# COST-BENEFIT ANALYSIS OF TECHNOLOGIES FOR ALTERNATIVE USE OF GRASS BIOMASS FROM GRASSLANDS

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**Abstract.** The article deals with the cost-benefit analysis of technological solutions for the alternative use of grass biomass from grasslands. There are three technological solutions assessed – production of biogas from grass biomass, production of biobutanol from grass biomass and production of pellets from grass biomass. These technologies offer an alternative to the use of grass biomass as fodder. Benefits and costs (expenditure) are analysed from the positions of the operators of the technological solutions. The cost-benefit analysis has been carried out by applying the method of discounted cash flow as this method allows assessing the entire life cycle of the technological solution including the investment cost. The assessments are based on the data from grasslands in two municipalities of Latvia as well as the data from pilot facilities. To measure the balance of benefits and costs, the net discounted cash flow or net present value is used as an indicator. The cost-benefit analysis has been conducted by examining several options (at least two) for each technological solution. According to the results of the analysis carried out, the balance of benefits and costs are negative for two technological solutions (for all the options analysed) – the production of biogas and the production of biobutanol. The balance of benefits and costs is positive for the production of pellets (for two options analysed). However, the production of biogas has prospects of achieving the positive balance of benefits and costs, as the benefits increasingly exceed operational expenditures at higher production capacity. Despite the negative balance of benefits and costs, the production of biobutanol can become economically effective, if it is combined with biogas production.

**Keywords:** cost-benefit analysis, grass biomass, biogas, biobutanol, grass pellets.

## Introduction

The traditional role of grasslands is the provisioning of fodder for livestock (mainly for cattle and sheep). However, this traditional role of grasslands has diminished in Europe as the part of grasslands is no longer needed for animal husbandry [1]. This trend is especially noticeable in Latvia that has experienced a significant decrease in the number of livestock (mainly cattle) since 1990 [2]. Therefore, quite high amounts of grass biomass are wasted on a field.

At the same time, grass biomass from grasslands has a heat energy potential and can be used as a resource for renewable energy [3]. This study focuses on three technological solutions – production of biogas from grass biomass, production of biobutanol from grass biomass and production of pellets from grass biomass – as the most prospective technological solutions for the use of grass biomass as fuel. The objective of the study is to analyse benefits and costs from these technological solutions. The cost-benefit analysis is carried out from the position of the user of the technological solution.

## Materials and methods

The main data source for the study is information and data yielded by the LIFE+ project "Alternative use of biomass for maintenance of grassland biodiversity and ecosystem services" (LIFE GRASSSERVICE, Nr. LIFE12BIO/LV/001130), including unpublished information provided by the project's partners. The project was carried out in two municipalities of Latvia – Sigulda Municipality and Ludza Municipality. The cost-benefit analysis of the three technological solutions mentioned above has been carried out on the basis of these data including the data about the yield of grass biomass, area of grasslands, etc. The data about the price of energy resources (natural gas, electricity, etc.) have been updated to the latest market prices (estimates).

The following options for the technological solutions are assessed in the study [4]:

1. Production of biogas from grass biomass:
   - Option I: pilot facility with a processing capacity of 50 kg in a day (16.5 t per year) of green biomass;
   - Option II: potential biogas production facility with a processing capacity of 1 000 kg in a day (330 t per year) of green biomass;

- Option III: potential biogas production facility with a processing capacity of 3 000 kg in a day (990 t per year) of green biomass.

2. Production of biobutanol from grass biomass:
   - Option I: pilot facility with a processing capacity of 1 t per year of dry biomass;
   - Option II: potential facility with a processing capacity of 10 t per year of dry biomass.

3. Production of pellets from grass biomass:
   - Option I: facility with a pellet production capacity of 45 kg per h;
   - Option II: facility with a pellet production capacity of 300 kg per h;
   - Option III: facility with a pellet production capacity of 1 000 kg per h.

It should be mention that the following three sub-options have been analysed for each option of the production of biogas from grass biomass:

- Only biogas production: the end product – biomethane;
- Only heat production: the end product – heat;
- Co-generation or combined heat and power (CHP): the end product – heat and electricity.

In order to achieve correct results, the cost-benefit analysis is performed by taking into account all the benefits and costs arising from the technological solution during its life cycle (lifetime). The discounted cash flow or the present value method is chosen as the most appropriate one as this method allows comparing benefits and costs arising during different periods of time. The net present value (*NPV*) is used as the indicator to measure the balance of benefits and costs. According the general meaning of the *NPV*, if the *NPV*<0, the balance of benefits and costs is negative. On the contrary, if the *NPV*>0, the balance of benefits and costs is positive. The overall *NPV* is calculated as follows [4]:

$$NPV = \sum_{i=0}^{n} \frac{B_i - C_i}{r} , \qquad (1)$$

where   $i$ – yearly index (within the range from 0 to $n$);
   $n$ – life time of the respective technological solution;
   $B_i$ – benefits from the respective technological solution (in year $i$);
   $C_i$ – costs of the respective technological solution (in year $i$);
   $r$ – discount rate used in the calculation.

The benefits and costs are discounted by applying real values instead of the nominal ones, i.e., the real benefits and costs (benefits and costs are expressed in the today's prices) and the real discount rate. The use of real values is recommended also by the EC guidelines for the cost-benefit analysis [5]. According to the author's assessment, the real annual discount rate is estimated 5 %. This discount rate approximately takes into account the risks related to future benefits as well as avoids future benefits being discounted excessively. The benefits and costs are assessed without the value-added tax (VAT). The calculations for the cost-benefit analysis are made without taking into account the corporate income tax (tax on income from business activities). However, taxes related to labour (payroll taxes) are taken into account.

The benefits of the technological solution (*B*) are determined by assessing the economic value of the final products (biogas, biobutanol, grass pellets) derived from the respective technological solution. The economic value of the final product is assessed by using reference products or values.

The benefits of the production of biogas from grass biomass are calculated by the following formulae for the sub-options mentioned above [4]:

- Only biogas production:

$$B_{ch4} = (V_{gross} - V_{sc}) \cdot P_{ng} , \qquad (2)$$

where      $B_{ch4}$ – economic value of biomethane, EUR per year;
   $V_{gross}$ – gross volume of methane, m$^3$ per year;
   $V_{sc}$ – self-consumption of methane in technological processes, m$^3$ per year;
   $P_{ng}$ – market price of natural gas, EUR per m$^3$.

- Only heat production:

$$B_{th} = (Q_{gross} - Q_{sc}) \cdot P_{th}, \tag{3}$$

where
$B_{th}$ – economic value of heat, EUR per year;
$Q_{gross}$ – gross volume of heat, MWh per year;
$Q_{sc}$ – self-consumption of heat in technological processes, MWh per year;
$P_{th}$ – reference value of heat, EUR per MWh.

- CHP:

$$B_{CHP} = (E_{gross} - E_{sc}) \cdot P_{el} + (Q_{gross*} - Q_{sc*}) \cdot P_{th}, \tag{4}$$

where
$B_{CHP}$ – economic value of end products of CHP, EUR per year;
$E_{gross}$ – gross volume of electricity, MWh per year;
$E_{sc}$ – self-consumption of electricity in technological processes, MWh per year;
$P_{el}$ – reference value of electricity, EURper MWh;
$Q_{gross*}$ – gross volume of heat in CHP, MWh per year;
$Q_{sc*}$ – self-consumption of heat in the technological processes of CHP, MWh per year;
$P_{th}$ – reference value of heat, EUR per MWh.

In order to assess $B_{ch4}$, as well as $B_{th}$ and $B_{CHP}$, the yield of methane is assumed as 174 normal m$^3$ per 1 t organic dry matter (ODM) [4]. This assumption is based on the laboratory tests run by "Bio Re" Ltd. According to the research carried out by "Bio Re" Ltd., the content of ODM in total dry matter is assumed 93 % [4]. It should be noted that the assumed yield of methane is lower than the levels mentioned in the literature [6; 7].

The price (tariff) for the annual consumption in range from 126 to 1 260 thousand n.m$^3$ is typically used as the reference in various regulatory acts (e.g., Cabinet of Ministers Regulation 262, of the year 2010) [8]. Therefore, the price for this range of consumption is also used in order to determine $P_{ng}$ in the study. Up to April of 2017 the Latvia's market of natural gas was a regulated market. The prices (tariffs) were regulated by the Public Utilities Commission and they depended on the volume of consumption. Since May of 2017 Latvia's market of natural gas has been liberalised and the prices for household consumers are only regulated. As there are available no public statistics on the market price for this range of consumption after April of 2017, $P_{ng}$ is estimated indirectly on the basis of the current price for the annual consumption in range from 0.5 to 25 thousand n·m$^3$ and the ratio of the price for range 126 to 1 260 thousand n·m$^3$ to the price for the range 0.5-25 thousand n·m$^3$. The current price for the range 0.5 to 25 thousand n·m$^3$ is 337.08 EUR per th.n.m$^3$ (without VAT) [9]. Thus, $P_{ng}$ is estimated 286.52 EUR per th.n.m$^3$.

To calculate $P_{th}$, the following formula is used [3; 4]:

$$P_{th} = (\frac{P_{ng}}{q_{ng} \cdot \eta_{ng}} + i_{ng}) \cdot 1000, \tag{5}$$

where
$q_{ng}$ – lower heating value (net calorific value) of natural gas, kWh per n.m$^3$;
$\eta_{gp}$ – specific efficiency of natural gas boiler;
$i_{ng}$ – specific investment cost for natural gas boiler, EUR per kWh.

According to available latest information, the actual higher heating value (gross calorific value) of natural gas is 10.538 kWh per n.m$^3$ [9]. The ratio of the higher heating value to the lower heating value is assumed 1.097 on the basis of the minimum parameters for the system of the distribution of natural gas required by the annex of the Cabinet of Ministers Regulation 78 (of the year 2010) [10]. Therefore, $q_{ng}$ is estimated 9.603 kWh per n.m$^3$. $\eta_{gp}$ is assumed the same as used in various regulatory acts (e.g., Cabinet of Ministers Regulation 262, of the year 2010) – 0.9 [8]. According to the author's previous study and methodology, $i_{ng}$ is assessed 0.003403 EUR per kWh [3; 4]. Thus, it is calculated that P$_{th}$ is 36.55 EUR per MWh.

The reference value of electricity ($P_{el}$) is determined as the market price of electricity at a consumer or as so-called DDP price (according to INCOTERMS) because the electricity derived from

the technological solution can substitute buying of electricity from outside. $P_{el}$ is estimated as follows [4]:

$$P_{el} = P_{NP} + \pi_T + \pi_D + \pi_{MPC},$$ (6)

where $P_{NP}$ – weighted average price of electricity in Nord Pool stock exchange, EUR per MWh;
$\pi_T$ – trader's (seller's) premium (trade commission), EUR per MWh;
$\pi_D$ – distribution fee, EUR per MWh;
$\pi_{MPC}$ – mandatory procurement components, EUR per MWh.

According to the data about the weighted average Nord Pool (NP) price published by JSC "Latvenergo" on monthly basis [11], $P_{NP}$ is estimated 43.89 EUR per MWh as the 12-month average. The average trader's premium ($\pi_T$) is estimated by the author 1.40 EUR per MWh. The components $\pi_D$ and $\pi_{MPC}$ are estimated 37.29 EUR per MWh and 14.63 EUR per MWh respectively according to the tariffs set by the Public Utilities Commission. Hence, $P_{el}$ is estimated 97.21 EUR per MWh.

As biobutanol is a second-generation biofuel having physico-chemical characteristics and applications very close to petrol, petrol is selected as the reference product for biobutanol. The benefits of the production of biobutanol from grass biomass are calculated as the economic value of biobutanol by the following formula [4]:

$$B_{bu} = V_{bu} \cdot q_{bu} \cdot \frac{P_{pe}}{q_{pe}},$$ (7)

where $B_{bu}$ – economic value of biobutanol, EUR per year;
$V_{bu}$ – outcome of biobutanol, l per year;
$q_{bu}$ – calorific value of biobutanol, kWh·l$^{-1}$;
$P_{pe}$ – price of petrol, EUR per l;
$q_{pe}$ – calorific value of petrol, kWh·l$^{-1}$.

$V_{bu}$ is assessed according to the results of the study of the Riga Technical University that 1 t of ODM yields 269 kg of sugars and 1 kg of sugars yields 0.332 l of butanol [4]. The calorific values $q_{bu}$ and $q_{pe}$ are assumed 7.50 kWh·l$^{-1}$ and 8.89 kWh·l$^{-1}$ respectively according to the literature [12]. $P_{pe}$ is estimated 1.008 EUR per l (retail price without VAT).

The benefits of the production of grass pellets from grass biomass are assessed as the economic value of heat from grass pellets [4]:

$$B_{gp\_th} = M_{gp} \cdot q_{pp} \cdot \eta_{gp} \cdot P_{th},$$ (8)

where $B_{gp\_th}$ – economic value of grass pellets, EUR per year;
$M_{gp}$ – outcome of grass pellets, t per year;
$q_{gp}$ – lower heat value of grass pellets, MWh per t;
$\eta_{gp}$ – rate of efficiency for grass pellet boiler.

The outcome of grass pellets ($M_{gp}$) is estimated by assuming that the content of dry matter in grass pellets is 90 % (a typical level for pellets) [3; 4]. According to the author's estimates, $q_{gp}$ is assumed 4.43 MWh per t [3; 4] and $\eta_{gp}$ – 0.85 [4].

The costs of the technological solution (C) are comprised of the investment cost and operational cost. Investment costs include the cost of the design, creation/acquisition of equipment and machinery, construction works and other investments. Mostly investment costs occur at the very beginning of the life cycle. However, in case of the biogas production there are planned reinvestment costs for a heat production module and for a CHP module, because their life cycle is assumed shorter (5 and 3 years respectively) than the life cycle of a biogas module (15 years).

Operational costs are formed by routine costs associated with the use of a technological solution (performance, operation). They mostly include [4]:
- incremental cost of preparation of grass biomass;
- cost of energy (heat, electricity);

- cost of consumables;
- maintenance cost;
- labour cost.

Only incremental cost of preparation of grass biomass is considered in the cost-benefit analysis as for the largest part of grasslands there is available public support (e.g., so-called single payment scheme) to finance costs of grassland management. Under the current terms of this support, grass should be cut and removed from the area being applied for the support. Incremental cost of preparation of biomass includes the cost of transportation of grass biomass (fresh grass biomass, hay, etc.) from grasslands to the site of the technological solution and, if necessary, the cost of the pre-processing (grinding, etc.) of the grass biomass. The transportation cost is assumed 0.444 EUR per t·km for fresh grass biomass and 0.889 EUR per t·km for hay. These assumptions are based on the estimates made by "Biore" Ltd.

The key assumptions and parameters for the production of biogas from grass biomass are presented in Table 1.

Table 1

**Key assumptions and parameters for production of biogas**

| Assumptions / parameters | Options | | |
|---|---|---|---|
| | I | II | III |
| **Investment cost:** | | | |
| Biogas module, EUR | 90 000 | 39 292 | 103 057 |
| Heat generation module (boiler), EUR | 200 | 3 031 | 9 093 |
| CHP module, EUR | 6 500 | 3 929 | 12 124 |
| **Technological parameters:** | | | |
| Biogas production: | | | |
| Total dry matter, t per year | 5.5 | 109.9 | 329.7 |
| Total organic dry matter, t per year | 5.1 | 102.2 | 306.6 |
| Methane, $m^3$ per year | 889 | 17 782 | 53 347 |
| Methane, MWh per year | 8.9 | 177.8 | 533.5 |
| Only heat production: | | | |
| Total heat energy, MWh per year | 8.0 | 160.0 | 480.1 |
| CHP: | | | |
| Electricity, MWh per year | 2.7 | 62.2 | 192.0 |
| Heat energy, MWh per year | 5.3 | 97.8 | 288.1 |

*Source: The author's calculation according to the data by "Biore" Ltd.*

The key assumptions and parameters for the production of biobutanol from grass biomass are presented in Table 2.

Table 2

**Key assumptions and parameters for production of biobutanol**

| Assumptions / parameters | Options | |
|---|---|---|
| | I | II |
| **Investment cost:** | | |
| Total investment cost, EUR | 100 000 | 50 000 |
| **Technological parameters:** | | |
| Needed hay amount, t per year | 1.2 | 11.8 |
| Total organic dry matter, t per year | 0.9 | 9.3 |
| Sugars, kg per year | 250 | 2 502 |
| Biobutanol, l per year | 83.1 | 830.6 |

*Source: The author's calculation according to the data by the Riga Technical University*

The key assumptions and parameters for the production of grass pellets from grass biomass are presented in Table 3. The investment cost for grass pellet boilers is estimated by assuming the specific investment cost 200 EUR per kW (higher than for a standard biogas boiler) [4].

Table 3

**Key assumptions and parameters for production of grass pellets**

| Assumptions / parameters | Options | | |
|---|---|---|---|
| | I | II | III |
| **Investment cost:** | | | |
| Equipment for production of grass pellets, EUR | 1 455 | 18 182 | 126 446 |
| Grass pellet boilers, EUR | 8 284 | 55 227 | 184 091 |
| **Technological parameters:** | | | |
| Produced pellet amount, t per year | 87.1 | 580.8 | 1 936.0 |
| Produced pellets in terms of energy | | | |
|    Gross production, MWh per year | 385.9 | 2 572.9 | 8 576.5 |
|    Net production, MWh per year | 328.1 | 2 187.0 | 7 290.0 |
| Needed amount of raw material | | | |
|    Dry matter of grass, t per year | 80.8 | 538.9 | 1 796.3 |
|    Hay, t per year | 95.1 | 634.0 | 2 113.3 |
| Needed capacity of grass pellet boiler, kW | 41.4 | 276.1 | 920.5 |

*Source: The author's calculation according to the data by "Baltic Unique Solutions" Ltd.*

In addition to the methods mentioned above, in the process of the study there have been used various appropriate qualitative and quantitative research methods: monographic, analysis and synthesis, logical and abstractive constructional etc.

**Results and discussion**

Based on the methodology, data and assumptions described above, *NPV* has been calculated for all the technological solutions to asses the balance of benefits and costs. The *NPV* has been calculated both for Sigulda Municipality and Ludza Municipality as the operational costs differ between these municipalities. The differences in *NPV* between Sigulda and Ludza Municipality are caused by the differences in the cost of transportation of grass biomass. As the yield of grass biomass is lower in Ludza Municipality, the larger area is necessary to collect the necessary amount of grass biomass. Thus, the weighted average distance of transportation is longer that results in higher transportation cost.

The *NPV* for the production of biogas from grass biomass is presented in Table 4.

Table 4

**_NPV_ for production of biogas (EUR)**

| Municipality | Options | | |
|---|---|---|---|
| | I | II | III |
| <u>Biogas production:</u> | | | |
| Sigulda Municipality | -150 994 | -91 653 | -169 058 |
| Ludza Municipality | -150 996 | -91 863 | -170 149 |
| <u>Only heat production:</u> | | | |
| Sigulda Municipality | -151 572 | -93 452 | -173 131 |
| Ludza Municipality | -151 574 | -93 662 | -174 222 |
| <u>CHP:</u> | | | |
| Sigulda Municipality | -182 076 | -77 430 | -107 653 |
| Ludza Municipality | -182 078 | -77 640 | -108 745 |

*Source: The author's calculation*

According to the results, the *NPV* is negative for all the options and sub-options of the production of biogas. Therefore, the balance is negative for this technological solution at given assumptions. However, it should be added that the balance of benefits and operational cost is positive for option's

III sub-option "CHP". Moreover, the most significant operational cost is the personnel cost. If the personnel cost is excluded, the balance of benefits and operational cost becomes also positive for option's II sub-option "CHP". Hence, it can be concluded that, although the costs exceed benefits for biogas production from grass biomass, this technological solution has a potential to become efficient, if the investment cost and/or personnel cost is reduced.

The *NPV* for production of biobutanol from grass biomass is presented in Table 5.

Table 5

**NPV for production of biobutanol**

| Municipality | Options | |
|---|---|---|
| | **I** | **II** |
| Sigulda Municipality | -158 680 | -145 244 |
| Ludza Municipality | -158 680 | -145 246 |

*Source: The author's calculation*

The results of the production of biobutanol from grass biomass indicate that this technological solution is not economically efficient as the *NPV* is negative for both options. Moreover, the operational costs exceed benefits (economic value of biobutanol) several times. The reason for such inefficiency is related to the fact that only a small part of organic dry matter is transformed into biobutanol. Thus, it seems that the production of biobutanol per se has hardly potential to become efficient by improving the efficiency of the technology. However, in addition to biobutanol, acetone is being formed (about 50 % of amount of biobutanol) as well as large amounts of dry matter remain as residual that can be used for biogas production. Thus, there is a potential of synergy, if this solution is combined with production of biogases.

The *NPV* for the production of grass pellets from grass biomass is presented in Table 6.

Table 6

**NPV for production of grass pellets**

| Municipality | Options | | |
|---|---|---|---|
| | **I** | **II** | **III** |
| Sigulda Municipality | -61 238 | 106 170 | 522 294 |
| Ludza Municipality | -61 283 | 105 387 | 517 531 |

*Source: The author's calculation*

The calculated results for the production of grass pellets indicate that this is the only solution that has a positive *NPV* at given assumptions. The balance of benefits and costs is positive for two options (option II and III). Thus, this solution can be regarded as economically efficient. Nevertheless, the assessment of the balance of benefits and cost for this solution is based on some assumptions that are estimated with high degree of approximation. For example, the specific investment cost for grass pellet boilers, efficiency rate of grass pellet boilers and the personnel cost are estimated very roughly. Moreover, the potential cost related to nitrogen oxide ($NO_X$) emissions from burning grass pellets has not been considered due to lack of information. However, this cost could become significant in the future.

It should be noted that the results presented in Table 6 have been calculated by using the price of natural gas as reference value (see formula (5) and (8)). Nevertheless, the direct competitor for grass pellets is wood pellets not natural gas. The price of wood pellets (in terms of energy) is lower than natural gas. Moreover, the market of wood pellet boilers is well established, while the market of grass pellet boilers is not developed enough. Thus, the results of the assessment of grass pellet production are quite ambiguous.

Although the study is based on quite local assumptions and estimates, the results outline the balance of benefits and costs for these three solutions generally. The findings of the study can serve as general directions for the developers of these technologies.

## Conclusions

1. The production of grass pellets from grass biomass is the only technological solution from the three ones that has a positive balance of benefits and costs at given assumptions. Nevertheless, there are some challenges for this solution (e.g., emissions of nitrogen oxide, the necessity for special boilers, etc.). The significant challenge is also the price of wood pellets that is quite low.
2. The production of biogas from grass biomass has a negative balance of benefits and cost at given assumptions. However, the results of the options with higher capacity indicate that this solution has a potential to reach a positive balance due to the development of the technology. At the levels of higher capacity the balance between benefits and operational costs is positive or negative only due to high personnel cost. Therefore, improvement and modernisation of this technological solution can make it economically efficient, if the relative investment cost and/or personnel cost is reduced.
3. The production of biobutanol from grass biomass has a negative balance of benefits and cost at given assumptions. Moreover, it is the only technological solution that has negative balance between benefits and operational costs for all the options analysed. This negative balance is caused by very high operational cost (operational cost exceeds benefits several times). Thus, it seems that this solution per se has hardly potential to become efficient due to improvements in the technology. However, as only the part of organic dry matter transforms into biobutanol, there is a potential of synergy, if this solution is combined with production of biogas.
4. Although the cost-benefit analysis of these technological solutions has been carried out on the basis of local data (assumptions, estimates, etc.), the results of the analysis outline the general assessment of these technological solutions. The findings of the study also sketch out the general directions of for the developers of these technologies.

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