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Biomass for Energy

Case Study Report

Development of agro-sidestreams for bioenergy

June 2015

Improving ***sustainable biomass utilisation*** *in North West Europe*

Colophon

This report was compiled in the framework of action 3 of the ARBOR[*] project.

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This report further received input from the other ARBOR partners on specific aspects related to the regional transferability of the investigated case study results. Willem Dhooge (FlandersBio, BE) also helped with text corrections and lay-out.

[*] Arbor is an Interreg IVB NWE project with 13 partners from 6 European regions dealing with the development of technological solutions and regional strategy development for improved sustainable biomass utilisation. ARBOR is cofunded by local authorities from the United Kingdom, Flanders, Saarland, Luxemburg, the Netherlands, and Ireland.

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Please check **www.arbornwe.eu** for the other reports that have been compiled within ARBOR:

- Five case study reports on a diversity of subjects like nutrient recovery, low impact energy crops, agro side streams, synergy parks and biomass closed-loop systems.
- An update of the 2012 Benchmark report on biomass for energy use in NWE
- A strategies report on biomass for energy for regional authorities in the North West European region.

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1 – Regional development of agro-sidestreams for bio-energy in Flanders (BE)

1.1 Case Study Description

1.1.1 Objectives

As the name of the project states ARBOR intends to 'Accelerate Renewable energies through valorization of Biogenic Organic Raw material' thus researching and activating bio-mass for energy purposes. One of the objectives in ARBOR was to investigate how to use biomass from agriculture that is available today but not yet valorized.

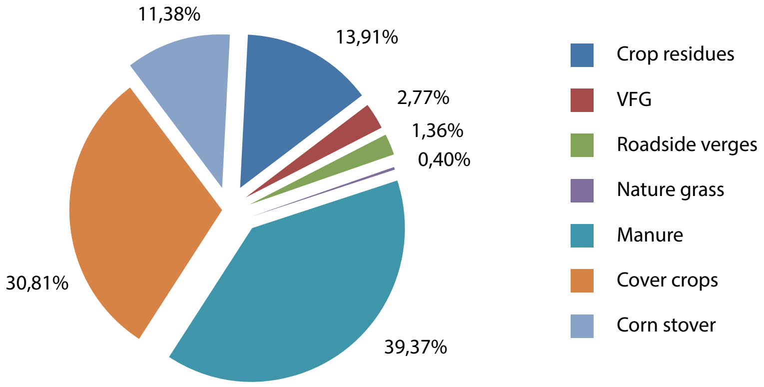

Figure 1: Estimate of the potential unused biomass streams in Flanders for energy production (Biogas-E, 2013)

Looking at the diagram showing the shares of all unused agro-sidestreams in Flanders (Figure 1) it is shown that (apart from cover crops[1]) manure and crop residues (including corn stover) show the largest potential for further valorization. The total calorific value (not yet corrected for efficiency in heat and electricity production) equals 7000 GWh (Biogas-E, 2013). To improve the sourcing of these bio-energy materials several challenges (e.g. technical, logistics, …) need to be countered in order to be able to develop a chain for these biomass products.

Figure 1 shows that the largest unused agro-sidestream in Flanders is in fact manure. Only 581 000 tons of manure or about 2,4% of the total amount of manure in Flanders is anaerobically digested and thus valorized for energy production (Biogas-E, 2013; VLM, 2013). Other than crop residues, manure is already available on the farm, is already stored and doesn't need extra pre-treatments before valorizing it energetically. A large share of the manure produced (46% of total nitrogen coming from manure in Flanders) is manure from cattle.

The in Flanders very new technology (°2011) of pocket or small anaerobic digestion makes it possible for dairy farmers to produce their own electricity and a part of their heat demand on the farm. This is done simply by on farm monodigestion of the on-farm manure. The technology requires a minimum of 80 productive animals, in Flanders alone this shows a potential for more than 900 farms to produce their own energy. In order to learn more about the performance of this new technology it was followed-up closely during the project.

Several types of crop residues were investigated in the project for their potential towards energetic valorization. Figure 2 shows an estimate of the total dry matter potential of crop residues in Flanders. Since **corn stover** takes in more than half of this total potential, corn residues were considered to be an important biomass source for further investigation.

Next to corn stover also several types of **vegetable residues** were investigated. Because of a quite large expected amount of biomass per ha for **Brussels sprouts** residues (Table 1), this stream was also investigated for biogas production. Other crop residues are known to be able to cause nitrate leaching and bad odor when they are left on or brought back to the field after the growing season. For these reasons **leek** and **cauliflower** leaves were also investigated for their potential use.

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[1] For the activities that were carried out on cover crops within ARBOR, see case study report on 'Low impact biomass'.

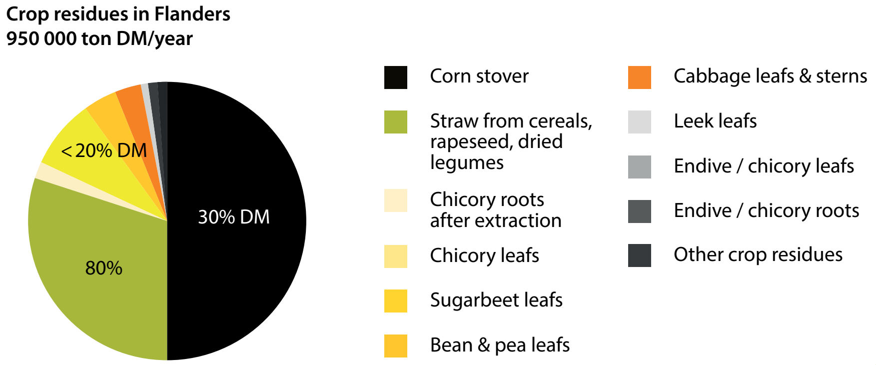

Figure 2: Total dry matter potential for crop residues in Flanders (Landbouw & Visserij, 2009)

Table 1: Overview of the fresh matter yield, nitrogen content and acreage of crop residues in Flanders (Van Labeke, 2010; FOD Economie, 2013)

Crop residues	Fresh matter (ton ha^{-1})	Nitrogen amount (kg N ha^{-1})	Area in Flanders (ha)
Brussel sprouts	50-60	140-200	2 314
White cabbage (industry)	40-50	170	104
Broccoli	50-60	180	163
White cabbage (fresh market)	30-40	170	233
Cauliflower	30-40	130	2 933
Peas	10-20	85	2 184
Beans	10-20	90	3 321
Carrots	20-30	90	2 465
Celery	50-60	110	2 346
Leek	10-20	60	3 329
Spinach	<10	30	2 026
Lettuce	<10	35	212

1.1.2 ARBOR objectives

In total, within the action focusing on agro-residues, the project realized:

- the follow-up of two small scale anaerobic mono-digesters on cattle manure;
- 2-monthly sampling of digestate & manure from 2 small scale digesters for a year long;
- follow-up of a field trial set out by one of the farmers comparing digestate with manure;
- a market study on small scale AD in the NWE region;
- a scoping study (harvest technology, biomass potential, pre-treatment, biogas potential) on corn stover for energetic valorization;
- a scoping study (harvest technology, biomass potential, pre-treatment, biogas potential) on vegetable residues (Brussel sprouts stems, leek & cauliflower leaves) for energetic valorization;
- an adapted harvester for collection of cauliflower residues;
- 2 pilot anaerobic digestion tests with corn stover;
- 3 pilot anaerobic digestion tests with corn cobs of which one in an installation of larger scale;
- 2 pilot anaerobic digestion tests with stems of Brussel sprouts;
- 1 pilot anaerobic digestion test with cauliflower residues;
- feasibility study on the adaptation of an anaerobic digester for the intake of crop residues.

To communicate and stimulate the valorization of the agro-sidestreams crop residues and manure, Inagro actively disseminated information on technologies and their potential through several tools and events: a calculation tool for farmers on the profitability of a small scale digester for their farm, several workshops, platform meetings, harvest demonstrations, presentations, press articles, a movie, brochures, …

1.2 ARBOR pilots

1.2.1 Energetic valorization of manure through small scale anaerobic digestion

1.2.1.1 Pilot Description

As mentioned earlier manure shows the largest energetic potential from all 'unused' agricultural sidestreams. Only about 2,4% of the Flemish manure is anaerobically digested (Biogas-E, 2013), this happens mainly on sites where this activity is combined with processing of manure coming from several different farms. Since about 2/3 of the manure produced in Flanders is used for fertilization of (mostly local) fields (about 1/3 of manure-N is processed and/or exported) (VLM, 2013). This leaves a lot of room for decentral on-farm energetic valorization, through so called small scale anaerobic digestion. In Flanders during the ARBOR-project anaerobic digestion of only cattle slurry (mono-digestion) on a very small (micro) scale has become very popular with more than 100 installations realized from 2011 up to now (April 2015).

Small scale anaerobic digestion aims at using proprietary biomass for energy production to be used on the farm itself. Though there is no strict legal definition for small scale AD, in Flanders there is a consensus that it concerns installations that take in maximally 5000 tons of input per year while the capacity of the engine stays below 200 kW electrical power. Small scale anaerobic digesters of 10 kW (also called micro digesters) like the ones installed in Flanders, can fulfil the energy demand for electricity of their farm when there is enough qualitative manure available on the farm: a 10 kW installation requires manure from about 80 productive animals. If manure can be delivered fresh to the digester, 50 cows are already sufficient.

Not only does this technology allow farmers to produce their own energy under the forms of electricity and heat, research abroad also indicates that emissions during manure storage can be reduced by on-farm (small scale) anaerobic digestion (Clemens *et al*., 2006; Marañón *et al*., 2011). In 2010 11% of the total amount of greenhouse gas emissions in Flanders originated from agriculture. 38% of these agricultural emissions comes from livestock production of cattle. And in this sector about 10% of the greenhouse gas emissions comes from manure storage. For this reason the Flemish Government has made a strategy of small scale AD for the reduction of greenhouse gases in agriculture. Starting from January 2015 on, investment support is granted through the Flemish Climate Fund for new side equipment and adapted stables for farmers who invest in a small scale AD installation. Even more investments in small scale AD are to be expected.

To learn more about this new technology in Flanders two of the first installations constructed were **followed-up** closely from the start by Inagro. To investigate possible differences concerning fertilization with digestate instead of manure, **samples were taken of both manure and digestate** during each visit for a little more than one year. One of the farmers set out an experiment to compare both products on grassland, Inagro compared biomass yield and the impact on nutrient leaching in this experiment.

Since there are also other types of installations than the one dominant in Flanders and since we wanted to learn more about the possibilities of small scale AD on other types of biomass (e.g. dry biomass, pig manure, …) Inagro and Biogas-E carried out a **market study**.

DLV Belgium (subcontractor of Ghent University) performed a **feasibility study** for digestion of cattle slurry at the experimental farm Hooibeekhoeve in the province of Antwerp. To inform farmers about the potential of small scale anaerobic digestion for their farm, Inagro developed an **online calculation tool**[2] which gives farmers a view on the potential profitability for their farm.

Both in 2014 and 2015 several **workshops** were organized on different locations in Flanders to inform farmers on this technology. With the aim of making a **brochure**[3] on small scale AD including the market study, Inagro, VCM, Biogas-E and DLV InnoVision zoomed in on five practical examples of small scale AD in the NWE region. Several of these installations were visited during the project. Each year, starting in 2012, together with Biogas-E and VCM, Inagro organized a **platform meeting** on small scale anaerobic digestion where several stakeholders (constructors, researchers, government, study bureaus, operators, farmers, …) were able to meet and discuss the progress and challenges concerning the technology, related legislation, etc. During these meetings several needs for further research were expressed.

1.2.1.2 Lessons learned

A. Technical follow-up of micro digesters in Flanders

Working principle: each day 5-7 m³ of digestate is pumped towards manure storage and a same volume of manure is pumped into the reactor. The reactor is fed once a day and is kept at a stable temperature. The first installations constructed were built out of a large manure bag, in which manure was pumped back and forth towards the heat exchanger in the CHP container. As it goes with technological innovations in the period of 2011-2014 small scale AD in Flanders also underwent makeovers, each time improving the technology. Manure is no longer circulated back and forth towards the CHP, nowadays heat exchange between CHP and the reactor is carried out with water. The digester also looks differently (standing silo-type). The biogas produced is collected below a double membrane on top of the reactor. After a desulfurization step, it is combusted in the CHP where heat and electricity are produced. The CHP has an electrical power just below 10 kW, allowing about 60 000 kWh to be produced on a year basis. Two of the first cases (bag type) were followed up by Inagro. A short description of the farmers' experiences is given below.

Case 1: Micro digester - Johan & Mieke Hollevoet
This company gives home to 100 – 110 dairy cows and 40 – 50 heifers. Each year 70 000 kWh of electricity is used. In February 2012 being amongst the first, Johan & Mieke decided to install a small scale anaerobic on their farm close to the stable. As one of a few exceptions the installation is not owned by the farmer, but leased from the constructor. The farmer pays € 0.06 – 0.08 per kWh of electricity produced.

Figure 3: Installation of Johan & Mieke Hollevoet

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[2] The tool is online available (in Dutch) through: http://application.inagro.be/Pocketvergisting/.

[3] This brochure is available on the ARBOR-website (www.arbornwe.eu).

Figure 5 shows the net electricity production of the micro digester of Johan & Mieke Hollevoet from its start-up till March 2015. The net electricity production was on average **35 464 kWh** per year, which is not large considering the fact that initially **56 000 to 64 000 kWh** of production was expected per year. Looking at figure 5 an irregular production curve is noticed. Below the graph a sequence of observations during this period is listed.

Figure 4: Installation of Patrick & Dorine Devreese

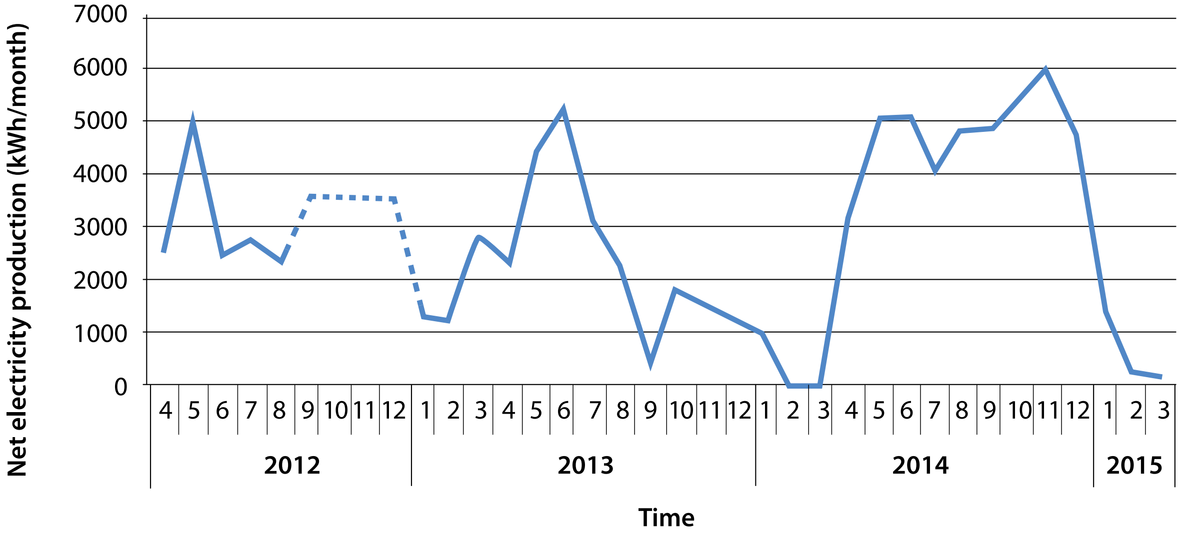

Figure 5: Net electricity production over time of the micro digester of Johan and Mieke Hollevoet

2012

- *February:* installation and start-up
- *2nd half of June:* defect by perforation of the balloon by overtension of the membrane because of a disfunctional pressure relief valve, new start-up with fresh digestate was needed.
- *Half July:* difficulties with temperature going up too slow
- *August:* good production, a little bit of problems with temperature running too high in the manure
- Because of a new measuring device installed, data from August till December represented in Figure 5 are only an average.
- *September:* new insulation because of a crack in and a shift of the insulation deck on top.
- *October-December:* no problems, the installation belonged to the top 5 of that month.

2013

- *Begin of January:* no oil in the engine, cable for measuring oil level was loose.
- *January:* frost, manure intake valve did not close, digestate ran back into the manure storage in the basement underneath the cows.
- *February - April:* weak production, too little manure available because of a problem with the pump. A new engine was placed in March. In April tubes clocked by which rinsing with a lot of water was necessary.
- *June:* installation ran ok.
- *July:* installation shut down, moisture in gas tube, more mixing of manure was necessary.
- *August:* a belowground gas piping was installed that continuously inflates the balloon with hot air. 2 tubes were installed for condensation of water from the gas. Unfortunately tubes that transfer the manure were damaged during installation of extra pipelines belowground.
- *September:* pump stops turning often, restart went difficult, new pump needed but old type was reinstalled because of easier cleaning. A leak was discovered in the tubes belowground and was closed. Mixer was defect several times.
- *Autumn & beginning of 2014:* problems with manure circulation, restart after exporting manure. The container will be moved more closely to the reactor, heat exchanging tubes will be installed in the reactor so heat exchange can be made easier.

2014

- After installation of the heat exchanging tubes by which from now on water was transported towards the CHP and back instead of manure, the installation produced very well till the beginning of 2015. At the beginning of 2015 there was a problem with water staying on the bag. This caused a lowering of the bag, due to this the gas tube was locked and the CHP was stopped because there was no gas available. A decrease in temperature of the reactor followed. A new start-up was needed in March together with some adaptations to stop the bag from lowering. In April the installation was running again.

The installation of Patrick & Dorine Devreese showed a higher production showing an average of **48 260 kWh** per year. Apart from three steep decreases, the electricity production of this micro digester was more stable (Figure 6).

Case 2: Micro digester - Patrick & Dorine Devreese
The digester on the site of Patrick & Dorine was installed in the summer of 2012. The company owns 95 dairy cows, 100 young cattle and 10 breeding bulls. The electricity demand is 70 000 kWh. The farmer invested in the installation himself.

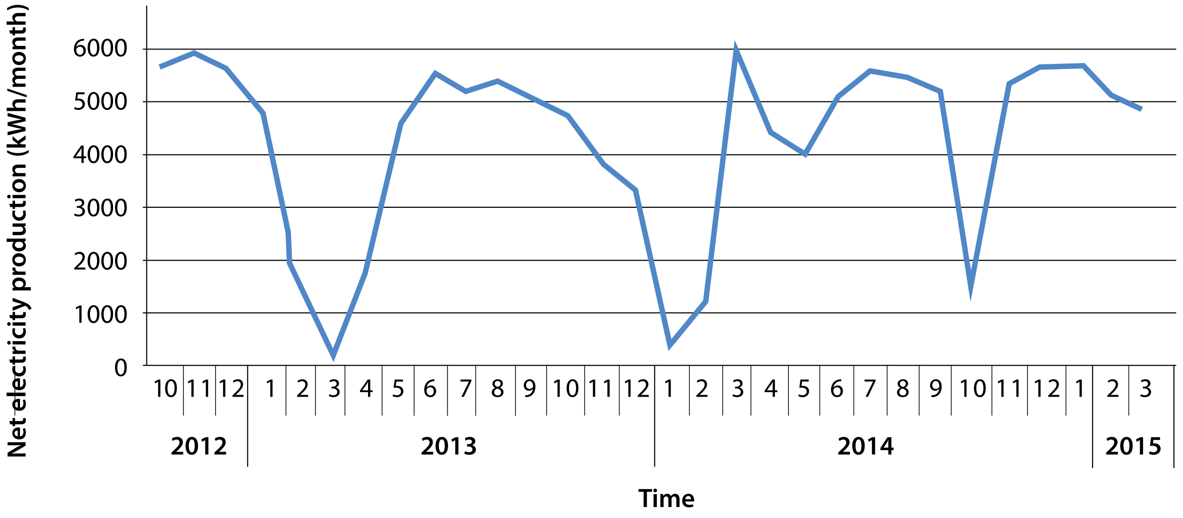

Figure 6: Net electricity production over time of the micro digester of Patrick and Dorine Devreese

2012

- *August:* installation didn't run for longer periods (>8u/day), too little biogas production
- *September:* short circuit of the pump, new mixer/pump was installed, after this the system ran more continuously
- *October:* sometimes manure was too hot, 6x shutdown for some hours
- *November:* need for sufficient mixing (2x/week), clogged pump. Installation didn't run twice for half a day. Warm water circuit was installed for recuperation of heat from the engine.
- *December:* replacement of heat sensor for the manure. Too little methane in the reactor, mixer didn't work for several days. Warm water circuit was turned off. Leakage of water at the gas outlet. Condensed water froze at the pressure relief valve.

2013

- *January:* no more clogging of pipes and pumps.
- *February-april:* a lot of clogging, crust formation because of a mixer that was installed wrongly (turned the opposite way)
- *May:* a lot of clogging because of a loosened crust
- *July:* new engine
- *August:* a lot of mixing
- *September:* gas piping broken and fixed; installation of a gas desulfurization system
- *October:* warm water circuit turned off
- *November:* clogging in tube going to the digester, manure seeping into the gas tube.
- *December-January 2014:* crust formation requiring a lot of mixing.

2014 – beginning of 2015

During this year there was only one larger period in which the digester wasn't working for some time. This is seen for October in the electricity production graph (Figure 6). The reason for this stop in production was that the constructor amended the entire system so no longer manure was pumped back and forth towards the CHP heat exchanger, but now water is used as a medium for heat exchange. Though these changes were put in place, the reactor still demands as much time as before in follow-up according to the farmer. On average 1,5 to 2 hours are needed each week.

Small scale AD in Flanders is a new technology. As it goes with a lot of innovations, technologies can experience some bottlenecks during the first year of market implementation. This was also what happened with the first small scale AD installations in Flanders. The most common problems were blockage in the system because of cow hairs and other items that fell into the manure. Also AD is a sensitive technology because it concerns **a living system**. When something interferes with the installation, the CHP stops turning and no more heat is produced. Since the bacteria require a stable temperature it is necessary to react quickly when problems occur, so the reactor doesn't cool down. Next to this the quality of the manure is very important. Using fresh manure is an advantage because biogas production will be higher in that case. It is advisable not to let rinse water run into the manure pit, since this can dilute the manure reducing its energetic potential. To cope with these beginner challenges the system was amended into a new one now sold by the constructor: heating tubes were put inside the reactor, manure was replaced by water as the medium for heat exchange, the reactor is no longer a bag but now has a more conventional CSTR (continuous stirred-tank reactor) anaerobic digestion look (see Figure 7). During the ARBOR project one of the new investors in the adapted small scale AD installation shared some first data on his electricity production. From September 2014 till March 2015 within these seven months the digester showed a net electricity production of **33 610 kWh**. This coincides with a production of 57 617 kWh per year if the same average production is maintained in the following months.

Figure 7: New Biolectric micro digestion system

B. Digestate from small scale mono-digestion vs. manure

During the visits for follow-up of both micro digesters each time samples were taken of both digestate and manure. Samples were taken about two-monthly (8 times at Johan Hollevoet and 7 times at Patrick Devreese).

Sampling & analysis of digestate and manure

Table 2 shows the results on 7 parameters (pH, DM, OM, Ammonia N, Kjeldahl N, Ammonia N/kjeldahl N, C/N) comparing digestate and manure. Next to these parameters also sodium, potassium, phosphorous, magnesium and calcium were analysed. The statistical analysis was performed in a non-paired comparison.

Table 2: Overview of parameters tested during analysis of digestate and manure

	Hollevoet				Devreese			
	Average	Stdev	5% signif.	1% signif.	Average	Stdev	5% signif.	1% signif.
pH								
Manure	7,02	0,19	b	B	7,03	0,10	b	B
Digestate	7,73	0,11	a	A	7,93	0,16	a	A
DM (kg/1000 kg fresh matter)								
Manure	99,24	13,85	a	A	88,67	17,44	a	A
Digestate	58,50	12,33	b	B	55,53	15,91	b	B
OM (kg/1000 kg fresh matter)								
Manure	75,58	11,18	a	A	68,36	14,15	a	A
Digestate	40,73	9,38	b	B	39,25	14,23	b	B
Ammonia N (kg N/1000 kg fresh matter)								
Manure	1,69	0,26	a	A	1,64	0,23	b	A
Digestate	1,81	0,17	a	A	1,81	0,12	a	A
Kjeldahl N (kg N/1000 kg fresh matter)								
Manure	3,72	0,73	a	A	3,38	0,96	a	A
Digestate	3,02	0,51	b	A	2,79	0,73	b	B
C / N								
Manure	10,73	0,84	a	A	10,37	0,98	a	A
Digestate	6,97	0,84	b	B	7,03	1,97	b	B
Phosphorous (kg/1000 kg P2O5 fresh matter)								
Manure	1,92	1,15	a	A	1,64	1,04	a	A
Digestate	1,56	1,16	b	A	1,35	1,13	b	A
Potassium (kg/1000 kg K2O fresh matter)								
Manure	4,38	0,59	a	A	4,02	0,40	a	A
Digestate	4,14	0,37	a	A	3,78	0,44	b	A
Sodium (kg/1000 kg Na2O fresh matter)								
Manure	0,82	0,22	a	A	1,50	0,24	a	A
Digestate	0,77	0,13	a	A	1,53	0,20	a	A
Calcium (kg/1000 kg CaO fresh matter)								
Manure	2,30	0,47	a	A	1,61	0,46	a	A
Digestate	1,78	0,30	b	A	1,20	0,27	b	A
Magnesium (kg/1000 kg MgO fresh matter)								
Manure	0,97	0,14	a	A	0,91	0,17	a	A
Digestate	0,76	0,13	b	A	0,71	0,11	b	B

From all parameters tested 4 parameters showed to be significantly different (both on the 5% and 1% level) between digestate and manure on both farms where samples were taken, these were: dry matter content, organic matter content, pH and the C to N ratio. The parameter that showed no significant difference (both on the 5% and 1% level) on both farms was sodium. Parameters that showed a significant difference only on the 5% level on both farms were: phosphorous, Kjeldahl nitrogen, magnesium and calcium. The content of ammonia-nitrogen and potassium showed differing results going from 5% significant difference on the one farm, and no significant difference on the other farm.

Follow-up field trial on grass land

Introduction

As digestion on family farm level is breaking through, it's important to assess all consequences. Next to samples being taken, Inagro also followed-up a field trial that was set out by the farmer, in which several plots of grassland were fertilized with digestate and manure. During this field trial the effect of small scale digestion of cattle slurry on its fertilizing value was tested. The farmer applied the same amounts (in tons) on each parcel. Yield was determined (both fresh & dry matter), soil samples were taken several times throughout and after the growing season. Digestion does not influence the amount of nutrients in the slurry much, but the chemical form wherein the nutrients occur.

Figure 8: Field trial set up of grassland fertilization with manure and digestate

Method

The field trial was established at a dairy farmer who uses the slurry from his animals to fertilize grassland. The grassland is not grazed upon, but mown through the growing season. Eight plots were made on a grass-clover grassland from the dairy farmer. The plots were all 10 m wide and 100 m long. Furthermore, the dairy farmer has a small scale sludge digester since two years. In this way 4 plots could be fertilized with the undigested cattle slurry and 4 plots were fertilized with the digested cattle slurry, hereafter called digestate.

During the growing season from April to September 2013, the plots were fertilized with an equivalent amount of cattle slurry and digestate, as the dairy farmer was used to do. This was complemented three times with chemical fertilizer, uniformly over all plots. During the growing season five cuts were mown and at each cut, the yield, the average dry matter content and the average crop height was determined of each plot.
The nitrate level of the soil was monitored at every plot during the mowing season. Each time the nitrate level was determined at three depths: 0-30 cm, 30-60 cm, 60-90 cm. The sum of those three is the nitrate level sum, which is a legal parameter.

Result

An analysis of these data did not result in a significant difference between both fertilization schemes. Neither in yield of fresh and dry matter nor in the height measurements, there was a significant difference.

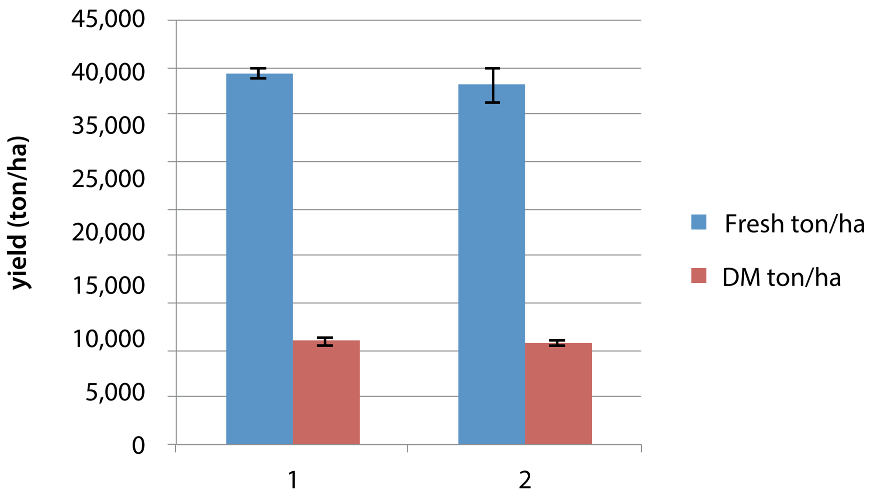

Figure 9: Average yield from the plots fertilized with cattle slurry (1) and digestate (2) (blue= fresh matter, red=dry matter)

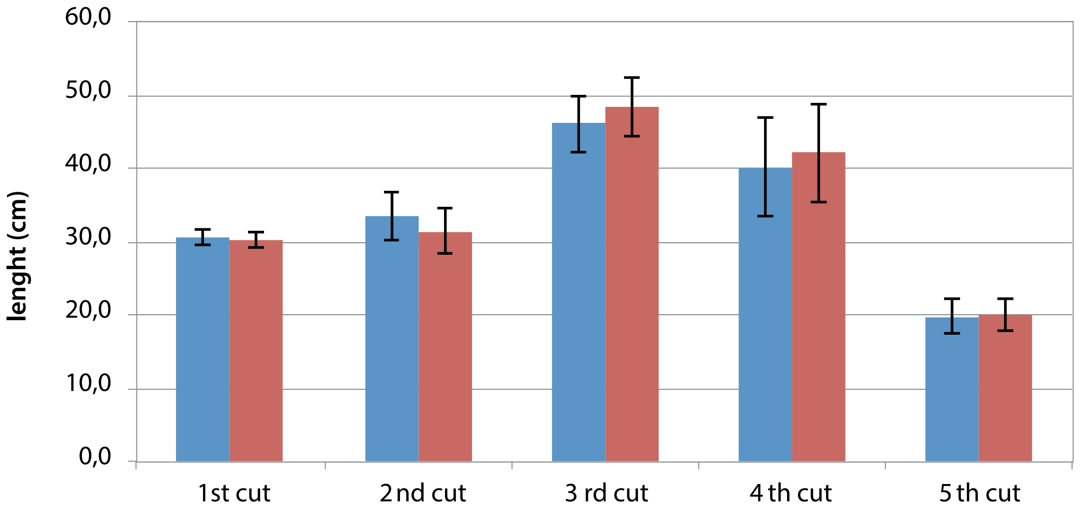

Figure 10: Average measured crop height at every cut (blue = digestate, red = cattle slurry)

The nitrate level in the soil from both fertilization schemes was compared. At the end of the growing season (30th October) there was no significant difference in nitrate residue between the two schemes.

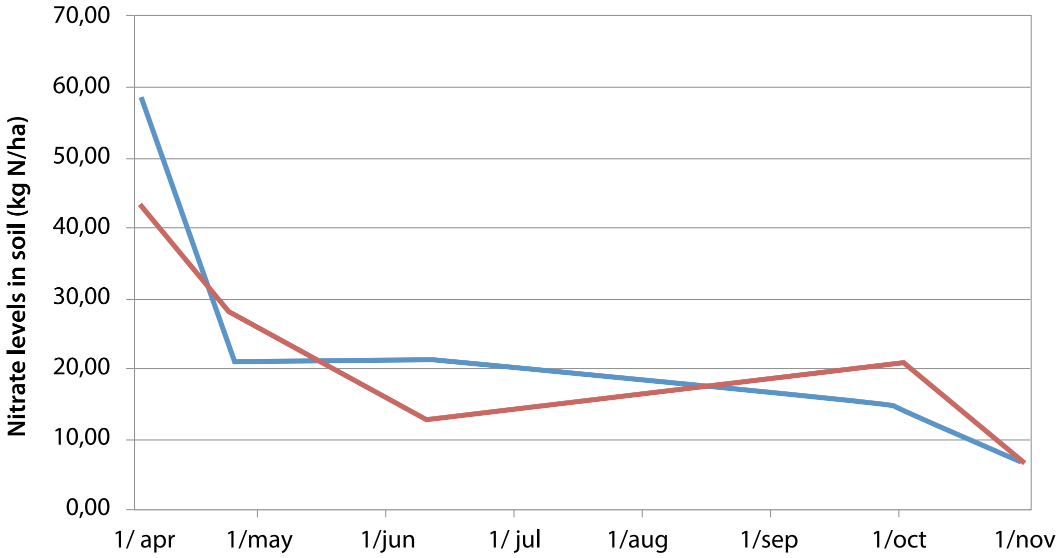

Figure 11: Average sum of the nitrate level in the soil during the growing season. (blue line = digestate, red line = cattle slurry)

C. Market study

Brochure of the market study on small scale AD. This document is available (in English & in Dutch) at www.arbornwe.eu.

Because there is only one main constructor of small scale AD installations in Flanders, together with Biogas-E, Inagro performed a market study to learn more about other installations in the partner regions and other countries worldwide.

The **market study** has shown that there are over 61 constructors of small scale AD installations in surrounding countries. Several small scale installations (installation of Green-Watt in Nijvel, ManurePower in Sterksel (NL), Erigène in Bois-Guilbert (FR) were visited during the project. Some of the constructors aim also on very small installations: about 7 focus on installations <50 kW, while others (about 21) aim both on <50 kW and 50-200 kW or even larger. About 30 constructors focus on the market >50 kW. Also about 20 companies mention to offer mono-digesters of manure. The market study also showed that there are several constructors aiming on the market of dry small scale anaerobic digestion: about 4 of them look at silo digesters, while 5 have constructed a batch container box system. Also there was one company offering a continuous dry digester, this system however was on the verge of what can still be called small scale AD.

Though (considering the amount of pig manure present in Flanders and the heat demand for pig farms with sows) it might be interesting to digest pig slurry in a small scale system, up to now mono-digestion of pig manure on a small scale has not been possible. Apart from the installation in Nijvel, no small scale AD (and certainly no micro) installations that run only on crop residues are known.

D. Raising awareness

Platform small scale AD

Workshop small scale AD in Haasdonk (2014).

For large scale AD installations several platforms exist where operators of installations and other stakeholders can share ideas, problems, challenges, needs for research, … For small scale AD before 2012 there was no platform. On November the 14th of 2012 VCM, Biogas-E and Inagro organized the first platform for small scale AD. A second platform was organized short after (5/02/2013) because of several changes in legislation that had an impact on the profitability and that needed to be discussed. The goal of the platform is to share information, exchange knowledge and experiences with the technology, identify problems and challenges and need for further research. On the 30th of September 2014 a third platform was organized where the market study was presented. During this meeting two prone questions for further research were charged: the first one was to investigate the potential of small scale AD to cope with several kinds of greenhouse gas emissions. The second one was to realize an installation that could work on pig manure.

Workshops small scale AD

To inform farmers, municipalities and local stakeholders about small scale AD, together with the department agriculture of the Province of East Flanders, Hooibeekhoeve, Biogas-E, VCM, Boerenbond, Innovatiesteunpunt and DLV InnoVision, Inagro organized 3 workshops on small scale AD of manure in February 2014, each on a different location in Flanders: in Knesselare, Meerhout and Haasdonk. The workshops were organized closely to an installation, which was then also visited. To promote the workshops a movie about the technique was made by the province of East Flanders. Even though in April 2015 more than 100 installations are installed (of which 86 in Flanders), there is still a growing interest in the technology: each of the **workshops** organized in February 2014 within ARBOR were fully booked and welcomed about 60 people, even more people were interested. In 2015 a new study event was organized in the province of West-Flanders with 100 people present, two are planned still in May/June.

E. Economical Assessment

For small scale installations of 10 kW showing an average to good production (net production of >45 000 kWh/year) without extra investments needed in manure **storage a payback period of 5-8 years can be reached**. If the farmer has to invest in an external facility for storage of digestate (assuming €50 000) then the payback period is set between 7-10 years. For farms having a larger energy need than what can be filled in with a 10 kW installation and also having enough manure to build a larger isntallation, several scenarios are possible. During the ARBOR project DLV Belgium in December 2013 performed a feasibility study in which they compared the profitability of four different investment scenarios for Hooibeekhoeve.

Feasibility study small scale anaerobic digestion of manure – case Hooibeekhoeve

Hooibeekhoeve is a practical center for dairy, fodder and rural development of the province of Antwerp. Before effectuating their plans for placing a biogas plant processing the manure a feasibility study was performed for different possible scenarios.

In the near future the farm will have 100 cows (30 m^3/y) and 40 young livestock (11 m^3/y) producing 3440 m^3 of manure per year. There are enough manure pits in place that can be used for keeping the digestate, so no extra investment is needed. Additionally there is enough land available (55 ha) to spread the digestate. No additional investment in digestate treatment is needed.

The electricity consumption of the farm is mainly for nearby offices and for operating the milking robots and cooling tanks, together around 120 MWhe. The electricity used for heating the water for the milk tanks and milk robots will be replaced by applying the rest heat of the CHP. Together with the sanitary water, the heating of the stables and offices, the total heat demand is around 167 MWhth.

Based on the input data, different investment analyses were calculated for a micro digester.
The results are summarized in the table below.

1. micro digester with full load use of the engine (9,7 kWe, 27% elect. eff., 60% heat eff.);
2. 2 micro digesters consuming all available manure (100 cows), at 72% load use of the engine;
3. 2 micro digesters at full load use of the engine (100 cows + 35 cows). The purpose of 2 micro digesters is to gradually expand the capacity of the farm;
4. 1 larger pocket digester on available manure instead off 2 micro digesters.

Table 3: Different scenarios of small scale digestion implementation at Hooibeekhoeve

Scenario	Input	Power produced	Energy coverage	Remarks
1. 1 x micro (100% load)	2395 tons	9,7 kWe	E: 64% Th: 100%*	- no additionel storage required - * additional heating cost (2800 €/y)
2. 2 x micro (72% load)	3440 tons	13,9 kWe	E: 92% Th: 100%	- potential expansion of capacity - investment not fully valorised at this moment - additional storage required
3. 2 x micro (100%)	4715 tons	19,4 kWe	E: 100% Th: 100%	- potential expansion of capacity - 35 cows / external manure supply - energy production not fully valorised
4. Pocket	3440 tons	15,1 kWe	E: 100% Th: 100%*	- * additional heating cost (1246 €/j) - additional storage required - high investment compared to additional return

Note: numbers are based on the micro digester concept, a turnkey solution from Biolectric (www.biolectric.be).

Looking at the heat demand (blue line) and the heat supply (red line) of the farm (Figure 12) shows that during winter additional heating fuel is required. An additional 37 MWhth is esti-mated, resulting in 3600 liter of heating fuel, or € 2800 per year.

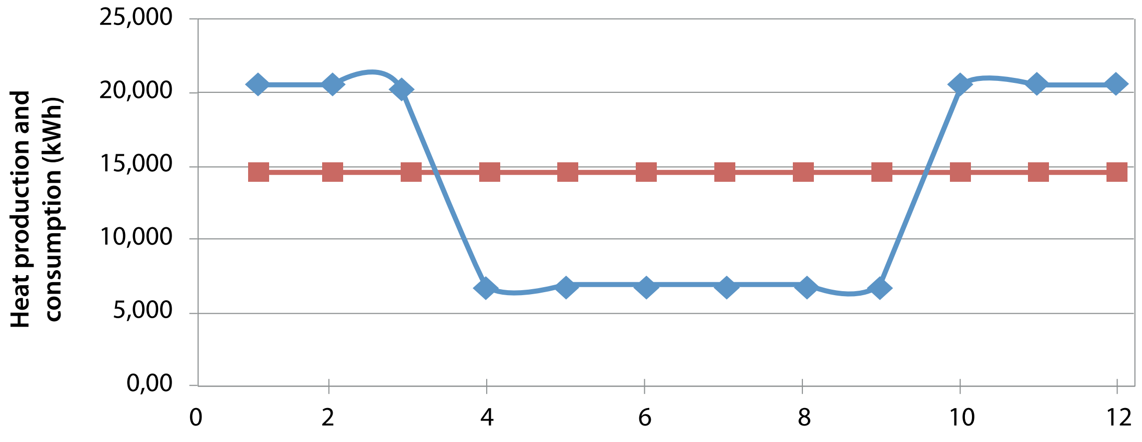

Figure 12 : Heat demand and consumption throughout the year in scenario 1 with heat consumption of Hooibeekhoeve (blue line) and available heat produced (red line)

In the case of 2 micro digesters, the heat supply is just enough to cover the heat demand of the farm completely, there is a quite big heat surplus in summer (see below).

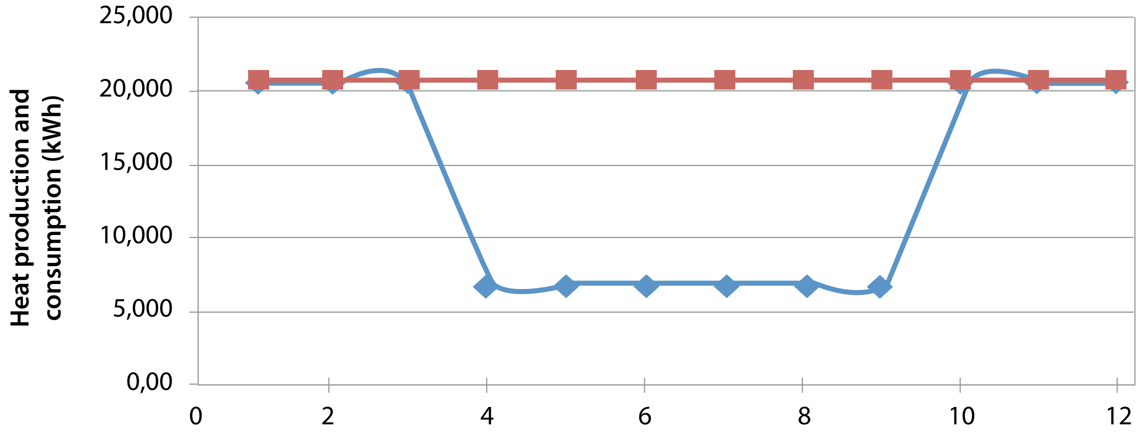

Figure 13 : Heat demand and consumption throughout the year in scenario 4 with heat consumption of Hooibeekhoeve (blue line) and available heat produced (red line)

A pocket digester that is constructed to fit entirely to the situation of the farm is not interesting due to the large investment cost compared to micro digesters which are modular and can be copied to a lot of companies. All 3 scenarios of micro digesters have a positive balance. None of these 3 scenarios have room for additional investments as this would have a big impact on the final balance (investment for a micro digester is about € 10-15 000/kWe). Therefore it is essential for a dairy farm to have the necessary synergies with the existing accommodation (storage capacity for the digestate and land for spreading the digestate).

A single micro digester is in this case the most convenient solution as it has no assumptions or extra risks. When full capacity use of 2 micro digesters (in the future) is possible, a second micro digester is recommended taking into account the energy consumption of this farm. This decision is site specific. For reasons of continuity and administrative load it is advisable to stick to the company's own manure.

1.2.1.3 Future implementation in Flanders

From about 900 farms in Flanders that own at least 80 cows, about 86 already invested in a small scale AD. This means that when looking at the innovation curve small scale AD of cattle slurry is situated in the early adopters phase, leaving still a lot of room for further adoption. From our experiences with some of the first installations we learnt that innovation in renewable energy indeed goes with some growing pains, which was felt both by the constructor and the first investors in small scale AD. However, after three years of experience, an adapted type of installation was put on the market, of which it can be expected that a lot of bottlenecks will have disappeared. Though the follow-up needed by the farmer is expected to be reduced, it is still important to stress that when a problem occurs (the farmer gets an alarm on his cell phone), fast reaction both from the farmer and the constructor is needed. Before investing in small scale AD several important factors need to be met: the farmer should have enough manure and also the demand for energy should be sufficiently large. Next to this also the manure should have a sufficient quality: manure that is stored too long, will not give a good energy production anymore. Therefore the biogas potential of the manure should be known before investments are made. Though there are 900 farms that have at least 80 cows, it can be expected that not all will have manure of sufficient quality.

Next to dairy farms a large potential is still seen for agroresidues not being valorized at the moment. Certainly for mono-digestion of pig slurry and vegetable residues new inventions might proof worthwhile, but are not on the market yet because of several technical and economic challenges still remaining.

1.2.2 Valorisation of corn stover

1.2.2.1 Pilot Description

Considering the total amount of biomass from crop residues in Flanders (about 950 000 tons of DM/year), corn stover takes in the largest share with more than half of this potential. With a dry matter content of about 30%, at the beginning of the ARBOR project, anaerobic digestion was considered to be the energetic conversion technology most suited for this type of biomass. The work carried out within ARBOR on corn stover consisted of a scoping investigation of technical possibilities, building up practical experiences on possibilities of how to valorize corn stover through anaerobic digestion and the potential of this input stream for anaerobic digestion.

During the project the **biomass potential of different fractions of corn stover** (corn cobs, corn, lowest stem part (10-40 cm), upper stem part (>40 cm)) was measured in two trials on a different location (2012). The purpose of measuring the biomass potential from the several parts of the plant was to take into account that it might be recommended to leave a certain part on the soil for the build-up of organic matter. Since the biogas potential of several fractions might be different, the **biogas potential** of these separate parts was also analyzed on a **lab scale** (2011). For maize several varieties are grown for the production of corn: some are very early varieties, others are half-early,… Since these varieties are grown for corn production, this does not necessarily mean that good corn varieties also give high yields regarding to corn stover. Also the greenness of the plant at harvesting might have an impact on the biogas potential of these varieties. To investigate the biomass potential from corn stover for several corn varieties a variety trial was carried out on two different locations.

One of the largest challenges for the valorization of corn stover is finding **adapted harvesting machines** that maximally fit all conditions: soil compaction needs to be avoided as much as possible, the costs for harvest should remain as low as possible so the number of passes on the field involving different kinds of machinery should also remain as low as possible, the extra time needed for harvest must be minimized, … To learn more about the technical possibilities Inagro carried out a **market study** looking at different types of machinery. Some installations were visited and two different **harvest demonstrations** were organized in Flanders.

Anaerobic digestion tests of biomass on a lab scale are interesting to investigate the biogas potential of the inputs tested. However, lab scale analysis don't have to deal with all the technical & practical constraints posed when digesting on the scale of the installation. To learn more about these elements several pilot scale biogas tests were performed with different fractions of corn stover: corn stover as a whole on the one hand and corn cobs on the other hand.

Due to the fact that certain pretreatment techniques can increase the biogas potential, a **literature study** was performed on several types of **pretreatment**. From this literature study extrusion was identified as a promising technology. Based on the conclusions from the literature study several **pretreatments were tested on a lab scale** on several types of agroresidues, amongst which on corn cobs.

During the project period while working on anaerobic digestion as a valorization strategy, Inagro was also contacted by and came into contact with several organizations (both companies and research institutes) that showed interest in corn stover for its use in **other valorization pathways**, e.g.: bio-refinery, fodder, combustion, building materials, substrate (mushroom culture), absorption material (e.g. absorption of paints, litter in stables), … To discuss **future strategies for the valorization of corn stover**, together with BioBase Europe Pilot Plant, Inagro organized a **workshop for companies**. Through a scoping literature study the potential of some of these other applications were listed.

1.2.2.2 Lessons learned

A. Assessment of the biomass potential through variety trials

In 2012 a variety trial was set out in Hoogstraten and Merelbeke in which different varieties of corn were grown. Of these varieties the yield of different plant parts: corn, spindle & husk, stem 10-40 cm and stem parts above 40 cm height, was determined. The stubble (0-10 cm) was excluded from yield determination. For each location plants were harvested in three replications. Samples were taken from each crop part, the parameters that were determined are: fresh yield, dry matter, organic matter, P and N. The ten varieties tested, are: P8000, Ricardiinio, Torres, Millesim, Ronaldinio, Grosso, Ajaxx, Coryphee, P7631, Nuxx, Sphinxx. P8000 and Ricardinio are for example very early varieties while Grosso is more of a late variety.
A summary of the average yields of the different parts of the maize plant in both field trials is given in Figure 14. Dry matter yield of all plant parts in both trials is summarized in Figure 15 and Figure 16. Figure 17 and Figure 18 give an overview of the average shares of each fraction in both field trials. The total fresh yield, including grain yield, varied between 37.2 and 49.9 ton/ha for Hoogstraten and between 40.2 and 50.2 ton/ha in Merelbeke. The total dry grain yield was between 9.7 and 13.3 ton/ha in Hoogstraten and 9.3 and 11.2 ton/ha in Merelbeke. The total stover yield was between 7.8 and 9.8 tons of DM/ha. Though corn yields differed significantly between plants, this cannot be said for the total corn stover yield (incl. spindle & husks). There was however a significant difference between varieties regarding to the spindle yield. In Hoogstraten the highest yield on spindle was for the variety Grosso, 2.1 ton DM/ha and in Merelbeke Torres had the highest yield of 1.7 ton DM/ha.

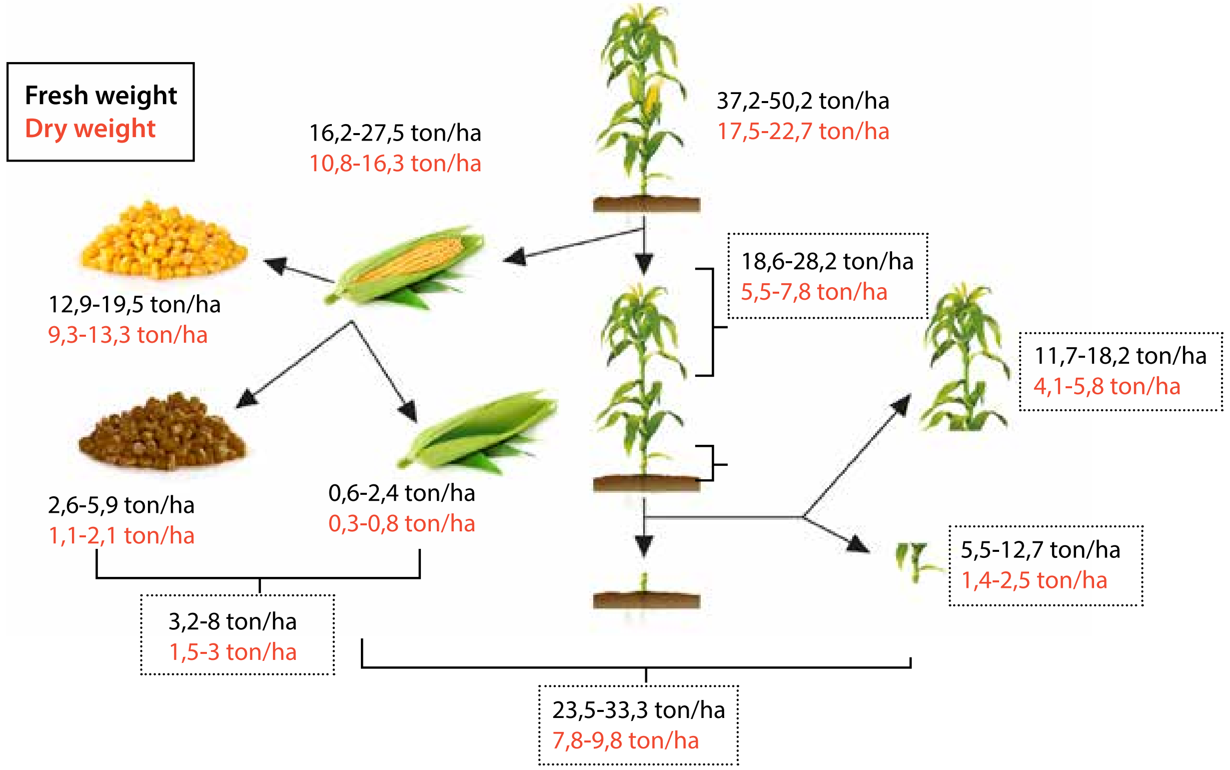

Figure 14: Biomass yield expressed in fresh (black) and dry (red) matter of the several plant part of maize

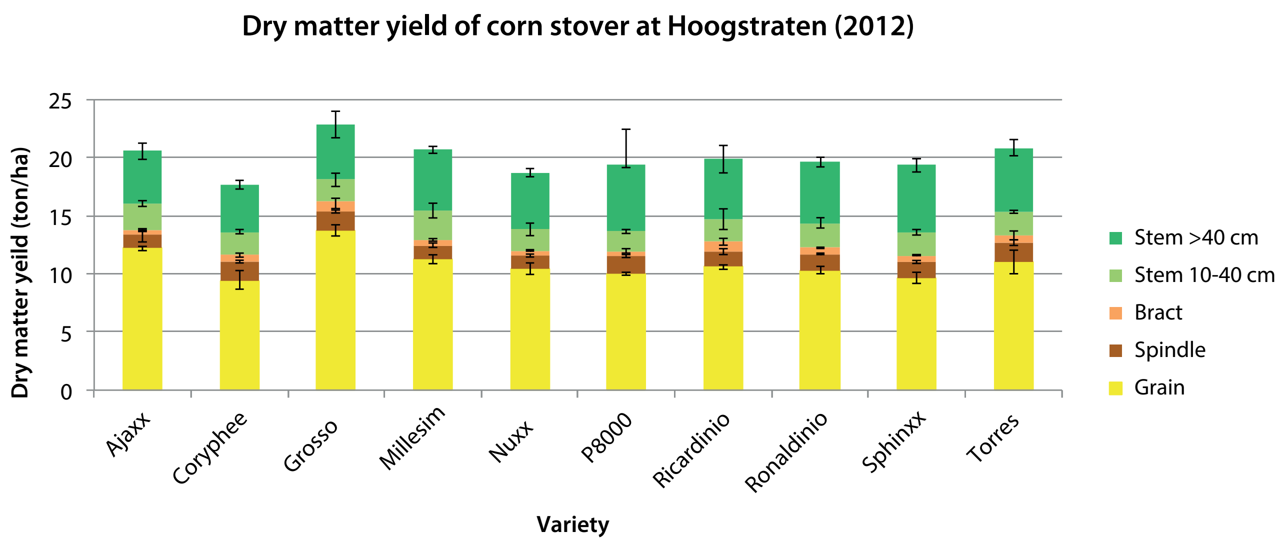

Figure 15: Dry matter yield of the different parts of corn stover at Hoogstraten (2012)

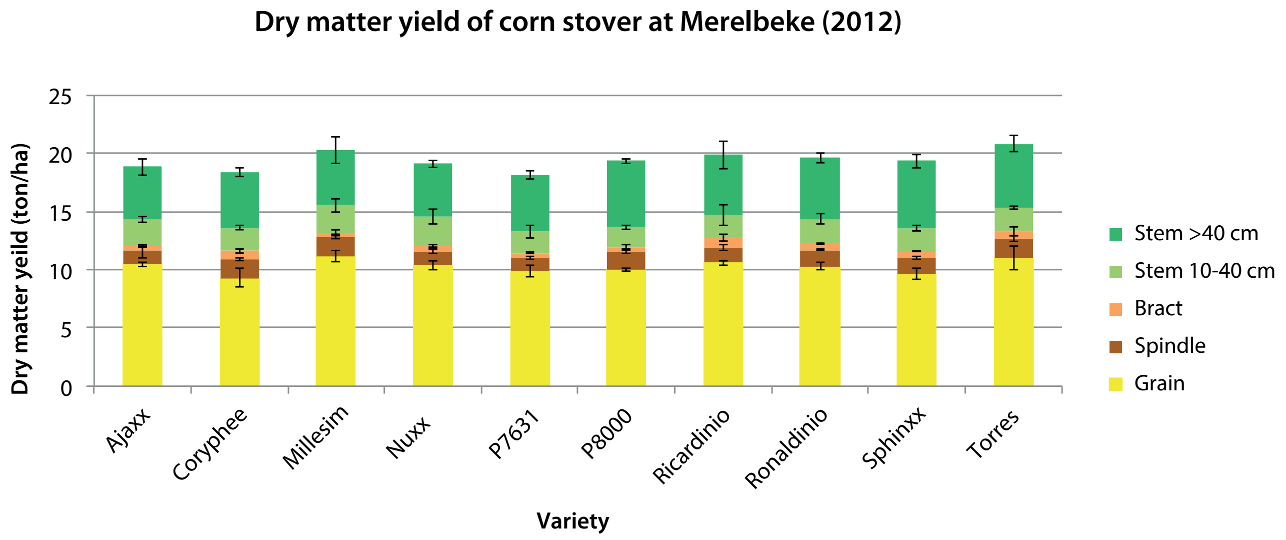

Figure 16: Dry matter yield of the different parts of corn stover at Merelbeke (2012)

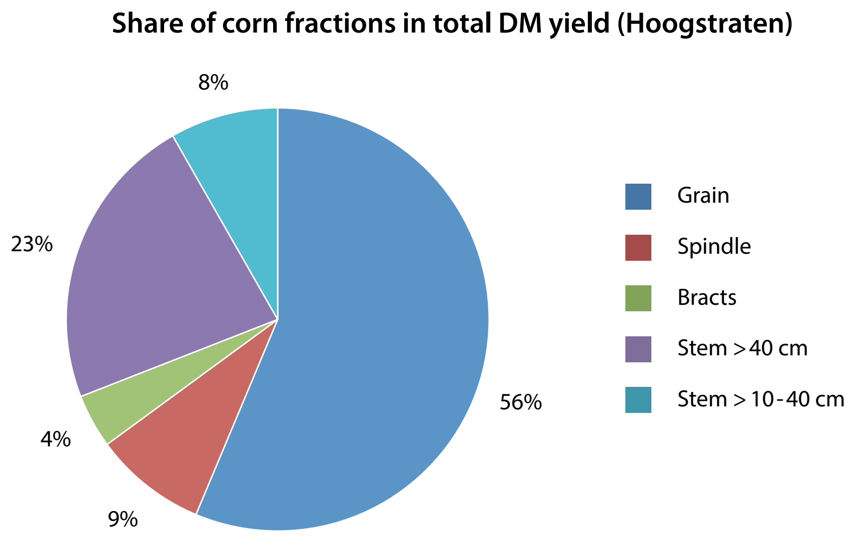

Figure 17: Share of corn stover fractions in total DM yield in Hoogstraten (2012)

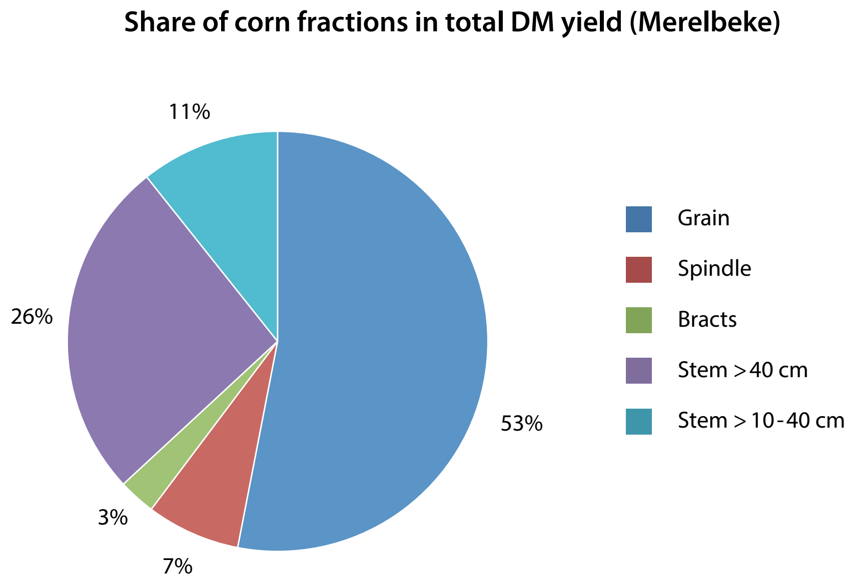

Figure 18: Share of corn stover fractions in total DM yield in Merelbeke (2012)

B. Biogas potential of corn stover on a lab scale

A field trial was set up in 2011 with maize on three different locations (Aalter, Beernem and Mesen). The purpose was to determine the biogas yield of different parts of the plant: cob & husk, straw 10-40 cm and straw >40cm. The stubble (lowest stem part, 0-10 cm) was again excluded. The cobs (excl. corn) seem to have the highest biogas potential of 531 Nm^3/ton DM (+/- 67.15), followed by the stem 10 - 40 cm, that has a potential of 441 Nm^3/ton DM (+/- 16.22). The upper part of the stem showed a biogas potential of 437 Nm1/ton DM (+/- 11.65). Though the biogas potential of corn cobs is high, anaerobic digestion of corn cobs demands a higher retention time in the digester, requiring 60 instead of 40 days.

C. Harvesting technologies

During the ARBOR project several pilots and demonstrations took place with adaptations of machinery only recently available in Flanders and tested for the first times on corn stover products. Next to this Inagro also performed a market study of different types of machinery to harvest (fractions of) corn stover abroad.

Pilots and demos

Collection of maize residues in bales

Figure 19: Merge Maxx 900 (Kuhn)

Different possibilities for the harvest of maize residues were investigated. One method is to rake the straw together after harvest. A demo with this type by Packo Agri was held in autumn 2013 at Lichtervelde (West-Flanders). The raker Merge Maxx 900 (Kuhn) is capable to rake the straw residues in windrow (Figure 19). Then a baler will pick up and press the straw in bales or the straw can be chopped and collected in bulk. The drawback of this method of raking in windrow, is that the straw is first laid on the ground. So there is a risk of contamination with sand and rocks, which is detrimental for digestion. Though the Merge Maxx 900 is specifically designed to restrict this contamination by a defined development of conveyor belts, during our experiments the straw contained quite some sand. Also a qualitative storage of the biomass with plastic bales seemed to be a difficulty. Another drawback is the fact that the machinery has to pass the field several times, this involves a higher risk for soil compaction.

Separate harvest of corn spindle (cob) in one pass

Figure 20: Adapted combine for spindle and husk collection in the bunker at the rear of the combine

To restrict the risk of soil contamination it is better to harvest the residues in one pass. This possibility was tested in autumn 2013 for corn cobs (spindles & husks). A conventional harvesting machine was adapted by a local contractor who bought and adapted a corn cob harvesting system from Austria. Corn and cobs (spindle incl. husks) were harvested separately with an adapted bunker at the rear of the combine to collect the spindles & husks. As can be seen in Figure 20 this bunker has a blowpipe to empty the biomass directly in a cart. The straw is left on the field. Unfortunately harvesting experiments have shown that it is not easy to harvest the cobs: only a small amount of spindle & husks was collected (about 1 ton of FM/ha) while harvest took a double amount of time. The new owner of the installation decided to remove the adaptation.

Another concept (Figure 21) is similar to the one mounted on the combine mentioned above. The advantage of this model is that the producers are able to adapt it to any kind of combine. It is developed in Blagny, North of France and is deployed successful in this region. The disadvantage of this adaptation is that the material has to be dumped at the side of the field, because a blowpipe or jackscrew is missing. This can lead to soil contamination of the biomass and causes extra work to load the cobs into a container for transport.

Figure 21: Adapted combine for spindle and husk collection in the bunker at the rear of the chopper

Prototype for separate harvest of full cobs and chopped stover

Figure 22: Front view of the adapted combine with two headers by Renders and Kenis

The machine can harvest maize straw and cobs (as a whole including the grain) separately in one working pass. This is possible by a an adapted combine with two headers. The upper one is for the collection of the cobs and the header underneath it is for cutting the stems. The cobs, coming from the upper header, are transported by a conveyer to the rear of the machine into a bunker. The stem, cut by the bottom header (Figure 22 & Figure 23), is transported into the machine, where it is chopped and then blown into a cart next to it. The owner of the machine is interested in this separated harvest, because the cobs are milled and used as fodder for cows. The chopped stems are intended for his digestion plant. A demonstration with this type was organized in autumn 2014.

Figure 23: Side view of the adapted combine with two headers by Renders and Kenis

Global market study

Conventional method to harvest corn (Figure 24)

The cutter head in the mowing board cuts the stem and separates it of the cob (1). The stem is then chopped and laid on the field immediately, while the cob is transported into the combine to the threshing part (2). After threshing the grains from the spindle they are transported to the separation part (3), where the husks are blown away. The grain falls down into the sieves (4) while at the back in the chopper (5) all the rest (husks and spindle) is chopped and spread again onto the field. The grain will be transported to the tank (6) (Pieters, 2011).

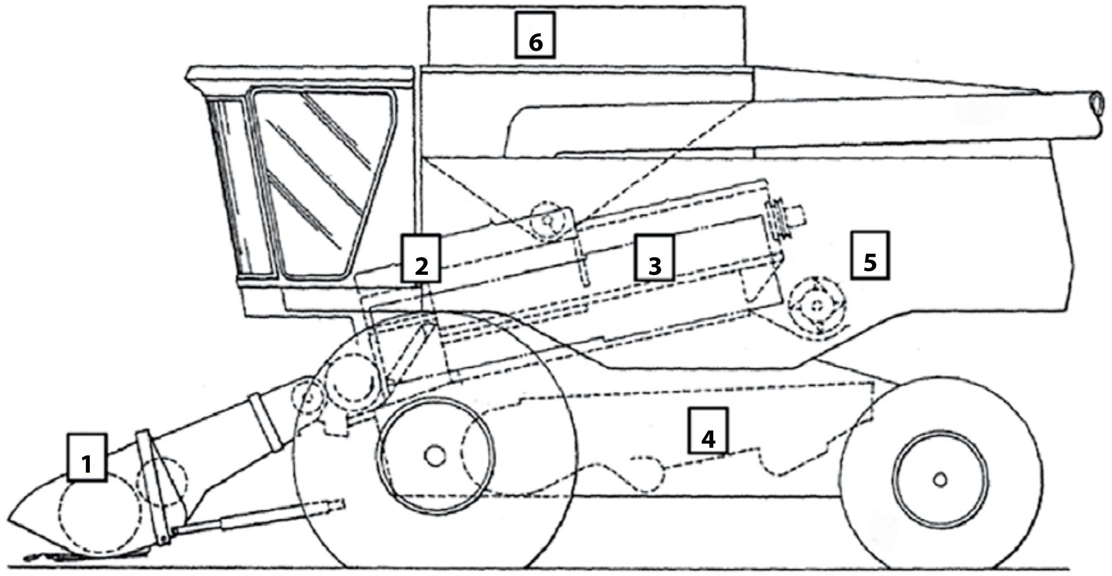

Figure 24: Combine (1) Cutter head, (2) Threshing part, (3) Separation compartiment, (4) Sieving system, (5) Chopper and (6) Grain tank (Mackin *et al*., 2006)

Harvest of stem, leaves, husk and spindle

Bulk collection

The concept is an adapted cutter head, mounted on any type of tractor which collects the plant as a whole (incl. corn). The stem is cut at its base and then chopped and collected in a cart through a jackscrew. The same jackscrew is used to transport the straw and corn to the cart. The threshing step happens afterwards. In this way the plant is entirely harvested and collected in one working pass (Birrel *et al*., 2004).

+ : simple harvest of bulk material in one pass, no large investments necessary

- : threshing step needs to be done afterwards, tractor and cart for collection of the bulk material necessary.

Figure 25: Bulk collection (Birrel et al., 2004)

Modified header & chopper

In this system the plant is collected as a whole in the combine by the modified head and after processing it is collected in two different streams (Green Car Congres, 2006). The first stream is corn, which is collected in the tank of the combine. The other stream is the material other than grain (MOG). The chopper and nozzle at the end of the combine blows this MOG into a cart, which is pulled by the combine, this can be seen in Figure 26 and Figure 27 (McNaull, 2010).

+ : collection of straw without contact with the soil in one pass, no extra tractor needed because the cart is towed by the combine, costs of adaption not very high (between € 15 000 and € 20 000)

- : lower harvest speed, loss of time for emptying of the cart

Figure 26: Combine with adapted cutter head to collect all the biomass (Shinners *et al*., 2009)

Figure 27: Adaption of the combine: chopper and nozzle (Green Car Congres, 2006)

Baler

The combination of a combine pulling a baler is called "the Glenvar system" (Figure 26). In this method the MOG is transported to a baler which is pulled by the combine. The threshing of the corn happens in the conventional way. The adaptation is that the chopper at the back of the combine is shut off. So the MOG is transported without reduction to the baler by a conveyor where it is packed to bales and laid on the field. Which can be collected afterwards (Keene *et al*., 2012; McBrayer, 2009).

+ : high density of the residues which lowers the transportation costs
no contamination with soil

- : high investment costs for extra baler, lower harvest speed, two working passes necessary for the collection of the bales, more space necessary on the field for turning of the combine

Figure 28: The combine pulling a baler (Verhaeghe, 2013)

Harvest of spindle and husk

To harvest spindle and husk a collection method is developed to collect the residues at the end of the combine. An example of such a concept is an extra tank for the residues on top of the tank of the grain, which can be seen in Figure 29. The spindle and husk are collected at the end and are blown by a fan into this upper tank. The advantage of this type is that the spindle and husk can be collected directly into a cart, without dumping it on the soil first (Johnson, 2008).

+ : no soil contamination of spindle

- : extra costs of tractor and cart for the collection of spindle and husks

Figure 29: Emptying the upper tank with maize residues into a cart (Davidson, 2008)

Harvest of straw

An adapted head which functions as a chopper and corn collector makes it possible to harvest the stem and leaves. The cob is collected and brought into the combine for conventional threshing. The stem and leaves are processed in the head, where they are chopped. Then the fan blows this material in a cart next to the combine (Figure 30).

+: chopped straw is directly blown in a cart without contamination of soil

- : extra costs of tractor and cart for collection of the chopped straw

Figure 30: Adapted combine with cutter head to collect and chop stem and leaves (Shinners *et al*., 2009)

Harvest of spindle

Towed cart

(Figure 31 & 32). The threshing step happens according to the conventional method. The biomass at the end of the combine (husk and spindle) is collected on a conveyor, which transports it to the cart. In the cart the separation of the husks and spindle takes place. While the spindles are collected, the leaves will be spread out on the field (McBrayer, 2009).

+ : no costs for adaption of the combine, no soil contamination of spindle

- : investment of the equipped cart, extra space necessary on the parcel for turning

Figure 31: Collection cart with separation of cob and husks (Vermeer, 2009)

Figure 32: Emptying cobs of the collection cart (Christiansen, 2009)

CCM

By the harvest of corn and cob together, corn cob mix (CCM) is produced. In this method the corn and cobs have to be separated afterwards by a drum sieve (Figure 33). The corn can pass the sieve and is transported with a conveyor. The cobs are collected at the other side of the drum sieve. The cobs can be stored and used for biogas or ethanol production, while the grains can be sold as fodder or feed. The residues remaining are spread on the field (Schafer, 2008).

+ : no influence on harvest speed

- : investments of a sieve and extra labor costs for sieving

Figure 33: Drum sieve (POET, 2008)

D. Pilot scale anaerobic digestion of corn stover

Different digestion trials on pilot scale were carried out with corn stover products in Inagro's digester. In January – February (22/01/2013 – 5/02/2013) the digester was fed with 500 kg maize cobs a day instead of energy maize. This is a ratio of 25% of the 2000 kg energy maize that was originally fed. The electricity production lowered in this period from 22 to 15 kWel. The problem was the storage of this type of biomass. It has to be fed immediately to the digester, otherwise mold will start growing on the biomass. Or it should be chopped, pressed and silaged short after harvesting (possibly with a product that has a lower DM content, see further), to obtain a good storage. Within a few weeks of storage the biomass showed a rapid degradation after it was brought to the site next to the digester. This, together with difficulties to reduce the size of the cobs and the longer retention time for corn cobs, can explain the lower yield of electricity.

Between the 20th of February – the 4th of March 2013 there was an indicative digestion trial with 4 bales of biomass (600 kg) which were obtained from a harvest trial of CNH. The replacement ratio was 15% corn straw and 25% rye. The electricity production in this period was 20 kWel. The problems were the presence of stones in the biomass, which were manually removed. This was a result of the harvesting method. This demonstrates the importance of fine tuning of the harvesting technologies, so there would be no contamination with other materials.
Between the 18th of May and the 5th of June 2013 there was a qualitative digestion pilot at the site of Inagro with maize straw. The replacement ratio this time was 25% of the energy maize. Before digestion the residues were chopped. The energy maize was well mixed with the straw before feeding. In this period there was a production of 20.8 kWel.

These trials show important indications of the potential of maize residues for digestion. In evaluation of the results one has to take into account that these trials were only carried out on short term. This gives just an indication of the potential. In every start of a trial the micro-organisms have to adapt to the new type of biomass fed. Actually a qualitative trial demands a testing period equal to at least two times the residence time of the biomass in the reactor. So in the pilot digestor this means 2 x 40 days, which means 80 days x 500 kg/day or 40 ton biomass. In the scope of the project it was not feasible to obtain this much of material at once, this can be explained by the fact that adapted harvesting machines and ways to optimally chop and store the biomass are still lacking.

E. Pretreatment of agroresidues for anaerobic digestion

The main objective of pretreating agroresidues for anaerobic digestion is to increase the biogas yield per unit of organic dry matter and lower the hydraulic retention time via faster conversion. A large variety of biomass pretreatments exists, but in general those processes result mostly in diminution of the particle size, reducing the crystallinity of the ligno-cellulosic matrix, rupture of plant cells and/or lowering the degree of polymerization (Ariunbaatar *et al*., 2014).

Chemical pretreatment techniques make use of a chemical substance. Following the type of chemicals used they are further classified as acid, alkaline and/or oxidative pretreatment. The main drawbacks of those techniques are the need for a noncorrosive pretreatment reactor, use of chemicals and the large use of water. Those disadvantages are often not in proportion to the extra biogas yield obtained by the pretreatment. However for the production of bio-ethanol from corn stover, the so-called second generation biofuels, chemical pretreatments are the method of choice because of the high rate of conversion and the high process control.

Thermal pretreatments require a high energy input. In Flanders these are only applied when the biomass needs to be hygienised, so called sanitation, due to legal restriction on export (in Flanders the requirements are 1 hour at 70 °C). Higher temperature treatments on manure (>110 °C) lead to brown color development caused by the maillard reaction and result in lower biogas yields (Luste *et al*., 2012). Nevertheless the use of steam explosion is often used to destroy the lignocellulosic matrix present in for example wheat straw, sprout stems, corn stover, etc.

The **addition of enzymes, fungi or specific microbial** cultures during ensilage, in the anaerobic digester tank or in separate tanks is referred to as biological treatment. Several studies have researched the effect of enzyme additives and found that the extra biogas yield via this pretreatment on manure and sludge was low. Furthermore due to the cost of enzymes it is unlikely to be economically feasible (Warthmann *et al*, 2012). Addition of homo- and heterofermentative cultures to biomass feedstocks showed in full scale experiments at Inagro a slightly higher biogas production of 3-7 % per organic dry matter (Vervaeren *et al*., 2010).

Physical pretreatments such as knife milling, ball milling or shredders reduce the particle sizes by cutting or squeezing the biomass and by this way enlarge the contact surface between the agro-residues and microbes. Thermochemical treatment such as extrusion combines the use of heat and particle size reduction to further lower the polymerization degree of the (hemi)cellulose and increase the contact surface. The main drawback of physical pretreatments is the susceptibility for soil contamination and stones, often present in agro residues as this will damage the blades, screws, etc. On the other hand does extrusion of difficult and lignocellulos biomass stream have a positive energy balance in regard to the electricity input and electricity of surplus biogas (Hjorth *et al*, 2011). Next to this it is a relative straight forward method and can thus be easily implemented on a farm scale. For those reasons extrusion was selected in the framework of the ARBOR project to execute experiments on the determination of biogas yield for sprout stems (see valorization of vegetable residues) and corn stover.

Extrusion on corn spindle

The dry matter content of corn spindle in this experiment was 38 % and about 34 % was determined as organic dry matter (of total fresh weight). Corn spindle has a high lignocellulosic content and for this reason digestion of untreated biomass is not optimal in regard to the total organic dry matter present. This can be clearly seen in Figure 34 where the untreated corn spindle has a methane production of almost half of the extruded samples after 30 days of incubation test. Next to this it can be seen that at around 7 days slow and fast extruded samples show the same methane production as untreated samples after 30 days. This indicates a higher accessibility of the pretreated substrate and thus the possibility in lowering the HRT for the digestion of corn stover.

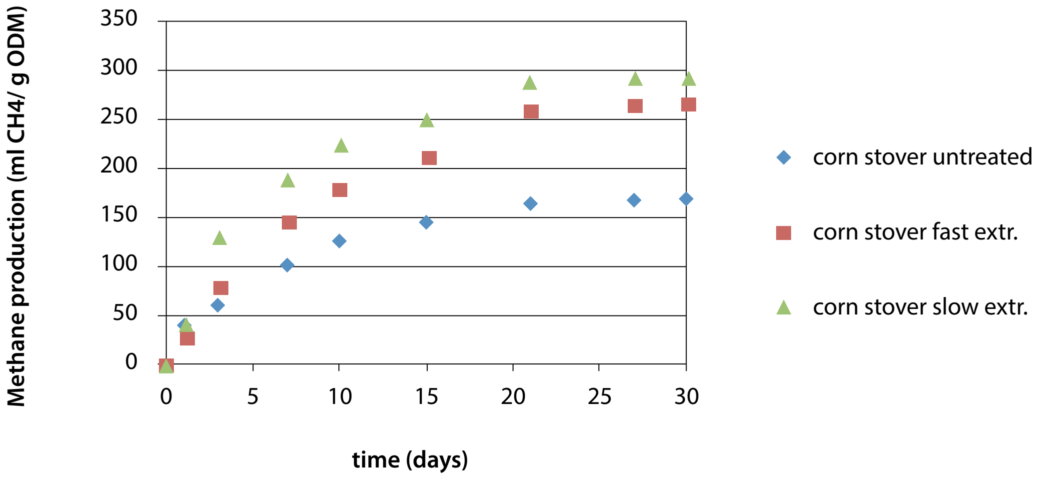

Figure 34: Methane production of extruded (extr.) and untreated corn stover

Figure 35: Biomass after extrusion

F. Other value chains for valorization of corn stover

Due to the fact that also companies and institutions representing other valorization pathways, showed interest in corn stover as a primary product, it should be taken into account that when setting up a logistic chain involving big investments, certainty is needed regarding to the (economic, ecologic and social) sustainability of the valorization chain in mind. When different end value chains aim on using the same product, of which some want to use it on a large scale while others want to use it on a small scale, competition might appear. To get a better view on other valorization possibilities than anaerobic digestion, for this reason a literature study was performed.

Biorefinery

Bioethanol production from corn stover is a so-called second generation biofuel as it does not make use of crops that are grown for food or feed. Corn stover consists mostly out of a lignocellulosic matrix and so it is less susceptible to fermentation than the amylose carbohy-drates in corn grain. For this reason most often a thermal and/or chemical pretreatment is used such as ammonium fibre explosion (AFEX), steam explosion, etc. A schematic overview of the production of ethanol from biomass is given in Figure 36.

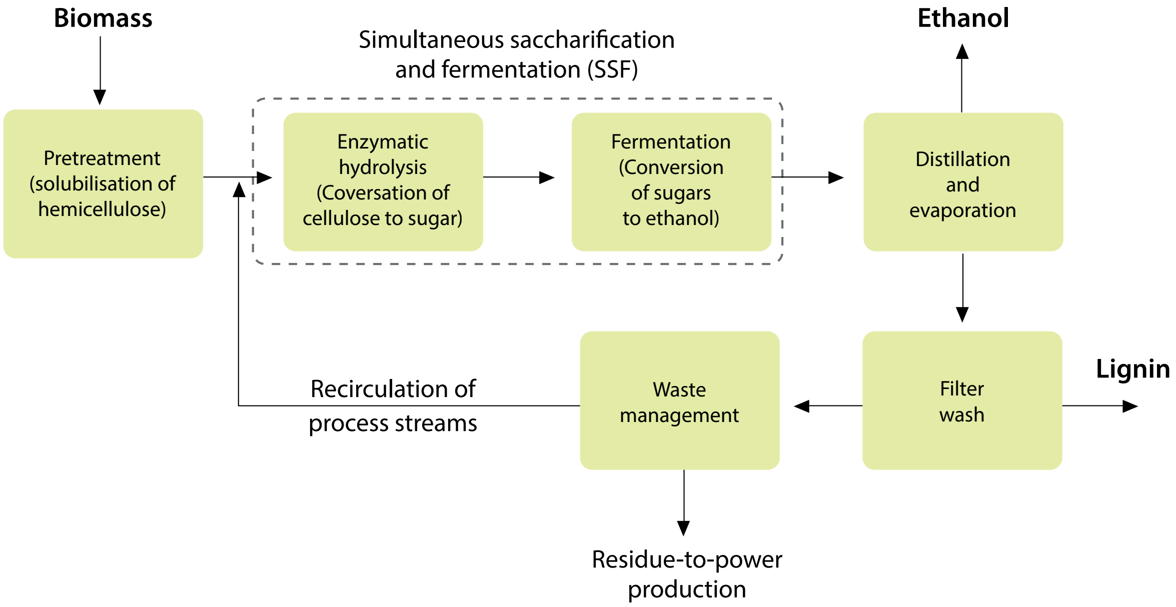

Figure 36: Schematic flowsheet for the conversion of biomass to ethanol (Hahn-Hägerdal *et al.*, 2006)

Burujana *et al*. (2014) calculated that every 100 g of pretreated corn stover resulted into 12,6 glucan. The more easily degradable carbohydrates obtained by pretreatment were then subjected to a simultaneous sacharifiation and fermentation (SSF) by addition of enzymes and yeast with an efficiency of 77 % to bioethanol.

In some regions the use of corn stover has left the experimental stage and was upscaled into a full operational plant. This is the case for the unique factory of Dupont® in the United States and more specific Nevada, Iowa. In this plant around 350 000 ton of corn stover is collected in a 48 km radius around the plant and converted into 113 million liter ethanol. The amount of corn stover harvested from the field is around 2 to 3 ton per hectare as this is enough to safe-guard an optimal organic matter content in the soil.

Another possible biorefinery pathway for corn stover is the conversion to lactic acid. This is being explored on an industrial base by a joint venture between Cargill and Dow chemicals in Nebraska. At the moment the plant produces a 150 million kg of poly lactic acid but is interested in the possibility of corn stover as input material (Paster *et al*., 2003).

Fodder

Corn stover can be applied in cattle diets. From experiments abroad it is shown that up to 20 % of corn grain replacement by stover gave no significant difference in the ratio of weight gained over feed for dry cattle and young stock used. However the stover was pretreated with 2-3% ammonium or 5 % CaOH (on DM base) during 7-21 days (Russel *et al*. 2011). In Flanders the company Avecom is researching the use of biological and microbial amendments to enhance the digestibility.

Next to this the use of corn cobs for pig feed was tested. When ground to a meal and mixed with the regular diet of Landrace pigs up to 20 %, it was shown that corn cobs could provide an economical attractive alternative (Fombad *et al*.).

Building materials

Oriental strand boards (OSB) or fibreboards are the two building materials in which corn stover has been applied nowadays. Cornboard manufacturing Inc. based in Illionois, USA makes an oriental strand board completely out of corn and with a biobased adhesive instead of formaldehyde. In the Netherlands the company Ecoboard produces fibreboards which contain corn stover.
The main problem of switching from wood waste to annual crops such as corn cover is that they contain higher levels of alkali metals and often contain an epicuticular wax. Both hinder the effectiveness of the adhesives and via this way lower the strength of the produced building material. Next to this the elevated levels of alkali metals cause problems in the down-stream processing via combustion as this will create corrosion in the burning chamber.

Substrate for mushrooms

Another possibility is the use of corn cobs as a substrate for mushroom cultivation. It has been shown that mushrooms grown on maize substrate show high nutritional properties (Adedokun *et al*, 2013). In countries like Hungaria corn based products are frequently used as a substrate. To obtain a good substrate a dry matter content from 85 to 88% is needed. Since the dry matter content of corn cobs is way lower, drying is necessary. Due to husks being attached to the spindle, this drying step is very difficult. In ARBOR two drying experiments were executed on a pilot scale with several tons of cobs. The first experiment was carried out with a large drum dryer (mainly used for feed drying). Spindle and husks were clogging the installation during the drying experiment. The goal was to test the biomass further as a substrate for mushrooms, however due to insufficient drying natural heating started to occur by biological activity. The second experiment in which corn cobs were dried in a solid container through which hot air was blown, showed better drying results, however there was not enough material to fill the container entirely.

Absorption material

Corn stover shows a similar water holding capacity as wheat straw (about 3,6 g of water per gram of bedding material). For this reason it is often applied as bedding material in cow stables in the United States of America. Next to this it is also found in pig stables but due to the coarser characteristics of the material than straw it is not recommended to use in farrowing boxes or the lactation room.

Another application where corn stover is found as an absorption material is the use in fiber blankets. Those biodegradable blankets, applied on the soil surface, are used for the faster germination of for example grass seeds, to retain water and to avoid erosion.

Combustion

Several pilot studies showed that the use of corn stover and cobs is possible in small scale installations in the form of pellets or untreated. This is the case for a 146 kW boiler in Canada that runs on corn stover bales (Brunner *et al*., 2012). That study demonstrated that corn stover has the potential to produce combustion energy but the biomass may need to be densified or the boiler should be modified to improve airflow, enhance combustion completeness and facilitate ash removal. Another example is the combustion of corn cobs in a 350 kW boiler in Austria . The study concluded that biomass boilers should be tailored to the special demands of this fuel to avoid slagging, corrosion and fine particle and NOx emissions. Corn cobs can be a meaningful fuel in maize dominant regions but due to the low density (and subsequently energy density) long transport distance should be avoided.

Next to a higher alkali metal concentration in corn stover, cob and bracts those agro residues also have a higher ash (5-7 % of DM) and nitrogen content in comparison to wood. This limits the use in combustion as it will cause problems in regard to NOx emission and the need of a more frequent removal of ash. The bract with a relative higher Cl, S and alkali metal content than corn stover and cobs is unsuited for combustion. Feasibility of combustion relies highly on the dry matter content of the agro residues and thus for most installation and experiments the corn stover and cobs have a dry matter content of around 90% (Morissette *et al*. 2011). In climatic conditions similar to Flanders the harvested corn residues show a much lower dry matter content of 30 to 50 % (for corn cobs). This explains the need for an additional drying step before combustion is possible. The energetic value of corn stover and cobs lies around 18 kJ/g of dry matter, which is similar to wood.

1.2.2.3 *Future implementation in Flanders*

The combines in Flanders nowadays are not able to harvest the residues of maize properly taking into account all side conditions (no soil contamination, harvest in a single pass, …) There were however several pilot initiatives in which local constructors adapted their machines or tried to harvest the stover using existing machines which are normally used for other purposes. When comparing however the cost for harvest & logistics of corn stover, at the moment it is very difficult to attain a cost that is less than the cost to just grow and harvest energy maize. It remains a challenge for developers to build a harvesting machine that is suited to cope with all side conditions. Abroad several constructors have machines in foreign countries who are able to harvest the stover. But it remains a question if these machines are adapted to our wet climate, where the harvest has to be in a minimum of passes, without soil contamination. A further in depth investigation of transferring possibilities from foreign countries towards our region is necessary. Other regions, like North America, have already more knowledge in this matter. Another problem in these cases is that these machines are prototypes and therefore not certified for the European market. During the project there have been several meetings with Case New Holland on the possibilities to build an adapted harvester. Before large businesses (like CNH) want to invest in this, there needs to be a sound business plan and the end product requirements need to be known. Since also other sectors have shown interest in corn stover and aim at valorization on a quite large scale, several end value chains need to be investigated and compared regarding to their (economical, ecological & social) sustainability. This will be the subject of further research.

1.2.3 Valorisation of vegetable residues

1.2.3.1 *Pilot Description*

The manure action program MAP IV (2011-2014) and further on MAP V have the goal to lower the nitrate content in the surface water at the measuring points in Flanders to less than 50 mg NO_3^-/l. By this strict fertilization legislation in Flanders the tillage of different vegetables in open field is under pressure. The intensive cultivation of vegetables leaves large quantities of crop residues on the field after harvest, or residues are brought back to the field after cleaning. These residues are rich in nitrogen and can generate severe nitrogen leaching when they are ploughed in the soil before winter. This because important quantities of mineral nitrogen can be released as a consequence of the easy degradability of these residues (e.g. leek, cauliflower, cabbages, celery, …). Especially during the wet winter months there is a great risk of nitrogen leaching in the surface water from crop residues. Even with lower temperatures in this period there is still a distinct nitrogen mineralization. The nitrogen content of harvest residues can rise quickly up to 100 – 200 kg N/ha (Landbouw & Visserij, 2011) as can be seen in Figure 37.

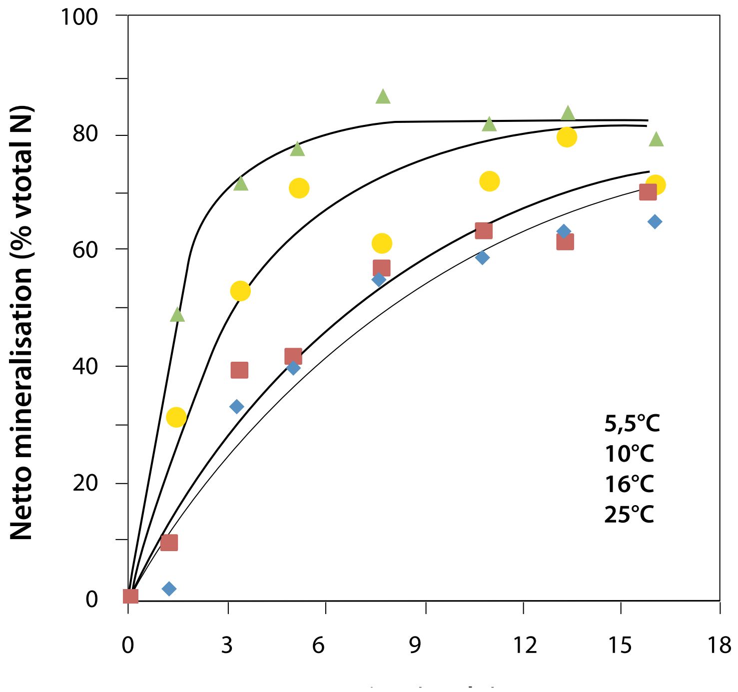

Figure 37: Nitrogen mineralisation from cauliflower leaf, horizontal axis shows the time in weeks, the vertical axis shows the net N mineralization as a % of total N (De Neve, 2000).

Next to nutrient leaching, crop residues (e.g. leek) can cause a bad odor, which is sometimes a reason for complaints of neighbors. An option that can lower the risk of N-losses of late vegetable cultivation and the bad odor caused by rotting of residues is the complete removal of these crop residues after harvest. Since all extra steps needed involve an extra cost for the farmer, valorization strategies need to be sought to reduce the costs involved. Due to the low DM content, at the beginning of the ARBOR project, anaerobic digestion was identified as the energetic valorization strategy to further investigate. Within the ARBOR project period Inagro also participated in a Flemish VLM project ('Oogstresten' or 'Crop residues'), in that project the impact of removing crop residues on nutrient leaching was investigated together with the comparison of several (also non-energy related) valorization strategies on a lab scale. The focus of ARBOR, parallel to the VLM project, was to investigate the **practical use of different crop residues in anaerobic digestion on a pilot scale**. Several data were exchanged between both projects. Within the ARBOR project Inagro focused on three different types of vegetables: **leek, Brussel sprouts** and **cabbages**. For each of these crops several tests were carried out on **lab & pilot scale** to investigate the **biomass & biogas potential**. Also **pre-treatment experiments** (extrusion and an alkaline treatment) were carried out to improve the biogas potential from residues. A market study was carried out on adapted machinery for harvesting vegetable residues, also a **harvester** was **adapted** so it can collect residues. Next to this Innova Energy as a subcontractor of Ghent University also investigated the potential of vegetable residues in a specific case for **chicory roots as a substrate for small scale anaerobic digestion**. Also there was a feasibility study in which GreenWatt investigated the possibilities for adjusting the anaerobic digester of Inagro to make it more suited for digesting crop residues.

1.2.3.2 *Lessons learned*

A. Biomass potential

From earlier practical experiences in field trials by different Flemish agricultural research centers (Inagro, PCG and PSKW, 2014) the following biomass potential can be summarized for leek and cauliflower.

Crop	Crop yield (ton FM/ha)	Residue yield (ton FM/ha)
Leek	45-55	20-25
Cauliflower	35-40	45-50

Table 4: Crop and residue yield for leek and cauliflower

For Brussel sprouts no exact amounts of crop residues were known from earlier field trials at Inagro. Therefore during the ARBOR project yield of Brussel sprout stems was determined in a new field trial. Though this amount is probably an underestimation (e.g. it was very difficult for collecting leaves that got stuck into the soil during harvest) a biomass potential of **47,0 tons of FM/ha** (± 10,0) was measured manually in November 2013 for stems of Brussel sprouts over 4 replications.

For the moment (apart from two pioneers who harvest Brussel sprout stems) none of these crop residues are harvested in Flanders. Both for leek and cauliflower at the moment **no harvesters exist that can harvest these residues together with (but separated from) the crop**. In order to search for technical solutions in 2013 Inagro invited several well-known constructors of horticultural harvesting machinery in the province of West-Flanders for a meeting. During this meeting one of the issues that arose was that it will be a difficulty to **convince farmers** to collect and harvest crop residues. According to them a **financial stimulus would be needed**.

Before going more into detail on technical harvesting & valorization opportunities, Inagro wanted to investigate if it could be a possibility to convert the anaerobic (pilot) digester of Inagro into a small synergy park (merely based on biomass potential). This was performed in close interaction with the idea of the action on synergy parks in the ARBOR project. The anaerobic digester of Inagro is an installation of 31 kW electrical power and is fed with pig slurry (1.1-1.6 tons/day) and energy maize (± 2 tons/day). Instead of growing energy maize for anaerobic digestion the goal was to identify if the energy maize could be (partly) replaced by the crop residues investigated in ARBOR. To investigate this more into depth a tender was written for a feasibility study on the opportunities of adapting Inagro's biogas installation towards a better intake and digestion of crop residues. The feasibility study was granted to GreenWatt. Next to this a **GIS study** was carried out on a radius of 2.5 km around Inagro investigating how much biomass from crop residues could be collected in a small area. Figure 38 shows the fields where in 2013 corn

Table 5: Surface of the different types of crops investigated in ARBOR in a radius of 2.5 km around Inagro

	Surface (ha)
Cauliflower (industry)	26.2
Cauliflower (fresh)	6.8
Leek (industry)	9.1
Leek (fresh)	41.2
Brussels sprouts (industry)	37.8
Brussels sprouts (fresh)	3.3
Corn	257.9
Total	412

maize (orange), cauliflower (yellow), leek (purple) and Brussel sprouts (blue) were grown. Inagro is marked by a red circle. Table 5 shows the areas for each crop in this 2.5 km radius. In this table a subdivision is made between crops for industry and those for the fresh market. Each year Inagro feeds about 600 tons of energy maize to its digester, looking at Table 5 it is clearly noted that within a radius of 2.5 km the amount of crop residues is more than sufficient to replace the same volume of biomass.

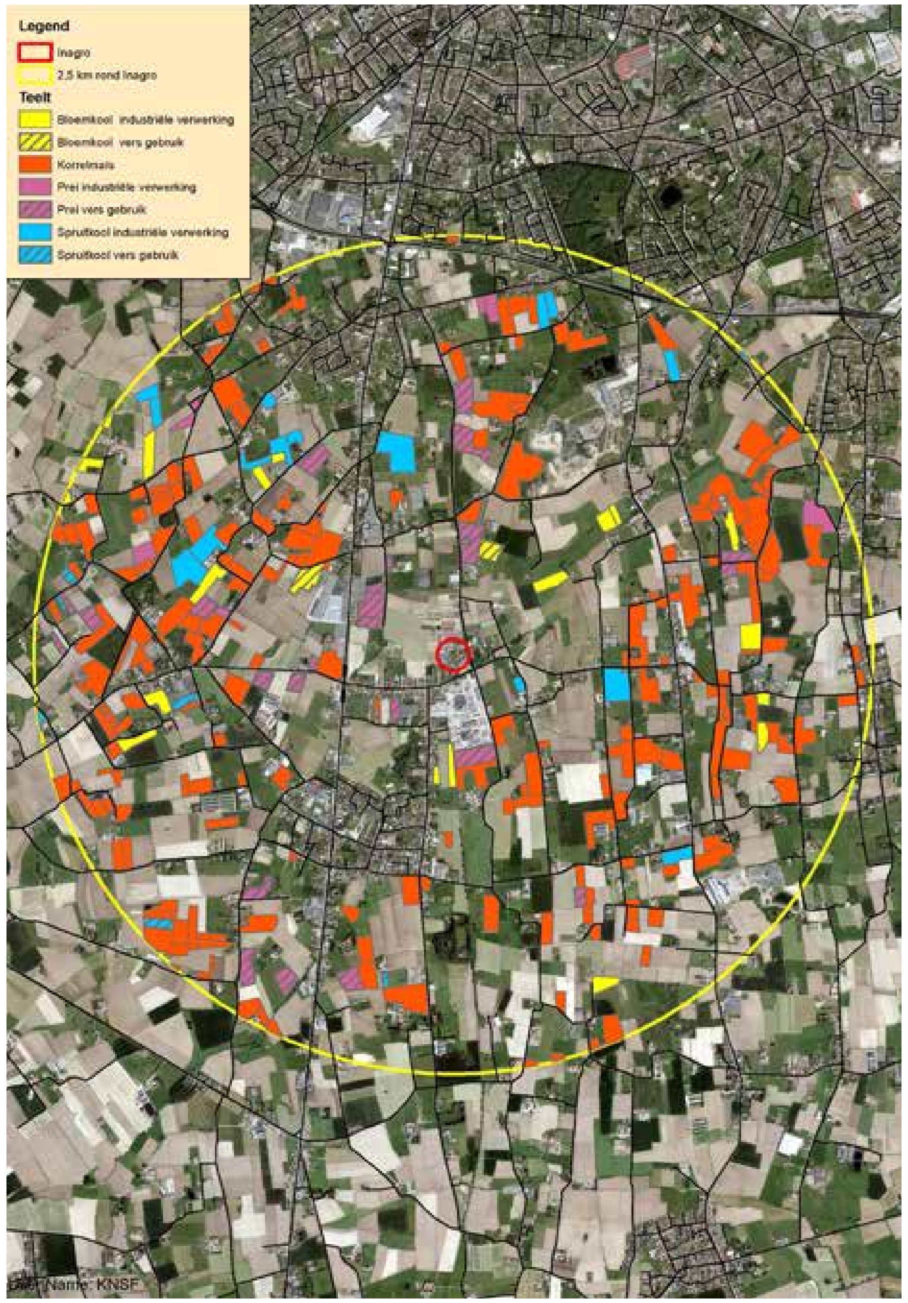

Figure 38: Radius of 2.5 km around Inagro (red circle) with the indication of different types of crop

Due to the condition mentioned by the constructors of harvesting machinery about the need to convince farmers to harvest and/or valorize crop residues, several farmers in a radius of 2.5 km around Inagro where interviewed about the possibilities to deliver crop residues to the pilot digester of Inagro. For each type of crop residue several farmers were interviewed by telephone. In total 22 of the 92 farmers were queried. They were asked about the current destination of their crop residues, the storage capacity at their exploitation and the willingness to harvest and transport the biomass.

Results questionnaire

- Cauliflower: none of the cauliflower farmers was very willing to collect the residues on field. Today residues are ploughed back into the field or left on the parcel, where they dry out. Collection of residues should be done after harvest, this means extra workload, an extra working pass and a higher risk for soil compaction. Another reason why the farmers don't wan't to collect the leaves is the fertiliziation potential of these leaves. Only if collection of cauliflower leaves wouldn't require extra work or an extra cost, they might be willing to collect them.

- Leek: only two of the leek growers were not convinced to collect residues. The other five were convinced to valorize them. Commonly residues from leek grown for the fresh market are collected on a pile after the cleaning and peeling line. When the pile becomes too high or after two years of composting (smaller farms) residues are transported back to the field and ploughed back into it. For two years no leek is grown on these fields to lower the risk of disease transferability. For industrial leek the cleaning happens directly on the field. All the residues are then dropped on the soil, no residues are collected.

- Brussels sprouts: four farmers were questioned about their willingness to collect and transport crop residues. All of them were prepared to do this. Most of the farmers recognized that in the past the stems of Brussels sprouts were collected as feed for the animals. So they saw potential in the collection. One of the farmers picks the sprouts manually throughout the growing season: after harvesting all sprouts in an extra single pass, crop residues are collected as a fodder for his cows.

- Maize: from the six farmers, one was not convinced of the collection of the crop residues, one was neutral about the concept and four were prepared to do so. The biggest concern is the second working pass on the field. In the period of corn harvest, a lot of fields are very moist. An extra pass with heavy machines will increase the risk of structural damage. If adapted combines would be available to collect stover and/or spindle at once this would convince most of the farmers to co-harvest the residues.

B. Harvesting technologies

During the meeting (Jan. 2013) with four constructors of vegetable harvesting machinery, harvesting possibilities for each of the investigated crops were discussed.

Cauliflower

Today cauliflowers grown for industry are harvested mainly manually by cutting the stem of the cabbages between the leaves, this way the rest of the plant remains standing. Cauliflowers grown for the fresh market are cut together with the leaves (cauliflowers are sold together with some leaves still attached), most of the leaves are then cut off and fall onto the soil. For anaerobic digestion, contamination of biomass with soil should be avoided as much as possible. For this reason mainly collection of **residues from cauliflowers for industry** seems interesting for anaerobic digestion at the moment. Residues from cauliflowers harvested for the fresh market could also be collected manually but this would involve a lot of extra manual work, which is considered unfeasible by the constructors.

During the meeting, of all crop residues discussed, constructors considered the harvest of cauliflower residues as most feasible. They suggested to harvest residues after cauliflowers are harvested and to do so by using an adapted type of **mulcher**. Another suggestion (not for cauliflower) was to adapt industrial cabbage harvesters (which are used for other types of cabbages than cauliflower, see Figure 39, this way instead of throwing the leaves of these cabbages back on the soil these machines can also collect them.

Figure 39: Industrial cabagge harvester (Vanhoucke, 2015)

During the ARBOR & VLM project different types of machines where visited and evaluated for their potential to harvest crop residues by mulching. The goal was not to create a complete new harvesting machine. There are already machines on the market who can collect crop residues, but these are older models which are mostly not used anymore. In association with N.V. Persyn – Steelandt the mowing mechanism of a beet defoliator was rebuilt to harvest the leaves of cauliflower. A conveyor transports the biomass to a cart next to the mower. Tests from Inagro with the adapted machine resulted in a harvest of 46 ton fresh biomass/ha (10% DM). To avoid soil the height of the cutter is very important. The lower it is positioned, the more sand it will collect. Also the conditions in which harvest takes place are important: to avoid soil sticking to the residues field conditions have to be as dry as possible. During the tests in 2014 the sand fraction was only 1.7% FM. A harvest demonstration took place during Autumn 2014 (Figure 40).

Figure 40: Adapted beet defoliator for the collection of cauliflower residues.

Leek

Also for leek the way of harvesting differs according to end usage. Leek that is harvested for the fresh market is tipped at the beginning of the harvester (see Figure 41), further cleaning is performed on the farm. When the constructors were asked if these tipping residues could be collected, they mentioned that the knives should be placed elsewhere, namely further on the machine like it used to be. It is because of the wishes the horticultural wholesale busines posed of having the residues cut off as soon as possible, that harvesters were revised over the past years. Because of this, during the meeting, constructors seemed reluctant to change harvesters, but they thought technically it should be feasible. The extra investment cost was estimated at 5000 euros. However the question still remains if this would be economically and energetically interesting enough. More potential was seen in valorizing the leek residues which are gathered already by cleaning on farm. There the challenge however will be to rinse residues from the soil. Due to the preliminary phase of research in agro-residues and the comments made by the constructors, within ARBOR it was decided to continue further efforts on how to deal with leek residues already available on the farm (see further: C. Pilot scale experiments).

Figure 41: Harvest of leek for fresh market use

Leek for industrial use is cleaned entirely on the field through a harvester which is assisted by several persons. When leek is pulled from the soil by the harvester (Figure 42), leek residues are cut and peeled off in several steps (knive – peelers – knive – people cleaning manually in a cabinet). Because cleaning occurs in these physically entirely separated steps, collecting all residues is considered to be very difficult. The same remarks were made as for the harvester of leek for fresh market use.

Figure 42: Harvester of leek for industrial use

Brussel sprouts

A market study of different types of harvesting machines was conducted to obtain a clear view on the possibilities. In Flanders only two constructors are known to have developed a machine that co-harvests the stems.

Working principle: there are harvesters that can be mounted on the tractor and types that can drive on their own. The harvesting speed depends on the amount of rows that can be harvested in one turn. There are machines who are able to harvest 2 up to 8 rows. The stem is cut off just above soil level. Then the worker places it in the machine, which strips the sprouts from the stem. The sprouts are then collected in a cart and the stems are chopped in pieces of 8 cm (this length makes it easier for cows to chew). Normally after chopping, the stems are released on the field. The adapted machines however have an extra conveyor belt, which transports the stems to the cart. Therefore the bunker is divided in 2 parts, one for the sprouts and one for the stems. The machine has caterpillars to make sure harvest can also take place under wet circumstances.

In Flanders only two farmers are known to be the owner of an adapted harvesting machine to collect the stems separate. Both farmers use the stem as fodder for their cattle. One farmer has a 2-row-harvesting machine, the other farmer a 4-row-machine. The extra cost for adapting the machines so they can co-harvest stems was estimated 10% on top of the investment cost.
Harvest takes about 1-1,15 h longer when stems are also harvested. Also a double amount of carts needs to be foreseen to transport the biomass.

The harvesting efficiency of the 4-row-machine was measured in one field trial over 4 replications: about 25,0 (±3,4) tons FM/ha of the 47,0 (±10,0) tons FM/ha remained on the field after harvesting the stems, meaning it is possible to harvest about **22 tons of Brussel sprout stems per ha.**

Figure 43: Harvest Brussel sprout stems

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[7] For the latest data on this experiment, please contact Inagro.

C. Pilot scale storage & anaerobic digestion of vegetable residues

Stems of Brussel sprouts

During the VLM project several ensiling experiments with crop residues were performed by ILVO on a lab scale. One of the results from these experiments was that ensiling wet vegetable residues together with dryer kinds of biomass (e.g. corn stover) can give low losses by leaching and a better storage. Within ARBOR an ensilage experiment was realized on a pilot scale adding Brussel sprouts stems with low DM content (~20%) to a much larger amount of a much dryer crop residue: maize spindle. Though storage quality was only assessed qualitatively rather than quantitatively and the particles of both spindles and Brussel sprout stems were quite large, a good preservation was noticed. After the biomass was ensiled, solutions were sought to further minimize the particle size of spindles and sprout stems. Three types of machines have been tested in several steps before an optimal way was found for size reduction. In the first experiment a test with small amount of biomass was successfu. When more biomass was added to the hammer mill however the machine was clogged (Figure 45). The second installation tested was a prototype, giving good results but since it was a prototype it was not possible to chop all spindles & sprout stems. Eventually the spindles and sprout stems were chopped by an industrial grinder (Figure 46). Due to the fact that it took a longer period than expected to find a good machine to reduce the size of the spindles and stems, the biomass was fed into the digester over several separate smaller periods with the biomass (after opening of the silo) not being preserved very well anymore at the end. Because of this no representative data are available on the pilot scale biogas potential.

Figure 44: Corn spindles and sprout stems product after hammer mill

Figure 45: Grinder used in the third size reduction experiment

Figure 46: Hammer mill used for first size reduction experiments on corn spindle and brussels sprout stems

As was done for Brussel sprout stems, in the autumn of 2014 also cauliflower residues (which were harvested with the adapted beet defoliator) were ensiled together with a dryer type of biomass, which was in this case maize chaff, to obtain a perfect moisture content for ensiling. 4 tons of chaff (88% DM) and 12.8 ton of cauliflower residues (10% DM) where mixed and ensiled together. The dry matter content of this mixture is around 30% DM, which is ideal for ensiling (Latré *et al.*, 2007). Inagro also tested the nutritional value of these residues. At the moment this case study report was written, the storage experiment was still on going, a biogas pilot experiment is planned soon.

Leek residues

As mentioned earlier for residues like leek, solutions need to be sought for **cleaning them from sand before inserting the biomass** into the biogas installation, to avoid it from accumulating soil. Together with a local constructor (Vermeulen nv) a test installation was assembled in which residues were washed and chopped. To avoid the input of a lot of water into the biogas installation a pressing step with a screw press was also added. The whole process is shown in Figure 48. The end products: a solid and liquid fraction of leek residues are shown in Figure 47 and Figure 49. After each step in the process samples were taken and analyzed for several parameters (see Table 6 and Table 7). The solid fraction was investigated further in a biomethane potential test on lab scale (see further).

1. Loading
2. Input
3. Washing
4. Conveyor
5. Screw
6. Hammer mill
7. Screw press
8. Output

Figure 47: Washing, chopping & pressing experiment with leek residues

Figure 48: Leek residues after washing, chopping and pressing.

Figure 49: Liquid fraction after pressing of leek reisdues.

Table 6 : Analysis of leek residues after each step in the washing pilot

	Unit	Input	Washed	Chopped	Pressed
C	% FM	3.40	2.90	4.00	7.40
Kjeldahl N	g/kg FM	1.34	1.09	1.30	1.88
K	g/kg FM	2.76	2.40	2.04	2.51
P	g/kg FM	0.21	0.15	0.19	0.27
DM	%	10.00	6.46	8.61	18.20
OM	% FM	6.16	5.23	7.17	13.28
Sand fraction	% FM	3.36	0.44	0.71	3.75

Table 7: Analysis of liquid fraction from cleaned & chopped leek residues

	Unit	Liquid fraction
Total oxidized N (TON)	mg/l	29
Nitrate	mg/l	123
Nitrite	mg/l	4,4
Ammonium	mg/l	122
Kjeldahl N	mg/l	975,45
Active Cl	mg/l	0
Ca	mg/l	458
Mg	mg/l	101
Na	mg/l	66
K	mg/l	1275
P	mg/l	129,25

The washing process clearly shows **a reduction of sand**: the ratio of sand fraction (%FM) to organic matter (%FM) is reduced from 0,55 to 0,08. When chopped the ratio stays more or less the same (0,10). After pressing the ratio is increased again (0,28) showing that from a mass balance point of view, part of the organic matter is probably lost in the liquid fraction during this additional step. This means that we were able to increase the organic matter content of this biomass making it more interesting for AD, but we lost a part by separation. The share of sand in the total amount of fresh matter however stays almost the same, which is seen as a disadvantage for anaerobic digesters that prefer biomass without sand. Additional to the solid fraction of leek residues a solution also needs to be sought for the liquid fraction. Due to the high nutrient content it is not possible to discharge it, e.g. the nitrate content is three times as high as what is allowed in the Flemish legislation (VLAREM II) for discharge. Possible solutions could be alternative valorization through for example: growth medium for algae production, nutraceuticals, reed beds or fertilization. When using this product for example for fertilization more research is needed regarding to storage and quality of the product (e.g. appearance of plant diseases, emissions, ...).

D. Biogas potential of vegetable residues on a lab scale

Different crop residues at harvest have been tested on biogas potential on lab scale at Inagro. It is to be noted that these results are in most ideal conditions (small parts, optimal temperature, good inoculum, etc.), and thus may not be seen as absolute figures. But they give a clear relative impression of the biogas potential between the individual substrates.

All substrates are tested in triplicate in air closed flasks of 2.5l placed in water tanks. The temperature of the water is kept constant at 38°C. A blanc is placed in the water tank as reference. For a detailed description of the method, see the Case study report of Low impact energy crops: Biomass from cover crops.
In Table 8 the biogas and methane yields obtained at Inagro from different crops are listed. The biogas yield of the substrates varies according to the content of organic substance and their composition: carbohydrates, protein and fat (Weiland, 2009). As expected the residues from leek, Brussels sprouts and cauliflower are the lowest in net biogas/FM production. According to studies performed by Gunaseelan (2003), Zhang *et al*. (2005) and Gómez *et al*. (2006) the biogas yield obtained from vegetables is in the range of 100m^3-150 biogas/ton FM in optimal biogas production. These results are in line with the trials performed at Inagro. They biogas from vegetables tend to have the largest share of methane in the gas (range 59-66% methane). The biogas production from vegetables in a conventional reactor will be lower than these lab scale trials. The yield will be in the range of 60-80m^3 biogas/FM of vegetables. The biogas yield of maize (223m^3 biogas/ton FM; 51% methane) is of the same level as noted in the review paper by Weiland (2009): 200m^3 biogas/ton FM, with 52% methane.

Table 8: Biogas and methane potential of different crops; Inagro trials (fresh matter: FM and organic dry matter: oDM)

	Net biogas/FM (m^3/ton)	Net biogas/oDM (m^3/ton)	Net CH4/FM (Nm^3/ton)	Net CH4/oDM (Nm^3/ton)	CH4/biogas (%)
Sugar	884	884	402	402	45
Cellulose	897	897	414	414	46
Maize	223	625	115	322	51
Leek	115	869	78	587	66
Sprouts	104	1195	61	703	59
Cauliflower	117	1178	69	694	59

E. Pretreatment of agroresidues for anaerobic digestion

The agroresidues from vegetable origin have often a lower dry matter content (10 % for cauliflower leaves to 20 % for sprout stems) and a less rigid lignocellulosic matrix than corn residues such as corn stover, cobs or bract. For this reason the main points of attention for the improvement of anaerobic digestion with agro residues are the reduction or removal of soil particles and the correct storage for preventing biomethane potential losses.

Extrusion on sprout stems

Stems of Brussels sprout have a dry matter content of about 20 % and 18 % organic dry matter (of total fresh weight). The dry matter content is lower than that of corn stover and this implicates also a less rigid lignocellulosic matrix which is more accessible for biological conversion to methane. This is confirmed in Figure 50 as the untreated and extruded sample show a similar curve in terms of methane production rate. The effect of the extrusion pre-treatment is rather on the total production of methane which is about 30% higher than untreated samples after 30 days.

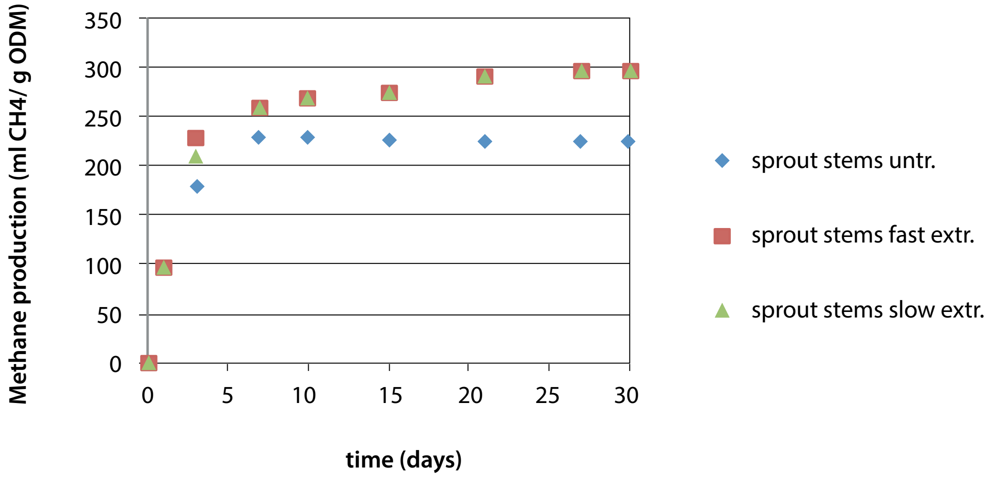

Figure 50: Methane production of extruded (extr.) and untreated sprout stems

F. Other value chains for valorization of vegetable residues

As was the case for corn stover, also other valorization strategies might be possible for vegetable residues. Below an overview is given on future possibilities.

Nutraceuticals

Leek is known to contain a lot of bioactive compounds such as polyphenols, vitamins, antioxidant, fructans, etc. From studies executed on leek residues it was found that after washing the following treatments could preserve or even enhance the nutritional value of leek residues: natural fermentation, freeze drying or drying. The use of leek residues as supplement to feed and food products such as pasta, bread and cheese can have a positive influence on the health of animal and human.

Feed

The stems of Brussels sprouts can be applied as feed for dairy cattle. It contains the same energetic value and protein as silage maize in regard to dry matter. In the two case studies in Flanders the shredded sprout stems replace one meal of silage maize a day.

Potatoes and cabbage residues unfit for food industry or market can be used as a feed for pigs. In Flanders a pilot project was started in which these residues are first washed, heated and fermented before feeding them to the pigs. Leaves of cauliflower can be used as well, but because of the high content of soil particles it will need more washing before it can be applied. Leek residues on the other hand have a more fibrous nature and are not easily digested by pigs. For those reasons these two agro residues have not been applied in pig fed yet.

Composting

Due to the low dry matter content of the vegetable agroresidues composting is only possible if other residues are added. In certain studies leek residues have been composted with tomato growing substrate and prunings. The application of agro residues in compost can help with closing the carbon cycle and prevent the loss of organic matter in the soil by mineralization. Furthermore it improved the microbial life and prevented a pH decrease in the soil.

Bio-fumigant

Large amount of sulfur compounds (dimethyl disulfide (DMDS) and dipropyl disulfide (DPDS)) are present in Allium species such as leek and especially onion. This has led to the suggestion that the residues of this plant family could be used in soil biofumigation. From the study it was shown that by-products and DMDS not only had a high level of biofumigant activity, but also stimulated vegetative growth. It even increased asparagus and strawberry productivity by 15–20% in comparison with Brassica-based biofumigation. The practical hindrance is the application of 75 ton per hectare of by-products. For this reason it is necessary to further investigate how to concentrate the active (sulfur) compounds by for example drying without losing the biofumigant potential.

G. Economic evaluation

Due to the fact that valorization of agro-residues during the project was still situated in a pre-liminary phase (e.g. the limited availability of machinery, first experiences in preservation, …), also for vegetable residues no case studies from the action on agro-residues were assessed economically by LIST. During ARBOR Inagro learned a lot regarding to the technical feasibility of dealing with crop residues, from these experiences some conclusions can be drawn by listing estimations of the costs we obtained so far linked to experiences from an-aerobic digesters in how they valorize these types of biomass at the moment. These estimations of costs known are listed below. Due to a lot of uncertainties still remaining, carefulness is needed in further use of these data.

Brussel sprout stems

The costs listed are merely for harvest, no costs were included yet for ensiling.

Table 9: Adaptation cost for Brussel sprout stems harvest

	4-row harvester
Investment cost for adaptation harvester = €30 000, harvester is used 70 ha/year, depreciation over 5 years	85,7 €/ha
1h15 min extra time needed per ha, calculated at a wage of €15/(h person) for 4 persons	75,0 €/ha
± 22,5 liters of fuel are used extra per ha Extra cart & transport for a full day (1 ha takes 12-15 h)	15,1€/ha
Extra cart & transport for a full day (1 ha takes 12-15 h)	125€/ha
Extra chopping: assumption of a price of € 10-20 per ton (depends on the amount biomass and milling technique)	220-440 €/ha
Total cost Cost per ton FM	520,8-740,8 €/ha 23,67-33,67 €/ton FM

Cauliflower

The cost for adaptation of the beet defoliator amounts 2000 euros. In the radius of 2.5 km around Inagro there is 26ha cauliflower (industry), which is suitable for the harvest of the leaves.

Table 10: Adaptation cost for the harvest of cauliflower leaves with an adapted beet defoliator

	Defoliator
Investment cost beet defoliator = €10 000 (26ha/year, depreciation over 5 years)	76.9 €/ha
Investment cost for adaptation harvester = €2000, defoliator is used 26 ha/year, depreciation over 5 years	15.4 €/ha
harvest at 1h per ha, calculated at a wage work of €75/h	75.0 €/ha
Extra wage work for an hour (cart, transport, etc.)	50.0 €/ha
Total cost Cost per ton FM	217.3 €/ha 4.8 €/ton FM

Leek

Adaptation of a harvester for collection of leek residues was estimated by the constructors at a price of about 5 000 euros. Also to take into account are: if necessary extra time needed for harvesting residues, extra carts needed for transport of the residues from the field towards the digester.

Even if residues would not be co-harvested and no investments would take place for this matter, when valorizing leek residues that are already available through cleaning on the farm, the investment cost of a washing, chopping & pressing installation was estimated at €35000. However for the washed, chopped and pressed leek residues from our experiment the farmer would still need to pay €10-15 per ton extra to the digester for it to take in its vegetable residues (instead of €20-25 per ton as what is paid today for processing of similar dirty streams like roadside clippings). E.g. even for clean waste streams from food industry (e.g. steamed potato or carrot peels) companies are paying €5-10 per ton to the digester.

From these preliminary data about the costs, it can be concluded that making investments to harvest crop residues and prepare them for further anaerobic digestion at an external biogas installation, at the moment (current market situation) **would only cost the farmer money**.

If the farmer needs to find a solution for processing or valorization of his crop residues **added value will need to be created**. A big challenge lies ahead **finding innovative technologies** for valorization of crop residues in our future **biobased economy**. E.g. early experiments by a local farmer & constructor in processing crop residues in pig fodder. Learning from the small scale AD cases on cattle slurry, if technically proven feasible another option could be on-farm small scale AD of crop residues. Certainly for residues that are already available on the farm and that do not require extra harvesting, this might be an option. Small scale AD of cattle slurry in Flanders has proven to be expanding successful over the past 4 years due to its concept of modularity enabling the constructor to profit from the possibility to copy one system on a lot of farms, this way reducing the investment cost for a system that would otherwise be constructed for the specific situation of the farm.
At the moment it is not known whether or not small scale AD of crop residues is technically feasible. Because of this it is also difficult to make assumptions on the economic feasibility. The experiences with anaerobic digestion of merely crop residues in Flanders on a large scale is also limited to only a few companies. E.g. GreenWatt is a company that built a biogas installation (100 kWe) in Nijvel (Wallonia) with chicory roots as the main input stream. To investigate the possibilities of an adapted on-farm system for the case of Inagro (31 kW installation) to increase the amount of crop residues as an input stream a feasibility study was carried out by GreenWatt. The adaptation of the digester (31 kW) making it a 2-phase digester that can cope with more difficult vegetable residues was estimated at a cost of € 174 000, all scenarios of input streams investigated gave a lower profitability than energy maize. Another interesting case where already some lessons can be learnt regarding to crop residues is the feasibility study Innova Energy made during the ARBOR project on pocket scale AD of chicory roots in the province of Vlaams-Brabant. Due to the fact that there is no technical solution yet on a micro scale basis for AD of chicory roots, they investigated the potential for several farmers cooperating in a biogas project on a pocket and a larger scale.

Pocket & large scale anaerobic digestion of chicory roots in a cooperative way

Approximately 3000 ha in Belgium is used for chicory production, 1 ha of chicory produces 24 tons of chicory roots as a waste stream. This specific Belgian industry is characterized by a decentralized small scale production. After production the chicory roots are a waste stream which still contains quite some energy that could be valorized through digesting. Lab analysis showed a biogas production of 62.8 Nm^3 biogas/ton with a dry matter content of 12% (washed roots). Another asset is the fact that chicory production is constant throughout the year causing a constant biomass supply, and a constant energy demand for the chicory producers.

To assess the feasibility for the different scenarios for digesting chicory, some assumptions related to energy use were made in collaboration with the National Chicory Center. A medium chicory company of 25 ha consumes around 12.500 l of heating fuel (129 MWhth) and 250 MWhel electricity.

In a first scenario it became clear that it is not beneficial to digest the chicory roots on the scale of a medium company (25 ha). Based on the own chicory production, the company can apply all the produced power in order to meet 21% of its electricity production and 50% of its heat production (taking into account seasonal variations in heat demand). Together with the certificate support this generates a profit of € 18 000 per year. Variable costs account for around € 9 000 per year, including spreading the digestate, administrative costs and maintenance of the installation. As there is no existing state-of-the-art concept for digesting chicory roots on this small scale, it is doesn't seem feasible for the moment to build a digester for less than € 10 000 per kWh (the roots allow a production of 9 kWe, amortization period is 10 years), taking into account the necessary different parts to be bought, installed, assembled and engineered.

In order to find out the different boundaries that permit a viable business plan when clustering different chicory farmers (upscaling), different theoretical standard scenarios were assessed for building a biogas plant in synergy with an existing site. In this exercise, we choose to set electricity coverage, heat coverage and the cost for spreading the digestate as the 3 variables to determine the boundaries (see table below for the different scenarios). A distinction was made between gas and fuel heating because of the difference in heating costs resulting in higher profits when leaving fuel heating. The 4 scenarios were altered for 5 000 tons and 10 000 tons of chicory roots.

Table 11: Overview of different paramaters in the scenarios for anaerobic digestion of chicory

	++ opt. scenario based on heat fuel	++ opt. scenario based on gas heating	+- medium scenario	-- negative scenario
Electricity	100% coverage	100% coverage	100% coverage	100% power in the grid
Heat	100% coverage mazout 0,78 €/L	100% coverage gas 0,04 €/kWh_{th}	100% thickening digestate	100% thickening digestate
Cost digestate	low 6.5 €/t	low 6.5 €/t	low 6.5 €/t	high 15 €/t

The result of the scenario analysis is shown in the table below. The numbers are expressed in the price that suppliers of chicory roots would receive when delivering it to the installation. This allows to estimate the expected income for the farmers. This price should be compared with their current offset cost. The prices mentioned in the table do not take into account transportation costs as these differ for every supplier.

Table 12: Economic evaluation of different scenario for anaerobic digestion of chicory

	++ opt. scenario obv mazout	++ opt. scenario obv gas	+- medium scenario	-- negative scenario
5000 ton	13.77 €/ton IRR 4.73%	6.91€/ton IRR < 0	0.6 €/ton IRR < 0	-6.84€/ton IRR < 0
10 000 ton	20.96 €/ton IRR 23.65%	15.59 €/ton IRR 15.04%	10.65 €/ton IRR 6.10%	-3.81€/ton IRR < 0

The resulting numbers should be put in the correct perspective: they are the result of standardized scenarios that are not likely to occur in reality. However they allow to interpret the different scenarios which allows us to define some necessary conditions in order to have a viable case.

The red numbers in the negative scenario indicate the importance for having a low digestate treatment cost.

As a result following conclusions can be made:

- The selection of an optimal site that can consume the rest heat of the CHP is a sharp right for determining the positive margin of the investment. This is the difference between the medium and optimal scenario.
- A low treatment cost (€ 6.5/ton) of the digestate is a must. The lowest treatment cost can be achieved by assembling a cooperation that possess sufficient grounds to spread the digestate themselves. Treating the digestate at high cost (€ 15.5/ton) makes a difference of € 40 000 per year.
- A cooperation is viable when attaining a critical mass of around 10 000 tons of chicory roots. The action radius of collecting and treating the roots should not be higher than 30 km in order to reduce the transport costs.

An important remark is that the labour and the land price for the site are not taken into account. Therefore it is advisory to have the land owner of the installation as a member of the consortium. His profit can be expressed in a lower energy and heating price, this will have its effect on the profit per ton of chicory roots.

1.2.3.3 Future implementation in Flanders

Under the current market situation and policy it is clearly **not profitable for a farmer to harvest, collect and transport crop residues towards an external large scale anaerobic digester**. At the moment there are **no technical options available yet in Flanders in which anaerobic digestion of these residues can occur on the farm on a small scale**. This means there are still **challenges** for technology constructors to build a viable concept. The cooperative case of chicory roots learns that it might be an option to collect residues from several farms in a central way, though all side conditions regarding to electricity and heat valorization and digestate processing or spreading need to be met. In the meanwhile an eye should be kept towards **other valorization strategies for vegetable residues than anaerobic digestion**, e.g. when residues can be used as a feed, these other valorization strategies than AD might be recommended.

1.3 Legal Assessment

1.3.1 Valorization of agro-sidestreams through (small scale) anaerobic digestion

1.3.1.1 Current legislative framework

In this chapter a summary is given of legislation & support measures both on European and Flemish level, that apply to the use of agroresidues in (small scale) anaerobic digestion. The summary given below is in fact incomplete since there is interference with quite some legislative documents originating from different sectors (CAP, REACH, sustainability criteria, …) when valorizing crop residues for different purposes. Since the scope of these documents is far too broad to be discussed here and mainly gives implications regarding to where agroresidues should be valorized, we focus on direct legislative implications only. Part B of this chapter does however summarize some visions from the action plan of how agroresidues should be valorized in Flanders.

A. European legislation

Nitrates Directive

In 1991 the European Nitrates Directive (Directive 91/676/EEC) was implemented for all member states. This Directive defines a limit of 50 mg/l of nitrate for surface water. If this limit is not respected by a Member State, this Member State can be condemned by the EU and obliged to take certain measures. One of the causes of too high nitrate levels in ground- and surface water is the amount of and the way of applying animal manure.

The Nitrates Directive defines a fertilizer as a substance containing a nitrogen compound or nitrogen compounds utilized on land to enhance growth of vegetation. It may include live-stock manure, the residues from fish farms and sewage sludge. A chemical fertilizer is defined as any fertilizer which is manufactured by an industrial process. Livestock manure is defined as a waste product excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form.

DG Environment (in charge of the Nitrates Directive) is preparing a report on the impact of digestate on water quality. The draft report shows that there are certain member states where digestate does not necessarily have an animal manure status, even if animal manure entered the biogas plant. This shows that the status of digestate is merely a national or regional interpretation of the Nitrates Directive (Grauwels, 2014).

Animal by-products Regulation

The Animal by-products Regulation ((EC) No 1069/2009) lays down instructions for the collection, transportation, storage, handling, use and removal of animal by-products. Companies executing one of these activities have to be certified according to this Regulation. The Regulation also contains instructions for the trade and transit of animal by-products and derived products.

In Flanders in principle all small-scale anaerobic digestion facilities that treat animal by-products have to be monitored by the Mestbank on their 1069/2009 compliance.

Fertilisers Regulation

Once the scope of the Fertiliser Regulation ((EC) No 2003/2003) will be widened to organic fertilisers, digestate will also have to comply with the essential quality and labelling requirements as defined in the Regulation.

Regulation on organic production and labelling of organic products
To evaluate which types of digestate are allowed in organic farming practices, depending on the ingoing types of biomass, this regulation (Regulation (EC) No 834/2007) should be consulted. The following articles can be of importance:

Article 4.b: Organic production shall be based on the restriction of the use of external inputs. Where external inputs are required, these shall be limited to:

- Inputs from organic production
- Natural or naturally-derived substances
- Low solubility mineral fertilizers

Article 12.1.b: the fertility and biological soil activity of the soil shall be maintained and increased by multiannual crop rotation including legumes and other green manure crops, and by the application of livestock manure or organic material, both preferably composted, from organic production

Article 12.1.d: in addition, fertilizers and soil conditioners, may only be used if they have been authorized for use in organic production under Article 16

Article 12.1.e: mineral nitrogen fertilizers shall not be used

Article 16.1.b: The Commission shall, in accordance with the procedure referred to in Article 37(2), authorize for use in organic production and include in a restricted list the products and substances, which may be used in organic farming for the following purposes: as fertilizers and soil conditioners.

B. Flemish and Belgian legislation

Sustainable management of biomass action plan

According to OVAM (the Flemish public waste agency) **biomass** can be defined as the bio-degradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste. **Biomass residues** comprise waste and residual fractions of biomass which 1) are not used for which the biomass was originally intended, or was produced, 2) are released and are mobilized and 3) for which a different, useful use is desired. E.g. unsold vegetables / fruits, residues from the food industry, animal by-products, organic waste, demolition wood, residues from the wood industry or flows stemming from the management of gardens, parks, roadsides, nature and landscape. In the course of 2014-2015 OVAM took the lead on the development of an action plan for biomass residues. The main goal is **to keep bio-based materials as long as possible in the biological cycle and reduce losses as much as possible**. If they can't be kept within this cycle, they should be used while respecting the **cascading principle**. Also for residues from agriculture goals are being set out till 2020 and 2030. For example: till 2020 less crop residues (production waste) should be brought back to the fields due to problems with nutrient leaching, some residues should be used as an alternative for feed production (possibly with a step in between through growing insects or algae) valorization strategies need to be sought in the food sector, … Till 2030 the goals are even more ambitious: e.g. farms should optimally use the potential of their biomass residues.

VLAREM - Environmental legislation regarding to emissions & necessary permits

All activities that can cause nuisance to local neighbors or the environment have to apply for an environmental permit. This is also valid for small-scale anaerobic digestion, due to the modularity of the system a same approach (study of the noise, safety, …) can be applied for most installations, this way reducing administration costs. The procedure to be followed depends on other activities the farmer has also planned (e.g. building a stable, …).

Due to a recent change in the Vlarem legislation, all plants producing biogas (including small-scale) will have to fulfill some requirements:

- Inaccessible to unauthorized people
- Pressure relief valve for biogas storage
- A certificate proving that the building works were carried out according to the rules of good workmanship
- A workplan of the installation

Installations producing > 50 Nm³/h need to be equipped with a torch or a similar device.

Building permit

For the construction of a small scale AD (< 10 kW) a building permit of the short type is needed. This requires no architect, a design of implantation and 3 photos of the surroundings together with a short description of the process are needed. For installations by which aspects of stability matter (e.g. a tank made with a prefabricated construction out of concrete) an architect will be needed. The request for permitting in these cases are more extensive and need longer periods for decisions to be made.

Legislation regarding the use of the digestate

- Flemish Manure Decree
  The Decree considers digestate from small-scale digestion of merely on-farm animal manure as being animal manure, so the same rules as for animal manure apply (limits to nutrient application, spreading techniques, spreading period, etc). Even when biomass is codigested, from the moment that one drop of manure is inserted into the digester, all digestate is considered to be animal manure. In a region where there is a surplus of manure, this can be seen as a disadvantage.

- Royal Decree on trade in fertilizers, soil improvers and growing media
  This federal law from 28/01/2013 regulates i.a. the trade within Belgium of end-products of manure and digestate processing. It defines that a fertiliser should appear on the list in Annex I of the legislation to be traded, unless it is considered "a natural product derived from the farm". The Annex I contains a description of the essential requirements for a fertiliser. If a certain product does not appear on the list, a derogation can be requested. This is the case for digestate from small-scale digestion, which is not considered "a natural product derived from the farm" and is also not present on the list of Annex I. The Federal Government for Public Health, Safety of the Food Chain and the Environment is in charge of the derogation allocation. The Federal Agency for Food Safety certifies the companies trading fertilisers and checks if the fertiliser standards are complied with.

C. Support

Apart from the certificates for production of green energy, no matter the size, investments in AD installations are not eligible for further support in Flanders. Every year the Flemish Agency for Energy (VEA) calculates the support that is needed to speak of a profitable installation for several renewable energy producing technologies. Depending on the results of these calculations every year a new banding factor is determined which is to be multiplied by the price of the certificates per MWh of electricity produced (€ 93/MWh minimum price) or heat saved (€ 31/MWh minimum price). This system with a banding factor differentiating between different technologies for renewable energy was introduced in 2013. Every year however the banding factor that was assigned to AD was lower than the one that was calculated to be needed to have a profitable system. Since small scale AD installations below 10 kW can work with a system of a back rotating counter for electricity, they don't have to sell non-used electricity on the market for a lower price. This together with a guaranteed supply of biomass gives more certainty about the profitability.

Additionally since the beginning of 2015 the Flemish Climate Fund foresees support (30%) for investments in equipment and adaptation of stables when farmers also invest in a small scale AD installation.
There is no additional support for the harvest or use of crop residues in anaerobic digestion.

1.3.1.2 Recommendations

In order to stimulate the distribution of small scale AD as a technology the organizations working on small scale AD in Flanders are convinced that an equilibrium is necessary for small scale AD to be performed as environmental friendly as possible but with a minimum of costly (incl. administrative) measures so that it can remain profitable to invest in.
The partners involved in the action of agroresidues are convinced that **all kinds of biomass need to be valorized in the best way possible**, meaning the most sustainable valorization strategies both in an economic, social and environmental way should be chosen. However if small scale AD seems the best way for valorization (which we do think might be for some residues on a lot of farms on a local scale), then it should be stressed that administrative burdens relating to crop residues being considered as a waste stream instead of biomass (e.g. **administrative burden** when transporting waste), should be **minimized** as much as possible.

1.4 Environmental assessment

Due to the fact that valorization of agro-residues during the project was still situated in a preliminary phase, unlike for SRC, nutrients from digestate or cover crops, no case studies from the action on agro-residues were environmentally assessed through LCA by LIST. Several actions have been undertaken to continue the research on these agro-sidestreams and their impact through new project proposals. The description below gives a view on what the expected impact can be and what challenges are lying ahead to be investigated further.

Harvest of crop residues

Crop residues are an important potential source of sustainable biomass because of their easy availability. Residue removal of maize may, however, have adverse impacts on soil quality due to depletion of nutrients (Blanco-Canqui *et al*., 2009). In particular the abduction of carbon results in a decrease of soil organic matter (SOM). SOM is important for stability in the soil. It provides better aeration, more captation of nutrients, better water flow and water uptake in the soil (Wilhelm *et al*., 2004). In the top layer SOM is mostly derived from plant residues. In deeper soil layers it is derived from roots and dissolved organic material (Lützow *et al*., 2006). Studies have shown that 50 to 75% from the fresh added carbon in the soil comes from plant roots (Gale *et al*., 2000; Wilhelm *et al*., 2004). While the concentration of SOM in the top layer (0-30cm) quickly responds to changes in soil management, such as the removal of straw (Mann *et al*., 2002). According to Lemke *et al*. (2010) a reasonable amount of maize straw can be removed during each cropping year without measurable effects on carbon concentration in the soil. Also fertilization management is linked to SOM levels. In particular a high nitrogen fertilization has negative effects on organic carbon losses (Smith *et al*., 2012). Threshold levels of residue removal must be assessed based on the needs to maintain soil productivity and environmental quality. Therefore a parcel related approach is necessary to adopt best management techniques (e.g. cover crops, crop rotation and manure application) to minimize adverse impacts, with attention to erosion, water quality, conversion of recalcitrant SOM and population dynamics of soil life (Blanco-Canqui *et al*., 2009; Cerubini *et al*., 2012). Together with Ghent University (dept. Soil management), ILVO and Inagro, a strategy was set out of how to quantify and model the parcel specific amount of maize that can be harvested in the Flemish agriculture. While approaching the end of the ARBOR projects efforts are put in new research proposals to investigate this issues in depth.

In contrast to maize, vegetable tillage creates no danger of depletion to the soil organic carbon. However, there is a risk of nitrogen leaching to the groundwater generated by the residues left on the fields after vegetable tillage. In precedent research at Inagro in cooperation with e.g. Ghent University, ILVO and other partners (VLM: Crop residues 2012-2014) it has been found that under some circumstances the removal of crop residues has a positive effect on the nitrate residue after harvest. In this trial approximately 30 fields were tested on soil nitrate residue. After harvest about 30 to 50 ton fresh biomass stays on the field. In that way there is a supply of 100 to 200 units of nitrogen in the soil by these residues per hectare (Agneessens *et al*., 2014). It can be concluded that the removal of crop residues from vegetables can reduce mineralization of nitrogen (VLM, 2000), though the effect was not proven to be significant on every field and crop that was researched.

Small scale AD

In Flanders 10% of GHG emissions from husbandry of cattle are generated during manure storage. When manure is anaerobically digested on a small scale, the storage time in the stable will be much shorter compared to storage until the fertilization season begins and when the storage is emptied. Due to this and due to the fact that methane is actually used to produce energy, it is expected that GHG emissions coming from manure storage in the stable will be reduced by small scale AD. For this reason the Flemish Government through the Climate Fund foresees an investment subsidy for side equipment of small scale AD. The exact amount of GHG emissions being reduced through anaerobic digestion shows quite some variation in literature. One of the reasons for this is the selection of system boundaries which differs amongst research. E.g. some studies only look at carbon (methane) emissions (Marañón *et al*., 2011), while others also look at nitrogen (Clemens *et al*., 2006), effects during fertilization are most of the time not considered. While for the methane emissions the small scale AD can certainly give a reduction in GHG emissions, the effect on N emissions no arbitrary conclusions can be drawn. GHG emissions from manure are variable in time and space and difficult to measure since they are influenced by a lot of factors (temperature, pH, type of spreading, covered storage of digestate, …), thus a holistic approach is needed: when one step of the manure handling process is altered, this can influence emissions in another step of the manure management continuum (Robinson, 2011, Chadwick *et al*., 2011). However, based on the findings summarized in Figure 51 it is clear that the highest GHG saving potential is linked to the mono-digestion of manure. In Flanders the potential for (small scale) anaerobic digestion as a measure reducing GHG emissions was not investigated before. During the ARBOR project Inagro was involved in several bachelor theses being written on small scale AD (and crop residues), one of the theses performed a modelling on the methane emission reduction potential of the Flemish most spread small scale AD system (Criel *et al*., 2013). It was calculated that small scale AD can reduce methane emissions by 21%. If extra measures could be implemented (e.g. increasing the retention time and volume of the reactor with 75%) then a theoretical reduction of 60% could be expected.

Due to the need for finding measures reducing greenhouse gas and nitrogen emissions from agriculture, it might proof worthwhile to investigate the potential of small scale AD from a holistic approach as a measure reducing GHG emissions within the manure management continuum.

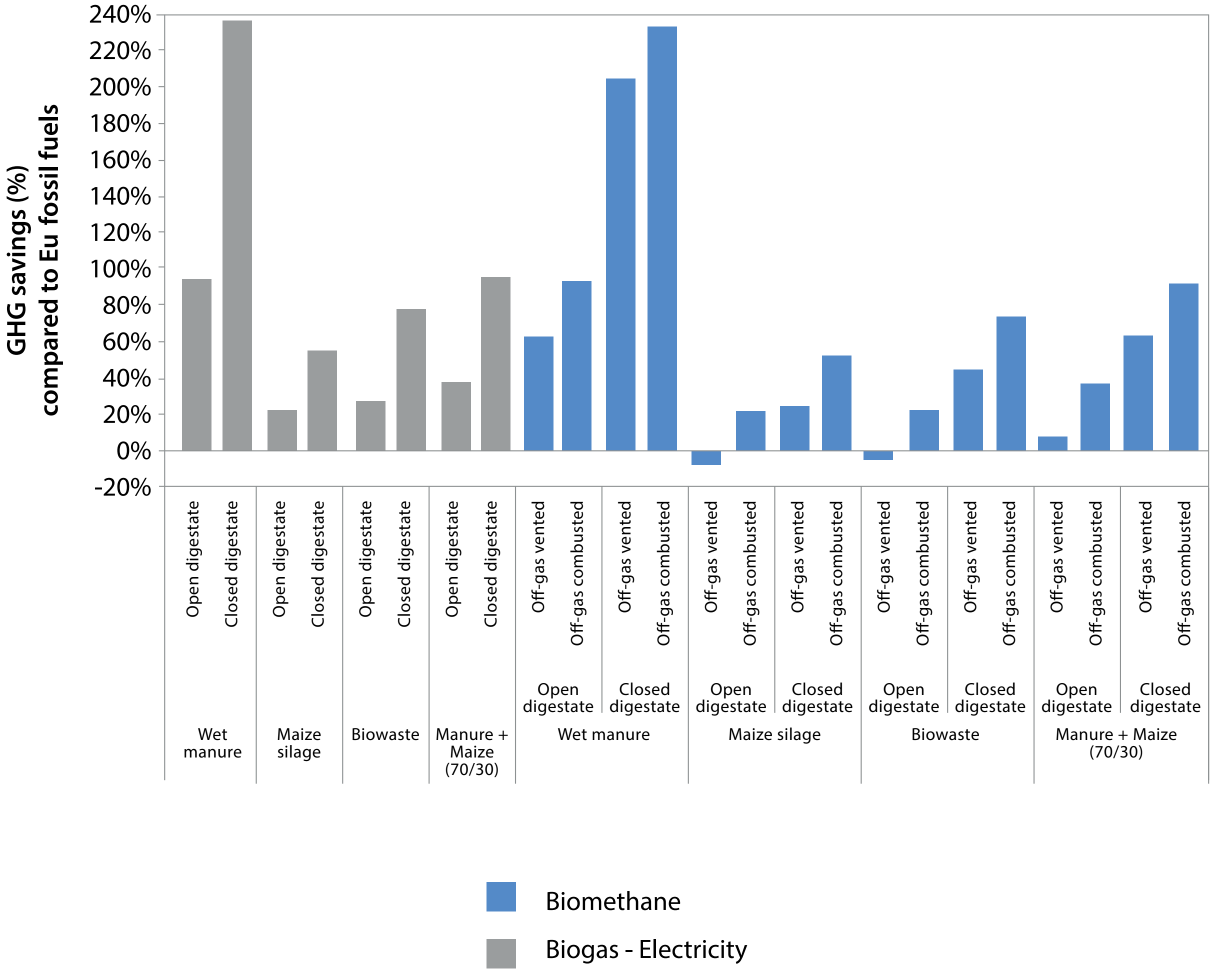

Figure 51: Sustainability of biogas production expressed in GHG savings (%) compared to the use of EU fossil fuels (European Commission 2014)

2 - Transferability questionnaire

To assess the transferability towards other regions, a questionnaire was set up and filled in by project partners. This chapter gives an overview of what the potential is for valorization of corn stover and vegetable residues and the implementation of small scale AD according to project partners for their regions.

2.1 Crop residues

2.1.1 Area with crop residues [8]

Table 13 summarizes the areas of crops which were investigated in ARBOR in regard to the potential agroresidues volumes.

Table 13: Acreage of investigated crops per ARBOR partner country

Area (ha)	Belgium (B)	Germany (D)	Ireland (IRL)	Luxembourg (LUX)	The Netherlands (NL)	United Kingdom (UK)
Grain maize	73 955	466 600	-	196	12 593	2 500
Leek	3 350	2 399	60	1,1	2 593	1 718
Brussel sprouts	2 544	517	176	-	2 729	3 041
Cabbages	3 931	17 009	1748	3,4	6 597	23 155
Total agricultural area	1 338 566	16 667 000	4 500 000	220 600	1 742 427	17 300 000

Of the partner countries with a significant amount of grain maize, the largest share compared to silage maize (177 456 ha) is noted in Belgium due to the intensive pig industry. Flanders is the region in Belgium where most of the grain maize is cultivated (65 957 ha) and in each Flemish province this account for a significant acreage of grain maize. The largest part of the vegetables listed, is also grown in Flanders (99%) and 85% of these vegetables are located in the province of West-Flanders.
Following the area of 2.8 mio ha occupied by silage maize, Germany also has quite a large area of grain maize cultivations. The area occupied by Brussel sprouts and leek as compared to the total area of agricultural land is rather limited. The fields are clustered in eleven vegetable growing areas in Germany (each varying between 100 and 5 300 ha).
In Ireland maize is only produced for the use as animal feed (14 500 ha). Except for cabbages the other vegetables listed here show rather limited areas.
In Luxembourg, due to the size of the country, the total area of agricultural land is rather small from an European perspective. Grain maize is the only culture grown on large scale (>100ha) which could generate crop residues. Compared to the area of silage maize in the Netherlands (226 146 ha) the area of grain maize is very small.
In the Netherlands the largest areas of grain maize are situated in the provinces of Limburg, Gelderland and Noord-Brabant. 80% of the land on which grain maize is grown in the Netherlands is situated in these provinces. For leek 98% is grown in the provinces of Noord-Brabant and Limburg. Brussel sprouts are for a large extent grown in the province of Zuid-Holland (51%), while 63% of cabbages are mainly grown in Noord-Holland.

In the United Kingdom only a small part of the total maize production (164 000 ha) is used for corn, most of which is grown in the far south of England. Compared to other regions the UK grows a large amount of cabbages.

Other crops leaving quite some residues on the field mentioned by the partner regions were:

- FL: wheat (337 910 ha), sugar beets (60,191 ha), beets (3,431 ha) and chicory roots (932 ha)
- D: wheat (6.5 mio ha) and rapes (1.3 mio. ha)
- IRL: potatoes (10 700 ha), beets (10 100 ha), iceberg lettuce (110 ha), carrots (618 ha), mushroom waste stalks or bad grading
- LUX: very limited production of crops generating field residues, mainly vegetables (chicory, celery, …) covering the area <25ha and grown for fresh market use.
- NL: potatoes (156,252 ha), cereals (193 128 ha), sugar beets (193 128 ha), chicory roots (2961 ha)
- UK: beans and peas (47,927 ha), sugar beet tops (117 000 ha), onion outgrades (dry bulk onions 8 859 ha)

Conclusions:
Based on the overview of the cultivation areas, it can be concluded that for the collection of corn stover the sites with the largest biomass potential are situated in Germany, Flanders and the Netherlands. For cabbages both the United Kingdom and Germany show large areas, followed by the Netherlands and Belgium. For Brussel sprouts total areas are quite similar between Belgium, the Netherlands and the United Kingdom. For leek the same applies, adding Germany also to this list. In Ireland and Luxembourg the biomass potential for all of these crop residues seems rather limited. This however doesn't necessarily mean that there is no potential for valorization of residues on a small and local scale.

2.1.2 Collection and use [10]

Up till now mainly wheat straw is harvested in Flanders and used for litter or fodder. Other agricultural residues that are valorised today and that don't require harvesting, are for example chicory roots after forcing, which are used as fodder. Chicory roots can also be an interesting source for anaerobic digestion (e.g. 100 kW biogas installation built by GreenWatt on the chicory farm of Joost De Paepe in Nijvel, Wallonia). In 2013 together with several regional actors Inagro started the cluster called Agreon where SME's, farmers and research institutes work together on the realisation of innovation in agrocleantech. One of the innovations that was built in this cluster is a washing, chopping & preheating installation for the use of vegetable residues (amongst which from cabbages) as a source of proteins in fodder on a local pig farm. At ILVO researchers managed to test several preservation techniques on leek in relation to its bioactive compounds. There might be potential to also use this on residues, though the demand for dried leek residues is still limited at the moment. In Flanders only two farmers harvest stems of Brussel sprouts to use them as a fodder. Several biogas installations have made attempts to incorporate corn stover as an input for their AD, it has shown to be very difficult to do this cost-efficiently due to the extra handling steps needed and the lack of suited machinery to reduce some of these costs. One company working in the sector of microbiology is also investigating pretreatment on agroresidues like corn stover to make them more suitable as a fodder, AD input, ... Several companies from different sectors (biore-finery, materials, AD, combustion, fodder, …) have shown interest in corn stover as a feed-stock. The sustainability of different supply chains need to be further investigated, before supply chains can be set up. Large construction companies show interest to develop suited machinery, but first it needs to be investigated what the most suited end markets are for these products.

In Germany, similar to Flanders, the main crop residue being used is wheat straw, this type of biomass is used as fodder, source of soil organic material (when it remains on the field) or as litter. As in Flanders the straw is dried on the field, pressed into bales, collected and stored. The machines used are: combine harvesters, baling presses and trailers. In rare cases this straw is used as a fuel for combustion or anaerobic digestion. The size of the burners differs from small-scale stoves up to large biomass plant with a power of 20 MW. About 4 bigger straw combustions are installed in Germany (Jena, Nestro, Emmlichheim, Rheinland-Pfalz). These plants produce mainly heat and

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[8] Sources: B – FOD Economie Algemene Directie Statistiek (2013), D – Hortipendium (2011), IRL – Department of Agriculture, Food and the Marine (2013), Central Statistics Office (2013) LUX - STATEC (2012), NL - Centraal Bureau voor de Statistiek (2014), UK – UK Agriculture (2010), Biomass Energy Centre (2015), Government UK (2013), Department of Enivronmental, Food and Rural Affairs (2013)

[9] Here a sum is made of several cabbage types that leave quite some residues on the soil: e.g. cauli-flower, red cabbages, white cabbages, spring cabbages, pointed cabbages, broccoli, Chinese cab-bage, … Note: depending on the end use (fresh market or industry) more/less crop residues remain on the field. No differentiation was however made regarding to end use. Numbers listed here will be an overestimation of fields having a significant amount of residues left.

[10] Sources: B – Agreon (2015), GreenWatt (2012), Bernaert (2013), D –Energetische biomassenutzung (2012) , IRL - Teagasc (2014), LUX - Administration de l'environnement (2012) ,NL – Van der Voort *et al.* (2006), De Wolf *et al.* (2005), UK – Allport (2015), Biomass energy centre (2015).

sometimes heat and electricity. Straw is a difficult input material for biogas plants. Therefore, it is used, but mainly in specialized dry fermentation plants. There are only some installations of these kinds. Rape straw is mainly left on the field. In the past in Germany some tests have been performed on the anaerobic digestion of corn stover, these archive a biogas potential of 250-300 Nm^3 methane/ton of dry matter. Corn stover seems to be difficult in handling and is therefore seen as cost intensive.

In Ireland crop residues remain on the field and are ploughed back into the soil. There are no collection methods/protocols in place. Residues produced during the processing phase may be used for composting or fodder. Anaerobic digestion is not popular in Ireland, also no refinery concepts have been adopted. Collection of crop residues is not seen as an option on the short term.

There is no systematic information available on the collection and use of crop residues in Luxembourg. Though according to the annual report of Administration de l'Environnement from 2012 6110 tonnes of plant-tissue waste originating from agriculture, horticulture, aquaculture, forestry, hunting and fishing is co-digested in Luxembourg.

In the Netherlands only straw from cereals is harvested and used as litter or fodder in stables. Next to this the straw is also used as a cover for flower bulbs or roots during wintertime. There is no demand for other crop residues in the Netherlands at the moment. The main risk seen is that extra handlings could damage soil structure. These extra handlings & transport also cost money. Research at Wageningen University came to the conclusion in the past that small scale anaerobic codigestion of crop residues might be an option which returns the costs for extra handling.

Similar to Belgium, Germany and the Netherlands wheat straw (2 million hectares) is the main crop residues which is collected in the United Kingdom. About 30 % of the wheat straw is used as animal bedding and another 30% is sold in the other cases the straw is ploughed in. Next to this straw from barley (1 million hectares) is mainly used for animal bedding and feed. Other crop residues are not routinely harvested or used. The Leek Growers Association however intends to use the residues (trimmings) of leek that are collec-ted during the cleaning of leek on farm (after transport of leek from the field) in an AD installation.

Research institutes, non-profit organizations, industry in the region dealing with this topic are:

- FL: Inagro, Biobase Europe Pilot Plant, Ghent University, ILVO, CINBIOS, Innovati-esteunpunt, Biogastec, GreenWatt, NPG Energy, Avecom, …
- D: several agricultural institutes and universities like Universität Hohenheim, Universi-tät Bonn, Thüringer Landesanstalt für Landwirtschaft (TLL), Technologiezentrum Straubing, Fachagentur Nachwachsende Rohstoffe e.V. (FNR), …
- IRL: Environmental Protection Agency (EPA), SEAI Teagasc
- LUX: LIST (group of Dr. Philippe Delfosse)
- NL: University of Wageningen, Sugar Union, Foundation Green Gas
- UK: Bio-Energy and Organic Resources Research Group (BORRG) (University of Southampton), SWR BioEnergy Limted

Conclusions:
Apart from wheat straw, the harvest and use of crop residues in the partner regions has remained limited until today. Though there have been some projects and research institutes working on this topic (mainly in the Netherlands, Germany, the United Kingdom and Flanders), crop residues from vegetables and corn stover are not harvested and used on a large scale yet. Interest in several of these residues remains, there are however still quite some challenges to realize sound supply chains for these products.

2.1.3 External stimuli and bottlenecks [11]

The European Nitrate directives dictates that the application of nitrogen fertilizer from animal origin can only be applied up to 170 kg of N per hectare per year. However because each member country has the freedom to implement the Nitrate directive according to their own wisdom different interpretation of the Nitrate directives can be found in partner countries legislation and definitions. This can influence the use of digestate from (small scale) digestion and the application of crop residues in anaerobic digestion and is explained in the following paragraphs.

2.1.3.1 Flanders (Belgium)

In Flanders no differentiation is made between subsidies whether or not crop residues are used as an input: all digesters using >50 % manure or streams from agriculture receive the same amount of subsidy. Today crop residues are situated in a grey zone as regards to considering them as a biomass or as a waste stream. When they are considered to be a waste stream, extra permitting is needed since the biogas installation takes in waste. Most large scale installations are already certified for digestion of waste streams and follow the necessary procedures. For small scale installations this might be more difficult involving more administrative costs. Furthermore are the digestion facilities obliged to take in a minimal of 60 % input material from agricultural origin and a maximal yearly input of 60,000 ton if build in agricultural areas. From the moment manure goes in the installation, when using also other input streams like energy crops or crop residues, all digestate is also considered as animal based. For fields where the digestate is used as a fertilizer, the same limit of 170 kg animal based N applies, so extra 'animal' based nutrients are created by co-digestion. However the Flemish regulatory body, Vlaamse Land Maatschappij (VLM), allows a research consortium (Ghent University, VCM, Biogas-E & Inagro) to investigate the pro-rato system in a pilot project. The pro rato system looks at the percentage of animal based input material in regard to all input materials and defines the same percentage of digestate as animal based. In this way the extra 'animal' based nutrients are avoided via the pro rato systems.

2.1.3.2 Germany

Before August 2014 in Germany the subsidies consisted of the Feed-In-Tariff (EEG) and the energy crop bonus. In the new version of the law (August 2014) there is no bonus like this. This stimulus is/was paid per produced kWh electricity and is/was only for installations <2MW electrical power. Straw is not a legal fuel for small-scale burners (<100 kW). Burning facilities bigger than 100 kW need a special legalization to use straw as fuel. Straw is declared as biomass, it is not a waste product. In general crop residues are not considered as waste, they are used as fertilizer or as fodder. Only when nobody uses it (in the law it is called "dispose of it"), than they are seen as waste. The current fertilizer law only calculates the nutrients of the manure part of digestate. This regulation will be changed in 2015 so all nutrients are counted. This will change because Germany has many biogas plant with energy crops while at the same time facing problems with the nitrate directive.

2.1.3.3 Ireland

In Ireland there are currently no stimuli to encourage the harvesting of crop residues, due to historical use of such residues as nutrients and incentives aimed mainly at food production. The slow uptake of energy crops in Ireland also impacts this aspect. At present there are no legal bottlenecks clearly identifiable to the harvest and use of crop residues in Ireland. The Environmental Department will be able to clarify whether or not a waste permit will be required. If the product is not considered a waste product, a permit will not be required but if an AD system will handle animal wastes, a permit is required. An EIS (Environmental Impact statement) will be required where the feedstock might be deemed as waste. Agricultural animal by-products (slurry etc.) will be considered a waste, while agricultural residues are not considered a waste. When agro residues are mixed with waste the agro residues will also become waste. This inflicts that the annual intake for a multiple input digester can be maximal 25 000 tonnes (animal by-products and agroresidues), if intake is higher the EIS threshold is triggered. In the situations encountered by Limerick County Council, no EIS was requested for the agriculturally-based AD projects which went through the planning system. Issues such as odours should also be discussed. It is likely that any odours would come from the feedstock arriving rather than from the process itself. In an agricultural context it is worth pointing

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[11] Sources: B – Vlaamse Codex (2015), D - Erneuerbare-Energien-Gesetz – EEG (2014), Bundesmi-nisteriums der Justiz und für Verbraucherschutz (2006, 2010), Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz (2013) IRL - Enviromental Protection Agency, LUX - Receuil de legislation (2000), NL – Netherlands Enterprise Agency (2015), Tideman (2015), Overheid.nl (2015), Agentschap NL (2010), UK – Banks (2011), Environment agency (2014), Gov.uk (2015), NNFCC (2015), The Andersons centre (2010).

out that subjecting animal wastes and slurry to the process would lead to a reduction in the odours that might arise from the handling and use of nutrient rich material. Such easily handled nutrients could also be incorporated into Nutrient Management Plans replacing en ergy intensive chemical fertiliser. When crop residues are harvested they are considered an agricultural by-product. They are not classed as a "Waste" but can be considered biomass. If fields are accounted for nitrate limiting conditions, the nutrients will be considered as an extra application of nutrients (and as animal waste) to the land and will be bound mainly by the nitrates directive.

2.1.3.4 Luxembourg

In Luxembourg there are no financial stimuli regarding to the use of crop residues. Crop residues can be digested in biogas plants without any extra permit procedure only if the crop producer is the owner of the biogas plant. Should the crop residues be transported to any biogas plant, than they are considered as an "external" waste stream, and the plants using such substrate need to obtain an extra permit for co-digestion of such substrates. There is no correction in legislation regarding to the nutrients coming from crop residues: When crop residues are put into an AD installation, the complete digestate produced has the status of organic fertilizer.

2.1.3.5 The Netherlands

The Dutch subsidy system for renewable energy is called SDE+ (Stimulation of Sustainable Energy Production). SDE+ compensates producers for the unprofitable component compared to fossil fuels for a fixed number of years, depending on the used technology. The SDE+ subsidy is limited by the maximum number of full load hours of the installation (=energy produced in one year divided by the maximum capacity of the installation). The subsidy differs for co-digestion of manure (>50% of the mix is manure) with €0,030 per kWh and mono-digestion of manure (>95% of the mix is manure) with €0.106 per kWh for 2015.

Input feedstocks that can be digested together with manure are listed in the Appendix Aa. In this appendix Aa crop residues are considered vegetal input and this influences the use of digestate as it is defined differently accordingly to the input material into the digester. If more than 50 % on weight basis is manure the digestate can be used as fertilizer. When less than 50% is manure then the digestate is considered as waste and should be treated and cannot be used as compost. Only when all the input material is from plant origin (such as crop residues) the digestate can be used as compost if it is stabilized (for example by the Oxitop method).

2.1.3.6 United Kingdom

In September 2014, the Environment Agency released a long-awaited Briefing Note that differentiated crop residues from food waste. Previously, leaves and roots or bruised, misshapen or undersized produce (outgrades) was classified as waste and operators had to apply for expensive environmental permits and implement extensive handling control regulations before they could use them in AD plants. Following the recent clarification, biogas producers will no longer need to pay for permits or waste handling controls to use fruit and vegetable by-products in AD installations, which should stimulate more crop residues being turned into biogas and fertiliser. When bringing back the nutrients of crop residues through digestate, these nutrients have to be part of the total amount allowed. The land classification affects the total amount. The removal of crop residues could be considered in the overall equation and justification of using more. There must be enough land in the vicinity of the digester that can accept the digestate within the restrictions of Nitrate Vulnerable Zones (NVZs), 62% of land in England and 4% in Wales falls within NVZs.

Conclusions:
There are no extra financial stimuli in the partner regions for harvesting and valorizing crop residues at the moment. Crop residues are considered as biomass in most of the regions. In Flanders their legal situation is not clear, while in Luxembourg they have a biomass status as long as they are valorized within the same company which produces the residues. In Germany crop residues are considered biomass for as long as the owner doesn't want to dispose them. In the Netherlands crop residues are considered to be biomass, there are, however, strict rules on the amount of manure that should be co-digested (min. 50%). If this rule is not followed, the digestate is considered as waste. In the UK from September 2014 on crop residues (fruit & vegetable by-products) have been exempted from being considered as waste. In all partner regions there is no correction in fertilizer regulations for nutrients in the digestate but originating from energy crops or agricultural residues. There used to be an exemption in Germany, but it no longer applies.

2.2 Small scale anaerobic digestion

2.2.1 Distribution & potential for distribution [12]

2.2.1.1 Flanders (Belgium)

There are about 140 anaerobic digesters in Flanders, about 100 of them are small scale in-stallations (<200 kW). Most of these small scale installations have an electrical power of maximally 40 kW. Only one has a power of 190 kW. Apart from the one research installation of Inagro (31 kW) and the 190 kW installation mentioned, all small scale installations are monodigesters of cattle slurry. Both installations of 31 kW (Inagro) and 190 kW are co-digesters of pig slurry with energy crops and waste streams (not at Inagro) as an additional input. The figure below gives an idea about the distribution of small scale installations in October 2014, at that time there were about 56 installations, there has been a serious increase from the beginning of 2015 on.

Figure 52: Distribution of small scale AD installations in Flanders (Oct. 2014) (Biogas-E, 2014).

Small scale AD requires a minimum amount of manure present on the farm: 10 kW installa-tions require about 80 productive cows in order to have a sufficient biomass input. If the ma-nure can be delivered fresh, then 50 cows even suffice. Regarding to the further distribution of small scale AD in Flanders the data in Figure 53 gives an idea on the distribution of farms in the five Flemish provinces according to the number of animals on the farm. In total there are more than 900 farms with more than 80 productive cows.

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[12] Sources: B – Biogas-E (2014); D - DBFZ (2014); IRL –rx3 (2014); LUX - Administration de l'environnement (2012); NL – Centraal Bureau voor de Statistiek (2014), Groot-Wassink (2014), iDelft (2015), van Bruggen (2012), LEI Wageningen UR (2015); UK – ADBA (2015), Farming Statistics (2014), Gov.uk (2014), KADA Research (2013), NNFCC (2015), NFUBriefing (2013), WRAP (2015).

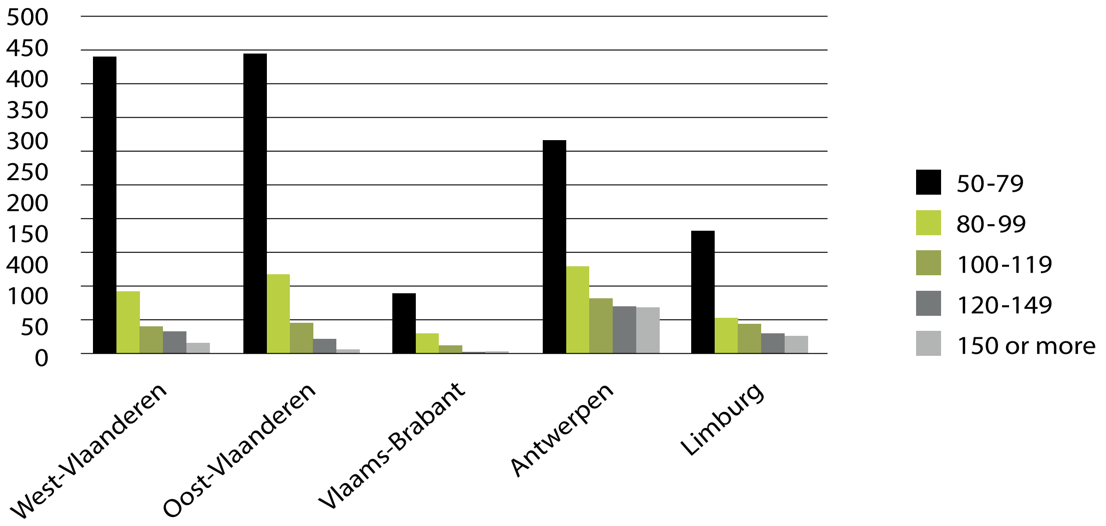

Figure 53: Numbers of dairy farms in Flanders according to number of animals and per province with West Flanders (West-Vlaanderen), East-Flanders (Oost-Vlaanderen), Flemish Brabant (Vlaams Brabant), Antwerp (Antwerpen), Limburg (Limburg) (Algemene Directie Statstiek en Economische informatie, 2013)

2.2.1.2 Germany

There are nearly 8,000 biogas plants (all sizes) in Germany. The focus areas are in the northwest and south, where farmers with large livestock farms are located. Other regions, where smaller farms (~200 cows) exist, like the Mittelgebirgsregion, have less biogas plants and a high potential for small-scale biogas plants on farm level. However, an exact number for this region is hard to prognose. The number of small scale installations in Germany is given in Table 14. These are mainly installed on dairy farms (80-200 cows). There is only one small scale installation (250 kW) is in the region biosphere reserve Bliesgau.

Table 14 : Number of installations in Germany in regard to their power ouput

Power (kW)	Surface (ha)
<70	~500
70-150	~750
150-500	~4,000

In the Bliesgau region there are about 203 farmers with only 25% having more than 100 cows. In Germany there are 144,850 farms with cattle of which 38,895 farms have more than 100 cows.

2.2.1.3 Ireland

While there are 7 anaerobic digestion plants in Ireland at present (see green markers in Figure 54), there is only 1 relatively successful plant in operation. The other facilities are small scale farmer developed systems or r&d systems in various stages of testing & operation. The plants are mostly located in the South and South-East of the country. The main AD plant in Ireland, is the GreenGas AD Plant (250 kW), in Dunoylan, Shanagolden, Co.Limerick. This plant, operating under the trade name of McDonnell Farms Biogas Limited, is a farm based AD facility, located next to a large family farm. The plant processes dairy (300 cows) and poultry manure with imported feedstock's such as hatchery waste & dairy sludge. The biogas produced is used as fuel in a CHP unit, with produced electric sold to the national grid, and heat recycled for heating in the plant and nearby poultry plant. The processed digestate is used ad fertilizer on local farm land. Information on the other plants is unknown. Regarding to the potential of small scale monodigestion of manure, there are 1,300 dairy farmers that have at least 80 productive cows on their farm. Ireland's agricultural advantage is a long growing season. Cows are housed in stables for a maximum of 16 weeks of the year, in many cases this is less. This means that the collection of a continuous supply of fresh cow manure is not possible as the cows are in the fields. Logistically, collecting cow manure from the field is considered not possible.

Figure 54: Distribution of organic resource management facilities in Ireland with CQAS:441 qualtiy compost (•), DAFF approved compost (•), other compost (•), anaerobic digestion (•) , mush-room compost (•)(rx3, 2014)

2.2.1.4 Luxembourg

Based on available data on electricity and power production (Administration de l'environnement, 2012) it can be estimated that only 2 installations in the country are between 10-50 kW; 1 is between 50-100 kW, while 3 are in the range 100-200 kW. The size of the further 2 small scale installations is unknown. These installations are mainly plants, in which agricultural residues sum up to 60-90% of the input. There is also at least one additional plant digesting mainly energy crops (85% of the input). No further information is available on the exact agricultural inputs of these particular plants, however mainly farmers having big cow herds or cooperatives of farmers are the owners of digesters. In total there are about 613 dairy farms with a mean cow number per herd/farm of 55 in Luxembourg, but based on the available information the number of farms with more than 80 cows (creating potential for feasible pocket digestion installation) could not be estimated.

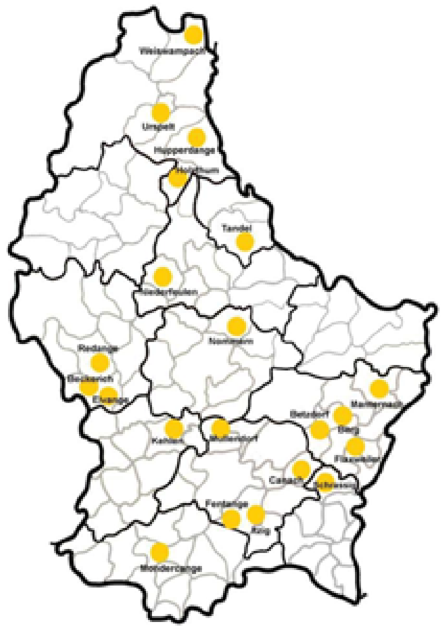

Figure 55: Distribution of the biogas plants in Luxembourg (Source: Administration de l'environnement,2012)

2.2.1.5 The Netherlands

In 2013 there were 95 co-digestion installations in The Netherlands. Through the high prices of co-products with high energy content (silage maize), the total energy production of these plants lowered through the years by less full load hours. The average power of these plants was in 2005 300 kW, in 2012 the average power raised up to 1400 kW. Figure 56 displays the co-digesters in The Netherlands with an electrical output of 1-500 kW. There are 24 installations with an electrical power below 500 kW. According to Groot-Wassink (2014), involved in the project 'small scale digesters in practice', most of the small scale digesters are situated in the province Noord-Brabant. This is due to the high amount of pig farmers in that region. Large co-digesters are exploited mainly by cooperatives of farmers. They are also exploited on intensive farms, like pig farms. Some co-digesters are exploited by energy-producing companies. Some of these co-digesters are not situated on a farm, but on industrial sites. In the northern regions of The Netherlands co-digesters are used on separate farms with dairy cattle. Small scale digesters are situated mainly on dairy farms.

Estimating the potential for small scale AD in the Netherlands, it is noticed that 30% of all the cows in the Netherlands are living mainly indoors. When cows do graze outdoors, they do that on an average of eight hours per day. In The Netherlands in 2014 there were in total 18,500 dairy farms. From the data in Table 15 about 6000 dairy farms have more than 80 cows for milk production, or can deliver at least 7 m^3 of fresh cow manure per day.

Table 15: Number of cow farms in regard to the number of cows per farm in the Netherlands

Number of cows/farm	Number of farms
1-50	4,400
50-100	8,500
100-200	5,000
200-500	600
>500	15

Figure 56: Location of co-digesters with electrical power output below 500 kW in the Netherlands

2.2.1.6 United Kingdom

In the UK, most farm-based AD plants are 500 kW and less, while industry-accepted definition of 'small-scale' AD is a digester with a capacity between 25 to 250 kW, where waste or feedstock is sourced and outputs are used locally. The Anaerobic Digestion and Biore-sources Association (ADBA) made a map of all AD plants (outside the water sector) currently in operation in the UK this can be seen in Figure 57. The majority of installations are located in England, followed by Northern Ireland and with very few recorded in Wales and Scotland. The agricultural AD plants are generally located in the more fertile agricultural rural areas with extensive arable and livestock production, such as the rural south west and western border counties, the east, and rural Northern Ireland. In Table 16 subdivision of agricultural anaerobic digestion installations is made according to their power.

Table 16: Number of agricultural anaerobic digestion plants in the United Kingdom in regard to electrical power output and the relative percentage to total anaerobic digestion installations

Total AD Installations:	148	100%
Total Agricultural heat and/or power (CHP) sites:	63	43%
0-10 kW	7	11%
10-50 kW	3	5%
50-100 kW	5	8%
100-200 kW	3	5%
200-500 kW	21	33%
over 500 kW	24	38%

Of all current AD systems, just under half (43%) are classified as agricultural installations. Of these, less than a third are under 200 kW capacity. The majority of the agricultural installa-tions are located on farms using cattle manure/slurry and are often supplemented with silage.

The 2013 data for UK show that there are about 4,400 farms with 50-99 cows, 3,100 farms with 100-149 cows and 3,800 farms with more than 3,800 cows. Regarding manure, accord-ing to the Biomass Energy Centre, dairy cattle typically produce between 42 kg and 64 kg (depending on body weight) of manure per day, so if they are housed for 50% of the year that corresponds to 7.6-11.6 tons per annum per cow. The UK herd of 2 million dairy cows produces around 20 million tons of slurry, equivalent to around 2 million tonnes of dry matter (at 10%). Currently only around 1% of UK livestock manure is treated by AD.

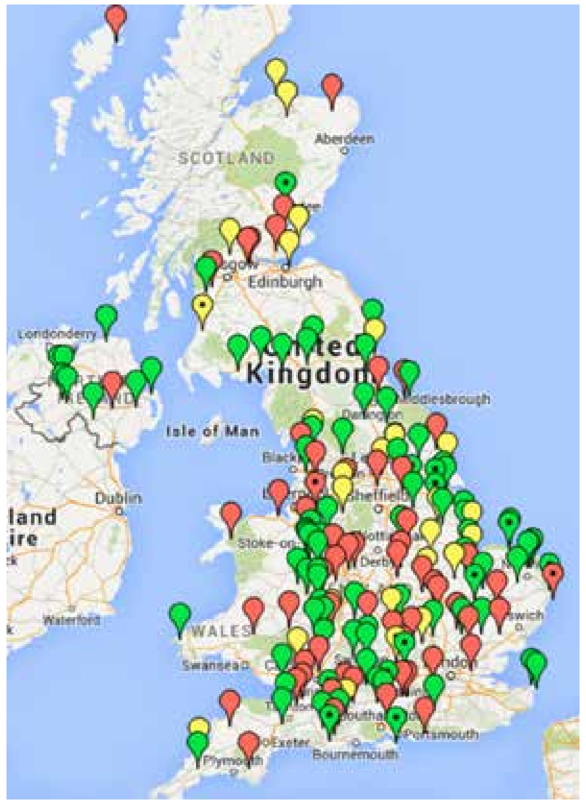

Figure 57: Distribution of anaerobic digestion plant in the United Kingdom with community installation (●), industrial installations (●) and agricultural installations (●)(Anaerobic Digestion and Bioresources Association (ADBA), 2015)

Conclusions:
Looking at the number of small scale AD installations at the moment, Germany and Flanders have shown to be the most populated regions with respectively 1250 and 100 small scale installations. For the other NWE countries the number of installations per country always stays below 25. Regarding the number of farms with at least 80 cows there is a huge potential (several thousands of companies) in Germany, the United Kingdom and the Netherlands for further distribution of this technology. Both in Belgium and Ireland the number of farms with at least 80 cows approximates one thousand. It should be noted that these numbers are very rough estimations, since it was not taken into account whether cows are held mainly within the stable or are kept outdoors, which has great influence on the manure production potential. Depending on the hours cows are grazing outdoors, there isless manure available for the AD. E.g. in Ireland this is seen as one of the obstacles for small scale AD distribution.

2.2.2 Manufacturers [13]

2.2.2.1 Flanders (Belgium)

All small scale installations on cattle slurry in Flanders were constructed by the same Flemish company (Biolectric). Together with Biogas-E, Inagro performed a market study on manufacturers of small scale AD installations in Flanders and neighboring countries. The conclusion from this market study was that there are over 60 companies aiming at small scale AD in the region for the moment. The market study was published in a brochure which is available on the ARBOR website (www.arbornwe.eu).

2.2.2.2 Germany

Small scale AD in Germany is defined < 75 kW, for these plants there are nearly 25 plant manufacturers. Lists of names and companies can be found at the webpage of Fachagentur Nachwachsende Rohstoffe e.V.

2.2.2.3 Ireland

In Ireland about 25 companies exist which build anaerobic digestion facilities or give advice. An overview and contact info of the several companies can be found on the webpage of Sustainable energie agency of Ireland.

2.2.2.4 Luxembourg

There are 2 companies in Luxemburg constructing Biogas plants: L.E.E. and IGLux. Both could construct small scale installations but have no special focus on small scale digestion.

2.2.2.5 The Netherlands

In the Netherlands there are several suppliers of small scale AD installations. These are listed below, the supplier is mentioned between brackets.

- Microferm (Host)
- Biolectric (PAS systems / ISS Tanks)
- Agrimodem (GET and Lely)
- Fermtech (Fermtech systems and Dorset)
- Aecobag (Nijhuis Water Technology and Thecogas)
- Bioclear (Multiple parties)
- Serigas (Serigas)

2.2.2.6 United Kingdom

There are two main directories for AD plant suppliers:

1. Official Information Portal On Anaerobic Digestion
2. ADBA's members' directory.

The ADBA's directory counts: 64 AD developers and operators (of these 25 are 'farm developers') and 52 AD system suppliers.

Conclusions:
The market study on small scale AD constructors together with the data from partner regions in this case study report has shown that there are over 60 companies in the NWE region aiming also at small scale AD installations.

2.2.3 External stimuli and bottlenecks [14]

2.2.1.1 Flanders (Belgium)

External stimuli
From January 2015 on, the Flemish Climate Fund foresees an investment subsidy of 30% for side infrastructure of small scale anaerobic digesters. There is no investment support for the digester (& CHP) itself. Elements that are seen as side infrastructure are: manure mixer, manure scraper, full stable floor, pumps & pipes, separation of wash water from the milk installation, covered manure & digestate storage.

Next to this investment subsidy, there is also a financial support for the production of renewable energy. The support amounts € 93/MWh gross electricity produced, for the net primary heat saved there is a subsidy of € 31/MWh heat.

At first for the microdigesters (~10 kW) a notification to the local government on the construction of the small scale AD was sufficient, this has however changed into the requirement for an environmental permit. The category under which the environmental permit is requested, is mainly determined by other changes the farmer wants to do on his farm at the same time. Since small scale AD is accepted much more by neighbors compared to large scale AD installations, this can somehow be seen as a stimulus as long as the additional administrative costs can remain low.

Bottlenecks
Due to the fact that all installations (incl. solar panels) in Flanders producing renewable energy with an electrical power below 10 kW are compensated through a counter that spins backwards when injecting electricity in the grid, it was noted by the government that these producers don't pay anything for the temporary usage of the electricity net as a battery on the moments that not all energy is consumed by the producer. Because of this, starting from July 2015 on these producers of renewable energy will have to pay an extra fee. This fee amounts 67 to 106 euro per kW electrical power, the exact amount differs between regions. Due to the fact that this fee was calculated for solar panels and the fact that the energy production profile of small scale AD is more stable, it might be recommendable to have a separate fee for small scale AD since it can be expected that these installations make less use of the electricity net as a temporary storage facility.

For other bottlenecks relating to the combination of animal manure with other inputs and the use of digestate, see the bottlenecks mentioned in the previous part on crop residues.

2.2.3.2 Germany

External stimuli
The feed-in-tariff (EEG) system in Germany has several stimuli for small scale biogas plants <75 kW. The electricity of these plants is paid with a subsidy equal to €0.2373/kWh. Installations with an electrical power below 150 kW are also rewarded slightly more compared to larger installations as can be seen in Table 17.

Electrical power	Basic remuneration	Small scale biogas	Biowaste
kWel	€/kWh	€/kWh	€/kWh
≤ 75	0.1366	0.2373	0.1526
≤ 150			
≤ 500	0.1178		
≤ 5,000	0.1055		0.1338
≤ 20,000	0.0585		

Table 17: Subsidies for anaerobic digestion plants in Germany

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[13] B – Biolectric (2015); D – FNR (2015); IRL – SEAI (2014); LUX – L.E.E. (2015), IGLUX (2015); NL – Microvergisters.nl (2015), Groot-Wassink (2015); UK – ADBA (2015), NNFCC (2015).

[14] B Sources: B – VREG (2015); D - Erneuerbare-Energien-Gesetz (2014) ; IRL – Sustainable energy authority Ireland (2014); LUX - Biogasvereenegung a.s.b.l. (2014) ; NL – RVO (2015), Groengasnl (2013), BioBased Economy (2015), Tideman (2015), Groot-Wassink (2015), Agentschap NL (2011), Lensink & van Zuijlen (2014), van Dorp (2013), NNFCC (2015); UK – Legislation.gov.uk (2015), Natio-nal Farmers Union (2013), Bywater (2011), REA (2013), Ofgem (2014).

Bottlenecks
Due to the fact that all installations (incl. solar panels) in Flanders producing renewable energy with an electrical The largest bottleneck for small scale AD in Germany is the high investment cost (because the legal standards are the same as for big plants) and the (older) farms don't have an optimal collect system for manure. When a new stable is built, farmers try to optimise these systems – but in these cases the investments cost could be the limiting factors.

The procedure for requesting a permit is a little bit easier for small scale as can be seen in Table 18:

- Small scale biogas plants need a permission according to the building law.
- Plants with more than 1.2 million m^3 gas production per year, 1 MW rated thermal output or 6 500 m^2 capacity or dangerous waste need a Immission control-legal permission. If ordered they need also an environmental impact assessment.

Table 18: Permission requirement according to gas production and input material in Germany

	Material	Material
<1.2 mio. gas production	-> ~ 3 000 m^3 liquid cow manure in small scale biogas plants (biogas yield 380 m^3/t oTM)	BauG – building law
>1.2 mio. gas production	-> > 3 000 m^3 liquid cow manure	Federal Immission Control Act

2.2.3.3 Ireland

External stimuli
At present there are no stimuli for AD or mono-digestion in Ireland. There are no real legislative or supportive differences between small and large scale installations, with the exception of Environmental Impact statement limits for larger plants (see above). Target stimuli do not exist in Ireland but larger projects have a greater chance of becoming a case study or trial plant with an energy body (such as SEAI), therefore potentially gaining financial support from such a body (as in the case with the GreenGas AD Plant). Larger AD systems also stand a much better chance of securing a prompt and successful grid connection when compared to smaller installations

Bottlenecks
Planning Permission and Grid Connection are the main bottlenecks for small scale AD. Since AD in general is not popular in Ireland, gaining planning permission and grid connection can be a long if at all successful process. Unfamiliarity with the technology involved in the regulatory bodies and a lack of support from government levels, mean convoluted and difficult planning, regulation and connection processes.

The conservative nature of the agricultural sector considering the implementation of these new technologies, might be seen somehow as a bottleneck. Also waste collection issues can be a bottleneck: cows are housed in stables for a maximum of 16 weeks of the year, in many cases this is less. This means that the collection of a continuous supply of fresh cow manure is not possible as the cows are in the fields.

2.2.3.4 Luxembourg

External stimuli
The general legislation to be followed is similar, independent of the size of biogas plant. There are some additional permits necessary in case the organic waste is one of the inputs. However, each permit procedure in Luxembourg is unique. For some issues there are no standardized procedures, which may prolong the whole permit application process.

There is a new legislation in force from 01.08.2014 on "Production of energy from renewable energy sources", defining the new feed-in tariffs for the new biogas plants, which started to produce and inject electricity after 01.01.2014. In general the decrease of feed-in tariffs for the produced electricity with the size of the plant and the construction year has been sustained. All the feed-in tariff has been elevated as compared to the previous legislation, but the highest increase was introduced for the installations <150kW:

New feed-in tariffs for electricity production from biogas:

<150 kW:	€192 x (1-(n-2014) x 0.25/100)/MWh
150 - <300 kW:	€181 x (1-(n-2014) x 0.25/100)/MWh
300 - <500 kW:	€171 x (1-(n-2014) x 0.25/100)/MWh
500 – 2500 kW:	€153 x (1-(n-2014) x 0.25/100)/MWh

with n = year of the electricity grid connection resp. first feed-in
Maximum size promoted: 2500 kW.

An additional heat usage bonus of € 30/MWh for commercialized heat from biogas can be paid, if strict conditions regarding the commercialization of heat are met, e.g. the use of biogas heat for treatment of digestate is not considered as "commercialized use of heat".
The new legislation also introduced a manure bonus of € 20/MWh of produced electricity for the biogas plants, in which manure constitutes at least 70% of the input. This is equal for all the plants but can be seen as a measure supporting pocket digestion installations.

Bottlenecks
The whole biogas industry in Luxemburg has been in stagnation for several years. Apart from 3 new big plants digesting mainly municipal waste there was no other development observed. The previous feed-in tariffs hardly allowed profitable operation of the biogas plants. To reach higher productivity biogas plants were forced over previous years to search for substrates with high energy density. However, the increased prices of such substrates and scarce local availability pushed plants towards biomass imports, which on the other hand contributed to cutting the investments subsidies (legal conditions for receiving investment subsidies restrict imports of biomass). The plants, which managed to increase their efficiency, had to bear the higher investments cost due to increased biomass streams (e.g. for more storage spaces). The new feed-in tariff system introduced in 2014 foresees the highest increase in feed-in tariffs for the installations smaller than 150 kW (42€/MWh for 2014). For the plants in the range from 150 kW – 300 kW and 300 kW – 500 kW the increase is equal and slightly lower as for the first category (41€/MWh for 2014). However, in the category 500 kW – 2500 kW the increase in the tariffs is not that high as for the other categories (33€/MWh for 2014). Additionally a manure bonus was created. This shows a clear tendency to promote pocket digestion with high contributions from manure.

2.2.3.5 The Netherlands

External stimuli
There are no external stimuli for small scale anaerobic digestion in the Netherlands. However in comparison with large digester, small scale digesters have to meet different regulations. To get a SDE+ subsidy, it is necessary for installations larger than 0.5 MW to perform a feasibility study. When the digester has a biogas storage of >4 000 m^3 and the digester is not limited to biomass ratios (like >50% has to be dairy fertilizer), the digester cannot be situated on a farm anymore, an industrial site is needed. So in relation to large disters, small scale digesters have less administrative hassle when implemented.

Bottlenecks
Two permits are necessary for large and small scale digesters: a so called 'Omgevingsvergunning' and a so called 'Natuurbeschermingswetvergunning'. It is not allowed to build anything without an 'Omgevingsvergunning'. With not much troubles, this permit can be granted within 20-30 weeks. Also it is necessary to have a recognition from the Dutch Food and Consumer Product Safety Authority, which has some demands on behalf of the facilities surrounding the installation (roads, safety issues, …). This is especially for small scale digesters a bottleneck, because the profits are relatively marginal on the investment which has to be done compared to larger digesters.

Producing gas on a small scale makes it in most cases unfeasible to improve the gas to a quality which can be delivered onto the gas network, which is available in most parts of The Netherlands. Because of that reason, the gas has to be burned to turn it into electricity. This is economically less interesting for a farmer. Electricity is cheap and the engine to burn the gas has an efficiency of maximum 50%. The heat which will be produced in this engine (were the efficiency comes from), can be used partly on the farm; to heat up the digester, for the heating of the residential house and so on. Finally an amount of heat will get lost, which is a loss in efficiency on small scale digesters. Besides this efficiency loss, the trend in The Netherlands has been seen, that it gets every year more expensive to produce electricity from a co-digester. The margin on this activity will get therefore smaller. Normally, the SDE+ subsidy will compensate that, but in practice this seems not always the case. The aspect of raising the subsidy is difficult, because entrepreneurs who started for example in 2014 a co-digester do not have the raise of the subsidy and will probably have a loss on entrepreneurs who are going to start a co-digester in 2015 and so on. In that way the subsidy covers a large part of the difference of sustainable and unsustainable energy, but not everything.

2.2.3.6 United Kingdom

External stimuli

Planning regulations:

- A simplified regulation is available for small-scale AD, owing to its low-risk nature.
  Planning permission is necessary for most anaerobic digestion installations. Small-scale digesters using only on-farm waste may be passed as Permitted Development in England. Permitted Development rights are subject to limitations and conditions designed to minimise impacts on neighbours and the wider environment, e.g.: the ground area covered must not exceed 465 m^2, the height of any building, structure or works must not exceed 3 m if within 3 km of the perimeter of an aerodrome, the development is on land used for agricultural or forestry purposes and the feed-stock is restricted to only that generated on the host farm or forestry holding.
- All AD plants will be required to obtain an environmental permit or exemption to operate and to spread digestate. However if the AD plant can meet the criteria as set out in Schedule 2 of the Environmental Permitting Regulations it may be able to get an exemption. By registering this Exemption, a business effectively places itself on the Environment Agency's radar who then have the right to visit the site to ensure it is operating to necessary criteria. An Exemption lasts for 3 years.

Feed-in-Tariff (FIT) and Renewable Heat Incentive (RHI):

- The higher FIT and RHI tariffs for farm-scale AD was intended to reflect the higher costs that would be incurred by these generators. However FITs have been criticised for disproportionately affecting the smaller players in the market (see bottlenecks).:

FIT tariff:

- Facilities of less than or equal to 250 kWe are entitled to 12.46 p/kWh.
- Facilities of between 250 and 500 kWe are entitled to 11.52 p/kWh.
- Facilities of between 500 kWe and 5 MWe are entitled to 9.49 p/kWh.

RHI Tariff (2012, incl. Dec 2013 update):

- Biogas combustion up to 200 kW scale receives 7.3 p/kWh.
- Biogas combustion of between 200 kW and 600 kW will receive 5.9 p/kWh.
- Biogas combustion over 600 kWth will be eligible for 2.2 p/kWh

Bottlenecks

- Planning permission and environmental permitting can act as bottlenecks for small scale AD due to the administrative and financial burden.
- There may also be issues with waste management regulations. According to the NFU Briefing (2013): *"A key priority for the NFU has been to ensure that smaller, farm-based AD plants are encouraged, and not mistakenly labelled and shunned as "waste management". Many agricultural digesters will use inputs from the farm or its near neighbours only, and under these circumstances the NFU has lobbied for on-farm AD plants to be exempted from Environmental Permitting, or subject only to simple low-cost Standard Permits. Together with other industry stakeholders, we have been working with Defra, the Environment Agency and the Waste and Resources Action Programme (WRAP) on making a clear distinction between low-risk on-farm digesters and larger centralised waste-licensed 'merchant' plants."*
  This has already resulted in the clarification of the Enivronment Agency which was issued in autumn 2014, so the actual effect of this has yet to be seen. The broader point made by the briefing of the NFU is also about planning regulations and exempting farm-size AD plants from the environmental permitting.

Other bottlenecks listed by Bywater (2011) are:

- To benefit from Feed-in-Tariff, farmers need to combine AD with CHP to create electricity. This is associated with a number of difficulties, including grid connection issues, significant extra capital/maintenance costs and plant complexity in terms of engineering a system which can continuously produce sufficient quantities of quality gas.
- Generally, the primary feedstock (cattle slurry) is only available for 6 – 7 months when cows are housed indoors over the winter months.
- Limited availability of sufficient year-round on-farm organic substrates.
- There are significant regulatory financial penalties imposed for digesting the off-farm substrates (which have to be returned to land, anyway), including those which can be fed to cows.
- Access to capital.
- For many of the average sized farms in the UK, direct use of the biogas from the AD slurry treatment system might be a simpler and more cost effective option. However, the only incentive that direct gas use is likely to attract is the Renewable Heat Incentive (RHI), which is unlikely to provide sufficient income to make it economic for many of these farmers to install AD. On smaller digesters, a relatively larger proportion of the biogas is used for digester heating and this use is unlikely to attract the RHI.
- Most farm-based AD plants are 500 kW or less and development of these projects is under extreme pressure because of cuts in their FIT rate. Also, stakeholders have been lobbying for a FIT tariff review because under current policy significant tariff reductions are being triggered by 'preliminary accreditations', making small and mid-scale AD (below 500 kW) uneconomic. However, the UK Government has confirmed it will not review the FIT for AD in 2014.

Conclusions:

External stimuli:

there are big differences between partner countries regarding to support measures installed. Some countries (D, LUX, UK) give a higher financial support per kWh electricity produced through small scale AD (compared to large scale AD). The difference with larger installations (>150 kW) is largest in Germany, also in Luxembourg the limit of 150 kW is applied. Luxembourg foresees an extra manure bonus when >70% of the input is manure. In the United Kingdom the support for installations <250 kW but >150 kW is a bit higher than for the smallest digesters but the difference is not that big. Both in the Netherlands and Ireland there is no extra financial support for small scale installations compared to larger ones. In Flanders there is no additional financial support per kWh produced for small scale AD. There is however support for investments that are combined with a small scale AD (e.g. manure/digestate storage, manure scraper, pumps & pipes, …).

Some countries (FL, D, NL, UK) also report a more simplified planning & permission regulation as an advantage.

Bottlenecks:

Ireland reports difficulties in getting permission and grid connection, also Luxembourg reports that the long permission procedure can be a bottleneck. For Germany high investment costs create difficulties, since all the installations independent of the size have to fulfill the same legal and technical requirements, which are very often financially not feasible for the small installations. Also the Netherlands and the United Kingdom report high investment costs. For the Netherlands an important constrain is created by the fact that for the moment small scale AD cannot inject biogas into the gas grid similar to larger installations. This could increase energy efficiency of small biogas plants. For Flanders the fee for temporarily using the electricity networks as temporary energy storage, can be seen as an additional cost that might be adapted more to the technology of small scale AD. Both the UK and Flanders mention difficulties with regard to digesting off-farm biomass (which is seen as waste or through which extra animal-based nutrients are created). The UK and Ireland also indicate the limited availability of feedstock throughout the year as a challenge for small scale AD. In the UK the reductions in the subsidy system create additional a bottleneck for smaller installations.

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Abbreviations

- AD: Anaerobic digestion
- CHP: Combined heat and power unit
- LCA: Life cycle analysis
- MAP: Manure action plan

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