Harvesting techniques and logistic chain

(WP5)

December 2019

BioBoost - Report Harvesting Techniques and Logistic Chain

Authors
Bockstael, T., De Mey, V., Miserez, A. (2019)

Disclaimer
This report is a summary of the literature study and experiments carried out in the framework of the BioBoost project. Not all raw data are included in this report, but they are available for interested stakeholders upon request, if non-confidential.
Reuse is authorised provided the source is acknowledged.

Contact info

BioBoost coordinators:	JCAJStraver@GemeenteWestland.nl; gerrit.walstra@haute-equipe.nl
Responsible author Inagro:	audrey.miserez@inagro.be
Project website:	https://www.bioboosteurope.com/

TABLE OF CONTENTS

SUMMARY

The BioBoost project aims at valorising various rest streams from the horticultural and agricultural sectors. During different phases in the food chain, by-products are produced. Part of these by-products can possibly be valorised.

This report focusses on the by-products created during harvesting. For the following six crops, cultivation method, rest streams and innovations are detailed: Brussel sprouts, Belgian endive, tomato, cauliflower, beans and peas. The aim of this report is to ease logistic chains by exploring challenges and opportunities towards harvesting and valorisation of produced by-products.

The main challenges who arose from this study are not new. These challenges are summarised below and some solutions are proposed, based on the mentioned innovations in this study.

Seasonality and small scale production. Most of the by-products are released within a short period, making it challenging to assure a continuous valorisation process, unless residues are stored in an appropriate way. Additionally, although by-products represent a large share of the total biomass produced during cultivation, the production is spread over the region and is relatively small scale.

Heterogeneity. The quality and composition of the by-products vary strongly based on varieties, harvesting period and soil conditions.

To compensate for the abovementioned challenges, stabilisation and storing techniques are developed and used. These methods should be adapted to the kind of residues and to the type of valorisation aimed. However, these also influence the composition of the by-products. Another solution might be to combine different by-products, to enlarge availability.

Harvesting of residues. Adapted harvesting machines should be developed. For different crops mentioned in this study, these already exist (e.g. Brussels sprouts and cauliflower) or are in development, which eases further valorisation.

*Extra costs for harvesting or other innovations***.** Innovation asks for investments. For the primary sector, these investments costs add additional costs to the total business budget, unless valorisation is seen as beneficial to the primary sector, also financially. Two opportunities are found to act towards cash proceeds instead of costs on the long term:

- Multivalorisation: Biorefining results in potential products with new by-products. In the scope of a zero waste approach, it is advisable to look at those new by-products. E.g. waste can often be separated in a liquid and a fibre part. Both have different valorisation potentials.
- Supply chain: To realise successful valorisations, it is crucial to set up supply chains and collaborations. Abovementioned challenges will have to be tackled such that the processing sector gets access to sufficient and qualitative by-products. Additionally, there should be a demand for the new products. Finally, the new product should be an improvement (technically, economically or environmentally), compared to the conventional product(s).

Out of BioBoost the supply chain Brussels sprouts stalks to paper will further be studied, in collaboration with the industry. As such, the different aspects will be taken into account.

1. INTRODUCTION

1.1. Circular economy

The circular economy aims at closing cycles and eradicate waste. In this report we further focus on the biological cycles, where biologically-based materials flow back into the system through different existing or potential processes. The aim is to provide renewable resources for the economy. This is in contrast with linear systems, where non-renewable resources are used for the production of materials, to be thrown away as a waste at the end-of-life (2). In this circular system, agriculture becomes a link between different cycles in different sectors. By-products are produced and can be delivered to other sectors. The cascade, or pyramid, stimulates the valorisation of the by-products towards high value products, in an efficient manner. The demand for resources and materials continuously increases and often implies import of different resources. Recycling and the use of waste as resources is an opportunity for making a region less dependent from others.

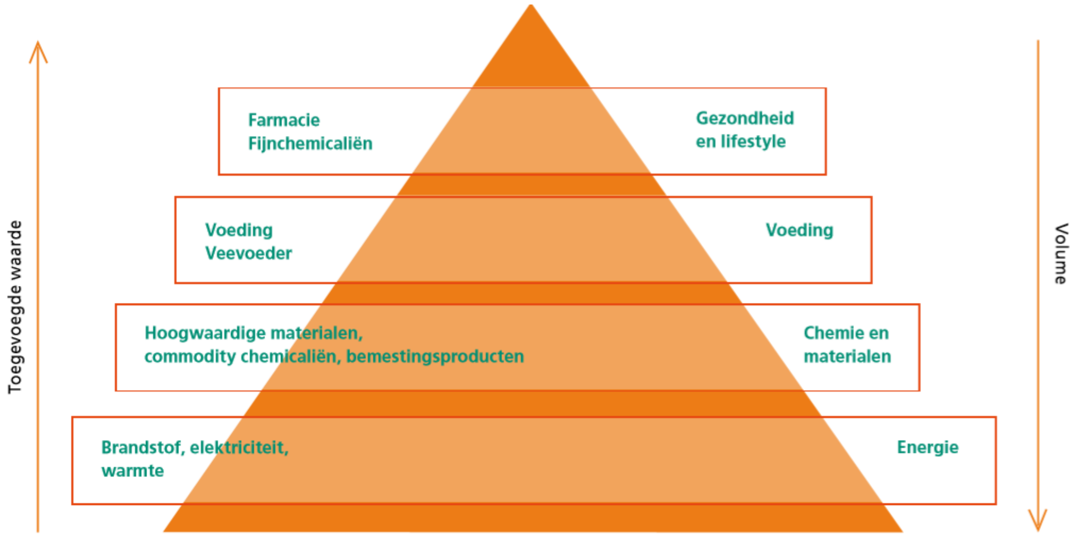

Figure 1 *Value pyramid based on functionality.*

For Flanders, biomass need to be used towards applications with highest value, based on economical, ecological and social aspects. This means 1) food, 2) feed, 3) chemicals and materials, 4) energy (3).

1.2. Horticulture in Belgium, the Netherlands and United Kingdom

Belgium, the Netherlands and United Kingdom are horticultural rich countries. As mentioned in the inventory report, following horticultural areas participate in the BioBoost project:

- Lea Valley (UK)
- Roeselare region (BE)
- Westland are (NL)

The selected crops represent the major part of the production volume of outdoor and greenhouse vegetables for the three horticultural areas .

1.3. Residues in horticulture

Some terminology

The agrifood chain	A series of consecutive actors producing, transporting, processing, distributing and selling food products (**Figure 2**) (4) .The consumer is found at the end of the chain. Flanders is actively making efforts towards the prevention of food losses. Prevention is one of the first steps but if prevention is not possible, valorisation is looked at, based on the value cascade (5). However, as mentioned in Figure 2, food losses and by-products are produced at different phases in this chain.
Food	End-product of the agrifood chain.
By-products	These are incidental or secondary products made in the agrifood chain. Edible and inedible by-products are not the primary goal of the production process but do have a valorization potential. These are not consumed or not yet industrially utilized and are produced along the fruit and vegetable supply chain.

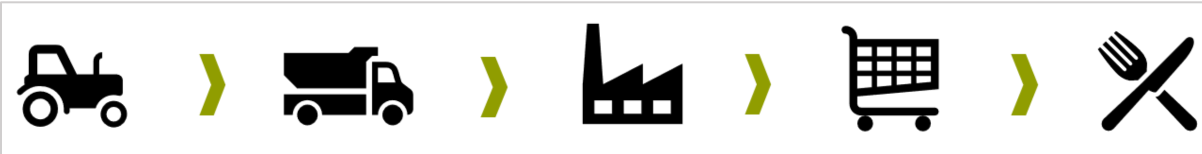

Figure 2 *Agrifood chain or logistic chain in the agrifood sector*

For Belgium, the primary sector accounts for 425 000 to 700 000 tons of food losses, the industry for 1 073 000 ton, the distribution sector for 116 000 ton and an additional 166 – 235 000 ton is wasted during consumption (6). Because food losses and the production of by-products happens at each actor in the chain, this problem could be tackled by collaborating.

Harvesting by-products

By cultivating agricultural and horticultural crops, residues are left on the field after harvesting or during limited processing such as separation of edible and inedible parts, sorting, washing, drying, storing and packing (7) (**Figure 3)**. These plant residues are defined as by-products. These by-products are an important source of nitrogen mineralisation and thus have potential to provide available nitrogen to the crops. However, part of the mineralisation occurs in the winter period, out of the growing period for many crops, but the amount of N in the by-products vary (8). The available nitrogen then leaches out into the surface and groundwaters (9). An efficient utilization of horticultural by-products is needed from different perspectives.

In this report, focus is laid on cultivation and harvesting by-products. These consist of edible and non-edible biomass parts. Attention is also paid to the by-products occurring during preparation for industrial processors. To ease valorisation of these by-products towards different potential sectors, the challenge is a proper harvest of these by-products and a better fit to existing logistic chains. For non-existing chains, attention should be paid to different actors and socio-economical aspects and assure the holistic greening of value chains. The actual challenge of segmented management of wastes should be tackled as such that waste minimization can be achieved from al actors perspective.

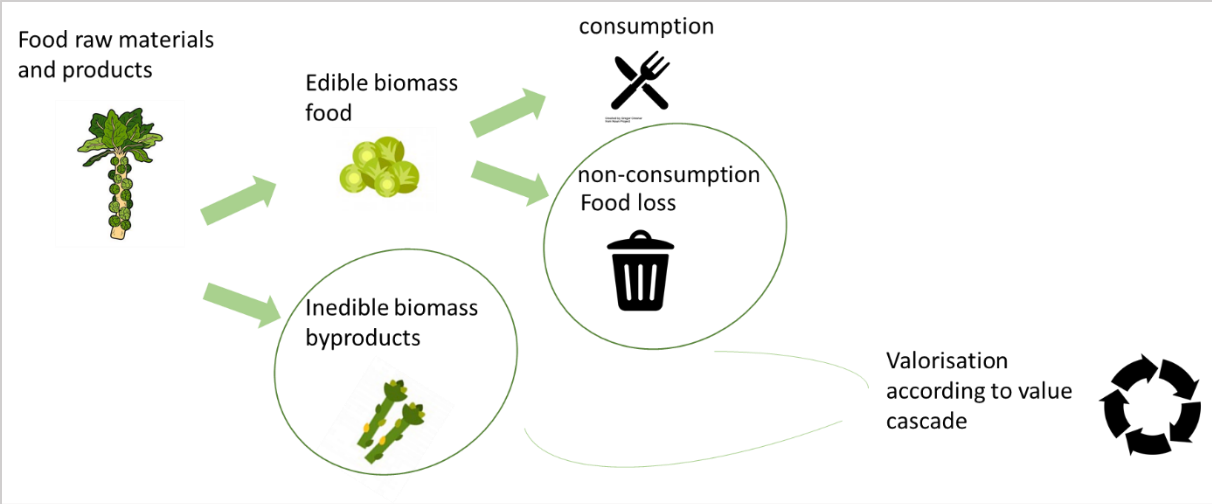

***Figure 3** Schematic overview of the production of food, by-products and waste, with Brussels Sprouts as example*

2. BY-PRODUCTS IN HORTICULTURE

For the 6 different crops, this section is divided in (i) introduction, (ii) cultivation, (iii) side streams and (iv) innovations, with special attention to harvesting techniques if relevant and to the logistic chain.

2.1. Brussels sprouts

Crop	Residue	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Brussels sprouts	Stalks and foliage												

Brussels sprouts are undeniably linked to Belgium. Apart from what the name suggests, these are now grown all over Flanders. The Netherlands and the United Kingdom also have a large share in the production of Brussels sprouts in Europe. The total area cultivated differs year after year but the average production in 2018 for Belgium (mainly Flanders and Brussels) (2400 ha), the Netherlands (2750 ha) and the United Kingdom (2800 ha) together accounts for nearly 90% of the European production (**Figure 4**) (10). The main part is produced for the industry and only a small share is intended for the fresh market. For Belgium, an important part is cultivated by Belgian growers in northern France, bringing the total amount of ha cultivated by Belgian growers to 3100 ha (10). For each hectare, 25 to 28 tons of unsorted sprouts can be harvested [1].

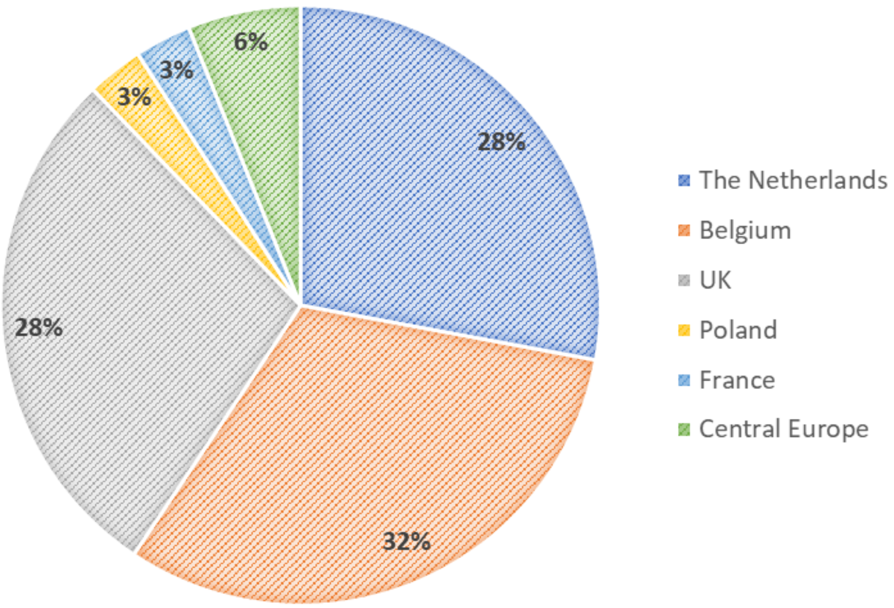

Figure 4 *Surface (ha) of Brussel sprouts production is the main producing countries in Europe*

[1] Taco-Vandewiele R. – personal mail 08-12-2017

2.1.1. Cultivation

Brussels sprout (**Figure 5**) are sown from half March (under glass) to the beginning of April. Delayed sowing can decrease the yield substantially. After 8 to 10 weeks, 33 000 to 40 000 young plants/ha can be transplanted in the open field, where more space is available to develop the typical large leaves (7). The sprouts develop in the armpit of the leaves. The whole plant can grow up to 1 m high. Depending on the variety, the top of the plant is cut out to allow better growth of the sprouts and obtain a higher yield. Harvest for the fresh market only represents a small share and starts mid-September and continues until early March. Harvest for industrial processing runs from the beginning of November.

Figure 5 Brussels sprouts

Due to high quality requirements, highly specialized harvesting machines (**Figure 6**) are needed. Therefore, farmers often buy this harvester together or rent a harvester that is owned by contractors. The two most famous producers of harvesters are Tumoba[2] from Barendrecht (the Netherlands) and Deman[3] from Passendale (Belgium).

Figure 6 Harvest of Brussels sprouts by a harvester from Tumoba, usually for bigger cultivators

For bigger cultivators, Tumboa SP2(3&4) was developed allowing higher yields with less labour. Stalks are cut by the machine and are manually put in the 'picking heads', separating leaves, stalks and sprouts. Stalks and leaves are left on the field, while the sprouts are collected.

2.1.2. Side streams

When harvesting the sprouts, stalks and foliage remain as a byproduct on the field. Harvesting residues are thus mainly produced from October to March (11). A variety test on Inagro resulted in 12 to 21 ton/ha stalks for Belindus and Sofia respectively Leaves varied between 17 to 31 ton/ha for HZ 16-675 and Sofie respectively. These are only representative data based on one variety test, performed in the winter of 2018-2019 in Moorslede, Flanders (Belgium) (Table 1). On average, residues represent 50-70 ton/ha (sprouts + stalks + foliage) (11). The masses of crop residue in sprout cultivation represent 150% to 250% compared to the marketed amount of sprouts[4].

For Flanders, the Netherlands and the United Kingdom, a total average of 230 000 tons of stalks and 190 000 tons of leaves is available. This high amount of available material makes this stream interesting for valorisation. Belgium accounts for 150 000 ton by-products (11). Because of the difference in composition of leaves and stalks, it is often not possible to valorise these together. Since the leaves and stalks are already separated thanks to the harvesting method (**Figure 7**), it is possible to look at the two flows separately. In a latter stage, bad sprouts are also selected and thrown away.

[2] https://tumoba.nl/spruitenplukker/
[3] https://www.nvdeman.be/
[4] Inagro, Variety Tests on Brussels Sprouts

Table 1 Average ton/ha of stems and leaves for different varieties of Brussels Sprouts (2019)

Variety	Stems ton/ha	Average	Leaves ton/ha	Average
Albarus	15,8		24,1	
Albarus	14,7	13,8	23,6	23,6
Albarus	10,7		23,1	
Belindus	14,1		33,5	
Belindus	10,4	12,0	30,2	32,3
Belindus	11,4		33,4	
Cryptus	15,8		27,8	
Cryptus	13,1	14,5	22,4	24,2
Cryptus	14,7		22,5	
Helios industrie	17,6		20,4	
Helios industrie	16,1	17,0	19,9	21,3
Helios industrie	17,4		23,6	
Hemera vers	17,0		18,6	
Hemera vers	15,8	15,5	17,0	17,9
Hemera vers	13,7		18,3	
Hey Melis (SGB1594)	14,7		36,0	
Hey Melis (SGB1594)	16,2	15,1	31,8	32,7
Hey Melis (SGB1594)	14,4		30,2	
HZ 16-675	16,9		15,9	
HZ 16-675	15,4	16,7	17,8	17,1
HZ 16-675	17,7		17,8	
HZ 16-702	19,7		39,4	
HZ 16-702	19,6	19,2	30,4	32,9
HZ 16-702	18,4		28,9	
Platinus (SGB1622)	14,5		26,8	
Platinus (SGB1622)	13,8	14,3	21,6	24,7
Platinus (SGB1622)	14,5		25,7	
Profitus	19,1		33,8	
Profitus	18,6	19,4	24,8	29,9
Profitus	20,5		31,1	
Sofia	22,2		40,6	
Sofia	18,0	20,7	28,2	35,6
Sofia	21,7		38,0	
Thamus (SGB1587)	17,3		33,6	
Thamus (SGB1587)	16,9	16,0	30,4	31,0
Thamus (SGB1587)	13,8		29,0	
Thor vers	15,7		20,3	
Thor vers	15,0	15,0	18,4	19,3
Thor vers	14,3		19,3	

Figure 7 Harvesting machine for smaller cultivators separating stems, leaves and sprouts

2.1.3. Innovations

The valorisation of Brussels sprout by-products was already successful in several small-scale projects.

Valorising the **leaves** is not easy, as a large part of the leaves has already wilted and fallen off, when sprouts are harvested (**Figure** 8). Because the remaining leaves contain only a small portion of dry matter content and rapidly degrade, storing them is rather difficult and involves some problems, such as silo juices, often seen at beet leaves ensilage in the past. Furthermore, adapting the harvesting machines for valorising the leaves is not easy due of safety reasons. Therefore, rather limited research has been carried out on the valorisation of the leaves. Nevertheless, leaves contain a great nutritional value, which might be interesting for use as animal feed (**Table 2**). Tests to process the leaves in slurry feed for pigs have proven that the setup of the installation is not optimal. Further research to optimize the installations is still needed.

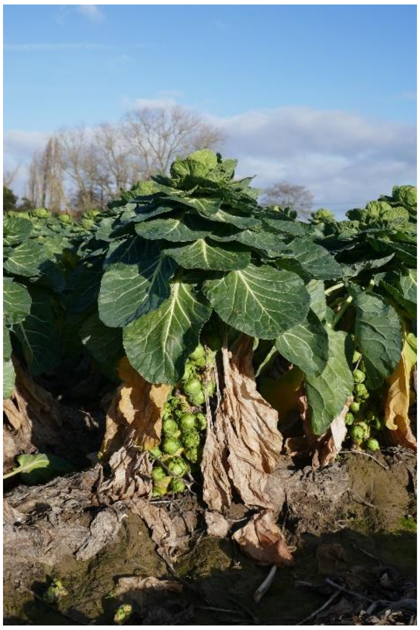

Figure 8 Wilted and fallen leaves

Similarly, **bad sprouts** are not easy to valorise as already often the rotting process has started by the harvesting moment. Tumoba developed a sorting system with integrated optical systems, which can be added to the harvester. This allows to remove the bad sprouts from the obtained harvest. The rotted sprouts are then left on the field.

Much more research has already been done on the valorisation of the **stems**. These contain more dry matter compared to the leaves and are easier to process and store. At least two active farmers have converted their harvester to ease the harvest of sprouts and stems in one step (*Figure 9*). These farmers use the stems to feed their cattle. One farmer mentioned that he stores the harvested stems loose without much extra effort[5]. Due to lower temperatures during the winter months he can continue feeding up to 1 are, 1,5 months after the harvest period. The harvester cuts the stems into pieces of ± 7cm, which, according to the farmer, was not problematic. This farmer also indicates that he can harvest more stems than he can use to feed his cattle, but that he does not find buyers for 35 €/ton. He once tried to build an ensilage pit, but in the end there was nothing left, except a pile of rotten garbage. His vet also indicated that he has little trouble with scabies at his farm. This is only an experience, not a scientifically substantiated statement.

Figure 9 Adapted harvester in which sprouts are collected directly in the bag, while the stems are collected separately

[5]Olivier J - Personal information 29-11-2017

Table 2 Feed value of Brussels sprouts, compared to Corn (12)

Parameter	Brussel sprout	Corn	Unit
VEM	1007	1190	/kg DM
FOS	645	425	/kg DM
DVE	93	169	/kg DM
OEB	18	49	/kg DM
SW	1,82	0,31	/kg DM
VW	0,9	0,26	/kg DM
VCOS	84	83	%

With:

VEM = Feed unit milk, with one VEM equivalent to 1g of barley (6.9 kJ)
FOS = Fermentable organic matter in the DVE/OEB system 1991
DVE = true protein digested in the small intestine
OEB = degraded protein balance
SW = structure value
VW = saturation value
VCOS = Digestion coefficient of the organic matter

In addition to processing the stems in cattle feed, high quality products have been made from this side stream in various small-scale projects.

Since the stems of Brussels sprout also have a high fibre content (Figure 10) it is possible to use this as raw material in, for example, **paper production** (Figure 11). The easiest way to do this, is to add the rough shredded fibres as a decorative accent in the paper. However, a maximum of 5 to 10% of raw natural fibres can be added to guarantee the strength of the paper. If the natural material is processed into pulp of cellulose fibres, these percentages can be increased but this means an extra processing step.

Figure 10 Fibrous structure of the Brussel sprouts stems

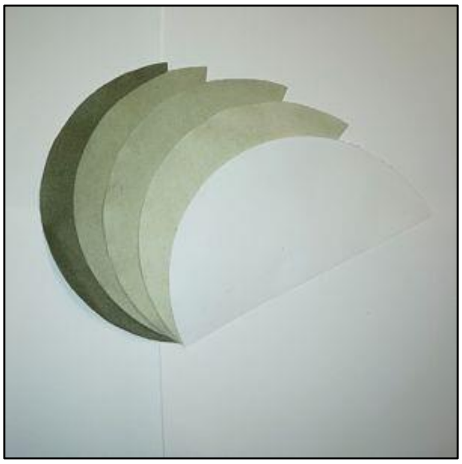

Figure 11 Paper from Brussels sprout stems (Millvision)

2.2. Belgian endive

Crop	Residue	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Belgian endive	Forced roots												

The cultivation of Belgian endive originated in Flanders around the mid 19th century and was centralized in the region Leuven-Mechelen-Brussels (13). An extract of the general agricultural census of 31 December 1929 (Figure 12) shows that in the beginning of the 20th century the heart of this cultivation has expanded but still located in central Belgium. Today, the region is spread over northern France, Belgium and the Netherlands.

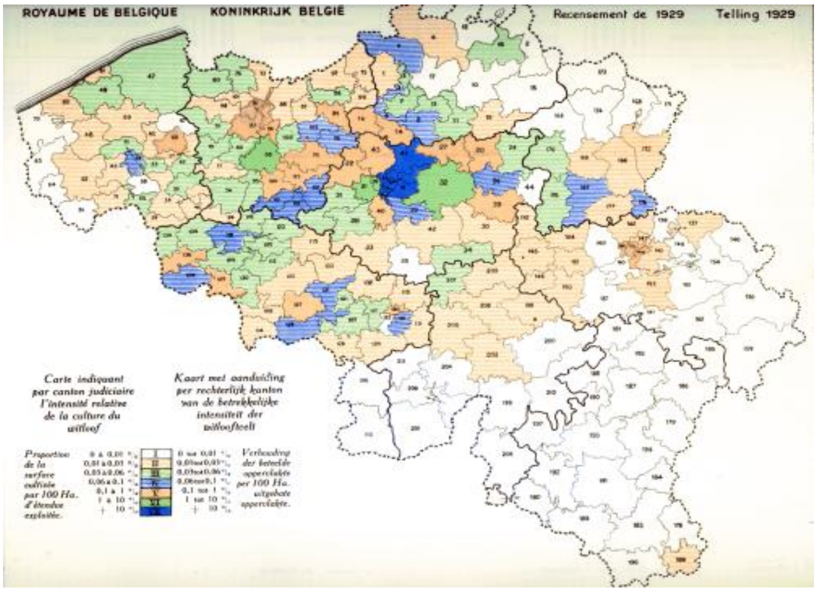

Figure 12 Extract of the general agricultural census (31 December 1929)

Figure 13 shows that the surfaces of Belgian endive cultivation has drastically decreased since the beginning of the 21st century[6,7,8]. Despite the strong drop of surfaces and number of growers (Figure 14) productivity has increased considerably and Belgian endive remains an important crop for Belgium (± 1685 ha in 2019)[9] and the Netherlands (± 1850 ha in 2018). Both countries are partner of the BioBoost project. For the UK, we have knowledge of only one farmer aiming at Belgian endive cultivation[10]. France is globally the biggest producer, with 7350 ha in 2018.The production accounted for 40 700 ton in Belgium in 2017, equivalent to €43 M.

[6] http://www.vilt.be/Internationale_Witloofbiennale_Lof_voor_Belgisch_witloof
[7] http://www.vilt.be/witloofareaal-is-op-zijn-retour
[8] https://www.vlam.be/public/uploads/files/feiten_en_cijfers/groenten_en_fruit/groenteareaal_2008-2017_n.pdf
[9] https://lv.vlaanderen.be/nl/nieuws/voorlopige-arealen-landbouwteelten-uit-de-verzamelaanvraag-2019
[10] https://dgmgrowers.co.uk/growing/

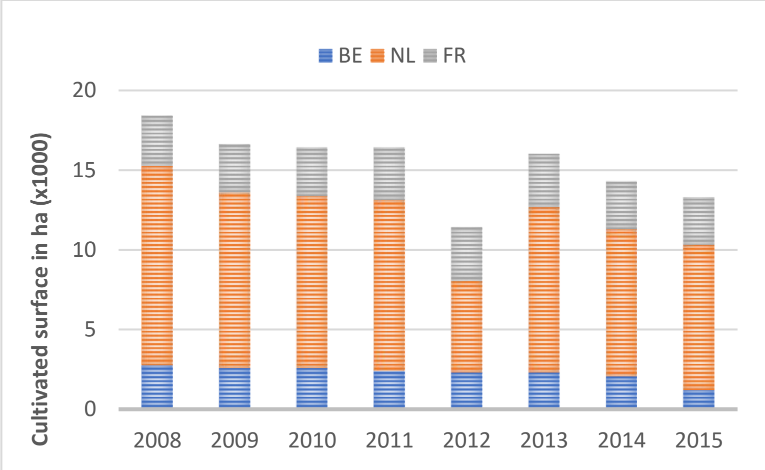

Figure 13 Surfaces of Belgian endive production Belgium, France and The Netherlands 2008 to 2015 (VLAM, 2018; (14))[11]

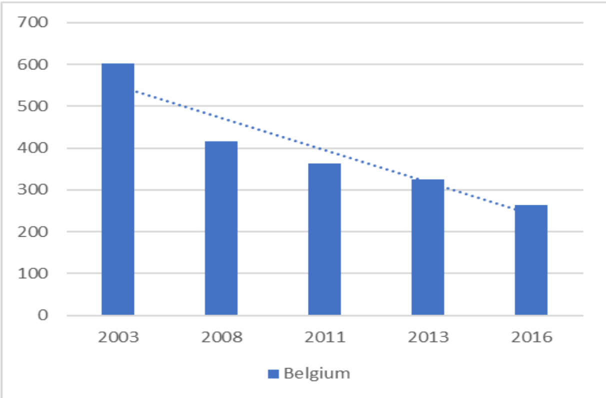

Figure 14 Number of Belgian endive growers in Belgium from 2003 to 2016

2.2.1. Cultivation

Belgian endive is a two-year crop. In the first cultivation year, the seeds are sown in the field around mid-May. This can be done both in full field as by ridge planting method, as shown in **Figure 15** and **Figure 16**. Two rows are sown when ridges are used. As a result, more uniform roots between 3 to 5 cm are obtained with an ideal weight of ± 150 g/root.

Figure 15 Full field cultivation

Figure 16 Ridge cultivation

[11] Available on https://www.vlam.be/public/uploads/files/feiten_en_cijfers/groenten_en_fruit/Groenteareaal_2009-2018_n.pdf

The roots are harvested mechanically from September to November. An average production of ± 200 000 roots/ha, corresponding to ± 30 tons/ha of roots, is used for the second step in the process: the forcing step.

After root harvesting, roots with ideal width (3 - 5 cm) are sorted out and stored in cold rooms. This is a necessary process for the required vernalization of Belgian endive. By storing them in cold rooms, Belgian endive can be forced throughout the whole year by planting them at different moments, presenting a solution to the huge amount of residues obtained over a short period.

There are two ways to force Belgian endive: (1) the labour-intensive soil-based cultivation (**Figure 17**) and (2) hydroponics (**Figure** 8). Today, only an average 10% of the total quantity is forced through soil cultivation. The vast majority is cultivated via hydroponics. **Table 3**3 gives an overview of the production of different Belgian endive cultivation methods in 2014, 2016 and 2018: hydroponics; soil-based; bio and red.

Table 3 *Production overview Belgium (Biennale, 2018)*[12]

	2014		2016		2018*	
	Tonnes	Surface/Ha.	Tonnes	Surface/Ha.	Tonnes	Surface/Ha.
Hydro	32.026	1.626	32.202	1.615	-10,9%	-7,9%
Pleine Terre	1.542	165	1.948	193	-6,6%	-14,7%
Bio	30	15	258	30	+16,7%	-6,7%
Rouge	26	4	32	4	+28,2%	+50%
Total	39.300	2.070	39.300	2.070	-10,5%	-8,5%

2018 : Estimated figures in %*

Figure 17 *Soil-based cultivation method*

Figure 18 *Hydroponics culitvation method*

2.2.2. Side streams

The specific white Belgian endive heads in the store are the result of a two-year crop. During the entire cultivation process, secondary streams are released at different times. First, **green leaves** are released during root harvest (Figure 19). Second**, too large or too small roots** are sorted out. Indeed, the aim is to obtain Belgian endive heads as uniform as possible after the forcing step. Only roots with an ideal size between 3 and 5 cm are used for the next step. After sorting the roots and the necessary vernalization- and/or storage period, the roots are planted again, in full soil or growing beds (hydroponics).

[12] https://biennale2018.eu/

Figure 19 Belgian endive root harvest

Third, to obtain the typical white colour of Belgian endive, forcing must be done in the absence of light. After a residence time of 21 days in dark conditions, the heads are fully grown and ready for harvesting. These heads are separated from the **root after forcing (25 ton/ha) (Figure 20)** are now separated from the **root**. Each root can be used only once to force Belgian endive as the growth point is removed from the root together with the head. For Belgium and the Netherlands, approximately 150 500 tons of roots are released as a third and largest side stream in this cultivation.

Figure 20 Roots left over after forcing

Fourth, the **imperfect crop heads** are sorted out and the **outer leaves** are released during the cleaning of the Belgian endive. In previous surveys this tonnage has been estimated at 5 ton/ha (11). As for Belgium and the Netherlands together this makes a total of 25 100 tons of material.

2.2.3. Innovations

Currently, most of the by-products from Belgian endive cultivation are processed as animal feed. This usually occurs through small-scale collaborations between growers and neighbouring livestock farmers. Different small-scale projects are working on upgrading the value of certain side streams: a biogas plant running on the residual streams from chicory cultivation for 90% (Chicory company Joluwa in Nijvel (BE); Belgian endive croquettes made from the outer leaves of the heads that are released during the cleaning; and last but not least beer[13,14].

[13] België heeft nu ook zijn witloofbier – persbericht HLN (08/03/2011)
[14] Grondwitloof om tot het laatste blaadje te eten – persbericht VILT (08/10/2018)

Previous research has shown that Belgian endive roots contain different bioactive compounds. The most promising ones are the bitter compounds, phenolic compounds and minerals. In addition to BioBoost, several projects are ongoing (e.g. CichOpt) for the further investigation on these properties, with the aim to upgrade the available residual biomass.

Within BioBoost, several tests were performed to evaluate the potential valorisation of the residual biomass as feeding for insects **(Figure 21)**. The biomass is thoroughly pulverized and mixed with water to obtain a slurry. Elaborated results are found in report on WP4 "test & pilot projects – insect breeding".

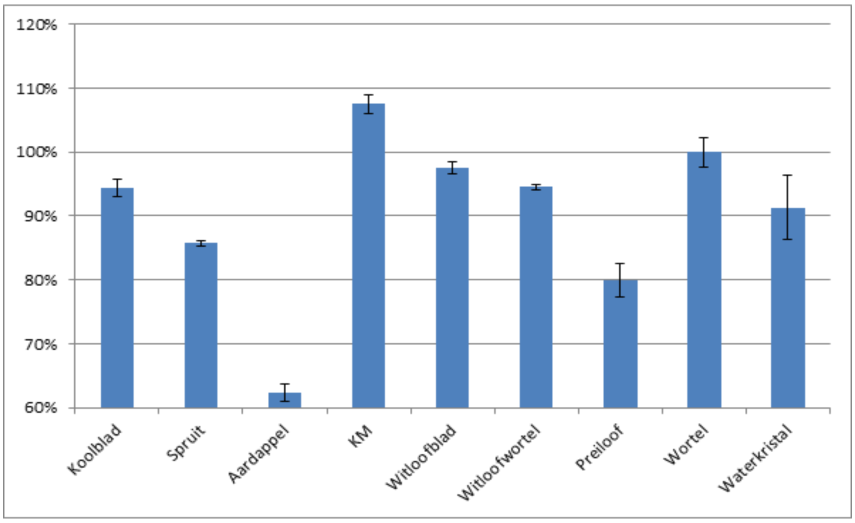

Figure 21 *Effectiveness of different (by)products as insect feed*

The majority of the streams is released separately on the grower's company. This eases the valorisation of the side streams and explains why so many of these side streams have already been valorised.

The most difficult side stream to valorise is probably the first one: the green leaves. The leaves are cut off sufficiently high not to damage the growth point of the plant. It is advisable to leave at least 3cm crop crown (**Figure 22**). Today, these leaves will remain on the field. Defoliation of the Belgian endive roots is similar to the defoliation of beet leaves. For the adaptations to the harvesting machines, it is certainly possible to revert to existing technologies, like the one used for catching beet leaves (**Figure 23**).

Because the harvest occurs from September to November, the chance on wet conditions is high. Not only the periodic availability of this side stream, but also the possibility that it can only be partly, or even completely not available in some growing years, must be taken into account in any case study. This is probably the reason why this stream was never given the highest priority. Further research is needed on the type of masses that are released and how they can be processed or stored.

Figure 22 *3cm crop crown*

Figure 23 *Existing technologies for beet leaves*

2.3. Tomato

Crop	Residue	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tomatoes	Foliage												

Belgium (536 ha)[15], the Netherlands (1790 ha) and England (200 ha) are certainly not among the superpowers when it comes to tomato (*Solanum lycopersicum*) cultivation under glass in Europe. This title goes to Spain (18 950 ha) and Italy (7080 ha). In 2017, the cultivation of tomatoes grown under glass covered a total area of 72 790 hectares in Europe[16].

Figure 24 shows that the cultivation of tomatoes among the partners within the BioBoost project is a very intensive cultivation. The Netherlands, United Kingdom and Belgium are situated in the top 10 producing countries based on yield per hectare.

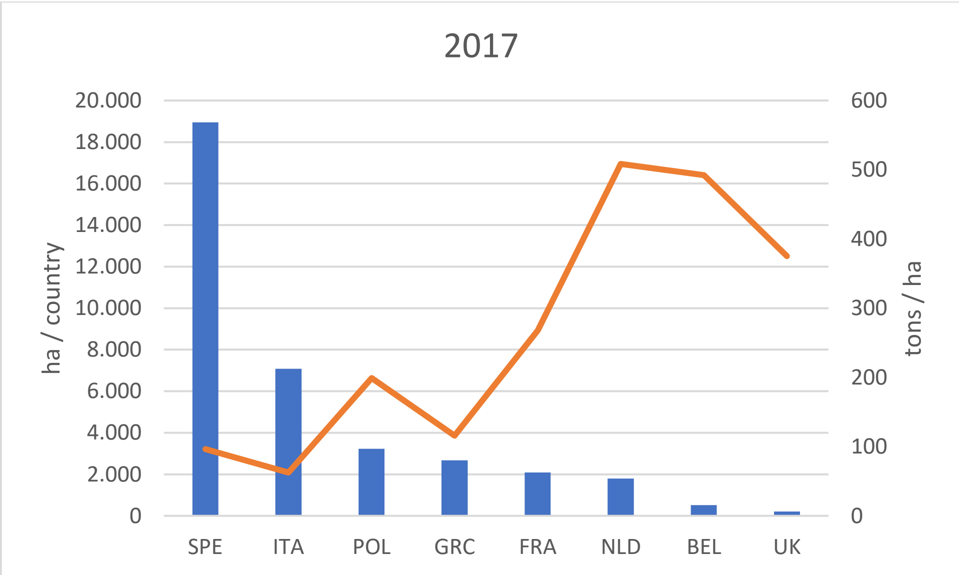

Figure 24 *Area and yield of tomatoes under glass in Europe [28]*

2.3.1. Cultivation

Two methods exist for growing tomatoes under glass: cultivation under warm/cold glass or cultivation in soil or substrate.

Table 4 shows how the distribution of these methods evolved from 2000 to 2014 (15). Due to the rise of energy prices since the early 2000, the intensity and productivity of tomato growing under glass has continued to increase. Soil cultivation is practically no longer applied due to accumulations of pathogens in soils (**Figure 5** (16)) is practically no longer applied. When growing tomatoes on substrate (**Figure 6** (8)), the grafted planting material is planted in to artificial soils above the ground. A drip irrigation system is then installed, which makes it possible to continuously adjust the nutrition and protection of the plants.

[15] http://www.vbt.eu/documents/pdfs-jaarverslagen/vbt-jv-2018.pdf
[16] http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do

Table 4 Tomato cultivation in Belgium [7](15)

Tomato cultivation Belgium (ha)	Surface in ha per year		
	2000	2005	2014
substrate cultivation	364	439	447,5
soil cultivation	150	83	16,5

Figure 25 Soil cultivation (8)

Figure 26 Substrate cultivation (8)

For
greenhouse cultivation, usually indeterminate plant types[17] are selected. These can be grown a year round. During the growing period, stem lengths can reach up to more than 8m (16). Stems of the tomato plant are insufficiently strong to be self-supporting. Therefore, the plants are tied to wires, by binding or by clipping (**Figure 27**). These wires and clips are traditionally made of non-sustainable materials as nylon and polypropylene.

Figure 27 Rope and clips

[17] Inderterminate tomatoes will grow unitll killed by frost and reach heights up to 8 m

2.3.2. Side streams

Three different residual flows are released during the entire cultivation of tomatoes. **Pruning waste** is released throughout the entire growing period, as a result of maintenance activities on the plants and is estimated at ± 5 ton / ha (17).

The **rejected tomatoes** are not suitable for sale and represent the so-called class III fruits and any production surpluses. Due to the far-reaching system of the auctions, aiming to match supply and demand, these losses can be reduced to approximately 5% (17, 18). This also includes the extensive network for free distribution, ensuring that surpluses are valorised as much as possible for human consumption. In 2015, approximately 700 tons of tomatoes were distributed this way in Belgium.

The largest side stream in this cultivation arises at the end of the growing season when all the tomatoes have been picked and the plants no longer carry fruits. All greenhouses are then emptied. This is often performed by specialized firms. All plants are cut just above the roots and collected on mats in the aisles between the rows of cultivation. **Figure 8** shows how these mats provide automatic supply of all the plant residues into the shredder which is located in the central aisle. Depending on the type of tomatoes, 30 to 50 tons of **plant residues** are released per hectare[18,19(7)]. For Belgium, the Netherlands and the United Kingdom together, this means that ± 100 000 tons of fibre- rich material is released yearly and must be disposed of.

Figure 28 *Cleaning greenhouse[38]*

Because the clips and wires are there to support the tomato plants in the first place, they are grown interchangeable with the plant material. Today, these wires and clips often remain in the plant residues and the whole is shredded together. As a result, the residual material is contaminated with small pieces of plastic. Due to increasing regulations on waste processing, the price for the processing of this residual flow has risen sharply in recent years (**Figure 29**), leading to higher share in budgets of horticultural companies. Additionally, the plastic pollution hinders different potential applications. For example, possibilities for livestock farming are nearly nihil with the current presence of plastic. To tackle this challenge two options exist: 1) use more sustainable clips and wires degrading or composting in time; 2) develop a cost-effective separation method to optimize the separation of green and plastic materials.

[18] Personal information Galle F. – 07/12/2018
[19] https://www.agro-chemie.nl/artikelen/vierkantsverwaarding-voorwaarde-rendabele-business-case/

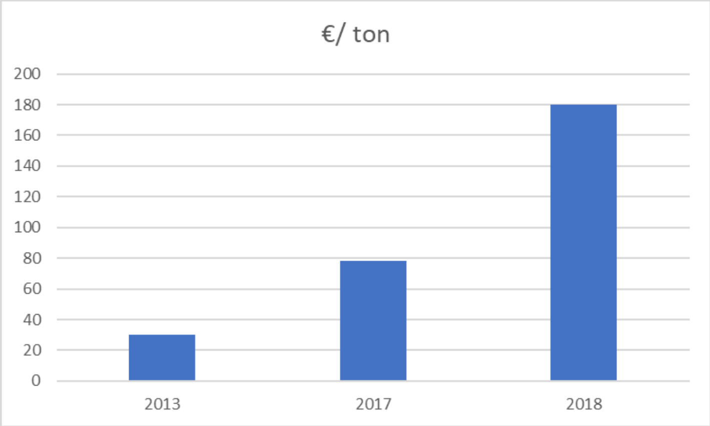

Figure 29 *Cleaning costs in Belgium [30;31;32]*

Experiments were set-up at Inagro vzw to compare compostable and biodegradable wires and clips to the conventional materials. This was done for tomato in 2017 and for cucumber in 2019. The experiment with alternative wires and clips for tomato was not successful. Metal clips were tested and these squeezed the wires until the wires broke down. Based on this experiment, Hortiware adapted the clipping machine as such that the clips are less squeezing the wires. This adapted machine was used in the experiment with cucumber (**Table 5**).

Table 5 Tested wires and clips in cucumber experiment (2019) at Inagro vzw

	Description	Results
CLIPS	BIO CLIPS 22 mm BATO	
	BIO CLIPS 23 mm Paskal	
	CLIPS optima 23 mm paskal	
	Metalen CLIPS Lankhorst	
WIRES	Benfried Bio touw	All wires stayed in good conditions during the whole growing season (July – October).
	Lankhorst bio touw	
	Lankhorst polypropylene	
	Paskal bio touw	

2.3.3. Innovations

Given the small amount of pruning waste and the spread of availability, little attention is paid to this residual stream.

The amount of rejected fruit is already strongly reduced by matching supply and demand as closely as possible. Previous studies have already shown that tomatoes can be processed both as concentrates for cattle and as slurry feed for pigs. Feeding cattle is possible with a feed mixer on conditions that the mixed feed does not get too wet. For the processing of the tomatoes in slurry feed for pigs, the tomatoes must first be ground into a pumpable mass, which is certainly possible given the small amount of dry matter. Adding fruits and vegetables in the diet definitely has a positive effect as these are a good source of antioxidants. It is recommended to feed a maximum of 2.4 - 3 kg DM / day for cattle and only 0.6 kg DM / day for pigs in the ration for pigs (17).

The limited shelf life of this stream has a major impact on the valorisation of this stream. It is therefore recommended to apply a conservation step when using this flow.

The third and last side stream from the tomato crop is understood as the foliage that is released at the end of the growing season at the cultivation change. Because the deposition / dumping of this material is a pure cost that has increased dramatically in recent years, many studies have already been carried out into the upgrading of this side stream. Some examples are processing as bedding material for cattle (17, 19), the production of compost and bio-char (20), fermentation in biogas plants, the extraction of active substances (e.g., tomatine) for use as biocides (21, 22) and perhaps the most widely investigated track of them all, the use of this fibre- rich material for the production of paper.

The paper sector is intensively searching for new and sustainable sources of fibre-rich material streams for the production of paper (23). In the past, various studies have already been conducted and pilot productions have been produced with tomato leaves as raw material. These tests show that pure tomato leaves certainly show potential, but different challenges are faced[20]:

- The whole flow is released all at once at the end of the growing season
- The nylon and polypropylene wires and clips pollute the plant residues
- The fibers must be released from the stems. Paper fibers are approximately 1.5-2.5 mm long and 20-50 µm wide. If the fibers are larger, they are clearly visible in the paper and that is not desirable. A process to remove the tomato fibers from the matrix (the stem) does not exist.

[20] Mail from paper producer (23/11/2017)

We have investigated a grinding process and an extrusion process. Both did not lead to the desired result. A chemical process is not desirable because of the residual flow, which is difficult to process.

- The tomato stems fibres are less strong than a tree fibre (recycled pare consists – ultimately – also of tree fibres), which weakens the paper if tomato fibres are used.

However, these reasons are all surmountable, but this leads to high litigation costs. These costs do not outweigh the current process and therefore the motivation to continue this research is lost. **Silage / fermentation** of the leaf appears to be a possibility if carried out carefully. Through various ongoing silage tests, including one on Inagro in the context of BioBoost, answers on the many questions are sought. One of these is the influence of the fermentation process at the opening and availability of the fibres in the stems.

Apart from all the possibilities to store the material for a long time, the main issue is the plastic pollution of the foliage by ropes, clips and brackets (**Figure 30**). Different tomato cultivators explained us that the costs for foliage disposal increased tremendously in a few years, from approximately 55€/ton in 2016 to 180€/ton in 2018, mainly due to plastic pollution[21]. In the Netherlands, a price distinction is made for polluted by-products compared to non-polluted by-products.

Figure 30 Plastic pollution of tomato foliage by ropes, clips and brackets

Today, there are already different clips and brackets from bioplastics and ropes from material of biological origin such as jute, Sisal, hemp, cotton cellulose, ... or a mix of previous ones. However, this does not mean that they are biodegradable, by definition.

Metal clips are also being used because they can be fairly easy removed from the shredded material with a large magnet. The application of a metal clip by means of an automatic clipper is also one of the fastest and easiest working methods[22]. However, practical opinions are divided as different growers indicate that the ropes dare to break halfway through the season, which causes the necessary problems and extra workload[23] It Is therefore important to choose the right rope for the right cultivation.

As an alternative, PLA material appears to have potential. This material has the great advantage that it breaks down completely within the legally required period when composted or fermented together

[21] Personal information, e.g mail from Tomato Masters (tomato cultivator Belgium, Kruishoutem)
[22] Hortiware - Haas D.J. – Personal mail 04-01-2018
[23] Galle F. – Personal mail 07-12-2018

with the plant material. Exploratory fermentation tests show that PLA material has a high methane production potential of ± 340m^3/ton. This means that it will certainly not affect the processing through fermentation negatively. Additional research is certainly needed to determine whether a long-term stable mono-fermentation is possible. Because the increasing prices for energy and waste processing, and since many growers use cogeneration to heat their greenhouses, this track has to be investigated further.

In the future, the choice of rope and the processing method of the tomato foliage should be determined at the beginning of the season. For processing the foliage into a fibre-rich stream, ropes of biological origin can be used if the fibres from which the ropes were made of can also serve as a raw material for the next step. By combining this type of rope with metal clips that can easily be removed from the foliage, it is possible to turn this side stream into a pure raw material in a simple way. However, if it is processed via composting or digestion, rope and clips of PLA- material are better suited.

Both possibilities need to be further developed, researched and intensively tested to provide conclusive answers to the current questions.

Finally, by-products are sometimes considered as a potential **litter for livestock**. However, again, clips and wires form a real difficulty and risk for the milk production. WUR (2014) (17) mentions that the rest streams from the production of 200 ha of bell pepper and tomato plants creates litter for 3000 animals after composting (for cubicle). Inagro was already contacted by a bell pepper cultivator for advise concerning possibilities of the bell pepper rest streams as litter for his livestock.

2.4. Cauliflower

Crop	Residue	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cauliflower	Foliage												

Cauliflower (*Brassica oleracea* var. *botrytis*) that is grown for industrial purposes has an area of 3305 hectares in Flanders in 2019[24], which makes it one of the biggest areas for outdoor vegetables. The massive area gives rise to a production of 84.500 tons per year. An additional 30 to 50 ton/ha of by-products is produced (11).

2.4.1. Cultivation

Cauliflower seeds get sown indoor to subsequently get transplanted in the field in the first weeks of march, where they further grow into a white cauliflower. The major share of cauliflower cultivation is intended for industrial use and is therefore deep frozen. Because cauliflowers are not ripe simultaneously, these need to be harvested by hand in multiple runs. During harvesting, leaves are manually removed with a blade and left on the field. Finally, crops are transported to the truck, by means of a transporter (**Figure 31**).

Figure 317 *Cauliflower harvest*

2.4.2. Waste streams

Leaves are a byproduct of cauliflower cultivation and account for 39-50 tons/ha[25] foliage per year, a contribution of about 50%of the total production of cauliflower. The collection of the leaves could be done manually. However, with simple alterations to the harvesting machine (transporter), leaves could be directly gathered in bins. The leaves are usually not consumed, although these are full of vitamins, minerals (e.g. C, Fe and pa), flavonoid compounds and could be cooked like any other green leafy vegetable (24). Additionally, the protein content of the leaves is equivalent to that of pulses such a soya beans (24).

2.4.3. Innovations

The use of cauliflower leaves is nowadays limited but has a future thanks to its rich source of dietary fibre, crude protein, micronutrients and natural antioxidants.

New harvesters are being developed. A smart harvester developed by researchers at the Fraunhofer Institute for Factory Operation and Automation[26] harvests cauliflowers faster than human but still very precisely, making use of hyperspectral camera detecting ripeness.

[24] https://lv.vlaanderen.be/nl/nieuws/voorlopige-arealen-landbouwteelten-uit-de-verzamelaanvraag-2019
[25] Ingelbeen, J., Sys,, M., Van Droogenbroeck, B. - SUSKOOL project – BioBoost seminarie - 21-06-2018 – Optimale valorisatie van bloemkool geteeld voor de diepvriesverwerking - Presentatie
[26] https://www.fraunhofer.de/en/press/research-news/2016/May/automatically-harvesting-cauliflower.html

2.5. Peas

Crop	Residue	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Peas	Foliage												

Peas are a beloved legume in Belgium and therefore largely produced. However, large production often equals to large side or waste stream. The pea production in Flanders represents about 2307 ha (2019)[27], with a total yearly production of 14840 tons. The produced waste stream contains leaves, stems and pods and accounts for an additional 70 000 tons a year (11).

2.5.1. Cultivation

Peas (Figure 32) are sown at the end of March to end of April with a precision sowing machine. Pea cultivation needs little fertilization, due to its ability to fix nitrogen from the air. Most of the peas are produced for industrial use. Time between sowing and harvest is 75 to 90 days, depending on the variety and weather, rom July till October. Peas show little susceptibility to diseases and parasites. The main enemies of pea plants are birds, which eat the pods. Peas are harvested with combine harvester. Leaves, stems and pods are left behind on the field.

Figure 32 *Pea plants in the field*

2.5.2. Waste streams

The combined harvester shakes the peas out of their pods, where after pods, stems and leaves are separated by a strong airflow and rotating sieves or nets. The waste streams of peas are generally left behind on the field and often collected to use as feed for cattle, due to the big amount of foliage. There has been little analysis on the foliage of peas for high end valorisation pertaining to bioactive compounds.

Figure 33 *Post-harvest foliage*

The waste stream of peas is very heterogenous and is therefore hard to use for other ends than feed (Figure 33). It should be researched how pea foliage can be applied after a pre-treatment such as silage or composting.

Possible adjustments to the harvesting machine to directly collect the foliage are an option. Yet, as the farmers already quite easily collect the waste from the field after harvest, this might not be the most efficient way to optimize the valorisation of pea waste material.

2.5.3. Innovations

There is little information available for the valorisation of pea foliage. Currently, rest streams of peas are often shredded during the harvesting process, making it very difficult for collection. Although, the

[27] https://lv.vlaanderen.be/nl/nieuws/voorlopige-arealen-landbouwteelten-uit-de-verzamelaanvraag-2019

most often used valorisation is feeding cattle. (25) characterized different by-products from the food and agro-industries for chemical and physicochemical properties. Pea hull characteristics varied widely between varieties and seasons and had following characteristics (Table 6). The variation in chemical composition makes pea hulls less interesting towards application. For pea foliage, tested as feed for insects, a DM (%FM) of 20.4 and a crude protein content (%DM) of 18.4 was measured.

Table 6 Chemical and physicochemical characteristics of pea hull (25)

	MEAN	SD
DM (g/kg)	896	11
Ash content	31	4
Crude protein	116	20
Sugar	15	5
Starch	8	31
Cellulose	452	40

2.6. Beans

Crop	Residue	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Beans	Foliage												

Cultivation of beans in Flanders has an area of 2340 hectares (2018)[28] which equals a production of 48.000 tons. This cultivation also produces 10 – 30 tons of by-products per hectare for a total of 70 000 tons per year, mainly including leaves and stems but also some leftover beans (0.5 ton/ha) (11). France is the biggest producer of beans.

2.6.1. Cultivation

Beans cultivation is similar to that of peas. Beans are sown later than peas, namely at the end of May. For most bean cultivars the cultivation period is about 70 days. Contrary to peas, beans are more susceptible to insects and need to be semi-regularly sprayed with insecticides. When the beans are full grown, they get harvested with a combine harvester that leaves de beans in their pods. The foliage gets separated and is left on the field.

2.6.2. Waste streams

Figure 34 Bean straw

Bean foliage is often left to dry on the field and is collected and processed as bean straw (Figure 34). Bean foliage is mainly available from May to September, Belgian spring and summer, when temperatures and humidity are optimal for the collection of straw.

2.6.3. Innovations

Bean foliage is generally left on the field or used as bean straw. Little literature is available on the valorisation of the waste streams from bean cultivation. Bean straw is sometimes also (co-)digested, as studied by (26).

[28] https://lv.vlaanderen.be/nl/nieuws/voorlopige-arealen-landbouwteelten-uit-de-verzamelaanvraag-2018

3. GENERAL DISCUSSION AND CONCLUSION

Some main challenges arose from this study. These challenges are not new. In the following paragraphs, these challenges are explained and some solutions are proposed, based on the mentioned innovations in this study.

Seasonality and small scale production. Most of the by-products are released within a short period, making it challenging to assure a continuous valorisation process, unless residues are stored in an appropriate way. Additionally, although by-products represent a large share of the total biomass produced during cultivation, the production is spread over the region and is relatively small scale.

Heterogeneity. The quality and composition of the by-products vary strongly based on varieties, harvesting period and soil conditions.

To compensate for the abovementioned challenges, stabilisation and storing techniques are developed and used. These methods should be adapted to the kind of residues and to the type of valorisation aimed. However, these also influence the composition of the by-products. Research is further needed to meet the requirements related to homogeneity and quality of the different sectors. Another solution might be to combine different by-products, to enlarge availability. Methods as VNIR spectroscopy could also offer faster and cheaper screenings of by-products chemical and physicochemical characteristics.

Harvesting of residues. Adapted harvesting machines should be developed. For different crops mentioned in this study, these already exist (e.g. Brussels sprouts and cauliflower) or are in development, which eases further valorisation.

Extra costs for harvesting or other innovations. Innovation asks for investments. For the primary sector, these investments costs add additional costs to the total business budget, unless valorisation is seen as beneficial to the primary sector, also financially. Two opportunities are found to act towards cash proceeds instead of costs on the long term.

- **Multivalorisation.** Biorefining results in potential products with new by-products. In the scope of a zero waste approach, it is advisable to look at those new by-products. E.g. waste can often be separated in a liquid and a fibre part. Both have different valorisation potentials.
- **Supply chain.** To realise successful valorisations, it is crucial to set up supply chains and collaborations. Abovementioned challenges will have to be tackled such that the processing sector gets access to sufficient and qualitative by-products. Additionally, there should be a demand for the new products. Finally, the new product should be an improvement (technically, economically or environmentally), compared to the conventional product(s). Out of BioBoost, as mentioned *in 4. Future research*, the supply chain Brussels sprouts stalks to paper will further be studied, in collaboration with the industry. As such, the different aspects will be taken into account.

4. FUTURE RESEARCH ON VALORISATION OF BY-PRODUCTS (BASED ON BIOBOOST)

Project name	Involved partners	start	End	Goal
Vlaanderen Circulair	Inagro (lead) UGent, Tectero, Stora Enso (suppporting partner)	1/12/19	31/12/21	By refining the Brussels sprouts stacks, two fractions are obtained: fibres and liquid. The fibres can serve as a raw material for paper, which means that this sector uses a totally new raw material for its production. The liquid fraction consists of various high-quality components that can e.g. be used in the oleochemistry for the production of soaps, candles, lubricants, etc. By valorising the Brussels sprouts, new links are being laid between various top sectors in Flanders.
Valorisation of by-products from high wire cultivation Vlaio-LA	Inagro (leading partner)	1/11/20 (if approved)	31/10/24	This projects aims at high valued valorisation of tomato, cucumber and bell pepper stems towards biopesticides and biostimulants. The remaining fraction will be valorised as energy, to fulfil a zero waste approach. This project includes the search for alternative wires and clips and for new separation techniques to split the remaining plastic from the green waste. Additionally, one work package is related to stabilisation and storage of the residues.

5. BIBLIOGRAPHY AND REFERENCES

1. Platteau J, Lambrechts G, Roels K, Van Bogaert T. Uitdagingen voor de vlaamse land en tuinbouw. 2018.
2. Egelyng H, Romsdal A, Hansen HO, Slizyte R, Carvajal AK, Jouvenot L, et al. Cascading Norwegian co-streams for bioeconomic transition. Journal of Cleaner Production. 2018;172:3864-73.
3. Van Buggenhout E, Vuylsteke A, Van Gijseghem D. Back to basics - Circulaire economie en landbouw. 2016.
4. FAO. Agrifood chains 2019 [Available from: http://www.fao.org/energy/agrifood-chains/en/.
5. OVAM. Actieplan Duurzaam beheer van biomassa(rest)stromen 2015-2020. Mechelen; 2014.
6. Roels K, Van Gijseghem D. Verlies en verspilling in de voedselketen. Departement Landbouw en Visserij; 2011.
7. Kips L. Characterization and processing of horticultural by-products: a case-study of tomato and Belgian endive roots. PhD. Ghent: Ghent University; 2017.
8. Chen B, Liu E, Tian Q, Yan C, Zhang Y. Soil nitrogen dynamics and crop residues. Agron Sustain Dev. 2014;34:429-42.
9. de Wolf M, de Haan J. Gewasresten afvoeren: utopie of optie? Wageningen: Praktijkonderzoek Plant & Omgeving BV; 2005.
10. Denys C. Vooruitblik areaal spruitkool Europa 2018-2019 2018 [Available from: https://www.syngenta.be/nieuws/koolgewassen/vooruitblik-areaal-spruitkool-europa-2018-2019.
11. Kips L, Van Droogenbroeck B. Valorisatie van groente- en fruitreststromen. Merelbeke: ILVO; 2014.
12. CVB. CVB Voedertabel 2018 - Chemische samenstellingen en nutritionele waarden van voedermiddelen. Federatie Nederlandse Diervoederketen 2018.
13. Plattelandswijzer. Groenten in openlucht: Witloof [Available from: http://plattelandswijzer.nettools.be/default.aspx?PageId=127.
14. Boerenbond. Dossier: Witloofteler s op zoek naar meerwaarde. Management & Techniek. 2017;2.
15. Boerenbond. Dossier, Tomatenteelt in volle evolutie. Management & Techniek 2015;22:42-7.
16. Plattelandswijzer. Groenten onder glas: Tomaat [Available from: http://plattelandswijzer.nettools.be/default.aspx?PageId=135.
17. Galema P, Vermeulen P, Klop A, Broeze J. Vee in de kas: samenwerking tussen (melk) veehouderij en glastuinbouw. Wageningen UR Livestock Research; 2014. Report No.: 1570-8616.
18. Voedselverlies VK. Voedselreststromen en voedselverliezen: preventie en valorisatie-monitoring Vlaanderen 2015, 2017. 2017.
19. Smolders G. Compost en ander strooisel in ligboxen voor melkvee= Compost and other bedding material in cubicle housing for dairy cow. Wageningen UR Livestock Research; 2012. Report No.: 1570-8616.
20. Fornasier F, Sinicco T, Vida E, Mondini C, editors. Biochar effects on C and N mineralization and biochemical properties of soil amended with bioenergy by-products [Conference poster]. RAMIRAN 2013 15th International Conference, Versailles, France, 3-5 June 2013 Proceedings; 2013: Institut National de la Recherche Agronomique (INRA).
21. Weber F, Ravensberg W, den Ouden M. Van kassenloof naar natuurlijke gewasbeschermingsmiddelen. 2013.
22. Joppen L. Gewassen beschermen met tomatenloof 2013 [Available from: https://www.agro-chemie.nl/artikelen/gewassen-beschermen-met-tomatenloof/#.
23. Bowyer J, Howe J, Pepke E, Bratkovich S, Frank M, Fernholz K. Tree-Free Paper: a path to saving trees and forests ? . 2014.
24. Revathi D, Sashidevi G, Hemalatha G, Kanchana S. Formulation of cookies from cauliflower leaves. Acta Horticulturae. 2019;1241:659-62.
25. Serena A, Bach Knudsen K. Chemical and physicochemical characterisation of co-products from the vegetable food and agro industries. Animal Feed Science and Technology 2007;139:109-24.
26. Gomez D, Castañeda P, Rosales J, Rodriguez L. Anaerobic digestion of bean straw applying a fungal pre-treatment and using cow manure as co-susbtrate. Environmental Technology. 2019:1479-87.