# PURE VEGETABLE OIL FUELS FOR CHP – TECHNICAL, ECONOMICAL AND SUSTAINABILITY ASPECTS UNDER GERMAN CONDITIONS

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ABSTRACT: Vegetable oil fuelled CHP units save fossil energy sources and greenhouse gas emissions effectively. Today more than 30 enterprises provide vegetable oil compatible CHP units in Germany. The number of plants and the installed electrical power decreased dramatically within the last two years. Reasons therefore are high prices for vegetable oil fuels in the year 2008, accompanied with inadequately performed heat use concepts. Besides that, the amendment of the Renewable Energy Sources Act led to a lack of planning reliability, regarding power feed-in compensation as well as certification issues of sustainable vegetable oil fuels. Small-scale vegetable oil compatible CHP units are predominantly fuelled with rapeseed oil, in plants of higher power ranges palm oil is mainly used. Quality demands for rapeseed oil fuel are defined in the standard DIN V 51605, simultaneously the standardisation of other vegetable oil fuels is in progress. Under German conditions with power feed-in compensation, heat generation costs vary between 0,09 and 0,14 Cent/kWh, depending on the plant size. However a sophisticated heat concept is essential. For higher market relevance of small-scale vegetable oil compatible CHP plants, the administrative expense has to be reduced and reliable framework conditions have to be secured.
Keywords: vegetable oil, combined heat and power generation (CHP), technology, economics.

## 1 INTRODUCTION

Vegetable oil fuels for combined heat and power (CHP) supply have become more and more important during the last decade in Germany. Due to the German Renewable Energy Sources Act, which ensures feed-in tariffs for electricity from renewable resources, economic efficiency is often given, provided that an appropriate heat use concept is incorporated. For a reliable and low emission operation, various aspects regarding fuel quality and technical equipment (e.g. exhaust gas aftertreatment) are to be considered. Additionally, with new demands on sustainability criteria for pure vegetable oil fuels, questions about verification management arise for operators. It is the purpose of this work, to show the state of the art of pure vegetable oil use in small-scale CHP units (Fig. 1) under German conditions. Based upon these facts, barriers and chances will be deduced.

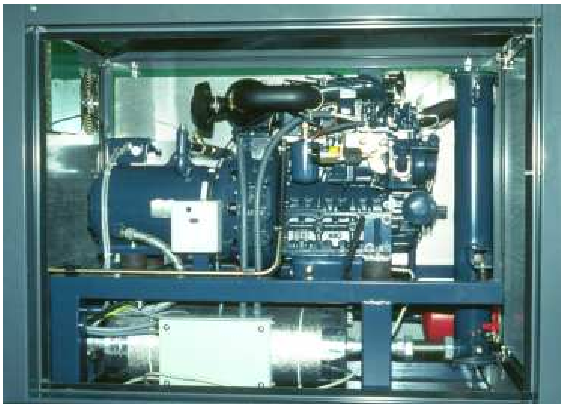


**Figure 1:** Vegetable oil compatible Mini-CHP plant with combustion engine (8 $kW_{el}$, 16 $kW_{th}$), manufacturer: KW-Energietechnik

## 2 APPROACH

Literature data, operators' experiences and results of various research works are combined to identify the technical state of art and the need for action of vegetable oil compatible CHP plants. Furthermore economic efficiency is calculated for different scenarios and consequences of new sustainability legislation for CHP operators are worked out.

## 3 RESULTS

### 3.1 Combined heat and power (CHP)

Combined heat and power (CHP) or cogeneration is the simultaneous generation of both, power (mainly for electricity) and useable heat in a single process by a power and heat supply station or engine.

CHP is a highly efficient way to use either fossil or renewable fuels and can therefore make a significant contribution to reach European and national sustainable energy goals. The benefits of CHP can be of a social, economic and environmental nature:

- Support of local economy,
- Contribution to energy security,
- Saving of fossil resources,
- Protection of environment and climate.

As it is shown in Fig. 2, with a fuel energy input of 100 kWh an internal combustion engine based CHP plant provides about 27 kWh electrical power and 61 kWh heat. This regards to an electrical efficiency of 27 %, a thermal efficiency of 61 % and an overall efficiency of 88 %. However, efficiency rates vary between different plant designs. For example the electrical power output can reach 40 % and more, if large-scale diesel engines are used. With increasing electrical efficiency, the thermal energy output is decreasing. The losses by heat emissions, mainly through the engine system and exhaust gas can add up to some 12 kWh.

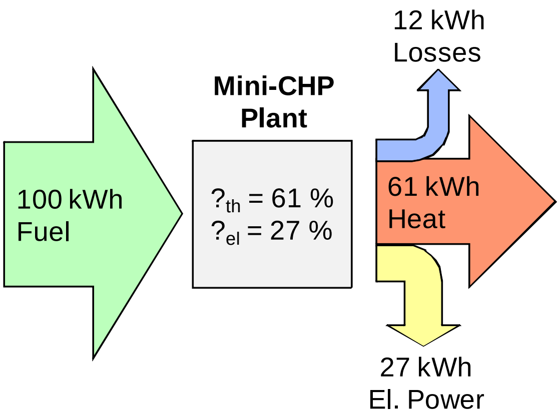



**Figure 2:** Energy flow of combined heat and power (CHP) supply with small-scale CHP plants, using internal combustion engines

In conventional power stations the heat is mostly wasted. This is due to a remote central production, which does normally not justify the costs of a pipe network for heat transportation and distribution to the users. To gain the same electrical and usable thermal energy output as in the example of a CHP plant in Fig. 2, by separate heat and power generation a fuel input of 67 kWh for the heating with burner plus 71 kWh for the power station (altogether 138 kWh) is necessary (Fig. 3). This results in primary energy savings of up to 28 % by cogeneration.

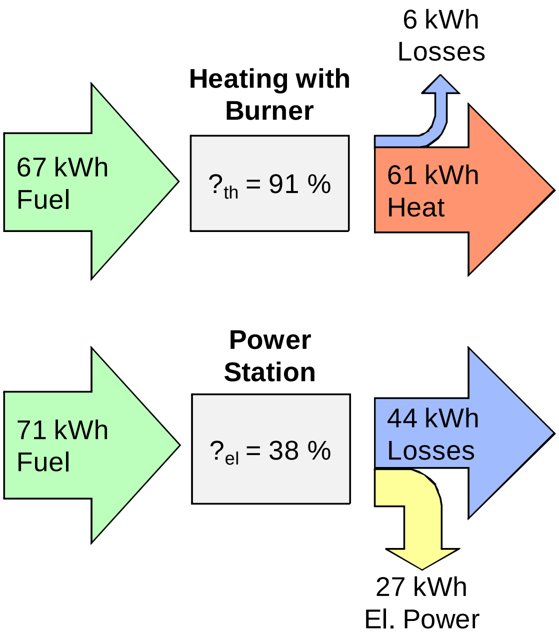



**Figure 3:** Energy flow of separate heat and power generation with burner heating and power station

For promotion of CHP the European legal framework is given in the Directive 2004/8/EU. Based on this directive, EU Member States need to introduce measures for fulfillment of their national sustainable energy goals.

It is estimated that more than 50 % of Germany's total electricity demand could be provided through cogeneration. As goal for 2020, 25 % of Germany's electricity demand should be produced by CHP. By the year 2007 with 12,5 % about half of the projected quota was reached.

Fig. 4 shows the development of the share of combined heat and power generation for selected countries in the EU. As a whole, the European Union currently generates about 11 % of its electricity by using cogeneration [1] [2]. There are big differences between the EU Member States. Among the Member States with the highest share of gross electricity generation by CHP are Denmark and Latvia with more than 40 %, followed by Finland (34 %) and the Netherlands (30 %) [2]. In France, United Kingdom, Spain and Sweden on the other hand, less than 10 % of gross electricity is generated by CHP (Fig. 4).

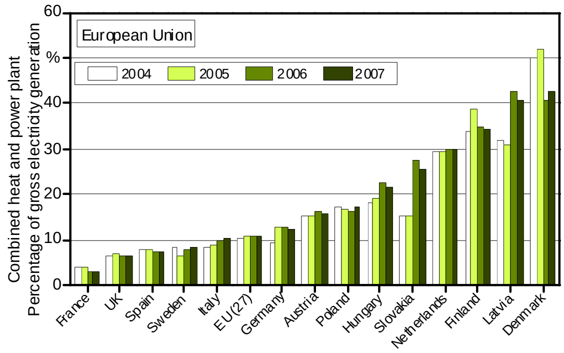



**Figure 4:** Share of combined heat and power on electricity generation - selected countries in the EU (EUROSTAT [2])

3.2 Vegetable oil fuels for CHP

CHP plants can have different sizes, ranging from few kilowatts to many megawatts. The power range of less than 1 $MW_{el}$ is dominated by engine driven CHP units. Vegetable oils are well suited to be used as fuels for CHP with self-ignition engines using the diesel principle. By using vegetable oil fuels additional benefits can be utilised in comparison to fossil diesel fuel or heating oil, respectively. Besides saving of fossil resources and the reduction of greenhouse gas emissions, vegetable oils contribute to soil and water protection. Because of their high biodegradability and low ecotoxicity, vegetable oil fuels are predestinated to be used in environmental sensitive areas such as alpine regions (Fig. 5) or water protection areas.

**Figure 5:** Housing of CHP with vegetable oil compatible combustion engine at "Coburger Hütte" in the Alps at 1920 m above sea level (picture: TFZ)

In rural areas with decentral production and use of the vegetable oil fuel and the co-product press cake a high level of closed mass flow circles can be obtained. In Germany rapeseed oil is the most important local vegetable oil fuel.

Although rapeseed oil can be used as a fuel in self-ignition engines, properties vary significantly from diesel fuel. This applies particularly for the ignition behaviour and the viscosity. The factor 10 higher viscosity of rapeseed oil fuel at ambient temperature is one main reason that the long term use in conventional, not adapted diesel engines is not possible.

Fig. 6 shows the viscosity curves for rapeseed oil and diesel fuel over the temperature. To guarantee a fine dispersion of the injection spray, a high combustion quality and to minimise deposit formation on injectors and pistons a technical adaptation of CHP engines and the periphery under consideration of the requirements of the vegetable oil fuel is essential. Measures of adaptation can include:

- Exchange of incompatible materials, fuel pipes, pumps, filter, injectors,
- Pre-heating of fuel, injectors or cooling water,
- Adjustment of injection parameters.

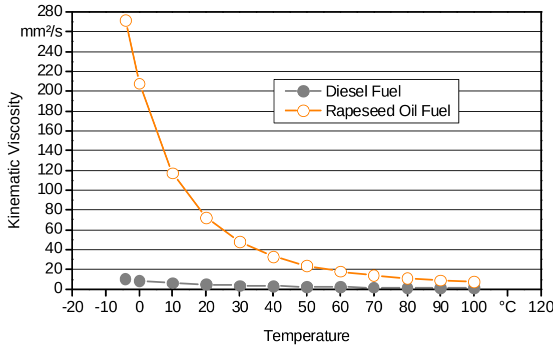



**Figure 6:** Viscosity of rapeseed oil and diesel fuel over the temperature

Today more than 30, mainly medium-sized enterprises provide vegetable oil compatible CHP units in Germany. After years of increasing numbers with the highest growth rates between 2006 and 2007, recently the demand on vegetable oil compatible CHP plants is strongly decreasing. As it can be seen in Fig. 7 the number of plants dropped from about 2700 in the year 2007 to 1400 in the year 2008, resulting in a reduction of installed electrical power from some 400 $MW_{el}$ to 310 $MW_{el}$ [3]. Presently this development is continuing: Suppliers of vegetable oil compatible CHP plants state an almost total absence of orders.

Reasons for this obvious downturn, which is recorded for all plant sizes up to 1 $MW_{el}$ were high prices for vegetable oil fuels in the year 2008, accompanied with inadequately performed heat use concepts of CHP units. Thus, many plants had to be shut down for economic reasons. Additionally, the amendment of the Renewable Energy Sources Act led to a lack of planning reliability, regarding power feed-in tariffs as well as certification issues of sustainable vegetable oil fuels.

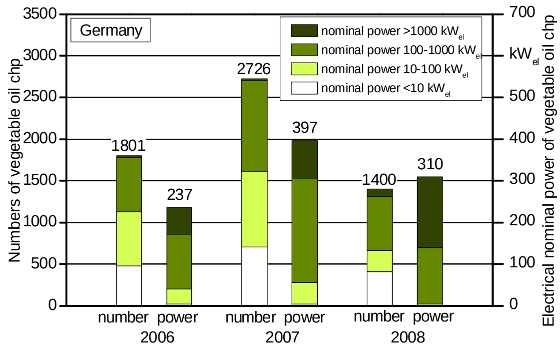



**Figure 7:** Development of number and installed electrical power of vegetable oil fueled CHP plants in Germany (TFZ according to DBFZ [3])

However, operators with favourable long-term contracts for vegetable oil fuels or CHP plants with a high degree of heat utilisation, could held up the operation. In general a tendency from small to large scale CHP plants could be noted (Fig. 7).

Fig. 8 shows that with 88 % the highest share of the total amount of vegetable oil that was used in CHP plants in Germany in the year 2007 (approx. 700 Mio. l) was palm oil. Small-scale vegetable oil compatible CHP plants however are predominantly fuelled with rapeseed oil, whereas with increasing electrical nominal power, less rapeseed oil and more palm oil as well as some soybean oil is used.

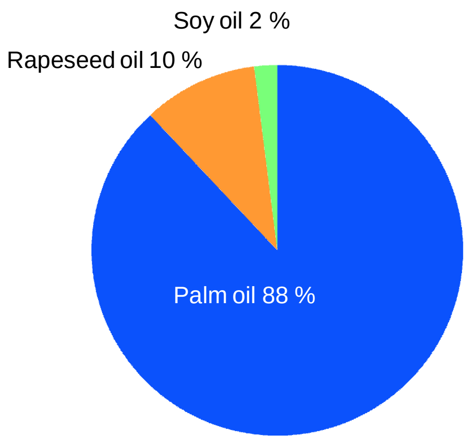



**Figure 8:** Share of vegetable oils, used as fuel for vegetable oil compatible CHP plants (TFZ according to DBFZ [3])

The main reason for the leading role of palm oil in large CHP plants is the lower market price of palm oil in comparison to rapeseed or soybean oil (Fig. 9). To ensure flowability of palm oil, extensive technical measures are necessary for heating up the entire fuel system. For small-scale CHP plants these measures are usually too expensive in terms of installation and operation. Hence, rapeseed oil is the preferred option within the lower power range.

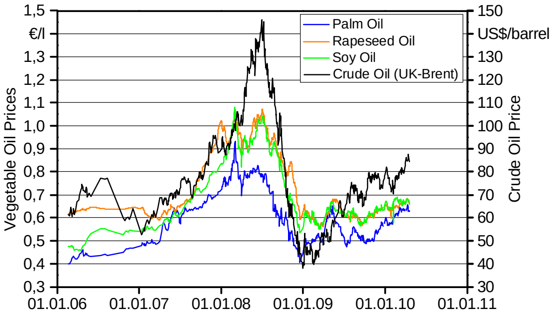
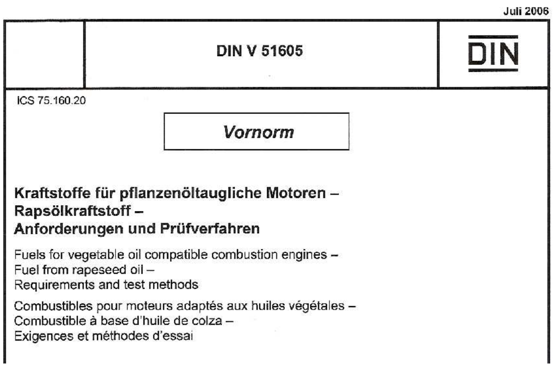



**Figure 9:** Development of prices for vegetable oils (TFZ according to SYMBOIL [4])

For sophisticated system adaptation and for a reliable and low emission long-term operation of vegetable oil fuelled CHP plants, relevant fuel properties have to be identified and range within defined limiting values.

So far, the demands on vegetable oil fuel quality were worked out solely for rapeseed oil. This was conducted by a standardisation committee of the German Institute for Standardisation (DIN). The widely accepted pre-standard DIN V 51605 was published in July 2006 (Fig. 10). In April 2010 the draft of the completed standard DIN 51605 was published. Besides that, an additional working group at DIN is going to work out a fuel standard for other vegetable oils than rapeseed oil.



Juli 2006

DIN V 51605

DIN

ICS 75.160.20

Vornorm

**Kraftstoffe für pflanzenöltaugliche Motoren – Rapsölkraftstoff – Anforderungen und Prüfverfahren**

Fuels for vegetable oil compatible combustion engines – Fuel from rapeseed oil – Requirements and test methods

Combustibles pour moteurs adaptés aux huiles végétales – Combustible à base d'huile de colza – Exigences et méthodes d'essai

**Figure 10:** Standard DIN V 51605 for rapeseed oil fuel

3.3 Framework conditions

The **Directive 2009/28/EC** of the European Parliament and the Council on the promotion of the use of energy and renewable sources (23rd April 2009) sets the goal of a 20 % share of energy from renewable sources in the Community's gross final consumption of energy in 2020 (Article 3).

To reach the target and to promote energy efficiency measures EU Member States have to adopt a national renewable energy action plan until 30th June 2010.

Biofuels such as bioethanol, biodiesel and vegetable oils are highlighted as an important option to meet the target. Though a sustainable production of biofuels is an unquestioned precondition. The sustainability criteria for biofuels are laid down in Article 17.

Sustainability criteria comprise a minimum share of greenhouse gas (GHG) emission savings, which are

- at least 35 % by 2010 for biofuels of facilities, in which operation started after 23rd Jan. 2008,
- at least 35 % by 2013 for biofuels produced in facilities, which were already in operation on 23rd Jan. 2010,
- at least 50 % by 2017 and
- at least 60 % by 2018, applying to facilities, in which production started in 2017 or later.

To determinate the greenhouse gas emission savings, reference values for different biofuel types are quoted in the directive. These default values are worst case scenarios which can be referred to without any further calculation. However, individual calculation is also possible. In Fig. 11 the default greenhouse gas emissions are illustrated for vegetable oil based fuels. Additionally the value of greenhouse gas emissions of fossil fuels for CHP application serves as a comparator. According to Directive 2009/28/EC pure rapeseed oil is rated to have the second largest GHG emission reduction (58 %) among different biodiesel and hydrotreated vegetable oil fuel options (Fig. 11). Only hydrotreated sunflower oil performs somewhat better (62 %).

For rapeseed oil the fertilizer input during cultivation is the main GHG factor (based on 137 kg N fertilizer per ha). However there is a huge optimisation potential of at least 20 to 30 % points higher GHG savings (source: DBFZ).

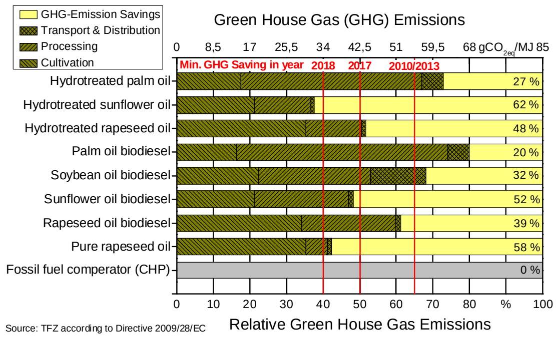



**Figure 11:** GHG default values (TFZ according to Directive 2009/28/EC)

Apart from a minimum contribution to greenhouse gas emission savings, biofuels, which claim excise tax reduction or power feed-in tariffs are not to be obtained from:

- land with high biodiversity value (e.g. primary forest) or nature protection purposes (endangered ecosystems or species)
- land with high carbon stock (wetlands, continuously forested areas)
- peatland

Besides that biofuels from agricultural raw materials, cultivated in the EU have to be produced according to "Cross Compliance" standards.

The German regulation for implementation of the Directive 2009/28/EC, which includes biofuels for electricity generation is the so-called **Biomassestrom-Nachhaltigkeitsverordnung** from 23rd July 2009. Starting from July 2010, verification certificates for the sustainable production of biofuels, used for electricity generation are necessary, to get payment of the feed-in tariffs. Biofuels from biomass, that was harvested before 2010 is excluded. However, certification systems are only available now for a very short time and are still not widely introduced in practice. This means, that long-term fuel contracts are still bearing big uncertainties. Operators of vegetable oil fuelled CHP plants need to register the plants in a list and are responsible for the validity of the sustainability certificates.

According to the **Energy Tax Act** (Energiesteuergesetz, EnergieStG, 1st August 2006) for vegetable oil fuels, used in CHP, basically a reduced tax rate of 6,13 Cent/l applies (like for heating oil). For CHP with a yearly utilisation ratio of at least 70 % an entire energy tax refund is granted.

The **Act on Granting Priority to Renewable Energies in the Heat Sector** (EEWärmeG, 1st January 2009) promotes renewable energies in the heat sector. The goal is to increase the share of renewable energies in the final energy consumption for heat from 7,7 % in the year 2008 to 14 % in the year 2020. This is intended to be realised by the introduction of a use obligation for renewable energies, which applies to all new buildings with a floor space exceeding 50 m². Apart from using renewable energies it is also possible for building owners to take alternative measures. Accordingly 50 % of the heating energy demand can be covered from highly efficient cogeneration plants.

The **Act on Reforming the Renewable Energies Law on Power Generation and Related Regulations** or **Renewable Energy Sources Act** (Erneuerbare-Energien-Gesetz, EEG) promotes power generation from renewable resources. The share of renewable energies in the gross power consumption amounts some 14,8 % and should be doubled to at least 30 % in the year 2020. The Renewable Energy Sources Act guarantees power feed-in tariffs for electricity, derived from renewable energy sources for 20 years. The tariff is decreasing with increasing power of the plant. Additional to a basic compensation a bonus for the use of purpose cultivated raw materials (NawaRo bonus) and a bonus for power production in cogeneration (KWK bonus) is granted. For latter the heat concept for CHP has to be proved by an authorised environmental auditor, which can cause high expenses for the operator. The compensation for power generated from newly commissioned biomass plants are reduced annually by 1 percent.

In Germany a **permission** of CHP plants under the immission control law is only necessary for CHP plants with a fuel thermal capacity of 1 MW and more (related to approx. 100 l/h fuel consumption).

But in general, also for small-scale plants a minimisation policy for harmful environmental impacts applies. According to that, oxidation catalysts are postulated for all vegetable oil compatible CHP units [5]. Besides carbon monoxide and hydrocarbon emissions, also odeur emissions are reduced efficiently by oxidation catalysts. A permission procedure under building law according to the German Statutory Code on Construction and Building (Baugesetzbuch) and the regional state building laws is carried out for plants with a nominal thermal power of at least 50 kW.

## 3.4 Economic Efficiency

The economic efficiency of CHP plants is mainly depending on the achievable prices or credits for generated electricity and heat. The payment for electricity from vegetable oil fuelled CHP plants is regulated in the Renewable Energy Sources Act (EEG, see chapter 3.3). The remuneration conforms mainly to the installed electrical nominal power of the plant, the year of commissioning, the fuel and the heat use. All expenses of the CHP plant are usually referred to the heat. The specific heat generation costs result from the total costs per year, less the compensation for the generated energy divided by the produced usable heat quantity per year.

In Tab. I the heat generation costs are calculated for three scenarios: "CHP 1", "CHP 2" and "CHP 3" (without peak load boiler, buffer vessel and planning). The three scenarios are characterised by three different plant sizes (8, 20 and 50 $kW_{el}$). According to Tab. I the heat production costs range from 8,5 Cent/kWh (CHP 3) to 14,5 Cent/kWh (CHP 1).

**Table I:** Economic efficiency of vegetable oil fuelled CHP plants – model calculation

| Assumption / Cost type | | CHP 1 | CHP 2 | CHP 3 |
|---|---|---|---|---|
| *Assumptions:* | | | | |
| CHP nominal electrical power | $kW_{el}$ | 8 | 20 | 50 |
| CHP nominal thermal power | $kW_{th}$ | 16 | 35 | 67 |
| Investment for CHP module | € | 20 000 | 32 000 | 55 000 |
| Investment for structure (tank, exhaust pipe) | € | 10 400 | 26 000 | 65 000 |
| Costs of maintenance per year CHP module | % of Invest. | 9,0 | 9,0 | 9,0 |
| Costs of maintenance per year for structure | % of Invest. | 1,5 | 1,5 | 1,5 |
| Labour/administrative costs per year (without structure) | % d. Invest. | 2,5 | 2,5 | 2,5 |
| Insurance costs per year (without structure) | % d. Invest. | 1,5 | 1,5 | 1,5 |
| Fuel consumption at nominal power | l/h | 3,1 | 6,7 | 14,0 |
| Fuel costs | €/l | 0,80 | 0,80 | 0,80 |
| Operating hours at nominal power per year | h | 4 000 | 4 000 | 4 000 |
| *Revenues (power feed-in credit: 0,2046 €/kWh$_{el}$ EEG)* | €/a | 6 547 | 16 368 | 40 920 |
| *Heat generation costs (incl. revenues):* | €/kWh | **0,141** | **0,107** | **0,085** |

In Fig. 12 heat generation costs are displayed for the three scenarios in dependence of the fuel costs. Under the assumptions of the calculation model (Tab. I), an increase of rapeseed oil fuel costs of 10 Cent/l is resulting in an increase of the heat generation costs of around 2 Cent/l. The break-even point, where economic efficiency is solely reached by power feed-in payment and heat is virtually available for "free" lies for CHP 3 with 50 $kW_{el}$ as the best option at a fuel price of 40 Cent/kWh. This shows as expected that for an economic efficient operation of vegetable oil compatible CHP plants, heat needs to be of monetary value.

A comparison of the heat generation costs of rapeseed oil fuelled CHP plants with a reference heating system of the same power range (heating oil price of 65 Cent/l) shows some advantages for CHP plants of a minimum power of 20 $kW_{el}$. However CHP usually require peak load boilers or buffer vessels for short-time heat storage, which are not included in the calculation. Furthermore these advantages only apply, when a high number of operating hours per year can be achieved.

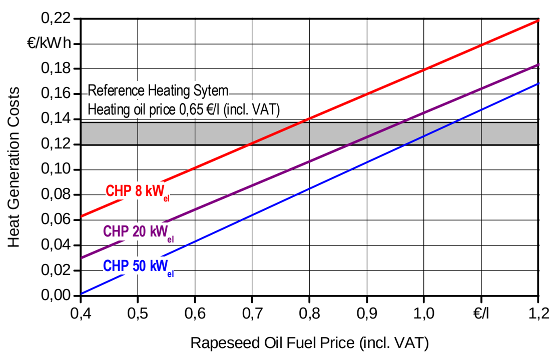



**Figure 12:** Economic efficiency of vegetable oil fuelled CHP plants – influence of the fuel price

Fig. 13 shows the influence of the yearly operating hours on the heat generation costs. As it can be seen, depending on the size of the CHP plant only at about 3000 to 5000 operating hours per year heat generation costs of 12 Cent/kWh are obtained. With decreasing operating hours, heat generation costs increase disproportionally. Thus, an economic efficient operation of rapeseed oil fuelled CHP plants is only possible, if the heat use concept is carefully considered.

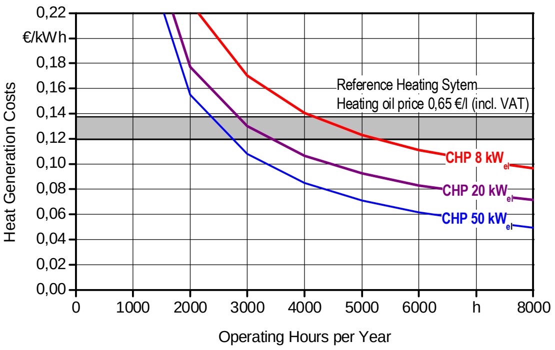



**Figure 13:** Economic efficiency of vegetable oil fuelled CHP plants – influence of the operating hours

## 4 CONCLUSIONS AND OUTLOOK

The number of vegetable oil fuelled CHP plants is lately decreasing in Germany due to unsecure planning framework. This concerns instability of fuel prices, frequent changes of regulations and incentive programmes. Furthermore administrative and cost expenses increased, which affects particularly small scale CHP plants. To obtain feed-in tariffs for the generated power, the sustainability of the used biofuels has soon to be proved by the operator. However certification systems are not long enough available and they are not sufficiently introduced into practice either. Additionally, for the cogeneration bonus, an authorised environmental auditor is mandatory, which can cause high expenses for the operator. Besides these obstacles, biofuels are still subject to oppositional discussions about social and environmental impacts.

Nevertheless, there is a broad consensus in the need of implementing measures to reduce GHG-emissions and energy dependency. The target values of the EU have to be reached by member states. Vegetable oil fuelled CHP plants can make a major contribution to meet these targets. The technology barriers of vegetable oil fuelled CHP are little, a high standard in operational reliability is already achieved. Economic efficiency is given, when the heat can be used within a long period of the year.

Objective debates on the perspectives of all available biofuels have to be continued. The high potential of pure vegetable oils needs to be utilised. Sustainably produced vegetable oil fuels for cogeneration are already on the market. However sustainability standards need to be introduced worldwide and for all kinds of agricultural crops independent from the utilisation. Additionally also fossil energy sources have to face sustainability discussions.

Framework conditions have to be improved by special regulations for small-scale vegetable oil compatible CHP plants. Moreover, regulations need to guarantee long term planning and investment security. Finally further research should aim on improvement of plant efficiency, implementation of exhaust gas aftertreatment systems and standardisation of promising vegetable oil fuels.

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