Integrated Renewable Energy Solutions for Seafood Processing Stations

By

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Abstract

The ENERFISH project aims to demonstrate a new poly-generation application with renewable energy sources for the fishery industry. The distributed energy system utilizes cleaning waste of a fish processing plant to produce biodiesel. The biodiesel is used to produce the locally needed cooling/freezing and heating energy. In addition, a power surplus is generated for the electricity network or local industrial use.
The research contribution focuses on optimisation, simulation, validation and planning of piloted concepts. A energy integration auditing and optimisation tools are being developed to carry out feasibility studies for the fishery industry. The advanced CO_2 based freezing/cooling system requires optimization and control system planning of special high-pressure equipments. The final biodiesel will be tested in appropriate engines. With a view to marketing possibilities the demonstration will take place in Vietnam. In the demonstration case, the main product of the fish processing plant is catfish filet (about 40 t/d). The fat content of 22 per cent in the fish cleaning waste results in a production of biodiesel of about 13 t/d. A part of the biodiesel is used to produce electricity for the locally needed cooling/freezing (0.3 MW) and heating (1,3 MW) energy. In addition, a power surplus (0,8 MW) is generated for the local industrial use. Fish farming and processing plants in Vietnam produce frozen fish fillet with capacity from some tonnes per day to dozens tonnes/day. One third of fresh fish is yielded as fillet and the rest of fish is treated as fish cleaning wastes. There are some alternatives for utilisation of fish cleaning wastes, one of them is biodiesel and energy production at the own factory. The energy demand at the fish processing factory is dominated by cooling and freezing facilities. 80 % of electricity consumed at the factory is supplied for cooling/freezing compressors, and the cold energy of low temperatures is needed in freezing and cold storage facilities of fillet. Cooling energy of about zero degrees is needed for space cooling of production halls. The specific electricity consumption is about 400 kWh per tonne fresh fish, or 1400 kWh per tonne fish fillet. The electricity load is typically very steady over a day and a year in the Vietnamese conditions. From the energy viewpoint the fish processing plant is energy self-sufficient, when the fish waste oil is processed in a biodiesel processor and further converted to electricity. In addition to this, a part of biodiesel can be sold to the fuel market. The fish processing factory producing fish fillet of 40 ton/day consumes electricity average at a power of 2 MW. 11 ton/day biodiesel is needed for that power production and a surplus biodiesel of 2 ton/day is available for fuel market. At the same time, diesel engine plant generates heat energy at a capacity of 2,6 MW, which is also available. The other end in possibilities of poly-generation is to generate all biodiesel, 13 ton/day, to the fuel market.In Vietnam, electricity and diesel fuel prices are very low being for electricity average 42,6 €/MWh for industry customers, and diesel fuel costs 400 €/ton. This results in shutdown of private electricity production (except during electricity blackout), even if cogeneration heat could be utilized. And the markets for biodiesel should be found outside Vietnam. According to the calculations and assumptions presented in this report, biodiesel production from fish cleaning wastes is profitable, and the payback period of the investment seems to be very short. However, more information on the technical and economical performances related to the operation and equipments are needed.

Introduction

This project aims to develop and demonstrate integrated renewable energy solutions for a fish-processing plant, based on high efficiency polygeneration using fishwaste derived fuel, and based on environmentally safe cascade cooling/freezing using CO_2.

This project proposes to develop and demonstrate polygeneration technologies in the fish processing sector using locally produced RES. It will be shown that in the fish-processing industry polygeneration can be used to produce the needed electricity, heat, steam, hot water and cooling/freezing energy. It is known that cogeneration on itself offers a substantial potential gain in efficiency. However, in addition, oil cooked out of waste (fish heads, entrails and skeletons) can be used to produce the biodiesel needed for polygeneration purposes. It is furthermore an objective to demonstrate that a substantial amount of surplus electricity can be produced.

This project furthermore proposes to develop and demonstrate a cooling/freezing cascade based on CO_2. There is an increasing pressure upon the refrigeration industry to look seriously into the use of natural (non-toxic) refrigerants, especially in the food sector. CO_2 is non-toxic, it does not harm the ozone layer and has a far less greenhouse warming potential (GWP) than currently used chemical refrigerants. However, because CO_2 is a high pressure refrigerant, the refrigeration system has to be designed and built in a way which differs from normal practice.
(Milestone 1: technical research/design completed)

It is furthermore an objective to erect the demonstration plant in Vietnam for the following reasons: Vietnam's output of tra and basa catfish has recorded high growth rates over the past ten years, increasing from 22,000 tonnes in 1997 to 800,000 tonnes in 2006. Vietnam has become a world player on this terrain. Catfish (pangasius) is especially suited for our project due to its high fat content. Furthermore choosing a demonstration site in Vietnam opens an enormous market for the demonstrated technology in SE Asia, where 9 out of 10 world’s top aquaculture producers are located.
Our project envisages that the demonstrated technology will be exploited and disseminated widely in Europe as well, by market potential surveys and training of staff. Furthermore a European feasibility/pilot study is envisaged. The fish processing sector in the European Union (EU) is an important economic activity that employs a significant number of people throughout the Union. The value of fishery products produced every year by the processing industry in the European Union amounts to about € 18 billion. The industry employs more than 135,000 people Union-wide, many of which work in firms with 20 employees or less. The most important types of products produced by the fish processing industry are preparations and canned fish (€ 6.7 billion) followed by fresh, chilled, frozen, smoked or dried fish (€ 5.2 billion). The EU is the world’s top pangasius importer.

The Industry

The scale of fish farming and fish processing varies very much in the target country of Enerfish project. According to the information of International Vietfish fair in 2009 (1) the largest fishery companies in Vietnam have a capacity of 200 ton fish fillet per day. In these cases the factories are located in different areas in Vietnam. Normally fishery companies have a factory area with necessary facilities and a capacity of 10 – 50 ton per day. The number of fish producer and exporter companies is about 150 in Vietnam (2).

The target fishery company presents a situation, where the whole chain from fish farming to fillet cold storing is integrated to a functional factory and the facilities are located at the same area. Fig. 1 shows the units including in the factory: Fish farming and fish food production facilities are located on a side of a river and fish processing on the opposite side of the river. The main part of fish food feedstock comes from the rice factory owned also the company. Fish processing, freezing and cold storing compose a functional and logistical entity. The main product, frozen pangasius, is exported to Asian and European countries. Fish cleaning wastes are sold to another company.

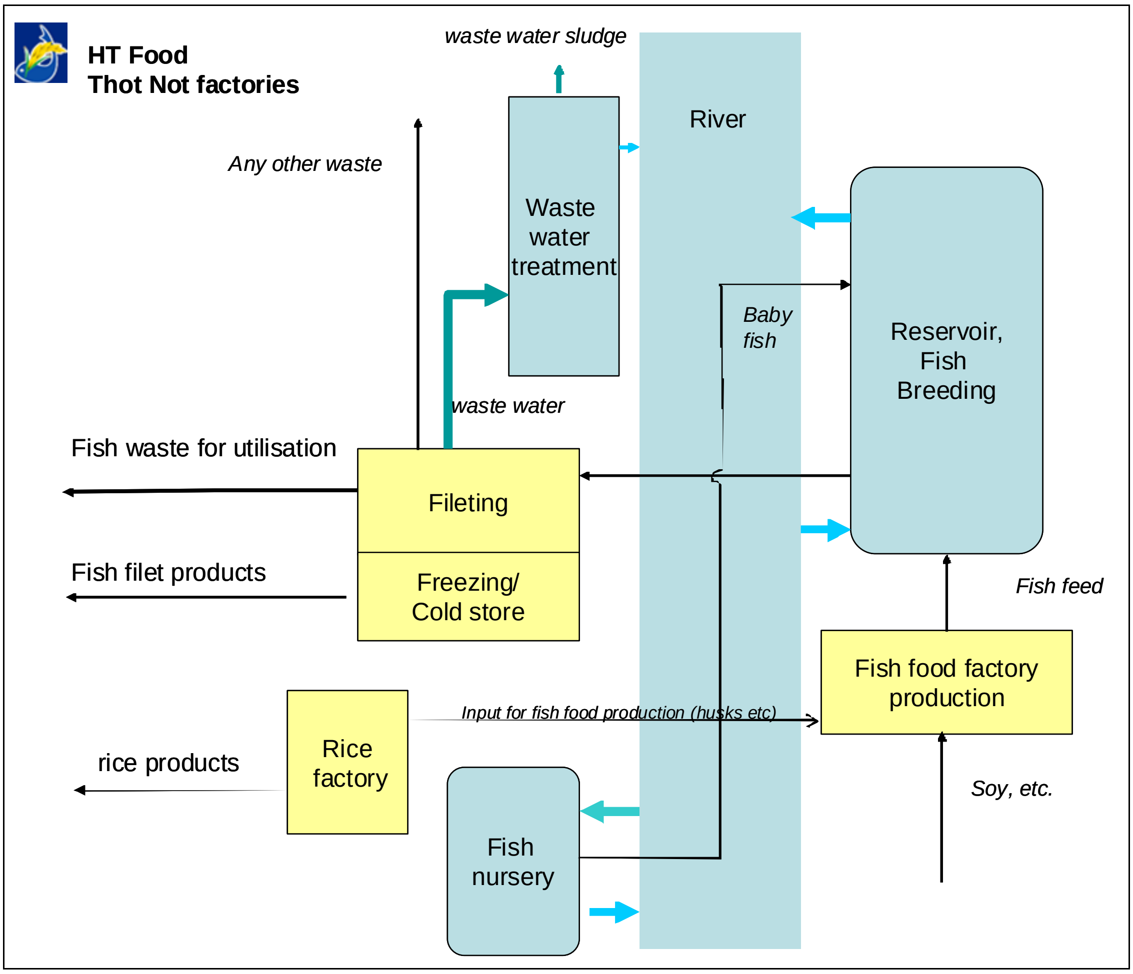

Figure1. Fish farming facilities.

Fish processing comprises various working phases. Most of the phases contain manual labour.

Figure 2. Manual labour in fish processing hall.

Receiving fish:The fish, each 0,9-1,2 kg, are transported by fish-containers to the processing factory and conveyed in bowls using conveyer chain for slaughtering. The fish is alive and fresh during the transportation process, and are slaughtered just before they are taken for processing. The fish receiving room is cooled with air cooler units.
Filleting and skinning:The fishes are then washed after slaughtering. The filleting process is done manually by knives. Next the fillets are washed and the skin is removed in the skin remover machine. Process room is cooled with air cooler fan units
Trimming and checking:The fillet and skinned fishes are trimmed. All the skins are removed and all the remaining fatty areas will be trimmed off. The trimming work is also done manually. Next the trimmed fishes pass through the quality check. After this process, the passed fillets are washed once again and wait for the next processing phase.
Sizing:Special parameters determine the size of the fillets and they are sorted into the corresponding boxes waiting for the next processing phase. The customers decide the size and condition of the fish they purchase.
Freezing:Before weighing and packing, the fillets have to pass through the block or IQF-freezer (Individual Quick Frozen). The fish are either frozen or frozen and glazed according to the demands of individual customers and products. Glazing is the name of the process where frozen fish is dipped into glazing water so that the ice solution builds up a good glaze.
Weighing and packaging: After freezing and glazing the fish products are transferred for weighing. The weighed fish are packed into plastic bags. The bags are vacuum sealed. Next the bags are packed into carton boxes, shifted through the metal detector to avoid possible foreign metal pieces. Finally the boxes are loaded onto the ballets.
Storing: The pallets are moved to the freezing store waiting for transportation. The end product is transported by insulated and cooled trucks to the customers.

Energy Systems

Based on the energy audit at the target fish processing factory of the project, the energy consumption calculated per live fish input is 414 kWh/ton, and the energy source is electricity. The amount of 3,6 litre oil per ton input has been used in diesel generators to produce electricity during the electricity supply shortages. If energy consumption is allocated to the fillet, the energy intensity is 1380 kWh per ton fillet. The demand of electricity is quit stabile over a day and over a year while due to the three-shift work and short annual breaks.

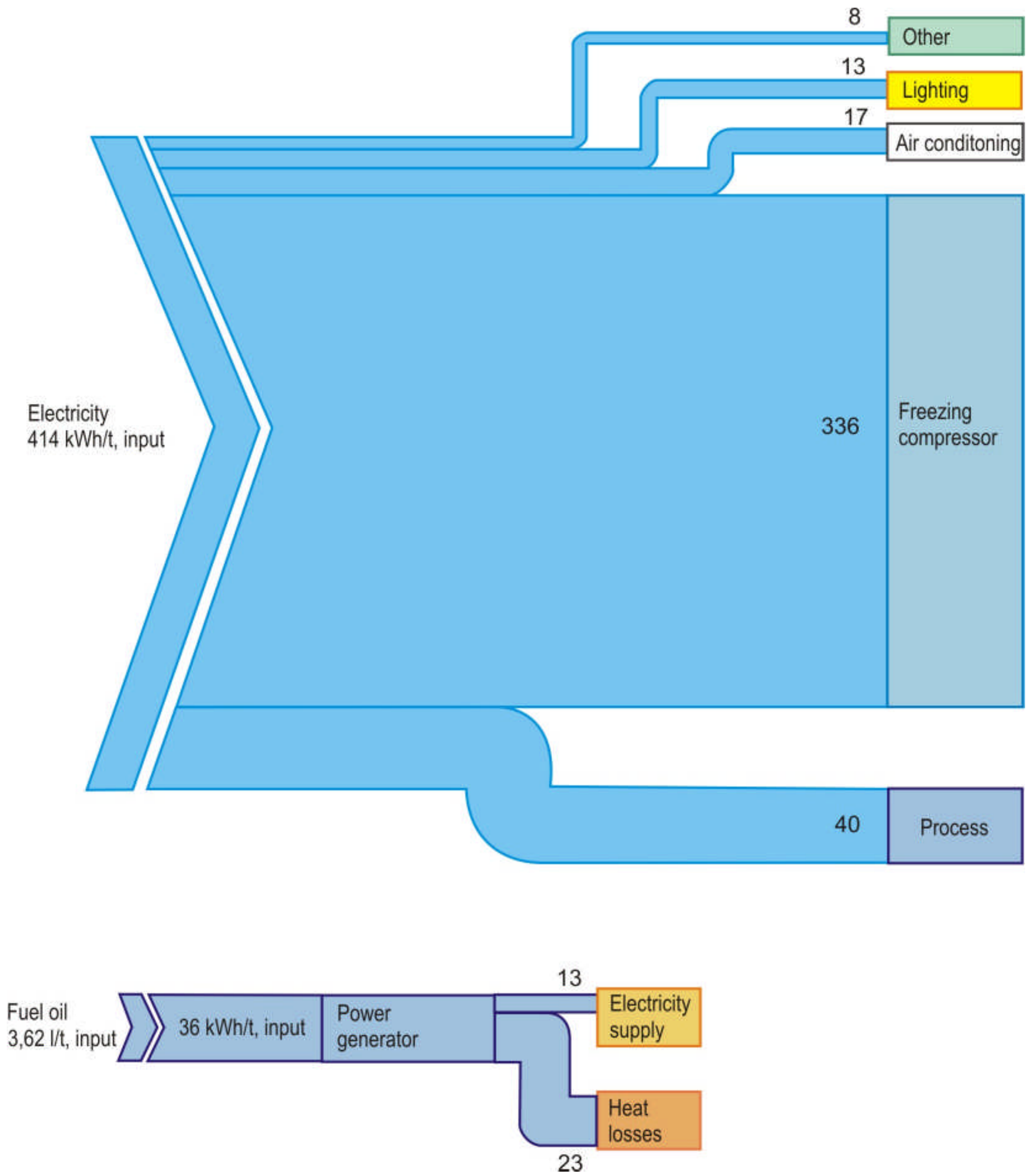

Figure 3. Energy characteristic use at fish processing factory allocated to the fish intake.

Fig. 3 shows the use of electricity in different sectors. The main consumption takes place in freezing systems, 336 kWh/ton input or 1120 kWh/ton fillet product. 80 % of electricity is needed for cooling/freezing compressors. Devices related to fish treatment take about 10 % of the electricity. The lighting system uses energy saving lamps and causes only 3 per cent share in electricity consumption. In air conditioning systems, fan units are located in suitable positions all over the fishery halls. Compressors use NH_3 as a coolant. Also in freezing system the coolant is NH_3. Heat relieving agent in cooling towers (evaporation condensers) is water. According to the energy audit energy saving possibilities can be found in storage systems, e.g.: Loading area should be closed and air conditioned all the time to minimize warm and humid air flow in to the store when opening the freezing store door. Freezing store loading door should be electrically operated and well sealed. In the freezing store, the air cooler units should be defrosted regularly.

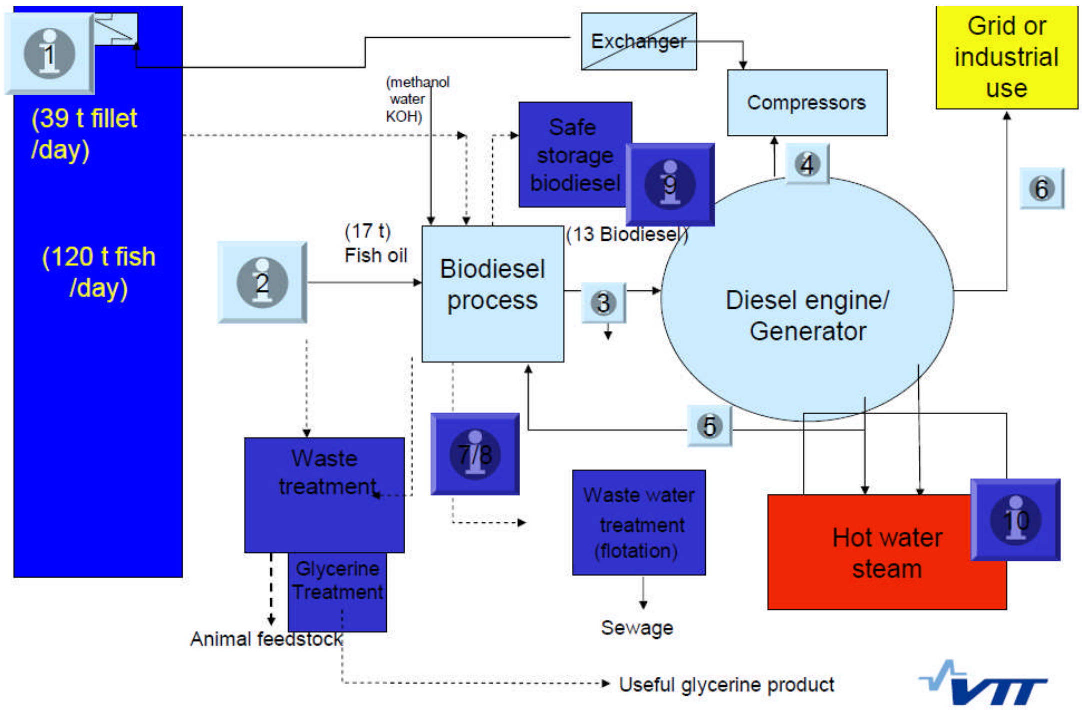

Figure 4. Integration of energy and mass flows at a fish processing factory.

There are some basic alternatives to utilise biodiesel locally in energy production or at the fuel market. These are given schematically above in Fig 4. An assumption is made that the amount of fish cleaning wastes available for biodiesel production is 80 ton/day and the biodiesel production is 13 ton/day, equivalent to about 150 MWh/day total energy content. It is noted (cf figures 3 and 4) that in the extreme the plant could be totally selfsufficient in electricity use since per day (414 x 120)= 50 MWh(e) is needed, whereas the biodiesel could exactly produce this amount (150 x 33%)= 50MWh(e).

However, since the project is a demonstration project we decided to initially dimension the CO2 cooling/freezing on the daily filet production, requiring about 6.3 MWh/day. We therefore will replace an ageing compressor combination unit

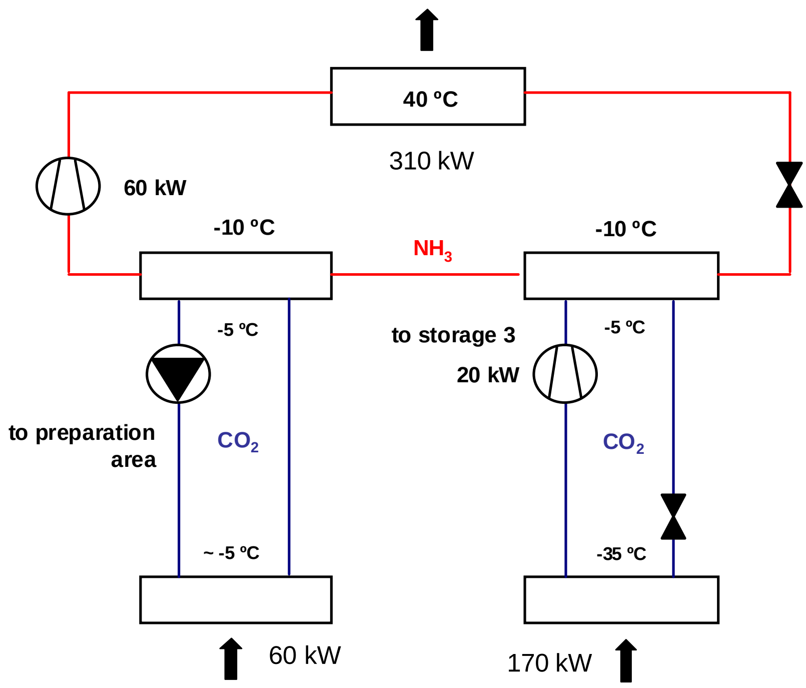

Fig 5 High Efficiency NH3/CO2 Cascade (see Lee et al.,Int.J.Refrigeration 29 (2006),1100

based on a Vahterus NH3/R404A reference system by a High Efficiency NH3/CO2 Cascade (13-18% more efficient than the reference) as given in Figure 5. Note furthermore that the GWP(R404A)=3800, whereas GWP(CO2)=1 and GWP(NH3)=0 (GWP:Greenhouse Warming Potential)

Moreover the Preseco biodiesel process (given schematically in Figure 6)

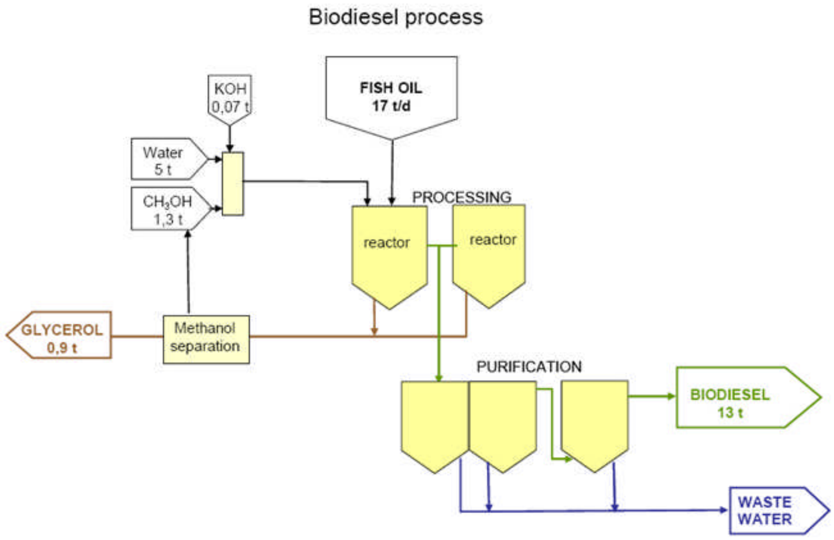

Fig.6 The Preseco Biodiesel PROCESS

will lead to the avoidance of about 14000t CO2e/year (13 tons biodiesel /d makes 4745 tons/year 1 ton diesel produces 2.92 t CO2e)

Operational Optimization of poly-generation

The purpose of creating an optimization model for fish oil based bio diesel process is to describe in a simple way cost-minimized operation of the production chain in order to e.g. perform sensitivity analysis of technical and economical parameters. Material flow chart of the optimization model is illustrated in Figure 7. The three separate process phases are fish oil extraction, bio diesel production and production of electricity and heat by diesel engines. In order to model the entire process properly but in a simplified manner, a linear optimization model is used with some integer variables. Time frame of the model is hourly operation of one day (t = 1,…,24), and these operational days are multiplied in order to obtain annual costs and revenues. Furthermore, these annual values are used in discounted cost analysis of infrastructure investments.

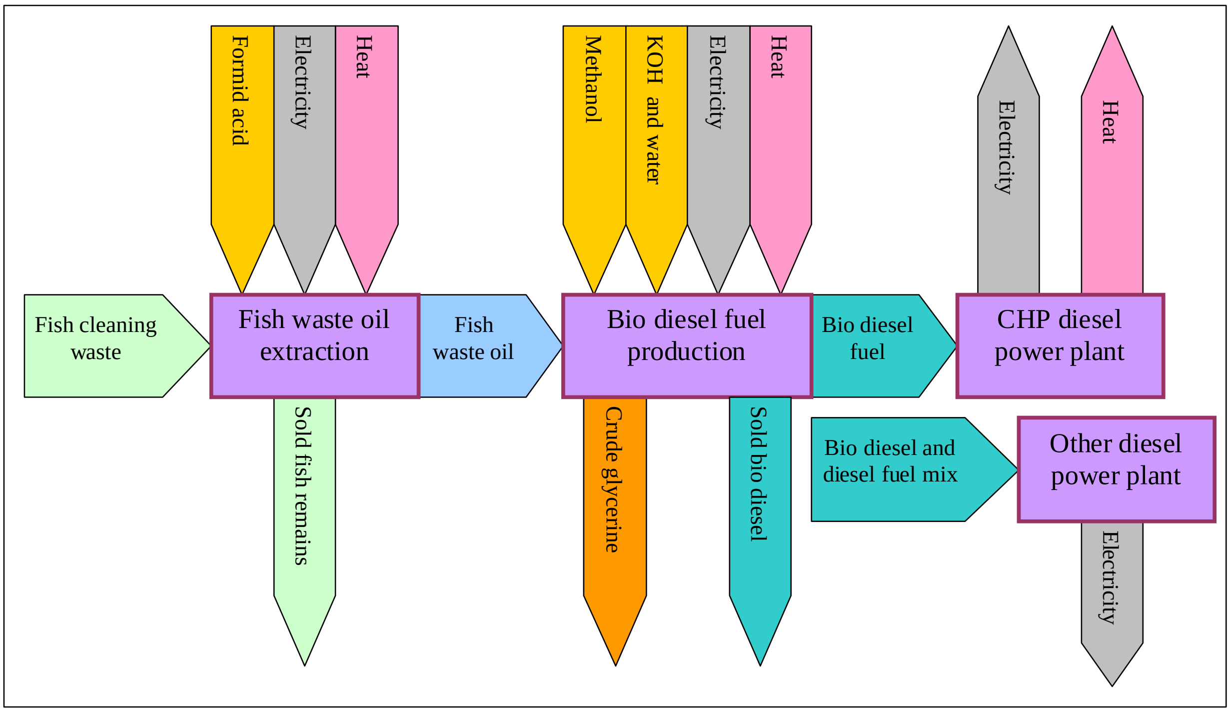

Figure 7. Process flow chart of the fish oil based bio diesel production used in optimization model.

Rates of consumption and production of materials per produced ton of fish waste oil are based on the daily parameters of the fish waste oil extraction plant.. Also, costs of materials, sold or purchased, are presented in Table 1.

Table 1. Consumption rates and costs of raw materials in fish waste oil extraction process.

Material	Daily rate	per ton of fish oil	Parameter	Cost/Profit	Parameter
Fish waste oil	17 ton	1.000 ton			
Fish cleaning waste	81 ton	4.765 ton	β_{fish}	100 €/ton	p_{fish}
Sold fish remains	18 ton	1.058 ton	λ_{remain}	280 €/ton	s_{remain}
Formid acid	2 ton	0.118 ton	β_{acid}	550 €/ton	p_{acid}
Heat	4000 kWh	235 kWh	θ_{fish}		
Electricity	700 kWh	41 kWh	ε_{fish}		

Rates of consumption and production are based on the daily rate values as in the case of fish waste oil extraction. These parameters as well as cost parameters of raw materials are presented in Table 2, whereas Table 3 gives the electricity tariff prices.

Table 2. Consumption rates and costs of raw materials in bio diesel production process.

Material	Daily rate	per ton of bio diesel	Parameter	Cost/revenue	Parameter
Bio diesel	13 ton	1.000 ton		650 €/ton	$s_{biodiesel}$
Fish waste oil	17 ton	1.308 ton	$\beta_{fishoil}$		
Methanol	3 ton	0.231 ton	$\beta_{methanol}$	250 €/ton	$p_{methanol}$
Glycerin	2 ton	0.231 ton	$\lambda_{glycerin}$	200 €/ton	$s_{glycerin}$
Heat	600 kWh	46 kWh	θ_{bio}		
Electricity	72 kWh	6 kWh	ε_{bio}		

Table3 . Electricity tariff prices.

Electricity tariff	Hours	Price
Normal	04-18	40 €/MWh
High-load hour	18-22	81 €/MWh
Low-load hour	22-04	23 €/MWh

Figure 8 and 9 show two main results: The electricity purchase from the national distribution grid at the average price of 42,6 €/MWh is so low-priced, that the CHP (diesel engine plant) is not economical to be in running, and, considering only operational incomes and costs, biodiesel production (category B configuration) becomes beneficial compared to the category A at the price of about 400 €/ton. In these calculations the price of heat energy is assumed to be quit low, 20 €/MWh. In these conditions, the cogeneration is beneficial, if the biodiesel price level is below 220 €/ton. However, at this price the biodiesel-alternative is not reasonable at all.

Because of low price of electricity, heat energy is often produced by electricity in Vietnam. Using this assumption, i.e. price of heating energy is 42,6 €/MWh instead of 20 €/MWh, the results presented in Fig. 18 are achieved. (will be inserted later.)

Nor the increase of electricity price by 50 % does any decisive improvements to the economy of the cogeneration, as shown in Fig. 19. The price of heat energy is 20

€/MWh in this case. The price of biodiesel should be around 325 €/ton to achieve economical use for co-generation plant.

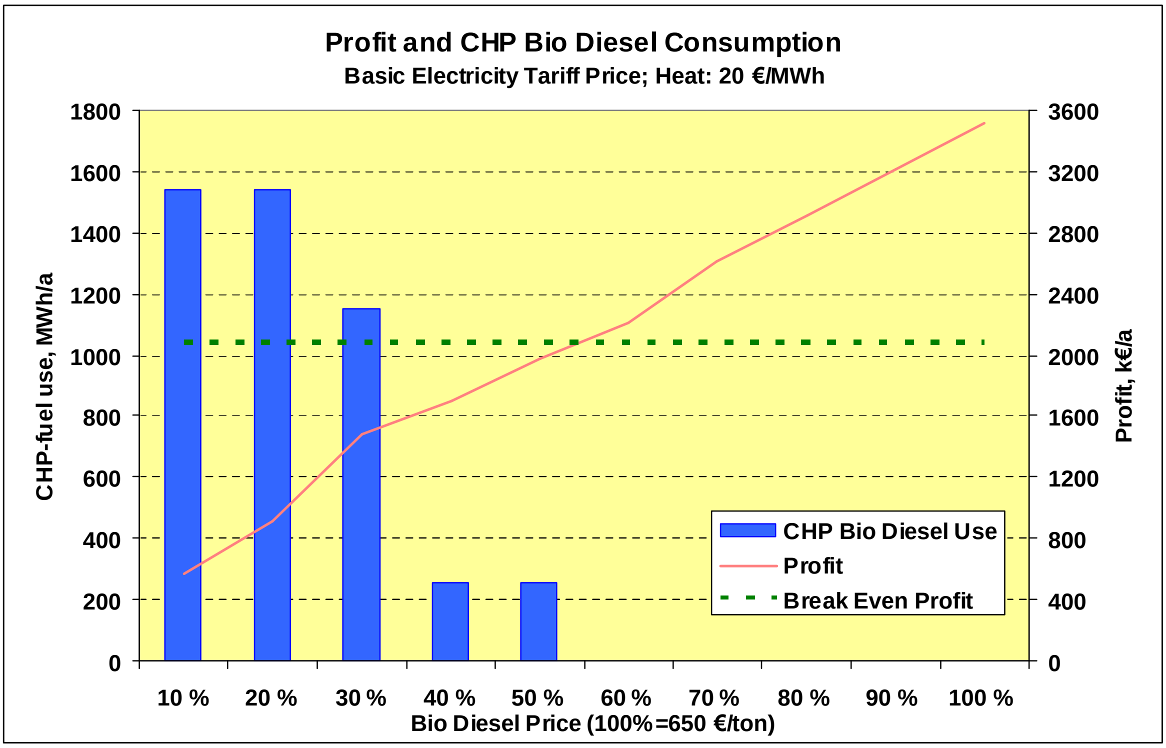

Figure 8. Economical use of cogeneration, and profit of biodiesel fuel alternative as a function of biodiesel market price. Price of heat energy is 20 €/MWh.

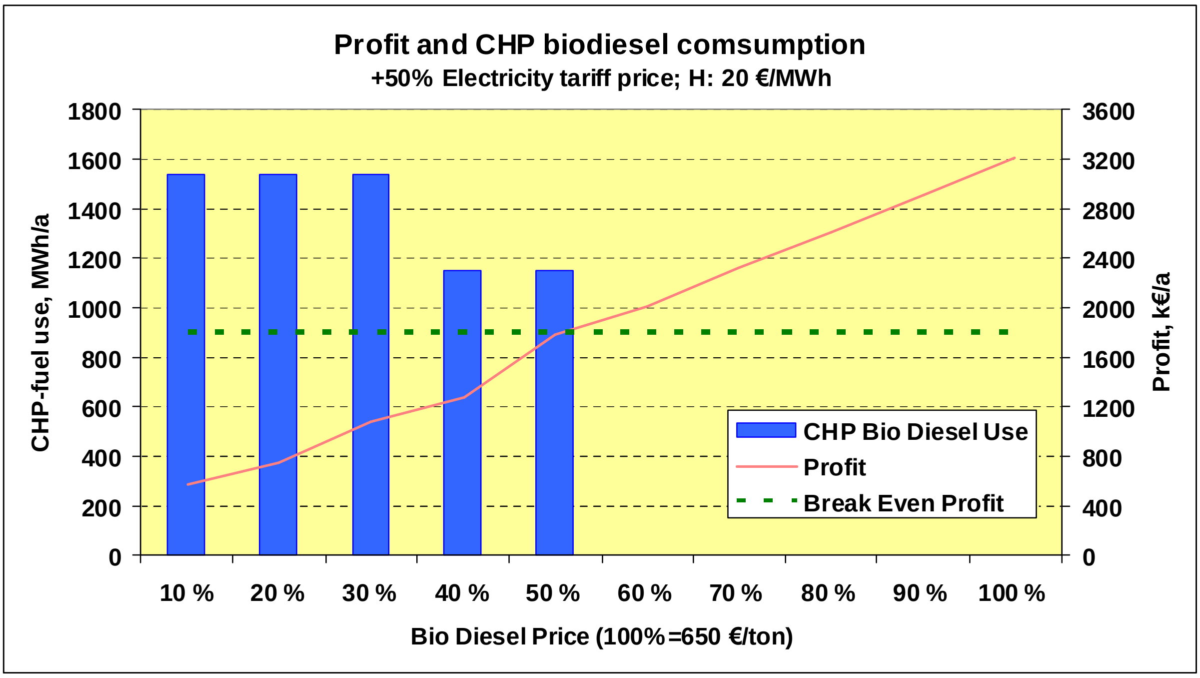

Figure 9. Economical use of cogeneration, and profit of biodiesel fuel alternative as a function of biodiesel market price. Electricity tariff +50 %, price of heat energy is 20 €/MWh.