed as

$$Fa(r,n) = \frac{1-(1+r)^{-n}}{r}.$$

The net present value of a project can be calculated as:

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

where the discount factor is calculated not only as a function of the duration of the project and the WACC but also as a function 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 new discount factor is:

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

VR is the sum of all residual values. It is discounted by the corresponding factor.

Additional values of profitability, apart from the NPV and the PI can be given, that is the payback time (PBT) and the internal rate of the return (IRR) which are defined by

$$NPV(n = PBT) = 0 \quad \text{and} \quad NPV(r = IRR) = 0$$

all other variables being constant. The PBT gives the number of years to reach a positive NPV and the IRR gives the maximum discount rate to achieve profitability.

The basic tools of the profitability analysis have now been presented. In the following sections, the different cash flows are going to be detailed for each component of the Enerfish process. The total investment of the project if defined as

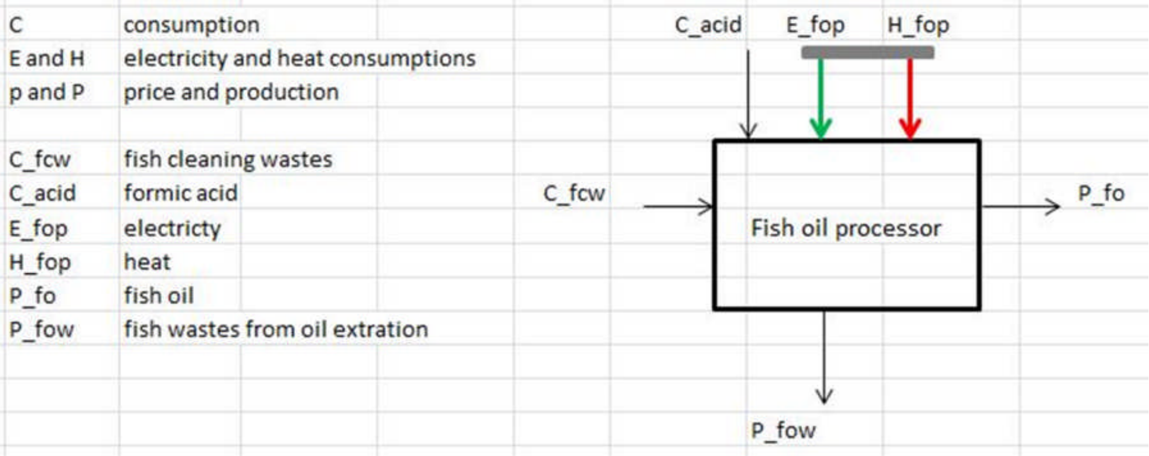
$$I = I_{fop}\, Z_{fop} + I_{Dop}\, Z_{Dop} + I_{CHP}\, Z_{CHP} + I_{cool}\, Z_{cool} + I_{aux},$$

where *Z* is a binary variable (0 or 1) to test different business models (whole process, production of diesel oil only, with or without a fish-processor and so on). The indices *fop*, *Dop*, *CHP*, *cool* and *aux* are related to the fish-oil processor, the Diesel-oil processor, the CHP, the cooling system and the auxiliaries respectively. Note that "auxiliaries" stands for all pipes, pumps, valves, control components, sensors, etc., which are needed for the process. This investment is a function of the "*Z*". It is not detailed here for the sake of expediency.

All flows are given per day, i.e. tonnes/day for the mass flow rates and MWh/day for the energy flows, cf. Figure 8.2 next page. The annual cash flows are computed by multiplying the daily cash flows with the number of processing days per year.

8.2.1 - Cash flows related to the fish-oil processor

Figure 8.3 shows the different flows associated with the fish-oil processor. In the following mass flow rates are denoted "C" if it is consumption (inflow) and "P" if it is a production (outflow). E and H designate the flow related to energy, i.e. electricity and heat respectively. The economic value, i.e. prices, of the different flows is denoted "p" with the associated subscript.



C	consumption
E and H	electricity and heat consumptions
p and P	price and production
C_fcw	fish cleaning wastes
C_acid	formic acid
E_fop	electricty
H_fop	heat
P_fo	fish oil
P_fow	fish wastes from oil extration

Figure 8.3: mass flows and energy (heat and electricity) flows for the fish oil processor.

In the case of no drifts on the prices of the different flows, the sum of the discounted cash flow related to the fish oil processor reads

$$CF_{fop} = \left(-C_{fcw}\, p_{fcw} - C_{acid}\, p_{acid} - E_{fop}\, p_E - H_{fop}\, p_H + P_{fow} p_{fow} + P_{fo} p_{fo}\right) * Z_{fop} * Fa(r,n).$$

If some of the cash flows have a drift, the discount factor has to be changed for the corresponding term, for example in the case of electricity and formic acid prices varying in time

$$CF_{fop} = \left(-C_{fcw}\, p_{fcw} - H_{fop}\, p_H + P_{fow} p_{fow} + P_{fo} p_{fo}\right) * Z_{fop} * Fa(r,n) + \left[-C_{acid}\, p_{acid} Fa_{acid}(r,n,t_{acid}) - E_{fop}\, p_E Fa_E(r,n,t_E)\right] * Z_{fop}.$$

In the following all component cash flows will be given without any drift for the different terms for the sake of simplicity. This can be implemented in the computations if needed.

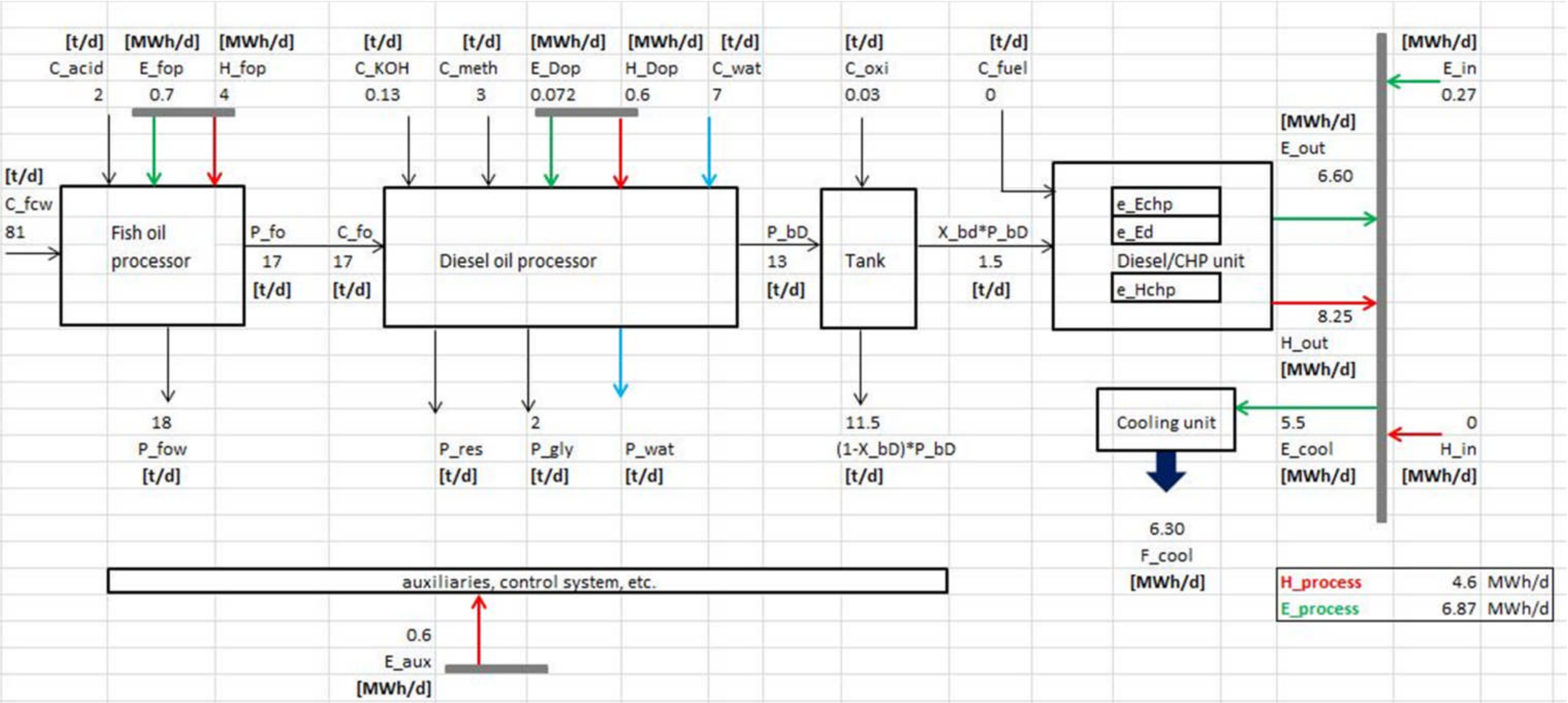


Figure 8.2: ENERFISH process in the full configuration (fish oil and diesel oil processors, tank, CHP unit and cooling/freezing unit). The numerical values are given for the demonstrator in Vietnam. All enthalpies (energies) are given in MWh per day, i.e. [MWh/d] and all mass flow rates are expressed in tonnes per day, i.e. [t/d]. Source: [D1].

Two additional variables are missing: the life span of the equipment, n_{fop}, which gives the residual value and the costs for operation and maintenance, vc_{fop}. The variable costs of the equipment are expressed as a function of an output, for example in euros per tonne of produced fish oil. The corresponding discount factor can be chosen as explained above.

As far as the life span is concerned, three cases can be encountered. When the lifespan of the equipment is equal to the economic duration of the project, n, one has $VR = 0$. If the life span of the equipment is less than n, the additional term corresponds to a new investment and a residual value, i.e.

$$-I_{fop}/(1+r)^{n_{fop}} + VR/(1+r)^{n},$$

where the residual value can be estimated as (it is assumed that the life span of the fish-oil processor is not less than half the economic duration)

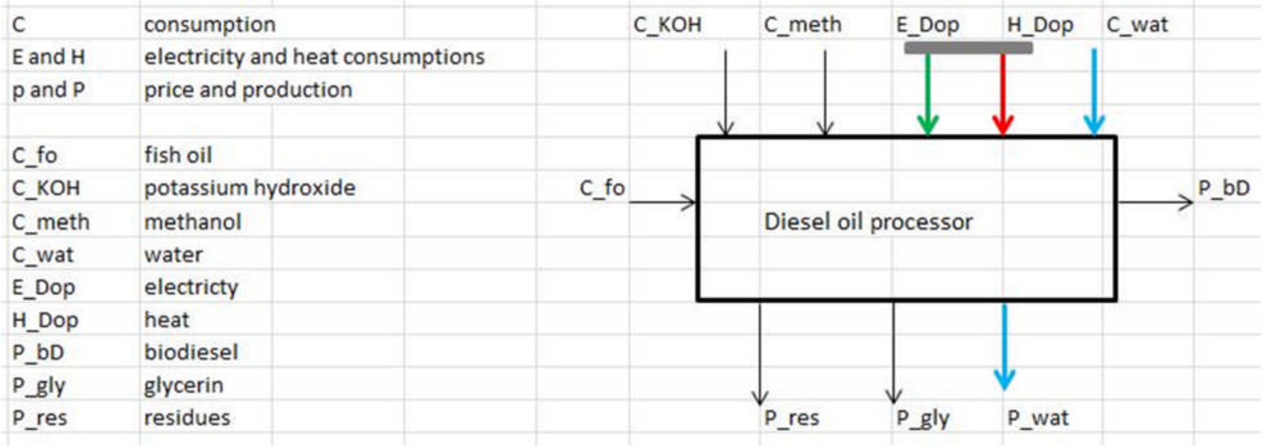
$$VR = \left[\left(2n_{fop} - n\right)/n_{fop}\right] I_{fop}.$$

If the life span of the equipment is greater than n, one can write:

$$VR = \left[\left(n - n_{fop}\right)/n_{fop}\right] I_{fop}.$$

8.2.2 - Cash-flows related to the Diesel-oil processor

Figure 8.4 shows the different flows associated with the fish-oil processor. In the following, the cash flow associated to the Diesel-oil processor is given for the Diesel-oil processor and the associated tank. cf. Figure 8.2. There is an additional term which is the consumption of antioxidant.



C	consumption
E and H	electricity and heat consumptions
p and P	price and production
C_fo	fish oil
C_KOH	potassium hydroxide
C_meth	methanol
C_wat	water
E_Dop	electricty
H_Dop	heat
P_bD	biodiesel
P_gly	glycerin
P_res	residues

Figure 8.4: mass flows and energy (heat and electricity) flows for the Diesel-oil processor.

The cash flow associated with the ensemble Diesel-oil processor and tank is:

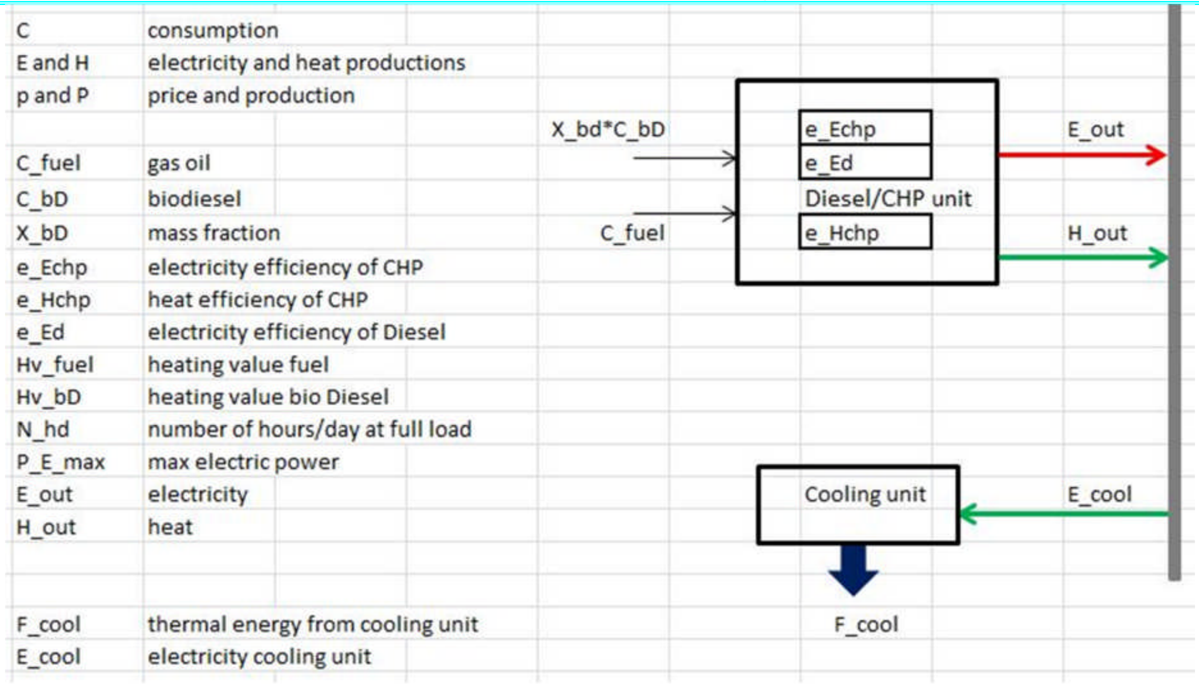
$$CF\_Dop = (-C_{fo}p_{fo} - C_{KOH}p_{KOH} - C_{meth}p_{meth} - C_{wat}p_{wat} - E_{Dop}p_{E} - H_{Dop}\,p_{H} - C_{oxi}p_{oxi} + P_{res}p_{res} + P_{res}p_{res} + P_{gly}p_{gly} + P_{bD}p_{bD}) * Z_{Dop} * Fa(r,n)$$

If drifts are defined for one of the terms entering the equation above, the equation can be re-written as detailed in section 8.1.

As far as the residual value is concerned, it can be computed as explained also in the above section. This could however be investigated since the residual value might also depend on the local market conditions. The operation and maintenance cost, vc_{Dop}, will be defined as a function of the processed flow of bio-Diesel.

8.2.3 - Cash-flows related to the CHP unit

Figure 8.5 shows the different flows associated with the CHP unit. In the following, it is assumed that the CHP is running only on bio-Diesel. The produced heat and electricity generate revenues which come either from selling to the network or from the avoided costs of energy since they are consumed on the spot.



C	consumption
E and H	electricity and heat productions
p and P	price and production
C_fuel	gas oil
C_bD	biodiesel
X_bD	mass fraction
e_Echp	electricity efficiency of CHP
e_Hchp	heat efficiency of CHP
e_Ed	electricity efficiency of Diesel
Hv_fuel	heating value fuel
Hv_bD	heating value bio Diesel
N_hd	number of hours/day at full load
P_E_max	max electric power
E_out	electricity
H_out	heat
F_cool	thermal energy from cooling unit
E_cool	electricity cooling unit

Figure 8.5 mass flows and energy (heat and electricity) flows for the CHP unit.

The cash flow related to the CHP unit are given by

$$CF_{CHP} = [-X_{bD}P_{bD}p_{bD} - vc_{CHP}(E_{out} + H_{out}) + E_{out}p_E + H_{out}p_H] * Z_{CHP} * Fa(r,n),$$

where the mass flow fraction of bio-Diesel necessary to produce a given amount of electricity is computed as follows:

$$X_{bD} = E_{out}/(Hv_{bD}C_{bD}e\_E_{CHP}).$$

The amount of produced electricity and heat are given by

$$E_{out} = Z_{CHP}P_{E\_max}N_{hd} \quad \text{and} \quad H_{out} = Z_{CHP}(e\_H_{CHP}/e\_E_{CHP})E_{out}.$$

The number of hours/day at full load will be used as a parameter of the model. The link between the varying load during the day and this variable is the ratio of the energy output (electricity) for instance, divided by the rated (electric) power of the CHP.

8.2.4 - Cash-flows related to the auxiliaries

The amount of electricity necessary to run the auxiliaries is estimated at 0.6 MWh/d for the Enerfish process with fish-oil and Diesel-oil processors as well as the CHP unit. The cash flow associated with this electricity consumption is very small compared to the other cash flows; it will nevertheless be accounted for even though not enough information is available to compute it as a function of the "Z", that is for different business models.

All equation displayed in sections 8.2.1 to 8.2.3 have in fact been written for daily cash flows. In the real computations they are multiplied by the number of operating days per year, cf. Table 8.1 in section 8.3.1 next page.

8.3 - Preliminary results

As mentioned in chapter 6, it is still difficult to find economic viability for the production of biodiesel and, in most markets, there are subsidies from the respective governments. Biofuels economics are strongly exposed to variations in oil (competitor) and bio-feedstock prices (raw materials) as shown in Figure 6.2. The price variations in crude oil prices have not allowed biofuels to become competitive with fossil fuels and, in addition, the growing needs of the biofuel industries have put some pressure on the prices of commodities from which biofuels are produced, cf. Figure 8.6 next page.

Figure 8.6 shows that the market prices of bio-feedstocks are exposed to very large variations directly linked to crude-oil prices. These quite significant variations make it difficult to make NPV based computations in real market conditions since the prices of feedstocks have doubled their prices twice during the last five years, with a decrease to the initial 2006 values in 2008. As a consequence, in the following computations, we will try to show in what market conditions (with or without subsidies) the different business models could be interesting.

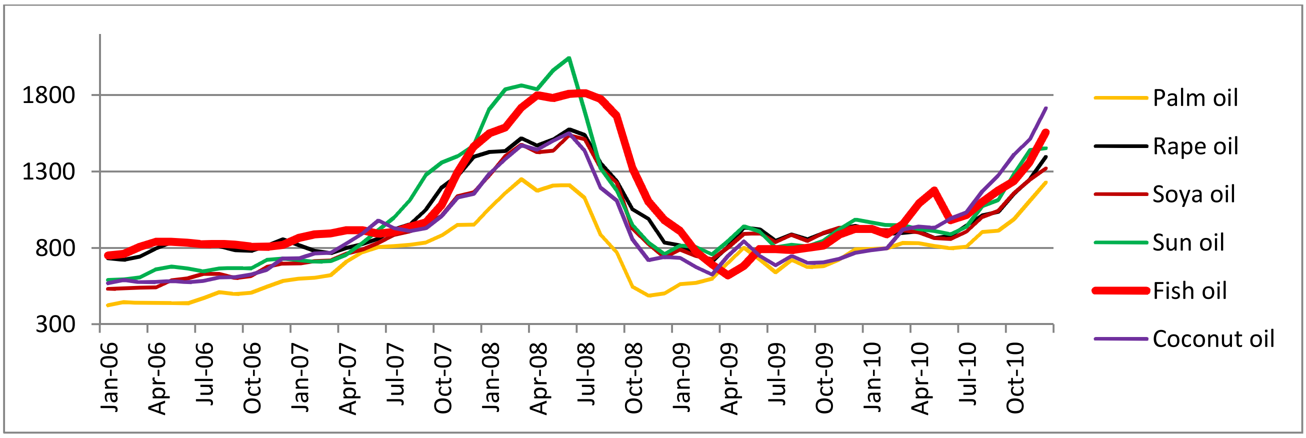


Figure 8.6: market prices for palm, rape, soya, sun, coconut and fish oils from January 2006 to December 2011. Source: [9].

8.3.1 - Main hypotheses and numerical values

Most of the main hypotheses have been put forward so far. An additional hypothesis is that all costs related to water consumption are neglected since no information was available. It is assumed that the water is pumped from the nearby river.

Table 8.1 displays the numerical values which are representative of the Enerfish process, cf. [D1]. Some of the numerical values have been recently given by ECC in Vietnam (March 2011), i.e. the current market prices (in Vietnam) of fish wastes, fish oil and biodiesel. Today, according to ECC, fish wastes are traded at 244 Euros/tonne, fish oil is traded at 678 Euros/tonne and biodiesel at 610 Euros/litre. These numerical values differ from the ones taken in [D1], especially fish wastes, i.e. 100 Euros per tonne instead of 244 Euros per tonne.

Table 8.2 shows the different cash flows associated with each component of the Enerfish process. The sum of these cash flows represents the total cash flow per day that 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.

Table 8.2: daily cash flow associated with the numerical values displayed in Table 8.1. (OM: operating and maintenance costs).

Fish oil processor	€/d
fish cleaning wastes	-19764
acid	-1100
fish oil wastes	5040
fish oil	11560
electricity	-30
heat	-80
OM*	
Total	**-4374**

Diesel oil processor + tank	€/d
fish oil	-11560
potassium hydroxide	-1040
methanol	-750
water	0
electricity	-3
heat	-12
biodiesel	8931
glycerine	400
residues	0
Anti-oxidant	-240
OM	
Total	**-4274**

CHP/Diesel unit	€/d
gas oil	0
bio Diesel	-1098.67
electricity	298
heat	162.855
OM	-175
Total	**-813**

Table 8.1: numerical values for the variables used in the computations. The values in bold will be used as parameters, that is the market prices of fish cleaning wastes, fish oil, biodiesel, electricity, heat and the number of hours at full load for the CHP unit (this last value gives the proportion of biodiesel which is used for energy production and the one which is sold to the market).

fish oil processor	C_fcw	fish cleaning wastes	81	t/d	**244**	€/t
	C_acid	formic acid	2	t/d	550	€/t
	E_fop	electricity	0.7	MWh/d	43	€/MWh
	H_fop	heat	4	MWh/d	20	€/MWh
	P_fo	fish oil	17	t/d	**680**	€/t
	P_fow	fish wastes from oil extraction	18	t/d	280	€/t
Diesel oil processor	C_fo	fish oil	17	t/d	680	€/t
	C_KOH	potassium hydroxide	0.13	t/d	8000	€/t
	C_meth	methanol	3	t/d	250	€/t
	C_wat	water	7	t/d	0	€/t
	E_Dop	electricity	0.072	MWh/d	43	€/MWh
	H_Dop	heat	0.6	MWh/d	20	€/MWh
	P_bD	bio Diesel	13	t/d	**687**	€/t
	P_gly	glycerine	2	t/d	200	€/t
	P_res	residues		t/d		€/t
Tank	C_bD	bio Diesel	13	t/d	687	€/t
	C_oxi	Anti-oxidant	0.03	t/d	8000	€/t
	X_bD	bio Diesel to Diesel/CHP unit	0.123			
CHP/ Diesel unit	C_fuel	gas oil	0	t/d	500	€/t
	C_bD	bio Diesel	13	t/d	687	€/t
	e_Echp	electricity efficiency of CHP	0.4			
	e_Hchp	heat efficiency of CHP	0.47			
	e_Ed	electricity efficiency of Diesel	0.38			
	Hv_fuel	heating value fuel	42	MJ/kg		
	Hv_bD	heating value bio Diesel	39	MJ/kg		
	N_hd	number of hours/day at full load	**6.3**	h/d		
	P_E_max	max electric power	1.1	MWh/d		
	E_out	electricity	6.93	MWh/d	**43**	€/MWh
	H_out	heat	8.14	MWh/d	**20**	€/MWh
cooling/ freezing system	F_cool	thermal energy from cooling unit	6.30	MWh/d		€/MWh
	E_cool	electricity cooling unit	5.5	MWh/d	43	€/MWh
process	H_process	heat to process	4.6	MWh/d	20	€/MWh
	E_aux	electricity to auxiliaries	0.6	MWh/d	43	€/MWh
	E_process	electricity to process	6.872	MWh/d	43	€/MWh

If a value of 100 Euros/tonne is taken, as in [D1], the cash flow for the fish-oil processor becomes positive (7290 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).

Table 8.3 puts forward the economic variables that have been chosen as a preliminary computation (inflation, equity, debt, investment and OM costs, etc.). Table 8.3 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.

With the numerical values of Tables 8.2 and 8.3, and a fish cleaning waste price of 100 Euros/tonne, the profitability of the project is extremely high, i.e. a PI of 3.37 is reached after 10 years. Ten years has been taken as the minimum of the possible lifespans of the different components. Table 8.4 displays the data provided for the usual lifespans of the different components. For the CHP unit, an average value of ten years has been taken. Note that in the case of a minimum lifespan of 5 years for the CHP unit, the PI would still be 2.68. As a matter of fact, under these assumptions 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 would be 2.6 years.

Table 8.3: 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

Table 8.4: lifespans of the different components of the Enerfish process: fish oil and diesel oil processors as well as the CHP unit, the cooling/freezing system and the auxiliaries.

Lifespans			
n_fop	fish oil processor	15	y
n_Dop	Diesel oil processor	20	y
n_CHP	Diesel/CHP unit	5 - 13	y
n_cool	cooling/freezing system	13	y
n_aux	auxiliaries, control system, etc.	10	y

8.4 - Sensitivity analysis

8.4.1 - 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 8.2 clearly show that it is more profitable to sell the biodiesel directly to the market that 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.

Figure 8.7 displays the PI as function of the fish cleaning waste price in two different cases: with a cooling unit and a 5 year lifespan for the CHP unit and without a cooling unit and a 10 year lifespan for the CHP unit. Economic duration of project: 10 years. In both cases the price of the fish cleaning wastes must be below 120 Euros/tonne 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% per cent 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/tonnes), a price for biodiesel of at least 1500 Euros per tonne would be necessary in order to reach profitability.

8.4.2 - 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/tonne can give profitability (it is the value which yields a zero NPV after 15 years).

For a market price of 244 Euros/tonnes for the fish wastes, the minimum price value of fish oil which gives profitability is 948 Euros/tonne. Therefore, under current market conditions, such an investment could be profitable, i.e. fish oil is currently traded in international markets at 1500 US$/tonne which is approximately 1100 Euros/tonne. However, Figure 8.6 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.

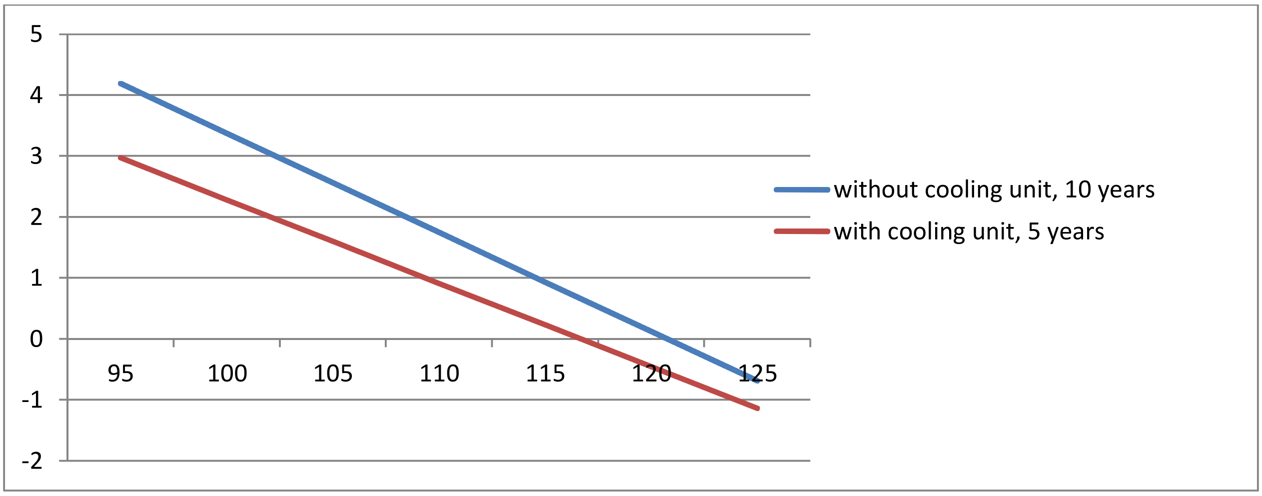


Figure 8.7: CHP business model. PI as function of the fish cleaning waste price in two different cases: with a cooling unit and a 5 year lifespan for the CHP unit and without a cooling unit and a 10 year lifespan for the CHP unit. Economic duration of the project: 10 years.

8.4.3 - Biodiesel_a business model

Table 8.2 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. An economic duration of 15 years is kept as in section 8.4.2.

The limit values are roughly the same as in the CHP business model. A market price of 133 Euros/tonne 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 wastes is set at 244 Euros/tonne, biodiesel must be sold at 1377 Euros/tonne to reach a zero NPV.

8.4.4 - Biodiesel_b business model

Again, in that case the prices of fish oil and biodiesel must reach values that are far from the market values in order to reach profitability.

8.5 - Preliminary conclusions

The preliminary computations carried out in sections 8.3 and 8.4 show that with the current investment costs and market prices, there is no profitability that can be found with the present process. The price of fish cleaning wastes is one of the main variables; profitability could be easily reached in plants where fish wastes are not sold to the market.

The preliminary findings show that as for biodiesel produced from vegetable oil, biodiesel produced from fish oil must be subsidised at the moment in order to reach profitability.

9 Recommended actions to encourage an early adoption of the technology

In order to encourage take up, the following options are advised:

- Obtain hard operating data from the pilot Enerfish plant, in order to be able to provide a credible marketing proposition.
- Target diesel demand in Europe other than for road fuels, especially in the fishing industry itself.
- Target outlying islands in Europe and Southeast Asia where there are no existing biodiesel production facilities, but where there is an existing source of fish waste, and where mineral based diesel is likely to be sold at a premium to the world price.
- Target areas with expanding or newly established aquaculture industries, especially of oily fish such as catfish or tuna, for which there may be no existing demand chains for by-products.
- Target ASEAN countries where there is no currently mandated level of biodiesel and insignificant areas planted to palm (including Vietnam, Cambodia and, potentially, Myanmar) so that fish-based biodiesel can be seen as a natural choice of fuel.

10 Conclusions

A study market study 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 wastes.

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 emissions generated by the transports. The main markets for aquaculture will be Asia, with China representing already today two third of the world’s aquaculture production; Europe is a rather small market, aquaculture is mainly focussed on cultured salmons.

There is no specific demand today for fish wastes or fish oil to produce biodiesel. The main uses of fish wastes are the production of fishmeal and fish oil (which is a by-product of fishmeal production) mainly 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 wastes.

The market prices of these two commodities (fish wastes and fish oil) exhibit large variations. Economic modelling shows that under current market conditions, there is no obvious profitability for Enerfish-like processes or any business model derived from it, i.e. production of fish oil from fish wastes, or production of biodiesel from fish oil or both. Enerfish-like processes are likely to remain technical solutions for niche markets where fish wastes are not valorised and/or where there is no organised supply of fuels. This might be the case of remote territories such as islands or regions in developing countries.

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