Czech-Austrian Winter and Summer School "Energetically potential of spent grain after beer processing"

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Content

1 INTRODUCTION

The brewing industry generates relatively large amounts of by-products and wastes, such as brewery spent grains, spent hops and yeast. However with increasing energy costs and ecological CO2 targets, the brewing industry strives to reduce its energy demand or use renewable energy sources. So far most of the spent grain as valuable waste material is used as animal feedingstuff, although the biological stability and the high amount of moisture content is narrowing its preservability. The idea is to use the remaining biomass directly and convert it energetically. This new thinking has the potential to bring a sustainable change concerning the heat requirement. Between 4 and 5 liters of heating oil is required to produce 100 liters of beer. Using this residue coming from their process, breweries can not only substitute a part of the electrical energy demand, but also heating energy, which can bring economic benefits as well as be environmentally compatible. With the possibility to produce biogas from the internal available biomass, new recycling concepts are developed.

In such perspective, anaerobic digestion has become an alternative to produce renewable energy through biogas from these waste substrates. With the installation of combustion process in a brewery, biogas can be produced and furthermore used for own a process, which brings efficiency enhancement, lowers the cost and saves the environment. The existing combustion systems are applicable at any brewery in the world, but as with any new process there are barriers to its widespread implementation.

We evaluate the energetic potential of reusing waste streams to produce energy for their own processes.

2 METHODOLOGY

In the context of this paper an attempt was made to form a concrete picture about the circumstances and the potential of the the energetic recovery and reutilisation of biogetic residues. For this review we focus on specific values from the Plzeňský Prazdroj, which is the largest brewery in Czech Republic, with an output of 9,9 million hectoliters annually and the Austrian Brau Union, which is not a single brewery but an association of several breweries, with 5,12 million hectoliters per year. Finally we limit ourselves and calculate the costs and profit of the power plant for the brewery Plzeňský Prazdroj.

This is primarily to clarify the question of whether an energetic usability in general has the potential and what conditions must be fulfilled. Furthermore, it should be answered whether energy recovery is economically reasonable. Due to the high number of influencing parameters, however, no indication of a specific brewery can be made in this paper, as a matter of not considered or observed local conditions and influences, such as the legal situation or investment costs in soil.

For a meaningful evaluation an average biogenic waste in beer production was quantified. Furthermore, the energy recovery options were limited and by means of research, the technical implementation of the residues were qualified in energy, where the energy output and the following characteristics were complied:

- average specific energy recovery of waste material (MWh/to)
- annual energy yield (MWh)
- theoretical construction size (MWel)

Using the researched information on waste and energy recovery as a further step we compare the actual status quo with the economic potential of reusing the waste as a source of energy.

In the calculations it was assumed that the selected residue is completely supplied to the biomass utilization. For economic considerations it was assumed that the need of spent grains, the beerproducion, the demand and price of energy are constant. Furthermore we don't consider taxes and subsidies.

3 POTENTIAL OF BIOMASS FOR BEER PRODUCTION

Large scaled biogas plants may represent an economically attractive business model under certain conditions. The output parameter for the assessment of the viability of energy recovery from biomass is the specific amount of residual substances produced per hectoliters of beer and the total emission of beer. For sizing the plant dimension the hourly throughput of biomass is essential.

If there are many small breweries of an association, the waste must be collected and recycled in a common power plant. In this case, the radius of the breweries is crucial to ensure that the transport costs are not too high.

The theoretical potential describes the entire energy supply, the technical and economic potential of the technically and economically exploitable part and the exploitable potential and the expected or actual expected ultimately proportion. The expected potential is considerably lower than the theoretical potential - due to technological progress and changes in the economic or energy policy framework. For the ultimate and total given possibilities and limits of renewable energy supply in the long term perspective, the technical potential is essential and can therefore only be referred to in the following examinations of this paper.

Company	Country	Year	Production 2011 Mio. hl
Plzeňský Prazdroj [1]	Czech Republic	2011	9,90
Brau Union [2]	Austria	2004	5,12

Figure 1 Breweries in Czech Republic and Austria

3.1 Waste of the brewing process

Emerging residues during beer brewing are mainly organic substances with high water content. In the beer production process product-specific residues are generated (see Figure 2) in which spent grains represent an absolute residue of more than 70% in the main component of the entire process chain. Spent grain is a residue of malt, which remains thourgh the mashing process in the so-called lauter tun.

Bi product	Average spec. Residues in kg/hl
Spent grain	18,00
Tank bottom	2,30
Hot trub	1,20
Kieselguhr sludge	0,75
Paper	0,29
Cold trub	0,20
Malt flour	0,15
Total	24,27

Figure 2 - Residues[3]

As already stated, this work deals with the analysis of residual material. Accordingly the paper provides the analyses of processing the bi product with the biggest ratio into energy as biomass - in this case spent grains. In a further analysis can be examined whether and at what expense the remaining residues can be incorporated into the biomass process so that 100% of the residues are recycled.

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[1] Vgl. (Tschechischer Verband der Brauereien und Mälzereien, 2012)
[2] Vgl. Biogas Großanlagen, S. 19
[3] Vgl. (Bochmann, 2010, S. 5)

3.2 Demand for energy

The breweries' energy requirement for the beer production can be approximate up to 26% of electrical energy and 74% of heat energy.[4] For the analysis of their own potential use of energy, the breweries energy characteristics of the breweries must be known. In our case, the beer output in hectoliters is to be examined as a reference. The specific energy demand of the filling quantity is dependent and decreases with increasing plant size.[5] Since the consumption behaves almost linearly to the amount of filling, it is further assumed in this paper, that the energy ratios remain constant. For a production plant with an output of 350,000 hl approximately 10,000 MWh of energy is required. Consequently, a specific energy consumption of 28.57 kWh/hl or 102 MJ/hl can be approximated.

Case Study Brau Union

For the validation of the numbers we shall use the consumption figures of Brau Union AG in 2010. This year Brau Union had an energy consumption of 457.8 TJ and bottled 4.688 million hectoliters of beer. Therefore 333.77 TJ of thermal energy and 124.04 TJ of electrical energy had to be spent. This corresponds to approximatly 73% of heat energy shares and 27% of current energy components and a specific heat consumption of 71.2 MJ/hl as well as a specific power consumption of 26.5 MJ/hl.[6] The approximate consumption values agree very well with the case study of Brau Union. Therefore the researched numbers of Brau Union for the facilities and investment account are considered in the following descriptions.

	Demand in GJ/a	Spezific demand MJ/hl
Heating energy	333.770	71,2
Electric energy	124.037	26,5

Figure 3 Demand of energy

4 RECYCLE POSSIBILITIES OF SPENT GRAINS

Owing to its high content of cellulose, hemicelluloses, lignin and proteins spent grain has a strong potential to be recycled[7]. Moreover, it is actually an industry waste with food characteristics which can be (and usually is) used in agriculture as a compound feed. Due to high organic capacity it has a significant capability to become the sustainable energy

4 Vgl. (Energieagentur)
5 Vgl. (Energieagentur)
6 Vgl. (Brau Union Österreich, 2011)
7 Vgl. (Bala & Aliyu, 2010, S. 324 f.)

resource. There are many more alternatives of using draff. Aliyu (2010) suggests production of construction bricks, metal absorption and immobilization, growth medium for microorganisms, bioethanol, lactic, pullulan and xylitol production. Due to its high moisture (75-85%), polysaccharides and proteins content that creates suitable conditions for microbial growth it is drawn into spoilage easily and in a short period of time (7 – 10 days)[8]. As a result wet spent grain is difficult to storage and its transportation is costly.

4.1 Material utilisation

The recyclability of spent grains can happen through composting, disposal and recycling. In Austria, approximatly the entire volume of biogenic residues from the brewing operations is passed to the feed industry and to agriculture. However, the proceeds of exploitation for agriculture and the food industry are low. [9] For example, Brau Union Austria, utilized approximately 93% of waste directly in agriculture as animal feed, 6.6% are sent to a recycling facility and only 0.5% must be disposed as industrial waste, which result in high costs for the brewery. [10]

4.2 Energy Recovery

Spent grain of energy recovery options are focused on the spent grain combustion and the anaerobic fermentation.

Advantages in general [11]

- Energy from the brewing process, reduction of fossil fuels (Eco-Friendly)
- Secure recovery of spent grains
- Recycling of by-products and waste products of thermal energy
- No disposal costs
- CO2-neutral process, reducing costs through the sale of CO2 certificates

4.2.1 Spent grain combustion

During combustion, the grains are directly incinerated. Therefore electric power from the combustion is obtained. A direct combustion of spent grains is not feasible due to the high water content of 80 percent. Requirement of this process is therefore the drying of grains. In a prior drying step, the biomass is mechanically dehydrated and then thermally dried to a residual moisture. Specifically for the combustion of spent grains optimized combustion

[8] Vgl. (Bala & Aliyu, 2010, S. 326)
[9] Biogas Großanlagen (S. 22)
[10] Biogas Großanlagen (S. 21)
[11] Vgl. (Flottweg, S. 7)

systems can be used to burn mechanically pressed-grains with a moisture content of 58%.

The **disadvantages** of spent grain combustion are, that during the combustion of spent grains high nitrogen oxide emissions are expected due to the high nitrogen content. Furthermore the drying process brings a high demand of energy with it and caused by that the energetical effectiveness is low. Subsequently, the biomass is thermically incinerated. Because of the processing costs of organically highly loaded press water and energy intensive dehumidification this method is economically difficult to use. [12]

4.2.2 Anareobic fermentation

The main advantage of this procedure is that cheap substrates are converted into valuable disproportionation products with a simultaneous formation of carbon dioxide. Biogas is generated by the anaerobic fermentation of the spent grains in a three-stage, continuous process. Through continuous feed, it is possible to produce a continuous gas yield. The biogas process is conducted in several phases. Thus, the process conditions can be better tailored to the requirements of each phase and a better gas yield can be achieved.

This produced biogas is incinerated in a subsequent process or sold directly as gas. The biogas consists of up to 65% methane (CH4) and about 30% carbon dioxide (CO2). Small amounts of hydrogen sulfide (H2S), hydrogen (H2) and ammonia (NH3) can be included. The fuel quality of the biogas depends on its preparation and is located between natural gas and sewage gas. The method can be extended because additionally to spent grains, other organic waste such as sewage sludge, may be involved in the process. This increases the energy content and the recovery of vapor. The mixture's treatment of spent grains and other organic waste occurs in the same way as explained in the process description. The process optimization by means of enzyme use and the recycling of various wastes are not treated any further in the ongoing of this paper. [13] The calorific value of methane is about 35.9 MJ/m³ [14].

The **disadvantage** is on the one hand, that the disposal of waste is not solved with this approach and on the other hand, the investment costs are a lot higher compared to direct combustion of spent grains.

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[12] Vgl. (Weber, 2009, S. 3)
[13] Vgl. (Erneuerbare Energien, 2011)
[14] Vgl. (Uni Magdeburg, S. 302)

Caused by the better efficiency and the lower processing costs we focus on the fermentation process with a combined heat and power generation plant.

Energy recovery

Researched by the emissions and the residue fraction (per hl), it is possible to determine the annual emissions of spent grains. Researched by the methane yield and calorific value of methane CH4 a determination of the theoretically, economically achievable thermal output thourgh the anaerobic fermentation is ascertainable.

Brewery	Beer production in mil. hl	Residues tons per hl	Residues in t	Methane yield m³ per ton	Calorific value in MJ/m³	Conversion kWh / MJ	Calorific potential in GWh
Plzeňský Prazdroj	9,9	0,019	188.100	65	35,9	0,000278	**121,93**
Brau Union	5,12	0,019	97.280	65	35,9	0,000278	**63,06**

Table 1 Energetical output

4.3 Combined heat and power plant [CHP]

Cogeneration is a technique that makes it possible to generate both electricity and useful heat. The heat is either availabe in form of hot water or steam at high pressure. In contrast to conventional power plants, in which the steam is directly derived by the chimney, the flue gases are cooled in cogeneration first. It is then discharged through the chimney, where the energy is transferred to a hot water and steam cycle. CHP systems can therefore achieve a very high efficiency. After breweries energetically have a higher heat demand than the current demand for beer production and the economy depends heavily on the efficiency, we use for the analysis of a cogeneration plant for the recovery of the produced biogas. Furthermore, we size the cogeneration plant to receive a full reuse of the resulting spent grains. As already mentioned, brewer's grains provide about 70% of the residues. In a further work, the complete utilization of all residues could be analyzed for a biogas plant.

CHP plant based on an ORC process

The ORC process and its connection to the biomass furnace provides a corresponding to the state of the art technology dar. Especially in the lower output range from 400 kWe ORC processes have a much higher efficiency. This applies to breweries with a small footprint and a resulting power production. Integrating a module ORC produces higher investment cost but increases the efficiency and consequently also economically more efficient for a continuous feed.

Especially in the lower output range from 400 kWe, ORC processes have a much higher efficiency. This applies to breweries with a small footprint and a resulting power production. The integration of a ORC module produces higher investment costs, but increases the efficiency and is therefore considered in the long terms economically more efficient for a continuous feed.

The advantages of the Processes ORC are primarily in the high efficiency of the turbine (up to 90%). Further, the turbine experiences a lower mechanical liability because of the low circumferential speed. In addition, the plant has a long life due to the characteristics of the working substance. This is not eroded in contrast to steam and also does not damage the various components of the plant such as valves and pipes.[15]

There are also other advantages such as the simplicity of procedures for starting and stopping the plant, low-noise operation, low maintenance and repair costs as well as the high efficiency of the modules, even at partial load. Thus, fluctuations of the beer production and therefore the resulting spent grains have a little impact on the efficiency of energy recovery.

In the following figure, the energy flow diagram of a biomass CHP plant is presented on the basis of a 200 kWe ORC module. The electrical efficiency of the overall plant as shown in this circuitry-variant has, considering the thermal oil economiser and air preheater around 15%, whereas the thermal efficiency of the overall plant is around 75%. The radiation and flue gas losses and the electrical and thermal losses of a biomass CHP plant, based on ORC process, are in total only around 10%.[16]

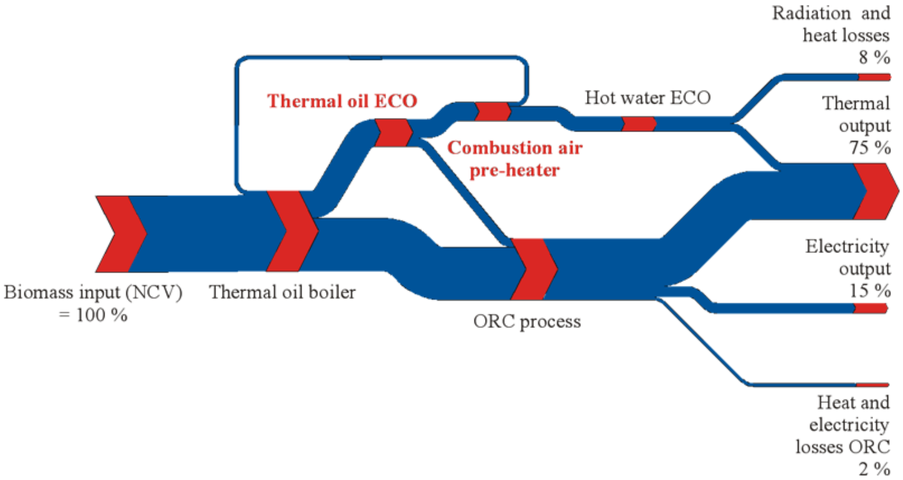

Figure 4 Efficiencies of the ORC process[17]

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[15] Vgl. (Turboden)
[16] Vgl. (Bios Energy, 2008)
[17] Vgl. (Bios Bioenergy)

5 ENERGETICALLY POTENTIAL OF A CHP FOR BREWERIES

The specific energy consumption for beer production, as already explained, is divided into the heat demand and the electricity demand. As an example for the brewery Plzeňský Prazdroj, the heat loss is at 195.80 GWh/year and the current consumption at 72.88 GWh/year. Thus a total energy consumption of 268.68 GWh/year is required.[18]

In case of the brewery Plzeňský Prazdroj, the CHP based on the ORC module with the assumed efficiency can generate 91.44 GWh of heat energy and 18.29 GWh of electrical energy. Consequently, approximately 50% of the heat energy and 25% of the electrical energy can be covered for the recovery of the spent grains. Due to the high efficiency of the ORC-based cogeneration plant an energy output of 109.73 GWh per year is produced.

Brewery	Calorific potential in GWh	Demand of heat in GWh	Supply of heat in GWh	Demand of electricity in GWh	Supply of electricity in GWh	Total energetical outcome in GWh
Plzeňský Prazdroj	121,93	195,80	91,44	72,88	18,29	109,73
Brau Union	63,06	101,26	47,29	37,69	9,46	56,75

Table 2 Energetical potential of spent grain (author´s computations)

6 PRODUCTION COSTS

The calculation oft he production costs for electricity is based on the VDI guideline 2067. This cost calculation scheme distinguishes four types of costs:[19]

- capital costs
- consumption based costs (fuel, consumables)
- operation-based costs (personnel costs, costs for maintenance)
- other costs (administration, insurance)

The capital costs reflect the costs to built the process, which extracts energy from spent grain. In our case we have to invest for a fermentation process and a cogeneration power plant. The consumption based costs are very low, because of the already existing fuel – spent grain.

[18] Vgl. (Brau Union Österreich, 2011)
[19] Vgl. (Turboden, 2002, S. 6)

6.1 Fermentation

The specific investment costs for the fermentation process are highly dependent on the plant size. With increasing plant size, however, they drop significantly. The higher level of automation in larger plants and the larger share of own performance in smaller plants act contrary to the scale of the investment costs.

Spent grain as a fresh substance has a density of about 0.997 to 1.102 t/m³.[20] Taking the brewery Plzeňský Prazdroj as an example with a produced amount of 188.100 t/y spent grains, we assume a volume of 170.000 m³/y. With a throughput of 25 m³/h, high investment costs of about € 12.500/m³ have to be expected. [21]

The investment costs for the fermentation plant can thus be approximated at about € 312.500.

6.2 CHP investments based on a OCR modul

Plant dimensioning

To extract energy from spent grain we have to consider the investment costs. By the economy of scale effect, the investment costs of an ORC system with the increase of the rated electrical output decline sharply. The specific electricity production costs decline from a rated electrical output of 500 kW with € 0.087/kWhel and with a rated electrical output of 1,000 kWe to approximately € 0.070/kWh$_{el}$.[22] The larger the system is dimensioned, the lower the specific investment costs are. For our design example, the brewery Plzeňský Prazdroj, which has an annual output of 9.9 million hectoliters of beer and therefore a spent grain volume of 188,100 t/a, we expect a theoretical combustion performance of 121.93 GWh.

The following graph shows the specific electricity generation costs in €/kWh$_{el}$ depending on the full load hours of a biomass ORC-system with a capacity of 500 kWel. The graph shows furthermore that the utilization of a combined heat and power plant has a very strong influence on the specific electricity generation costs. A plant must therefore be designed so that it can reach at least 5,000 full load hours.

On the one hand, the biogas for combustion is fed by a continuous fermentation and on the other hand the purchase and therefore the economical efficiency is ensured by our own, very high energy and power requirements. Consequently, we expect at least 7,000 annual full load hours to keep the specific electricity generation costs as low as possible.

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[20] Vgl. (Obernberger, Bini, & Hammerschmid, S. 106)
[21] Vgl. (Biogas Netzeinspeisung, 2008)
[22] Vgl. (Obernberger, Bini, & Hammerschmid, S. 15 f.)

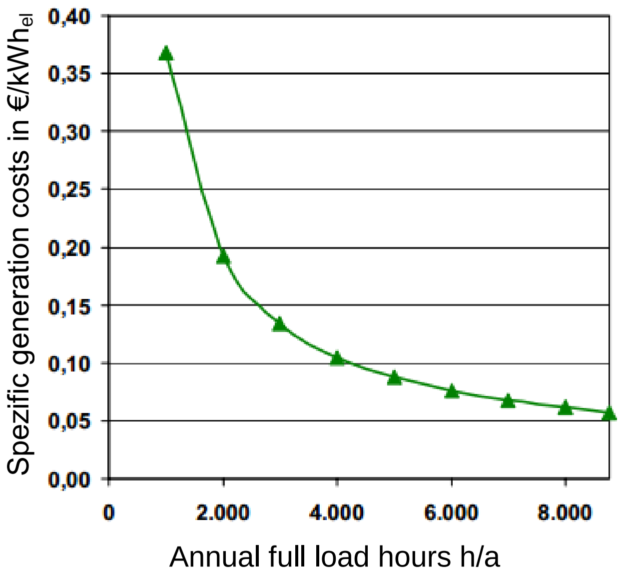

Figure 5 Specific generation costs depending on annual full load hours

Investment costs

For the economic recovery of the spent grains, we size the thermal oil boiler at about 7.000 full-load hours and the calculated theoretical combustion performance of 121,93 GWh, consequently, with a capacity of 17,4 MW. On the one hand the investment costs of the cogeneration plant are highly dependent on the electrical power and on the other hand increased by ORC module. The following table shows the investment costs of a CHP plant based on an ORC module with a rated power of 3.2 MW. The investment costs are € 2.9 million, the electrical power rating is 480 kW and hence the capital costs are about € 6.000/kWe.

The combined heat and power plant for the Plzeňský Prazdroj brewery requires a nominal output of 18.0 MW and a rated electrical output of 2,700 kW. Due to the strong economy-of-scale effect in cogeneration plants, we expect specific capital costs of € 5.500/kW_{el} and a total investment sum of about € 14.85 million.

Investment costs	
3,2 MW Thermal oil boiler	€ 1.100.000
Emission measurement	€ 30.000
Flow measurement	€ 6.500
Electrostatic filter	€ 110.000
Chimney	€ 20.000
ORC-Modul	€ 945.000
Building	€ 250.000
Storage	€ 125.000
Approvals	€ 150.000
Planing	€ 190.000
Total	**€ 2.900.000**

Table 3 Investment costs of a CHP based on an ORC module [23]

Due to numerous cost-relevant factors, the listed investment costs can be regarded only as a guideline. The actual expected production costs have to be calculated depending on the system specification and can sometimes vary, depending on the system, which in this case is refering to a biogas plant. Excluded from the investment costs are ground costs, as these, depending on the location, are not predictable.

[23] Vgl. (Wilhelm, 2011, S. 11)

7 ECONOMIC ANALYSIS

To find out whether the use of potential of spent grain is more profitable in energy production than in agriculture we will calculate the approximate revenue from both sectors. Consecutively, we will compare this values.

Assumptions

- The brewery Plzeňský Prazdroj is selling or converting 100% of the accumulating spent grain
- The distance from the brewery and the cattle farms is approximately 20 km
- Plzeňský Prazdroj is selling wet and no dry spent grain to the farms
- The yearly production of spent grain in Plzeňský Prazdroj is 188 100 tons

7.1 Business Model – selling spent grains to cattle farms

The main aspects to calculate the profit is the brewers distance to the farms and the revenue per ton spent grain. The market price for spent grain such as fooder differs strong. Prices vary from € 9,5/ton[24] to € 4,10/ton[25]. This depends on the needed silage, the dryness of spent grains, the size of the brewery and their situation. To compare the two business models we assume the higher price with € 9,5/ton and subtract the transportation costs.

It means that the sale of the whole production of spent grain for the Plzeňský Prazdroj brewery might bring € 1.786.950 if the transportation costs are zero. Otherwise the revenues would be lowered by transportation costs and other operation costs. We just consider transportation, which effects the price more than other aspects.

In general, the transportation costs are affected by the distance between the brewery and the cattle farm as well as the vehicle´s load size. That means transportation costs can be calcutlated as the cost per loaded km multiplied by the distance to the cattle farm. The study from Ben-Hamed (2011) that deals with economic returns of using spent grain as fodder assumes a loading sizes of vehicles of 4 tons. In our study we will consider 20 km long distance between brewery and feedlot. The transportation costs of load (4 ton) per km can be considered with € 0,841.

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[24] Vgl. (Dr. E.A. Richards)
[25] Vgl. (LFT, 2008, S. 26)

	Plzeňský Prazdroj
Income	1.786.950 €
Transportation costs	-395 480 €
Approximate profit	***1.391.470 €***

Figure 6 Approximated profit from using spent grains as compound feed (Author´s computations)

The Table above indicates that a 20 km long distance between brewery and feedlot affects already a 20% reduction of sale revenues. This circumstances greatly affects the economic effectiveness of selling spent grain to farms.

7.2 Business Model – processing spent grains into energy

The use of biomass instead of fossil fuels is gaining an acceptance as cost effective process. Brewery´s relative savings from using draff as source of energy are running up as prices of fossil fuels are increasing gradually. The electricity tariff differs country to country. In Czech republic 1 MWh of electric energy costs on average € 65,0[26] and in Austria € 61,6[27]. The previous calculations showed that the draff production of Plzeňský Prazdroj (188.100 tons) is equal to 109,73 GWh and of Brau Union (97.000 tons) is equal to 56,75 GWh.

It is clear that in case of furnace in brewery or in case that power plant is situated right next to the beer producer, transportation costs don‘t affect the overall revenues. This scenario is not always possible, because breweries in Czech Republic and Austria are also located in urban area whereas power plants are usually suburban.

Effect of distance between brewery and power plant indicates a strong impact on revenues from energy utilization of spent grain. In our paper we want to recycle the energetical output of the power plant to the initial beer processing. Accordingly the power plant is considered to be next to the brewery and we don’t have to consider transportation costs.

The new process requires an investment which is approximately € 12,23 millions [28]. The profit can be calculated as € 3,00 millions and the specific energy costs would be € 10,23 per MWh.

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[26] Vgl. (ceny produktů Skupiny ČEZ, 2013)
[27] Vgl. (Steiner, 2012)
[28] Vgl. (Berlinger, 2013)

Investment Power Plant	7.500.000,00
Investment Fermentation	350.000,00
Total Investments	7.850.000,00
Discounted Investments (20 Years, 3% interrest rate)	**12.230.044,22**
Machine life	20 Years
Capital costs per year	**611.502,21**
Fuel costs (7000 h/a)	-
Machinery materials (0,3% of the Investment)	40.637,50
Variable costs	**40.637,50**
Labor costs	10.000,00
Costs of maintenance (1,5% of the Investment)	203.187,51
Costs of operation	**213.187,51**
Insurance and Administration (0,5% of Investment)	67.729,17
Total costs per year	**933.056,40**
Energetical savings	
Income by Electricity Energy (18,29 GWh/a; 7000 h/a, 65 €/MWh)	1.188.772,41
Income by Heat (91,44 GWh/a; 7000 h/a, 30 €/MWh[29])	2.743.320,94
Revenue per year	**3.932.093,34**
Profit per year	**2.999.036,94**
Specific costs €/MWh	**10,23**

Table 4 Autor‘s compilation

[29] Vgl. (Control, 2012)

8 CONCLUSION

Spent grain is the by-product with the biggest ratio of beer production which is traditionally used as compound feed in agriculture.

Besides using spent grain as fooder, we can consider it as a biomass fuel with a caloric value of 0,65 MWh per ton. With cogeneration, spent grains are transformable to 0,58 MWh energy per ton. According to the constantly increasing tendency of fuel prices and according to the recycling trend, environmental protection and enlargement of renewables as well, this energy source is able to reduce energy costs and even lower the CO2 emissions in the brewing process. As a result, employing the new technology for the energy conversion, it is not only environmentally friendly and sustainable but also profitable. According to our analysis the utilization of spent grain for energy purposes is economically more effective than its utilization as fodder. On the other hand, the use of spent grains as a power source depends on a large number of boundary conditions. The most important factors are the plant size, the brewery's situation, the current incomes as fodder and finally the enery prices.

We suggested price of fuels, transportation costs, volume of investment and related operational costs to be the most important factors affecting the brewery's profit. Fuel costs are continuously escalating and are relatively high. For the purposes of our analysis we decided to use the outputs of Plzeňský Prazdroj and Brau Union Österreich AG. Our calculations showed that the annual energetical savings of these breweries are approximately 109,73 GWh and 56,75 GWh.

Plzeňský Prazdroj´s calculated profit for a CHP is € 3,00 million a year which is more profitable compared the compound feed with about € 1,39 million a year.

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