Grassification

D3.1.2-3.1.4 and D3.2.4
Techno-Economic Assessment of Agricultural digester

Document Control Page

Title	D3.1.2-3.1.4 Techno-Economic Assessment of Agricultural digester
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Nature	Document
Dissemination Level	Public
Version number	1.0
Version date	31 05 2021

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1 The GRASSIFCATION project

Processing roadside grass clippings is a challenge throughout the 2 Seas Programme area due to their high volume, high processing costs and legal status. The industrial sector, however, is interested in the possibility of using roadside grass clippings as an alternative resource (as opposed to fossil sources or dedicated agricultural produce, e.g. isolation material). The common challenges for applying roadside grass clippings as a renewable feedstock in industrial processes are currently threefold:

- the supply chains are not yet optimal, resulting in higher costs;
- a highly variable and heterogeneous quantity;
- an unsupportive institutional framework leading to legal and political challenges.

The overall objective of the Grassification project is to apply a multi-dimensional approach to roadside grass clippings refining to optimize it into a viable value chain for the biobased and circular economy. The project commits itself to optimize logistics and technical aspects of the grass clippings supply chain and processing, demonstrate its market potential as well as formulate policy and legal recommendations to create a more supportive framework for the recycling of this renewable resource. These actions will increase the volume of usable material, lower costs, and generate a higher added-value for this so-called 'waste' streams. In this way, the use of roadside grass clippings as a renewable resource for the production of biobased products and hence the circular economy will become more attractive.

In this report we specifically evaluate the sustainability of using roadside grass as feedstock for digestion. In the second chapter we describe the methodology used to evaluate the sustainability of this case. Next we introduce the base case, as well as the two reference cases and the assumptions used to do our calculations. In the fourth chapter we describe the results for the three cases. We end this report with the main conclusions.

Project No. 2S03-014:

With the financial support of

www.interreg2seas.eu/en/grassification

2 Methodology

2.1 Techno-Economic Assessment

When developing technologies it is important to have a clear idea on the economic performance of the process. A techno-economic assessment (TEA) can help to optimize the development of a process and to determine the most important parameters. Consistently applying the methodology will enhance chances of success when introducing (innovative) processes on the market. A TEA takes into account the entire value chain and can be applied during every technology readiness level (TRL). The methodology can be divided into four different phases. First, a market study is performed. Second, a preliminary process design is defined and translated into a simplified process flow diagram (PFD) and mass and energy balance. Third, this information is directly integrated into a dynamic cost-benefit analysis (CBA) (i.e. economic evaluation). From this analysis, the profitability is identified. Fourth, an uncertainty analysis is performed to identify the potential barriers. As information gathering is expensive, a TEA is performed in an iterative way with a go/no-go decision after every iteration. A graphical representation of the methodology is provided in Figure 1. A detailed description of the methodology can be found in [1].

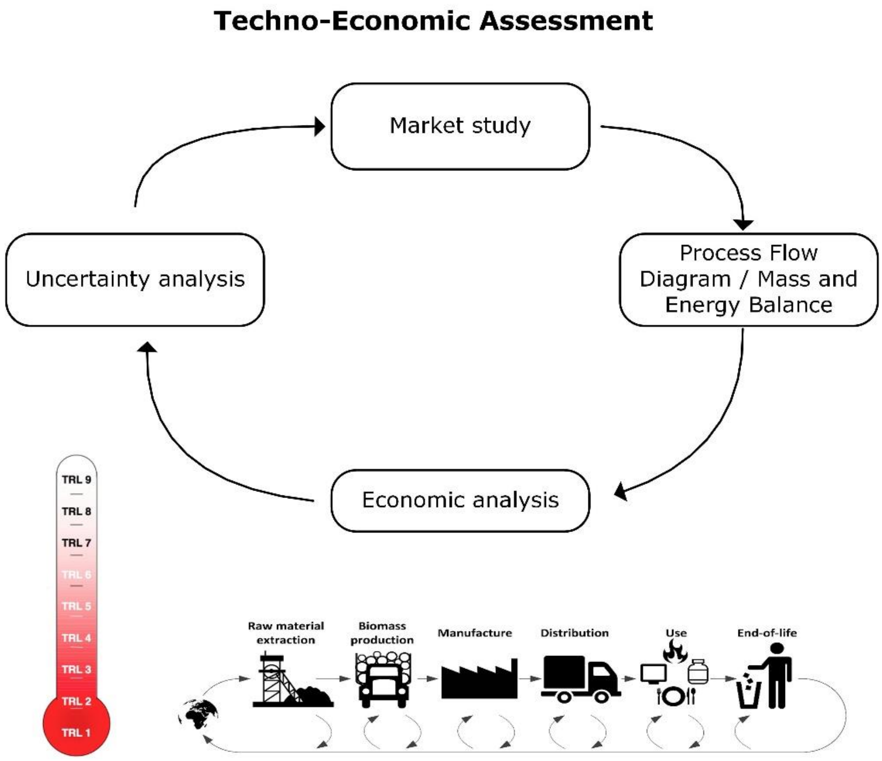

Figure 1. *Techno-economic assessment (TEA)*

2.1.1 Market study

The market study allows the researcher to identify the competitors and customers. It also provides information concerning the size of the market, the needs of the market, and the alternatives on the market. Furthermore, it will also provide information concerning the costs and revenues. Moreover, a market study contains a study of the legislation that is in place. Finally, a market research provides insight into market trends. However, the latter is more difficult to estimate when working with innovative technologies. The results of the market study can be consulted in a separate deliverable 3.1.1.

2.1.2 Process flow diagram and Mass and energy balance

The PFD provides a schematic overview of the main parts in the process and its inputs and outputs. In the first iteration it can even be a block scheme that only shows what goes in and what comes out of the process. Later on, more details can be added when moving through the different development phases. However, keep in mind that a PFD shows only major parts of the process and not details such as piping.

In the mass and energy balance the amount of mass and energy that goes into the process is calculated. It is analysed how this mass and energy use and production is divided over the different steps and how much comes out of the process. When making the mass and energy balance calculations, one should try to make them dependent on each other as much as possible. In other words, the less fixed values that need to be filled when calculating the balances, the better. This is especially important for the fourth phase (i.e. the uncertainty analysis) in which the influence of a change in a technical or economic parameter on the economic feasibility is analysed.

2.1.3 Economic assessment

To check whether the process is economically feasible and thus worthwhile of investigating from an investors point of view, the mass and energy balance calculations are directly coupled with the economic assessment. The economic assessment should give a clear idea of the capital expenditures (CAPEX) and operational expenditures (OPEX) of the technology, and also contains a calculation of the benefits. Using this information, the net present value (NPV), internal rate of return (IRR), payback period (PBP) and discounted payback period (DPBP) are calculated.

The NPV gives an indication of the profitability of the technology using equation [1], where T is the life span of the investment, CF_n the difference between revenues and costs in year n, I_0 the initial investment in year 0, and i the discount rate. A technology is considered interesting when the NPV is positive [2, 3]. The NPV compares the amount of money invested in a project today to the present value of the future cash receipts from the investment. In other words, the amount invested is compared to the future cash amounts after they are discounted by a specified rate of return (i.e. discount rate). The NPV considers the investment today and the revenues and expenses from each year of the lifetime of a project. The more risky an investment, the higher the estimated discount rate has to be. Typical discount rates are (i) 10% for cost improvement of conventional technologies, (ii) 15% for the expansion of conventional technologies, (iii) 20% for product development, and (iv) 30% for speculative venture [4]. However, in most articles a discount rate of 10-15% is opted in combination with a life span of 10-15 years.

$$NPV = \sum_{n=1}^{T} \frac{CF_n}{(1+i)^n} - I_0 \qquad [1]$$

Other popular measures for evaluating whether an investment is financially worthwhile are the DPBP and the internal rate of return IRR. The payback period is defined as the point in time when the initial investment is paid back by the net incoming cash flows, but it has the disadvantage of not taking into account the time value of money. Therefore, one can use the discounted payback period (DPBP) that does take into account the time value of money. The DPBP can be calculated using equation [2]. In the equation CF is the difference between revenues and costs, i is the discount rate and I_0 is the initial investment cost. The shorter the DPBP the more attractive the investment is. The IRR is the discount rate at which the NPV is zero. It thus equates the present value of the future cash flows of an investment with the initial investment and provides the effective interest rate being earned on a project after taking into consideration the time periods when the various cash amounts are flowing in or out. For an IRR to be attractive for an investor it must be higher than the return rate that can be generated in lower risk markets or investments than the project, e.g. saving the investment money in a bank or investing in safe, low-risk bonds. Because the IRR is a percentage, it can only be used as a decision rule for selecting projects when there is only one alternative to a status quo and should certainly not be used to select one project from a group of mutually exclusive projects that differ in size [5]. Therefore, when one has to choose between more than one technology or process (i.e. alternatives), the NPV ranking is mostly preferred over the IRR ranking [6].

$$DPBP = \frac{ln\left(\frac{CF}{CF-iI_0}\right)}{\ln(1+i)} \qquad [2]$$

2.1.4 Uncertainty analysis

As the values used for the calculations are uncertain, an uncertainty analysis or risk analysis is performed. The prediction of the values is often based on literature and checked with expert opinion. The values are therefore deterministic rather than stochastic. A Monte Carlo simulation (50,000 trials) is performed to identify the parameters that have the highest influence on the economic feasibility. Within this analysis, the variables (technical as well as economic) are varied following a triangular distribution with a positive and negative change of maximum 10% [7]. The goal of this kind of quick scan is to determine the parameters that have the highest impact on the variance of e.g. the NPV. The analysis searches for the parameters that should be investigated into more detail. For these parameters a local sensitivity using what-if analysis is performed to see how changes in these parameters influence the economic feasibility.

3 Agricultural digester

3.1 Base case description

In the base case of 'Agricultural digester' we evaluate the techno-economic feasibility of co-digestion of roadside grass with VeDoWS manure and pig slurry in a pocket digester.

For the models we make maximal use of the data that is available from the pilot tests that were performed at Inagro in their pocket digester. Inagro has a continuous stirred-tank reactor (CSTR) available of 200 m^3 that is operated at mesophilic conditions (i.e. temperature of approximately 38°C). The biogas is sent to a combined heat and power (CHP) engine. The co-digestion installation runs the entire year and preferably has a homogenized input, whereas the roadside grass is only cut twice a year. Therefore, ensiling of the grass is needed. The grass Inagro received within the Grassification project was ensiled in a trench silo, without any pre-treatment or additives. The presence of litter in the roadside grass can damage the installation and should therefore be removed. For the pilot test at Inagro, the litter is removed by hand picking. A more detailed technical description of the pilot test at Inagro can be found in D 1.4.1 'Co-digestion of roadside grass with VeDoWS manure and pig slurry' of the Grassification project.

A small scale digester or pocket digester has a size up to 200 kWe[1] and a typical pocket digester in Flanders has a size of 10 kWe to 30 kWe. We start our base case scenario with a total digester input of 3000 ton per year which is in line with the pilot test at Inagro. With the assumptions made in this study, we calculated a required pocket digester size of ca. 55 kWe, which is a bit larger than the pocket digester at Inagro. We assume that roadside grass is brought to the co-digestion site on a yearly basis. Following the assumptions of the Transbio project, we assume that 50% of the grass is ensiled on site as the grass is not available during the full year. The other 50% is fed directly into the digester when it comes available or is stored for only a very short time span [8]. In the pilot test, roadside grass is mown, after which it is ensiled without any further pre-treatment. However, one needs to take into account that in practice, depending on the amount of sand and litter, some pre-treatment might be necessary.

The sand is less of a problem as it mainly influences the available active volume of the reactor after a while, but does not cause significant damage to the reactor or its components. It might cause some damage to e.g. the pumps or screws, however, it is expected that this impact will be limited. The sand might also affect the biogas production, but more research needs to be done to identify the exact effect. One might think of washing the grass to remove the sand, however, it is not sure that this would greatly impact the amount of sand that enters the reactor and with the increased pressure on our water availability, this is not the preferred option. Therefore, for the sand it is best to adapt the mowing head and as such minimize the amount of sand in the roadside grass mown, as is done within the Grassification project, i.e. new,

[1] https://www.inagro.be/DNN_DropZone/Publicaties/6633/pocketvergisting-module1.pdf

adapted mowing head of Vandaele (see Deliverable 1.1.2). The sand that still enters the reactor will have to be removed after a couple of years. Adapting the design of the pocket digester with e.g. a ground scraper would be too costly [9].

To remove the litter, one can look at the pre-treatment processes used at a composting facility. There they can use a magnetic separator (either before or after composting), a shredder, a sieve and a wind shifter (rather used on the end product and not before composting). In the 'Graskracht' project they looked at potential pre-treatment steps and concluded that probably a sieve can be used. However, in the OVAM report (2009)[2] on the integrated processing possibilities for roadside grass, they report a loss of around 1/3rd of the grass when using a star sieve. A washing step is not used at composting facilities and will probably also not be used as a pre-treatment before digestion due to reasons described in the previous paragraph. Some pre-treatment steps that are used to homogenize the feedstock, also contain a 'heavy-object'-removal systems for e.g. stones as described in the final report of the Graskracht project. It is clear that different pre-treatment technologies exist, however, that none of them has proven to be highly efficient for roadside grass. Probably the best option is to make good agreements with the mowing contractor on the required quality of the roadside grass as they often know best in which areas a lot of litter is present, e.g. in the neighbourhood of take-away fast food chains, and as a consequence can be kept separate from rather clean roadside grass for further processing in a (pocket) digester. A more elaborated overview of options for litter removal is provided in the Grassification deliverable 1.6.1 on pre-treatment of grass cuttings.

The roadside grass is fed into the pocket digester, together with VeDoWS manure and pig slurry, in a ratio of 20wt%, 33wt% and 47wt% respectively. Feeding only roadside grass into the CSTR reactor is not possible due to its fibrous structure, i.e. the fibres rotate tightly around the mixer. Adding the roadside grass has the advantage of stabilizing the digestion process, maintaining an optimal pH for methanogens, decrease the ammonia/ammonium inhibition and to provide a better carbon/nitrogen (C/N) ratio[3]. To have a sufficient biogas production, VeDoWS manure is added, however, pig slurry is also needed to allow mixing, i.e. have the right viscosity as the dry matter (DM) content of the VeDoWS manure is too high. For a pocket digester the dry matter content of the input should be below 20% [9]. The roadside grass and VeDoWS manure are fed into the digester using a feeder to size and homogenize the input.

The biogas potential in the base case is ca. 110 m^3/ton, 25 m^3/ton and 130 m^3/ton for respectively roadside grass, pig slurry and VeDoWS manure. Note that we do not take a different biogas yield into account for spring or autumn cuttings or for fresh or ensiled roadside grass. According to several studies in Flanders such as Graskracht, Bermg(r)as and Syneco, the biogas yield of grass ranges between 40 and 180 Nm^3/ton, therefore, an average value of 110 m^3/ton seems reasonable [8, 10]. The biogas yield for manure is based on the results of the Grassification pilot tests and the pocket power report where they use a biogas yield of 25 m^3/ton for pig slurry and 110 m^3/ton for VeDoWS manure with the highest measured value of 138 m^3/ton for VeDoWS manure. The impact of the biogas yield on the economic feasibility is

[2] https://www.ovam.be/sites/default/files/Ge%C3%AFntegreerde%20verwerkingsmogelijkheden%20van%20bermmaaisel.pdf
[3] Anaerobic co-digestion of grass clippings – Decentralized biogas production. Grassification project.

provided in the sensitivity analysis. The methane content of the biogas remained at around 58%, despite the lower methane content in the biogas originating from the grass, i.e. ca. 54%. The retention time at Inagro was 35 days. For pocket digestion a minimum of 30 days is required [9]. We assume total operating hours of 7500 per year, in accordance with what is guaranteed by the technology providers. Due to the input of grass, the mixer needed to be used more intensively to assure a good mixing and as such avoid a floating layer. Therefore, we assume an electricity use of 25% of the own production. To keep the digester at temperature during the whole year, we assume that all produced heat is needed.

The biogas is sent to a CHP installation with an overall efficiency of 85%. The electrical efficiency amounts to 35% and thermal efficiency to 50%. The operating hours are equal to these of the digester. For the lifetime of the CHP installation we take a total of 30,000 hours into account, or in our case a lifetime of 4 years is assumed. This assumption is based on the feedback that Inagro received from a questionnaire in 2020 over the period 2011-2019.

The digestate that results from pocket digestion has a dry matter content of around 9-14%. In case only manure is digested, a hygienization of the thick fraction, after separation, during 60 min at 70°C is obliged if it is transported abroad (Regulation (EG) 142/2011 Annex XI, Chapter I, Section 2). However, when roadside grass is added to the digester, this post-treatment is not sufficient to guarantee the elimination of all weed seeds and plant pathogens. Instead a post-composting of the digestate in its entirety is obliged according to the 'Actieplan Duurzaam beheer van biomassa(rest)stromen 2015-2020' if it is used as fertilizer or soil conditioner[4]. The digestate needs to be composted according to the conditions for organic municipal solid waste (OMSW) for at least four weeks at 45°C, of which a minimum of four consecutive days the temperature needs to be minimally 60°C or for minimum four weeks with a minimum temperature of 45°C and a minimum of twelve consecutive days a temperature of 55°C. Normally roadside grass is categorized as green waste, however, due to the pre-digestion, it is acceptable to follow the hygienization requirements for OMSW pre-digestion with post-composting. During the post-composting the moisture content needs to be controlled. In this report we will use the term OMSW to refer to what in Dutch is called GFT – Groente, Fruit en Tuinafval or vegetable, fruit and garden waste.

For composting the dry matter content should be between 40% and 50%, this means that we need to add e.g. structure material or green waste to the digestate as the dry matter content is only around 12%. An installation that has a permit for manure composting can add green waste that results from their own facilities and the land belonging to the facility. However, roadside grass will not come from their own facilities. Therefore, due to the co-feeding of roadside grass and manure, the digestate needs to be composted at a facility with a permit for waste and manure treatment in accordance with the Waste and Manure Decree. In this study we assume that 10% green waste, 15% structure material and 25% sieve overflow is added to the digestate, this is in line with what is described in the Syneco project[5]. We assume an

[4] https://www.ovam.be/voorwaarden-voor-het-vergisten-van-bermmaaisel

[5] https://www.vlaco.be/kenniscentrum/onderzoeksprojecten/syneco

electricity use of 45 kWh/ton[6]. After post-composting, a star sieve is used to further refine the end-product, however, the costs for such a sieve are not taken into account in this assessment.

A schematic representation of the base case process flow diagram is provided in Figure 2.

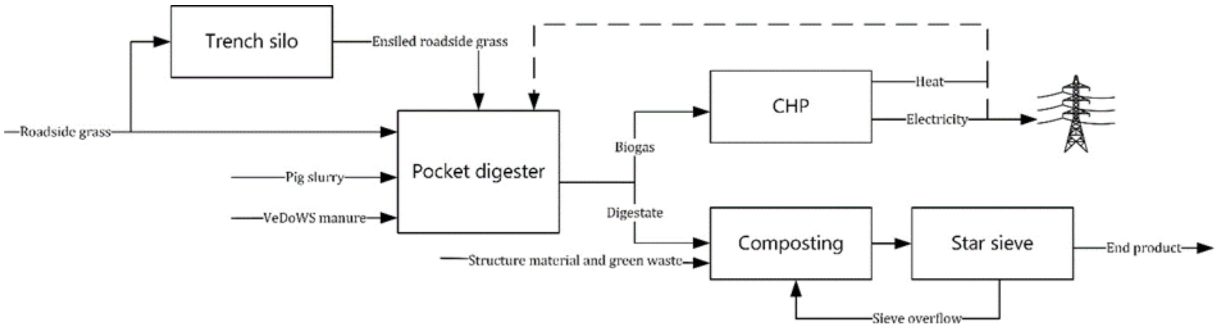

Figure 2. *Process flow diagram - base case*

Based on the process flow diagram, a dynamic mass and energy balance is built in Excel. The values for the input parameters of the base case are provided in Table 1. Many of the parameters are still uncertain and more tests need to be performed to better understand the technical operating window. However, starting from these base values, combined with a sensitivity analysis, we can already identify the most important technical parameters that influence the economic feasibility and also define some target values that should be reached. Most of the data is coming from or confirmed by Inagro or described in the paragraphs above.

Table 1. *Input parameters mass and energy balance - base case*

Parameter	Value	Unit
Input roadside grass	20	wt%
Input VeDoWS manure	33	wt%
Input pig slurry	47	wt%
Biogas potential roadside grass	110	m^3/ton
Biogas potential VeDoWS manure	130	m^3/ton
Biogas potential pig slurry	25	m^3/ton
Methane content biogas roadside grass	54	%
Methane content biogas manure	58	%
Methane content biogas overall	58	%
Density roadside grass in reactor	700	kg/m^3
Density pig slurry	1040	kg/m^3
Density VeDoWS	800	kg/m^3
Temperature digester	38	°C
Retention time digester	35	days
Void fraction digester	30	%
Electricity use digester	25	% own production
Heat use digester	100	% own production
Total efficiency CHP	85	%
Electrical efficiency CHP	35	%
Thermal efficiency CHP	50	%
Operating hours CHP	7500	hours/year

[6] https://emis.vito.be/sites/emis/files/pages/migrated/BBT_rapport_composteerinstallaties_volledig_document.pdf

Dry matter digestate	12	wt%
Storage digestate	270	days
Retention time composting	4	weeks
Green waste in composting	10	wt% input
Structure material in composting	15	wt% input
Sieve overflow in composting	25	wt% input
Electricity use composting	45	kWh/ton
Compost	35	wt% input
CHP = Combined heat and power		

The dynamic mass and energy balance is directly linked with the economic assessment in Excel. The base values for the economic parameters in the base case are provided in Table 2. Also these parameters are uncertain and the impact of changes in these are evaluated in the sensitivity analysis described in the next chapter. Note that we do not take any subsidies into account, nor do we take all cost factors into account. In this study we focus on the large cost factors to get an idea of the possibilities. Including all costs is relevant if one wants to calculate the specific business case at a specific farm.

For roadside grass we use the same gate fee that is currently paid at a composting facility as the base value. Current gate fees at the composting facility range from 20-60 euro/ton according to several sources, however, most studies use a gate fee of 35 to 40 euro/ton for grass or green waste [8]. For the manure we use a gate fee of 17 euro/ton for pig slurry and 12 euro/ton for VeDoWS manure. For manure a price of 16-18 euro/ton needs to be paid at a manure processing facility as reported in the 'addendum BBT voor mestverwerking'[7]. The gate fee for manure is only taken into account when the digester owner processes manure from another farmer. In the base case we assume that the farmer only processes its own manure and no gate fee is considered, nor an avoided cost.

The investment cost of the pocket digester and CHP is estimated based on costs reported in the Pocket Power, Transbio and Bin2Grid project. For the Bin2Grid project the cogeneration was not included, and therefore was added using data available at VITO. The resulting regression function is provided in the graph in Figure 3. The lifetime of the pocket digester and CHP are different. We assume a reinvest of 25% of the reported pocket digester + CHP investment to replace the CHP only.

[7] https://emis.vito.be/sites/emis/files/study/Eindrapport_addendum_bij_BBT_mestverwerking_versie_sept_2020.pdf

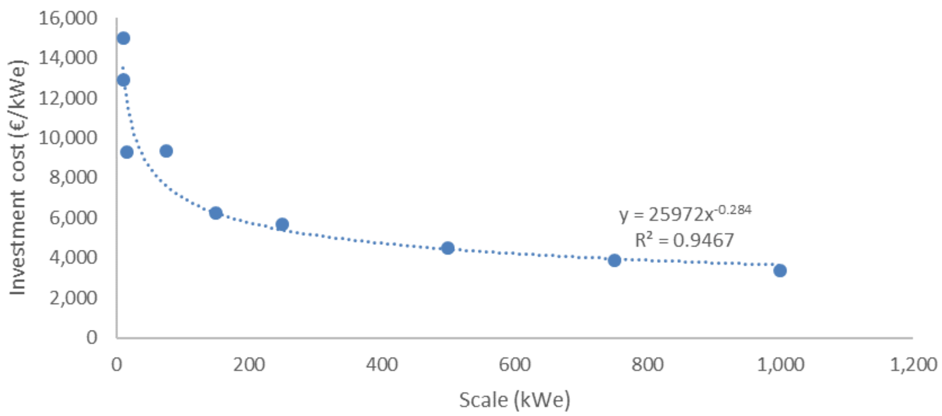

Figure 3. *Investment cost pocket digester + CHP*

Similar to the investment cost, we estimated the operation and maintenance (O&M) cost of the digester and CHP based on values reported in the Pocket Power and Bin2Grid project. The regression function is provided in Figure 4.

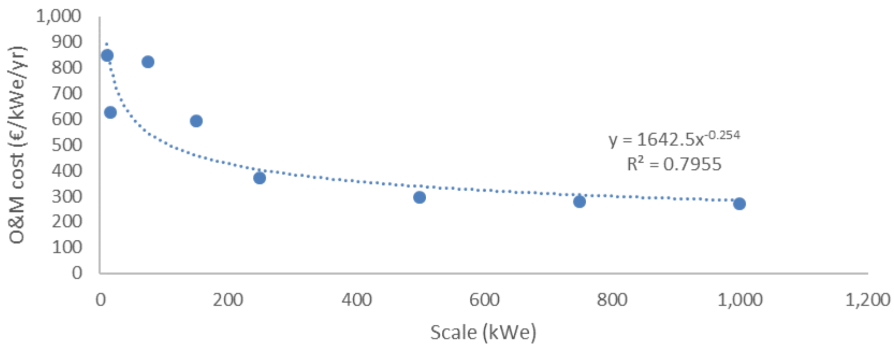

Figure 4. *Operating and maintenance cost pocket digester + CHP*

Most of the cost reported in Table 2 are either VITO or Inagro data, or are reported by the Transbio or Pocket power project. For the silage we used a scaling factor of 0.6 in case the volume needed per silo is below the reference size of 600 m^3. The cost for silage is ca. 40 euro/m^3, however, this cost might be higher if you would also consider costs for e.g. access roads and drainage to sewers.

Table 2. *Input parameters economic assessment - base case*

Parameter	Value	Unit
WACC	5.5	%
Economic lifetime	10	year
Site preparation	10	% total investment
Personnel	30	€/hour
Purchase price natural gas	30	€/MWh
Selling price electricity	47	€/MWh
Gate fee grass @digester	35	€/ton
Gate fee green waste @composting	35	€/ton
Repair cost	1	% total investment

Insurance cost	0.5	% total investment
Investment cost silage	25,000	€ for 600m^3
Lifetime silage	10	year
O&M cost silage	1.6	€/ton
Investment cost feeder	33,000	€
Lifetime feeder	10	year
Investment cost digester + CHP	See formula	€/kWe
Reinvestment cost CHP	25	% investment digester + CHP
Lifetime digester	10	year
Lifetime CHP	30.000	hr
O&M cost digester + CHP	See formula	€/kWe
Operating personnel digester	1	hr/week
Investment storage tank digestate	30	€/m^3
Total cost composting	35	€/ton
Selling price end-product	4	€/ton
CHP = Combined heat and power		
O&M = Operation and maintenance		
WACC = Weighted average cost of capital		

3.2 Reference cases description

To have a good idea of the impact of roadside grass as feedstock for pocket digestion on the economic feasibility, we also perform a techno-economic assessment for a reference case with a pocket digester without roadside grass. We also do the calculations for a second reference case where we add roadside grass to a OMSW digester. We describe the two reference cases below in detail.

3.2.1 Reference case 1 – pocket digestion without roadside grass

The first reference case is a pocket digester in which no roadside grass is added. In this case the roadside grass is replaced by more VeDoWS manure and the resulting digestate is not composted in its entirety, however, is separated into a thin and thick fraction using a centrifuge. The thin fraction is spread on the fields of the farmer and the thick fraction is further processed using a biothermal drying, i.e. composting, after which the end-product is exported.

For the centrifuge, we base ourselves on the assumptions described in the DIMA report[8]. We assume that 85% of the input is separated as the thin fraction and 15% as thick fraction. The electricity consumption amounts to 4 kWh/ton. We take an investment cost into account of 100,000 euro and an operational cost of 2 euro/ton, however, the centrifuge can also be rented at a cost of ca. 4 euro/m^3. A minimum of 1000-2000 ton is reported by Gorissen and Snauwaert [11] to invest in an own centrifuge.

For the composting of the thick fraction, we assume a closed system comparable to the OMSW composting and therefore, assume the same energy consumption. As the composting takes less time, we assume a lower cost per ton processed. An alternative can be trommel composting. It needs to be noted that, independent of the exact system, the composting of the thick fraction alone might not meet the hygienization requirements (i.e. 1hr at 70°C). In

[8] https://www.vlaco.be/kenniscentrum/onderzoeksprojecten/dima

practice often chicken manure is added to make sure that a sufficiently high temperature is reached. In this report we did not include this.

Here we assume that the thin fraction is spread on the fields at a cost of 5 €/ton, however, in case that is not possible, the thin fraction needs to be further processed in e.g. a biology. The cost per ton of thin fraction processed will, in that case, be much higher and amount to ca. 14 euro/ton[7].

The process flow diagram of this reference case can be found in Figure 5.

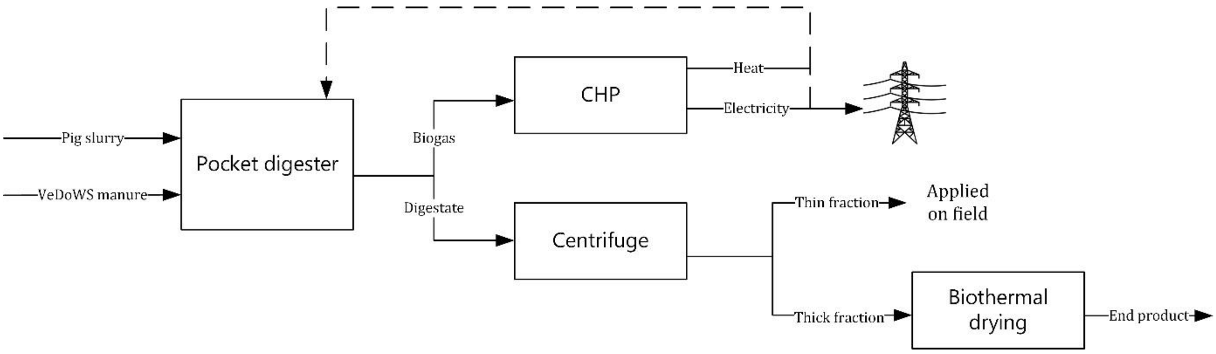

Figure 5. *Process flow diagram - reference case 1*

The assumptions for the mass and energy balance and the economic assessment of the reference case can be found in Table 3 and Table 4 respectively.

Table 3. *Input parameters mass and energy balance - reference case 1*

Parameter	Value	Unit
Input VeDoWS manure	53	wt%
Input pig slurry	47	wt%
Biogas potential VeDoWS manure	130	m^3/ton
Biogas potential pig slurry	25	m^3/ton
Methane content biogas manure	58	%
Density pig slurry	1040	kg/m^3
Density VeDoWS	800	kg/m^3
Temperature digester	38	°C
Retention time digester	35	days
Void fraction digester	30	%
Electricity use digester	15	% own production
Heat use digester	100	% own production
Total efficiency CHP	85	%
Electrical efficiency CHP	35	%
Thermal efficiency CHP	50	%
Maximum operating hours CHP	7500	hours/year
Dry matter digestate	12	wt%
Storage digestate	270	days
Thin fraction centrifuge	85	wt%
Thick fraction centrifuge	15	wt%
Electricity use centrifuge	4	kWh/ton
Retention time composting	72	hours
Compost	50	wt% input

Electricity use composting	45	kWh/ton
CHP = Combined heat and power		

Table 4. *Input parameters economic assessment - reference case 1*

Parameter	Value	Unit
WACC	5.5	%
Economic lifetime	10	year
Site preparation	10	% of total investment
Internal personnel	30	€/hour
Purchase price natural gas	30	€/MWh
Selling price electricity	47	€/MWh
Gate fee pig slurry @digester	17	€/ton
Gate fee VeDoWS @digester	12	€/ton
Repair cost	1	% investment
Insurance cost	0.5	% investment
Investment cost silage	25,000	€ for 600m^3
Lifetime silage	10	year
O&M cost silage	1.6	€/ton
Investment cost feeder	33,000	€
Lifetime feeder	10	year
Investment cost digester + CHP	See formula	€/kWe
Lifetime digester + CHP	10	year
O&M cost digester + CHP	See formula	€/kWe
Personnel digester - operation	1	hr/week
Investment storage tank digestate	30	€/m^3
Investment cost centrifuge	100,000	€
Operational cost centrifuge	2	€/ton
Rent mobile centrifuge	4	€/ton
Disposal cost thin fraction	5	€/ton
Total cost composting	15	€/ton
Selling price end-product	4	€/ton
WACC = Weighted average cost of capital O&M = Operation and maintenance		

3.2.2 Reference case 2 – OMSW digestion with roadside grass

We add a second reference case to be able to compare the impact of a different type of digester, as well as a different scale. In this case we add the roadside grass into a dry, thermophilic digester of the dranco type together with OMSW. The digestate is mixed with green waste and structure material to be further processed in a tunnel composting to produce qualitative compost. Figure 6 gives a schematic representation of the case.

For this reference case there are already existing facilities in Flanders such as the installation at IOK in Beerse and IGEAN in Brecht. Both intercommunal waste processors have a dry digester for OMSW with a composting installation. Also IVVO in Ieper has invested in a digester, however, they make use of a wet digester for OMSW, combined with a composting installation. Other intercommunal waste processors also planned to build a digester for OMSW, i.e. Verko and Ecowerf. At Verko they even plan to add roadside grass as feedstock.[9] Currently only IOK has installed a biogas upgrading facility. Verko is also planning to invest in such an upgrading installation. The others have installed a CHP for the biogas. Also in our reference case we will include a CHP.

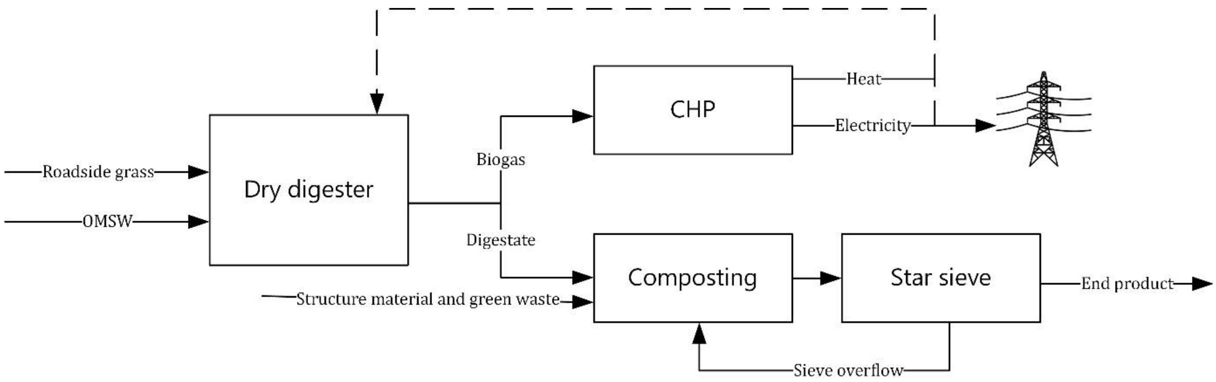

Figure 6. *Process flow diagram - reference case 2*

In our model we assume a total digestion capacity of 30,000 ton per year, of which 20% is roadside grass and the remainder is OMSW. We will use the same biogas potential for roadside grass as in the case for pocket digestion. A difference might exists in practice, however, seeing the large potential range provided in literature and the impact of several external parameters on this potential yield, we will use the same biogas yield of 110 Nm^3/ton. For OMSW we take a biogas yield of 120 Nm^3/ton into account. For the dry digester we consider a shorter retention time of 25 days and an electricity and heat consumption of 15% and 10% of the own production respectively. Here we do not take an ensiling into account, nor a storage of the digestate and assume that the roadside grass is added to the digester when it becomes available. When the roadside grass is not available, the digester shifts to 100% OMSW. However, taking into account that the composting facilities are interested in roadside grass to compensate for the reduced availability of OMSW in winter, it might be more beneficial to foresee an ensiling in this second reference case as well.

For the dry digester we take the investment cost into account as described in Van Dael, Kreps [12]. We also consider a maintenance cost of 2% of the investment cost and a gate fee for OMSW of 60 euro/ton.

For the CHP we assume the same efficiencies, however, investment and operational costs will be calculated separately from the digester in this reference case. For the composting installation we will use the same assumptions as in the base case. An overview of the different parameters is provided in Table 5 for the mass and energy balance and Table 6 for the economic assumptions.

[9] https://www.vlaco.be/nieuws/nieuwe-voorvergistingsinstallaties-van-gft-bij-verko-en-ecowerf

Table 5. *Input parameters mass and energy balance - reference case 2*

Parameter	Value	Unit
Input roadside grass	20	wt%
Input OMSW	80	wt%
Biogas potential roadside grass	110	m^3/ton
Biogas potential OMSW	120	m^3/ton
Methane content biogas roadside grass	54	%
Methane content biogas OMSW	55	%
Density roadside grass in reactor	700	kg/m^3
Density OMSW	600	kg/m^3
Temperature digester	48	°C
Retention time digester	25	days
Electricity use digester	15	% own production
Heat use digester	10	% own production
Total efficiency CHP	85	%
Electrical efficiency CHP	35	%
Thermal efficiency CHP	50	%
Operating hours CHP	7500	hours/year
Dry matter digestate	20	wt%
Retention time composting	4	weeks
Green waste in composting	10	Wt% input
Structure material in composting	15	wt% input
Sieve overflow in composting	25	wt% input
Electricity use composting	45	kWh/ton
Compost	35	wt% input
CHP = Combined heat and power OMSW = Organic municipal solid waste		

Table 6. *Input parameters economic assessment - reference case 2*

Parameter	Value	Unit
WACC	5.5	%
Economic lifetime	10	year
Site preparation	10	% total investment
Personnel	30	€/hour
Purchase price natural gas	30	€/MWh
Selling price electricity	47	€/MWh
Gate fee grass @digester	35	€/ton
Gate fee OMSW @digester	60	€/ton
Gate fee green waste @composting	35	€/ton
Repair cost	1	% total investment
Insurance cost	0.5	% total investment
Investment cost digester	See [12]	€/m^3
Investment cost CHP	1025	€/kWe
Lifetime digester	10	year
Lifetime CHP	10	year
Maintenance digester	2	% investment digester
Maintenance CHP	8	% investment CHP
Repair cost CHP	4	% investment CHP

Total cost composting	35	€/ton
Selling price end-product	4	€/ton
CHP = Combined heat and power		
O&M = Operation and maintenance		
OMSW = Organic municipal solid waste		
WACC = Weighted average cost of capital		

The results for all cases are described in the next chapter.

4 Results and sensitivity

In this chapter the results of the three cases will be discussed. We present the mass and energy balance, result of the economic assessment, as well as the sensitivity analysis.

4.1.1 Base case – Pocket digester with roadside grass

The mass and energy balance is visually represented in Figure 7. The total input is 3000 ton of feedstock per year in the digester and an additional 1365 ton in the composting installation, resulting in 1430 ton of end-product and 75 MWh of electricity sold to the grid.

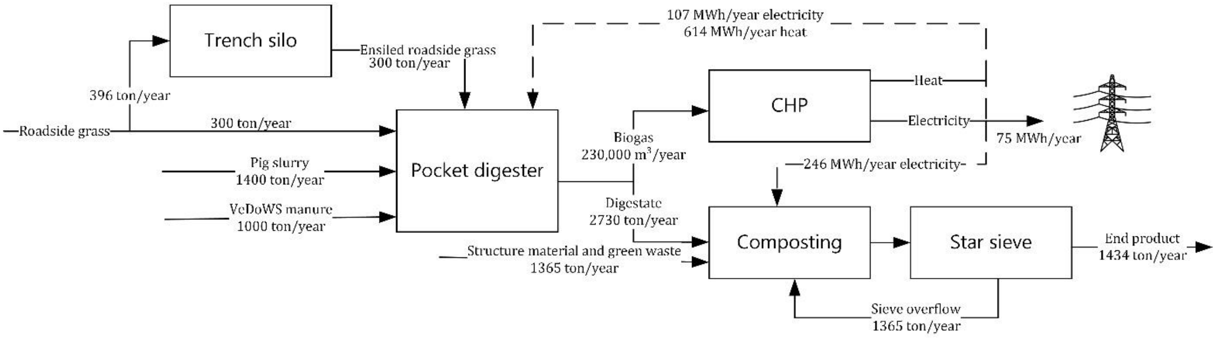

Figure 7. *Mass and energy balance – base case*

The total investment cost for the base case amounts to ca. 660,000 euro. The investment in the digester and CHP take up more than 70% of this cost. The yearly operational costs are 235,000 euro, mainly consisting of the operation and maintenance cost of the digester and CHP, as well as the costs for composting with a share of 14% and 81% respectively. The high costs for composting are due to the obligation to compost the digestate in its entirety. The revenues from the selling of the excess electricity and compost and the gate fees for roadside grass and green waste do not compensate for the costs and amount to ca. 50,000 euro per year. A cost breakdown based on the annualized investment costs and operational costs is provided in Figure 8.

If we calculate the cost per ton of feedstock processed in the digester, i.e. excluding green waste and structure material that are added at the composting facility, we find a cost of more than 100 euro/ton. This is very high compared to the potential gate fee for roadside grass of 35 euro/ton at a composting installation and of 12-18 euro/ton depending on the manure type at a manure processing facility.

The biogas is produced at a cost of 0.49 euro/m^3, exclusive the costs for the digestate treatment. All other costs are allocated to the biogas production. If we take the revenues into account, the costs for the biogas production amount to 0.39 euro/m^3 or almost 19 euro/GJ which is higher compared to the natural gas price of 12.5 euro/GJ for a small industrial user according to the prices of Eurostat 2020. Furthermore, the biogas is not yet upgraded to natural gas quality and therefore, additional investments in an upgrading installation should be made and the amount of biomethane is lower compared to the biogas yield.

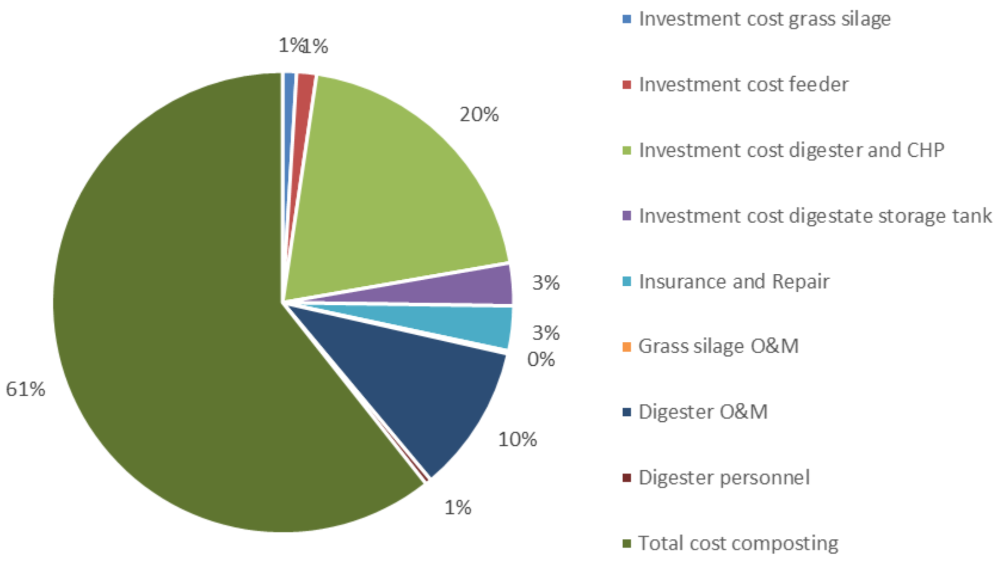

Figure 8. *Cost breakdown – base case*

To have an idea of the impact of the biogas potential from the feedstock on the biogas production cost, we varied the biogas potential of pig slurry and roadside grass. We kept the input amount and the size of the digester and CHP constant. In Figure 9 it can be seen that varying the biogas yield over the chosen ranges, varies the biogas production cost from 0.45 to 0.65 euro/m^3. If we, however, assume that also the size of the CHP needed varies due to the higher biogas volumes, the range is smaller and varies from 0.48 to 0.55 euro/m^3. If we would vary the biogas yield of the VeDoWS manure you will have the same effect as varying the biogas yield of the roadside grass as the biogas yields for both feedstocks are in the same order of magnitude.

Roadside grass (Nm³/ton) \ Pig slurry (Nm³/ton)	15	20	25	30	35
40	€ 0.65	€ 0.63	€ 0.60	€ 0.58	€ 0.56
50	€ 0.63	€ 0.61	€ 0.58	€ 0.56	€ 0.54
60	€ 0.61	€ 0.59	€ 0.57	€ 0.55	€ 0.53
70	€ 0.59	€ 0.57	€ 0.55	€ 0.53	€ 0.51
80	€ 0.57	€ 0.55	€ 0.53	€ 0.52	€ 0.50
90	€ 0.56	€ 0.54	€ 0.52	€ 0.50	€ 0.49
100	€ 0.54	€ 0.52	€ 0.51	€ 0.49	€ 0.48
110	€ 0.52	€ 0.51	€ 0.49	€ 0.48	€ 0.46
115	€ 0.52	€ 0.50	€ 0.49	€ 0.47	€ 0.46
120	€ 0.51	€ 0.49	€ 0.48	€ 0.47	€ 0.45

High cost
Low cost

Figure 9. *Impact biogas yield on biogas production cost – base case*

To evaluate the effect of adding roadside grass to the reactor, we vary the amount of roadside grass from 5 to 20 wt% of the total feedstock. We keep the amount of pig slurry constant at 47 wt% and the rest is VeDoWS manure. At the same time we vary the biogas potential of the roadside grass from 40 to 120 Nm^3/ton. Figure 10 clearly shows that the effect of roadside grass on the biogas cost is highest with a lower biogas yield and higher share in the total feedstock. This effect decreases strongly and almost disappears when the biogas yield is higher than 100 Nm^3/ton. In case the amount of roadside grass is only 5%, there is barely an effect noticeable on the biogas production cost. With lower amounts of roadside grass, a small effect might take place due to the lower need for electricity to stir the reactor, however, we did not calculate that effect in this sensitivity analysis as the effect is very small. Varying the electricity use in the reactor over a range of 5% to 30%, only varies the biogas production cost with 0.02 euro/m^3.

It should be noted that the effect of varying the biogas potential yield of roadside grass on the biogas production cost is very limited with low amounts of roadside grass, however, the biggest impact of adding roadside grass is on the digestate processing cost and this is independent of the amount of roadside grass that is added. Therefore, we included the first reference case to see how the economic feasibility of the pocket digester changes when adding no roadside grass at all.

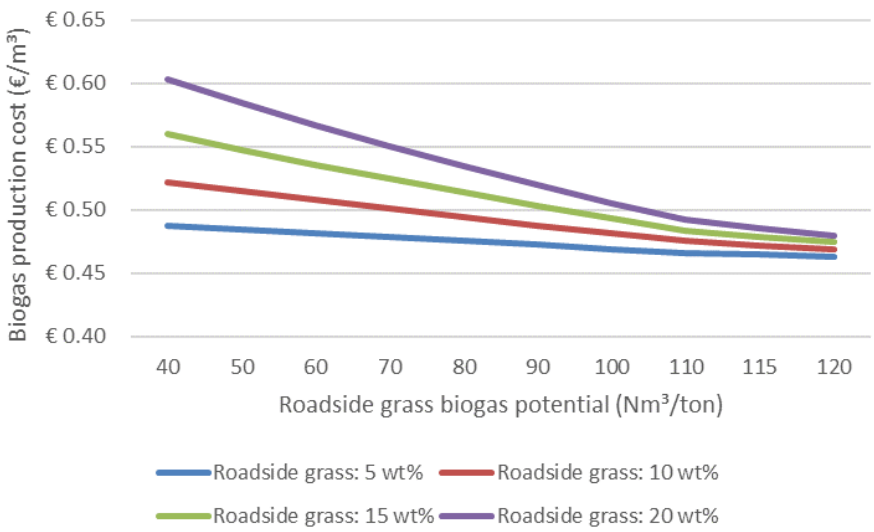

Figure 10. *Impact roadside grass amount and biogas yield on biogas production cost – base case*

4.1.2 Reference case 1 – Pocket digester without roadside grass

In the first reference case a total of 3000 ton consisting of only pig slurry and VeDoWS manure is processed in the digester, resulting in 204 ton of end-product and 314 MWh/year of electricity sold to the grid. A graphical representation of the mass and energy balance is provided in Figure 11.

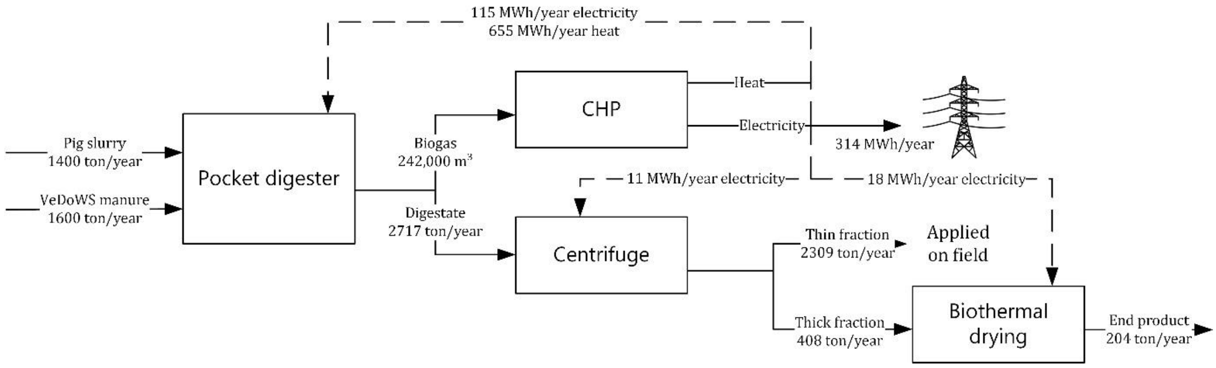

Figure 11. *Mass and energy balance – reference case 1*

In the reference case the total investment cost is slightly higher compared to the base case and amounts to almost 770,000 euro. The reason for the higher investment cost is the addition of the centrifuge which is much higher compared to the avoided cost in the silage. The operational costs are much lower and amount to only 70,000 euro per year compared to over 200,000 euro in the base case. This is due to the combination that only the thick fraction needs to be composted and the lower cost per ton for composting. Note that we took a lower cost per ton input for composting into account compared to the base case, as the composting duration is less long and therefore, the same composting facility can be used for a larger throughput per year. Not only the operational costs decrease in this case, but also the revenues are highly decreased as no gate fee is received in this first reference scenario. The revenues are only coming from the sale of the end-product and excess electricity sold to the grid.

The total processing cost per ton of feedstock is reduced with 50% compared to the base case to 50 euro/ton, however, the production cost for the biogas is slightly increased to 0.42 euro/m^3 if we take the revenues into account. This is due to the fact that we did not allocate the cost for digestate treatment to the biogas production. In the first reference case it is mainly the digestate treatment that is impacted. A cost breakdown per m^3 of biogas produced, excluding the digestate treatment costs, is provided in Figure 12. In this figure the CAPEX or capital expenditures are synonym for the investment costs. We annualized the investment costs to calculate the production cost per m^3 of biogas. From the figure it is clear that the revenues are not sufficient to compensate for the costs. The revenues from the electricity can be slightly increased if we would assume that the electricity is used at the farm and as such avoid the use of electricity from the grid. The avoided cost for electricity is higher compared to the selling price of excess electricity to the grid as we also avoid e.g. distribution costs if we buy electricity from the grid. The distribution costs and taxes etc. make up almost half of the electricity price. However, more important is to find a good application for the end-product where it is valued much higher.

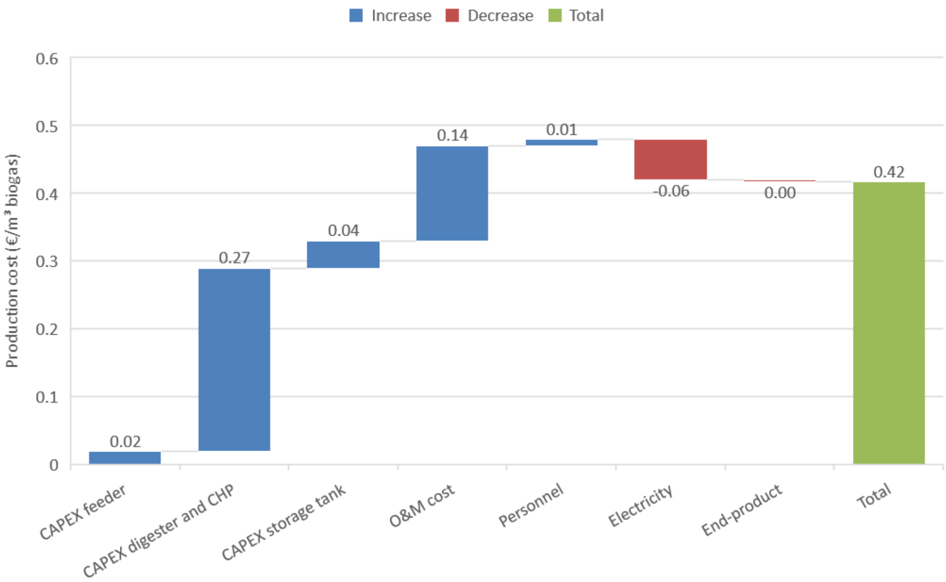

Figure 12. *Cost breakdown per m^3 of biogas produced – reference case 1*

Based on these results we conclude that without subsidies, investing in a pocket digester is not interesting for a farmer, even without the inclusion of roadside grass. Considering the high cost per ton of feedstock in the base case and first reference case, it is more interesting for a farmer to separate the manure and transport the thick fraction to a manure processing facility at a cost of 20-30 euro/ton and the thin fraction to a biology or spread on the fields at a cost of 5-10 euro/ton if the farmer would not be incentivized by subsidies. The disposal cost at the manure processing facilities is lower as these facilities can also benefit from scale advantages. The main reason for the economic infeasibility is that in our model the investment costs and operational costs need to be compensated solely by the sale of the end-product and some excess electricity. Despite the interesting fertilization value of the end-product, the market price seems quite low. This is something that needs further attention to make sure that the business case is improved and that we can also benefit from the advantage that pocket digestion contributes to climate goals by reducing greenhouse gases.

Having the focus of the Grassification project in mind, the most important conclusion from the base case versus the first reference case is that from the perspective of the pocket digester owner, it is not interesting to include roadside grass as the processing costs per ton feedstock are doubled due to the obliged post-treatment of the digestate, despite the acceptable potential biogas yield and potential positive effect on the stability of the digestion process itself. In case the post-treatment is not required by legislation, adding roadside grass to the pocket digester does not have a negative effect on the business case, if we keep the same assumptions. Note that the biogas potential of roadside grass is comparable to the biogas potential of VeDoWS manure and that the gate fee for roadside grass is higher. Furthermore, pocket digesters are typically stirred reactors where the presence of litter is an issue that causes additional work for the digester owner to remove it beforehand. Also additional attention needs to be spent on good mixing to avoid floating layers in the reactor. If a pre-treatment would be available to avoid the formation of floating layers, the cost for stirring can be reduced.

However, the pre-treatment needs to be low-cost to make sure that the avoided cost of stirring is not overcome by the cost of the pre-treatment.

4.1.3 Reference case 2 – OMSW digester with roadside grass

In the second reference case we vary the scale and the digester type. In this case we start with 30,000 ton input material in the digester, which is in line with the order of magnitude of most OMSW digesters in Flanders. Having a share of 20% roadside grass in the feedstock, the total amount of grass amounts to 6000 ton per year in this reference case. From this almost 26,000 ton digestate results which is mixed with 5000 ton green waste and 7800 ton structure material to result in 13,500 ton of compost. From the CHP we sell the excess electricity of 3000 MWh per year to the grid. A graphical representation of the mass and energy balance can be found in Figure 13.

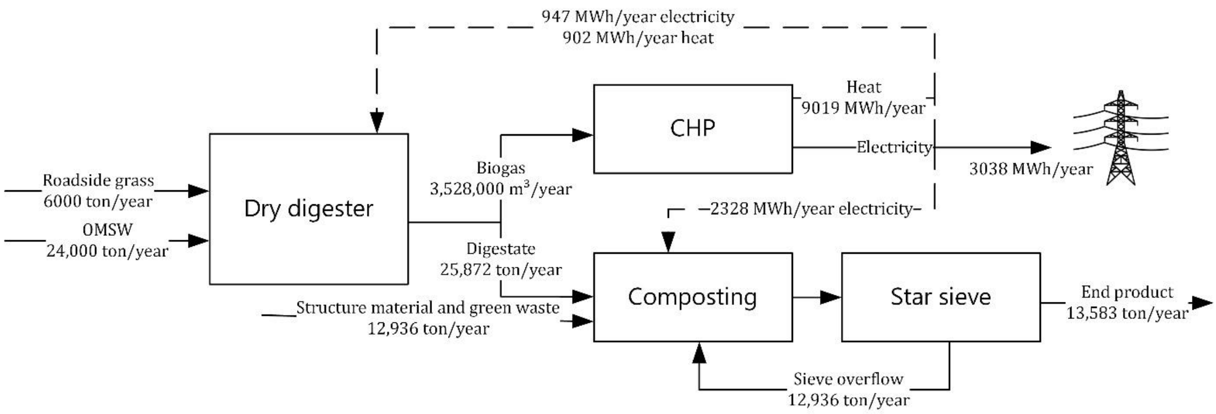

Figure 13. *Mass and energy balance – reference case 2*

The total investment cost amounts to ca. 8.3 million euro of which 6.5 million euro for the digester alone. The operational costs are almost 2.2 million euro per year and the revenues amount to 2 million euro per year with the assumptions made. Note that we did not take a separate investment cost into account for the composting facility, but as in the other cases, used a total cost per year. In case a composting installation is already in place and is depreciated, the cost might be lower per ton input. Note that this is also valid for the other cases. The largest revenues are coming from the gate fee of OMSW, i.e. 70% of the total revenues.

The total production cost of biogas is 0.32 euro/m^3, compared to 0.49 euro/m^3 in the base case. Note that we do not allocate the composting cost of the digestate, to the biogas production. If we compare the total cost per ton input at the digester, i.e. excluding the green waste and structure material at the composting site, we find the same cost of slightly more than 100 euro as in the base case. The majority of this cost (i.e. 60%) is determined by the composting facility for which we take the same assumptions into account as in the base case. Note that in practice, the cost for composting in case of OMSW composting can be lower as these installations are already existing and in some cases are depreciated, meaning that only operational costs need to be taken into account.

If we would allocate all costs and revenues to the production of biogas and calculate the cost per ton biogas produced, taking into account the revenues from the sale of electricity and compost and the gate fees of the feedstock, we find a cost of 0.3 euro/m^3. This cost can be reduced more if one would be able to valorize the produced heat from the CHP. An alternative for an OMSW digester is to partly send the biogas to a CHP engine to produce the necessary electricity and heat to run the reactor and send the rest of the biogas to an upgrading facility that allows to further valorize the biogas. From Figure 14 it is clear that the revenues do not compensate for the total costs and that the cost for composting mainly impacts the total cost per m^3 biogas produced. The gate fee for OMSW has the largest impact on the cost reduction.

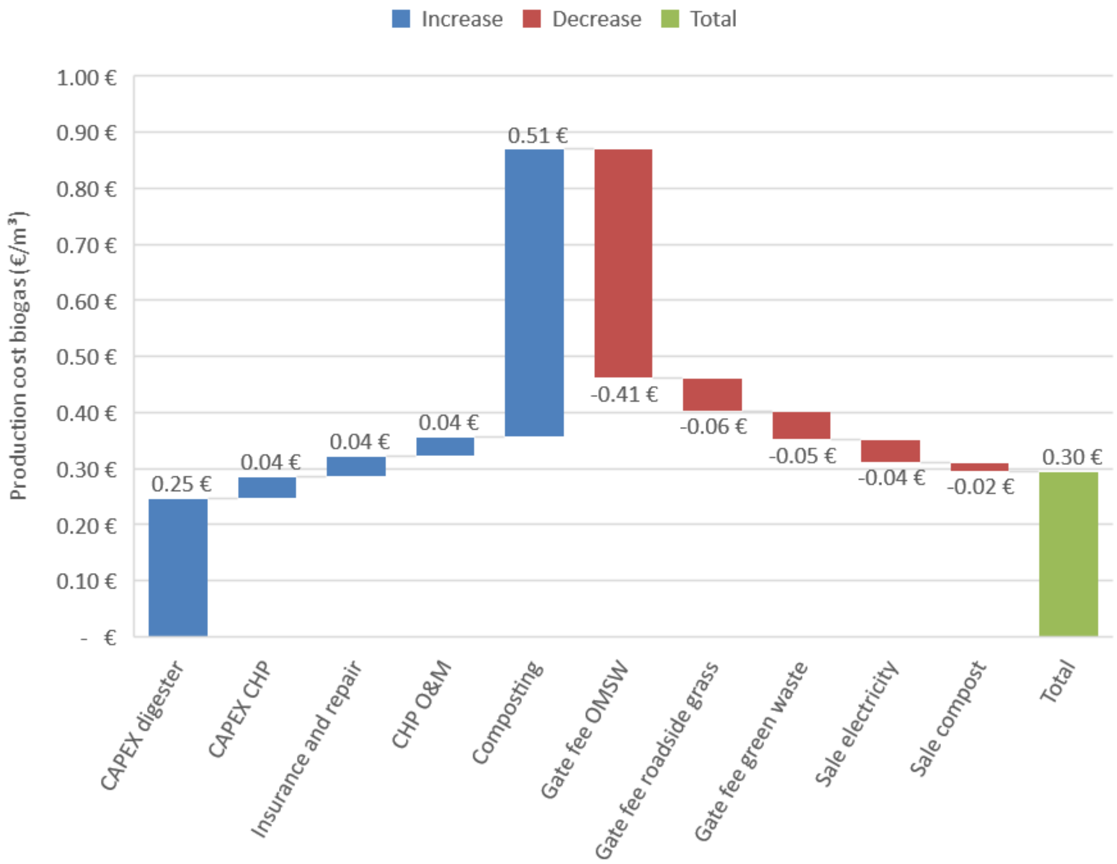

Figure 14. *Cost breakdown per m^3 of biogas produced – reference case 2*

In the base case we assumed an input of 600 ton per year for a typical size pocket digester in Flanders, so this means that you would need 10 pocket digesters to process the same amount of roadside grass per year as one OMSW digester. In 2018 almost 60 pocket digesters were installed in Flanders[1] and as mentioned before, currently we have 3 active OMSW digesters and 2 planned facilities.

The main advantages of the OMSW digester compared to a pocket digester to process roadside grass are:

- The dry digester is not stirred so litter causes less problems in the reactor itself;

- Often pre- and post-treatment processes needed to remove the litter are already in place at facilities that process OMSW;
- Due to the waste status of roadside grass and the obliged post-treatment of the digestate, it is more interesting and straightforward to use an existing OMSW composting facility for this as the right permits are already in place;
- The feedstock processing costs are the same, however, the biogas production cost is much lower in case of a large scale dry digester.

5 Conclusion

In this report we evaluate the potential of roadside grass digestion from an economic point of view. We compare a base case in which roadside grass is digested together with pig slurry and VeDoWS manure in a pocket digester, with two reference cases. The first reference case is a pocket digester of the same size that only processes manure and the second reference case is a large scale dry OMSW digester with roadside grass. The aim is to evaluate to what extent the addition of roadside grass in a digester is interesting from an economic point of view.

Based on the assessment we can conclude that the biogas potential of (roadside) grass is sufficiently large to make it interesting as a feedstock for digestion. However, due to the status of roadside grass as waste, strict post-treatment conditions have to be met that largely impact the processing costs. In both the base case and the second reference case, the processing costs per ton feedstock amount to ca. 100 euro per ton, compared to a cost of around 50 euro per ton in the first reference case. If we instead evaluate the biogas production cost across the three cases, we conclude that this is the same for the base case and first reference case at approximately 0.5 euro/m^3 compared to approximately 0.3 euro/m^3 in the second reference case. To calculate the biogas production cost, we do not allocate the cost for the digestate post-treatment. It can be concluded that, with the assumptions made, none of the cases is economically feasible without subsidies.

From these results it is clear that adding roadside grass to a pocket digester, together with manure, is not interesting for the farmer from an economic point of view due to the strict post-treatment conditions that have to be met. Furthermore, also technical challenges exist with the presence of sand and litter for which no good solutions are available at the moment. From an economic point of view it is therefore more interesting to process the roadside grass in a large scale OMSW digester compared to the pocket digester. One advantage is that the dry digester is not stirred and therefore the litter does not cause much harm in the reactor. Second, OMSW composting facilities already have pre- and post-treatment processes available that can also be used for roadside grass and/or the end-product. Third, the conditions for post-treatment of digestate from OMSW digestion are the same as for roadside grass, implying that OMSW digesters already have the correct post-treatment processes in place, as well as the needed permits.

In this study we compared pocket digestion, with and without roadside grass with a large scale dry digester that processes OMSW with roadside grass. We did not make a comparison with a large scale agricultural digester. Due to scale advantages, the costs might be reduced in a large scale agricultural digester compared to a pocket digester, however, the additional complexities that adding roadside grass with a waste status causes to a pocket digester, are also valid for a large scale agricultural digester. Therefore, it seems more straightforward to add roadside grass to a large scale OMSW digester.

If one wants to continue the pathway of mixing roadside grass and manure in a digester as a potential technical solution for processing roadside grass, one first needs to prove that plant pathogens and weed seed are eliminated, i.e. that the legal hygienization requirements for plant pathogens and weed seeds are met, with a cheaper treatment process than post composting of the entire digestate fraction as is required now.

Another point of attention is the presence of litter that cannot be removed efficiently with the current available technologies. This presence of litter is not only a challenge for digestion, but also for other potential uses, like in the biocomposites case. If a technology can be developed to remove the litter efficiently, this would open up many opportunities. Considering the current situation, dry digestion or composting seem the most interesting options. Avoiding the amount of litter by having good agreements with the contractor or stimulating initiatives such as 'de mooimakers' where volunteers help to clean the roadsides can be alternative solutions. The latter is of course not possible at all roadsides.

References

1. Van Dael, M., et al., *Techno-economic Assessment Methodology for Ultrasonic Production of Biofuels*, in *Production of Biofuels and Chemicals with Ultrasound*, Z. Fang, J.R.L. Smith, and X. Qi, Editors. 2015, Springer Netherlands: Dordrecht. p. 317-345.
2. Fiala, M., G. Pellizzi, and G. Riva, *A Model for the Optimal Dimensioning of Biomass-fuelled Electric Power Plants.* Journal of Agricultural Engineering Research, 1997. **67**(1): p. 17-25.
3. Levy, H. and M. Sarnat, *Capital investment and financial decisions*. 1994: Prentice Hall.
4. Mercken, R., *De investeringsbeslissing. Een beleidsgerichte analyse*. 2004, Antwerpen: Garant.
5. Boardman, A.E., D.H. Greenberg, and A.R. Vining, *Cost benefit analysis. Concepts and practice*. 2006, New Jersey: Pearson Education.
6. Lorie, J.H. and L.J. Savage, *Three problems in rationing capital.* Journal of Business, 1955. **28**.
7. Van Dael, M., et al., *A techno-economic evaluation of a biomass energy conversion park.* Applied Energy, 2013. **104**: p. 611-622.
8. Decorte, M. and S. Tessens, *Monovergisting van gemeentelijk bermmaaisel*. 2019, Biogas-e.
9. Vandendriessche, S., et al., *Onderzoeksrapport Pocket Power*. 2020. p. 287.
10. Consultancy, B., *Biogas uit gras - een onderbenut potentieel*. 2014. p. 54.