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Grass management: mobilisation strategies & a circular perspective

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Grass management: mobilisation strategies & a circular perspective

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Executive Summary

*This study investigates six **mobilisation strategies** for grass from road verges and nature reserves in Flanders - complemented with a holistic **circular perspective** on grass as a secondary raw material.*

Management of road verges and nature reserves produces a large quantity of grass cuttings every year. The total grass acreage sums to 29.600 ha distributed over nature reserves (15.050 ha or 50%), municipal road verges (10.300 ha or 35%) and highway & regional road verges (4.250 ha or 15%). The total harvestable grass from road verges and nature reserves in Flanders amounts to circa 427.000 tonnes fresh matter or 141.000 tonnes dry matter each year.

Composting, and to much lesser extent anaerobic digestion, are the established processing options in Flanders. However, the processing of grass fibres into bio-materials is investigated such as alternative emerging processing options. At the same time there is a significant amount of grass potential that remains unharvested, unprocessed and/or are exported.

Still, processing of these cuttings is a problem rather than an opportunity and comes at a high societal cost. At the same time, Flanders sets ambitious goals for further deployment of grass cuttings in a circular bio-based economy.

This study investigates six grass mobilisation scenarios – one AS IS and five TO BE scenarios. The scenarios are in line with policy ambitions put forward and take into account all major characteristics throughout the supply chain; such as origin-destination (transport & storage), quantity (acreage & production), quality (harvest type & litter) and planning (peaks & seasonal effects). The results show how each strategy can be met at minimised mobilisation costs.

> The AS IS scenario reflects the current situation for processing grass cuttings, i.e. green composting and processing of a part of nature grass towards feed. This scenario sets the baseline for total mobilisation cost and other KPIs being; the total mileage and the number of vehicle movements.
>
> The five TO BE scenarios investigate potential future scenarios. Each scenario differs in i) type of end-processes, ii) the capacity of the end-processes and/or iii) the allowed feedstock quality for the end-process. This differentiation allows to test the impact on mobilisation cost of each scenario.

To address the complexity of mobilisation scenarios, VITO's MooV model has been used (https://moov.vito.be). MooV is a supply chain optimisation model that analyses different scenarios in search of the best value chain configuration within a geographical context. This with the general objective to increase mobilisation rates and reduce risks and costs.

The scenario results are discussed in detailed in section 2.5, from which the following conclusions and recommendations were drawn (see also chapter 4 for more details).

Conclusion 1: Solid data is important to (scientifically) underpin policy making and strategic planning of a circular bioeconomy. Current data is too often incomplete, inaccurate, fragmented,…

- *with a risk of data quality being insufficient to make adequate policy decisions and/or frame action plans;*
- *leading to the need for recurring intensive (and often parallel) data-gathering efforts*

Recommendation 1: Continue to strengthen a holistic and coordinated (big) data centralization with regard to a circular bioeconomy.

Conclusion 2: The resulting grass map of road verges and nature reserves and related processing activities with differentiation to location, acreage, ownership, capacity and production is currently the best available for Flanders.

Recommendation 2: The map could be further capitalised on i) by further completion (e.g. adding waterway verges, or other biomass(residual)streams or ii) by challenging the map's fit for purpose in view of data centralization (see recommendation 1).

Conclusion 3: The MooV scenarios show that the assessed grass potential allows for the co-existence of established (compost, digesting, feed) and near-future (biomaterials) commercial-scale end-processing sites. Source separation of feedstock qualities shows enough feedstock is available for higher end biomaterials.

Recommendation 3: The developed model can be used to assess the impact of alternative strategies or re-assess variations on current strategies.

Conclusion 4: As grass processing currently comes at a societal cost – management mainly occurs due to regulation/obligation or environmental development goals. With increased demand, feedstock differentiation (e.g. by origin) or need for higher grass qualities; mobilisation costs tend to increase. The scenarios show a mobilization cost in the range of 45-70 € per tonne fresh. The higher end of the range reflects scenarios with higher demand for mass and quality; but could be compensated by higher willingness to pay better feedstock quality.

Recommendation 4: Use study results to test the feasibility of current and future biomass mobilisation strategies of local biomass resources in a circular bioeconomy. For further detailing a case-by-case approach is advisable.

Conclusion 5: The study results address economic optimisation; however environmental or circular optimisation can be addressed as well. Multiple feedstock use already shows the interaction between economic and circular benefits.

Recommendation 5: Investigate further how circularity can be incorporated in optimization modelling.

Conclusion 6: Trade-off tipping points between mobilisation cost increase vs. increased local valorisation of local feedstock could be defined – and deployment scenarios can be tested on their expected increase/decrease of societal mobilisation cost.

Recommendation 6: This study sets the scene and developed the base-model to make such assessments. Further detailing of assumptions and constraints will benefit result accuracy.

Conclusion 7: Increasing the knowledge on the quantities, characteristics and qualities of grass cuttings available for mobilisation, allows to properly identify, for each distinguishable and relevant quality parameter, the corresponding processing option(s) that produce(s) the secondary resource(s) with the highest potential to substitute for its primary equivalent(s). By selecting for each quality or grade the best circular fit, the sum of the environmental gains from converting the different qualities of grass feedstock into different secondary resources, will be higher than when all qualities were processed into a single type of product without acknowledging for feedstock quality.

Recommendation 7: This study sets the scene and developed the base-model to make it possible to distinguish and display cuttings feedstock qualities, thus facilitating the selection of the most circular processing option in each case. Further detailing of assumptions and constraints will allow to provide the most circular solution for a particular feedstock quality, and to optimize roadside management in function of the available and targeted processing options.

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1 Introduction

Management of road verges and nature reserves produces a large quantity of grass cuttings every year[1]. Processing of these cuttings is often conceived as a problem due to their high volume, low density, distributed origin, variable and heterogeneous supply, and fragmented ownership which leads to high mobilisation costs. With current low value end-products, these costs are only marginally compensated for, leading to a high societal cost.

Composting, and to much lesser extent anaerobic digestion, are the established processing options in Flanders. However, the processing of grass fibres into bio-materials is investigated such as alternative emerging processing options. At the same time there is a significant amount of grass potential that remains unharvested, unprocessed and/or are exported.

The first part of this study addresses five future mobilisation strategies for grass cuttings – with focus on a mix of end-processing options (Chapter 2). In the second part, the management of grass cuttings is discussed from a circular viewpoint, as the Flemish government's general vision for a sustainable bio-economy focuses on local biomass cycles – and increased circularity (Chapter 3). Chapter 4.1 summarizes the discussions and conclusions of Chapter 2 and 3.

This study addresses six ***mobilisation strategies*** *for future management of grass cuttings complemented with a holistic* ***circular perspective*** *on grass as a secondary raw material.*

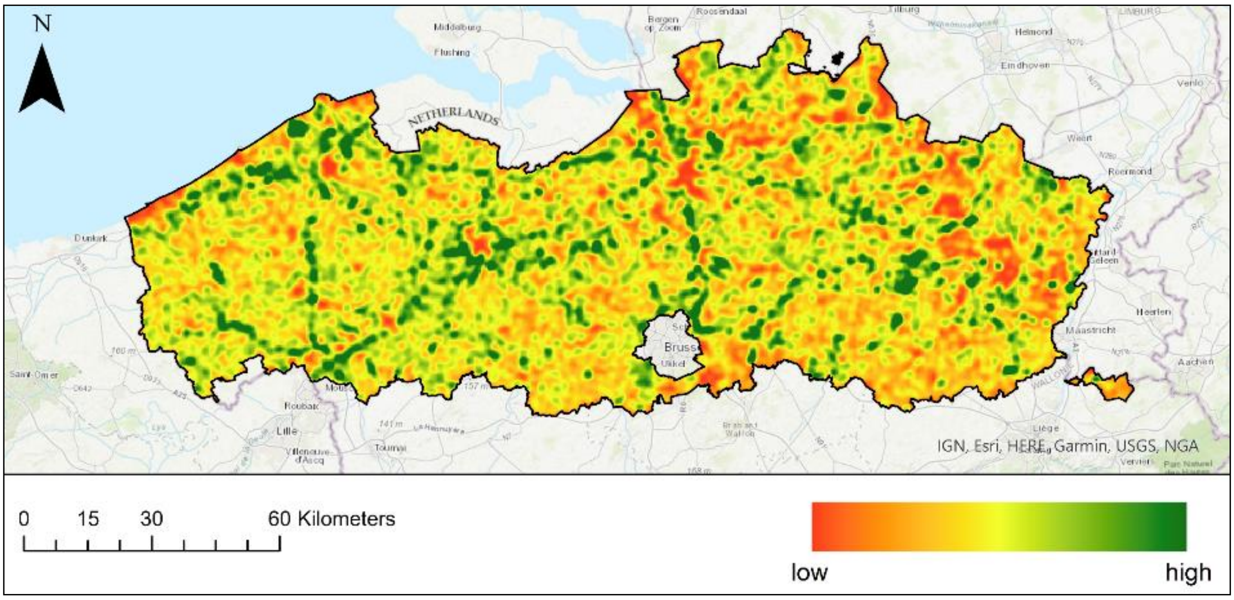

Figure 1: Presence of verge and nature grass in Flanders.

[1] *Note: grass cuttings from other verge types (waterways and railways) and private gardens are not considered in this study scope.*

2 Mobilisation strategies

Authors: De Meyer A., Guisson R. (VITO)

2.1 Context

The *Flemish Action Plan Biomass(residual)streams (2015-2020)* states:

> *Due to the variety of management measures and the different actors involved, local cooperation could improve the efficient management of biomass (residual) flows. At a local level, local actors work together around management of biomass, including woody biomass. Such cooperation can possibly take place both in the chain itself and between different biomass supply chains. Possible cooperation can happen at central biomass hubs: storage spaces for storage and pre-treatment of biomass storage awaiting further processing (e.g. storage of (verge) cuttings).*

The subsequent *Progress Report on the same Action Plan Biomass(rest)streams (2015-2020)* states:

> *The sustainable and cost-efficient management of verge grass remains a challenge. Via targeted measures throughout the chain it is attempted to use this biomass rest stream more optimally.*[2]

While the targeted measures are legion this chapter assesses grass mobilisation strategies from a holistic Flemish perspective with the aim to address the challenge for a more sustainable and cost-efficient management. Aforementioned key elements such as - different supply chains, different management measures, different actors, central biomass hubs and storage facilities, further processing to products – are captured in the assessment.

The starting point of this chapter is the reality that grass on verges and in nature reserves yearly grows back and needs to be cut, collected and processed – which comes at a societal cost. However, a significant part of the grass cuttings is not (locally) processed in Flanders because it is; simply not cut, not processed after cutting or exported. When cuttings are indeed locally processed, the established option is dominantly composting, complemented with feeding (of nature grass) and digesting. These options lead to relatively low value products such as compost, biogas and digestate. New alternatives look at higher value applications like bio-material (grass fibres) and feed products (protein extraction), which are getting attention in research and (early) commercial development.

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[2] https://www.ovam.be/sites/default/files/atoms/files/Voortgangsrapport%20actieplan%20duurzaam%20beheer%20van%20biomassastromen%202015-2020.pdf

Figure 2 shows the main activities in grass processing chains (from left-to-right): growth & harvesting, pre-processing, storage, processing towards end-product. The activities are interconnected via transport modes. For an optimal mobilisation strategy simultaneous compliance with all major conditions related to location, quantity, cost, quality and planning is needed. Simultaneously meeting all conditions is complex. Many variations are possible which offers a great freedom to operate but at the same time increases risks of suboptimal strategies leading to less performant supply chains.

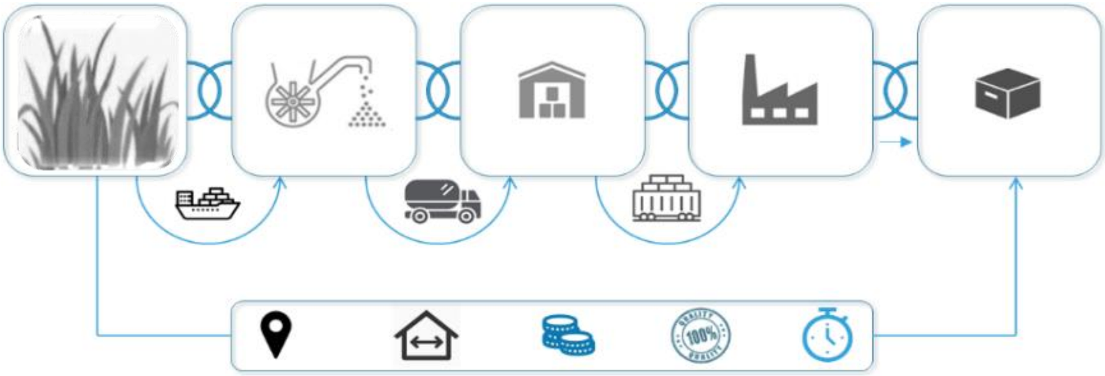

Figure 2: Main activities & key conditions in a grass supply chain considered by MooV.

While Flanders sets some ambitious goals for further deployment of grass cuttings in a circular bio-based economy, assessment of different mobilisation strategies - in which established as well as new value chains can co-exist – provides vital insights on impact and realism of these ambitions.

2.2 Methodology

To address the complexity of a grass mobilisation strategy, VITO's MooV model[3] has been used. MooV is a supply chain optimisation model that analyses different scenarios in search of the best value chain configuration within a geographical context. This with the general objective to increase mobilisation rates and reduce risks and costs.

The MooV model has a core/shell design[4]. The MooV-core is generic and captures the universal supply chain logics. The MooV-shell which is customisable and captures the specifics of the grass case; e.g. costs, feedstock types, qualities, product types, locations, capacities, seasonal effects… Additionally, specific preferences can be taken into account such as; preference for a specific end-product (e.g. bio-materials), preference for a harvesting type (e.g. flail vs. rotary mowing), preference for a storage type (e.g. silage vs. bale) or preference for a specific feedstock quality (e.g. degree of litter).

Figure 3 shows the three main steps of the MooV methodology. Each step is explained in more detail in the following sections:

- Define-phase: defining the case specifics, and gathering and processing data in the MooV-database (section 2.3)
- Design-phase: scripting the case specifics into the MooV-shell by linear programming (section2.4).
- Deliver-phase: running the MooV-model for various scenarios and analysing the results (section 2.5)

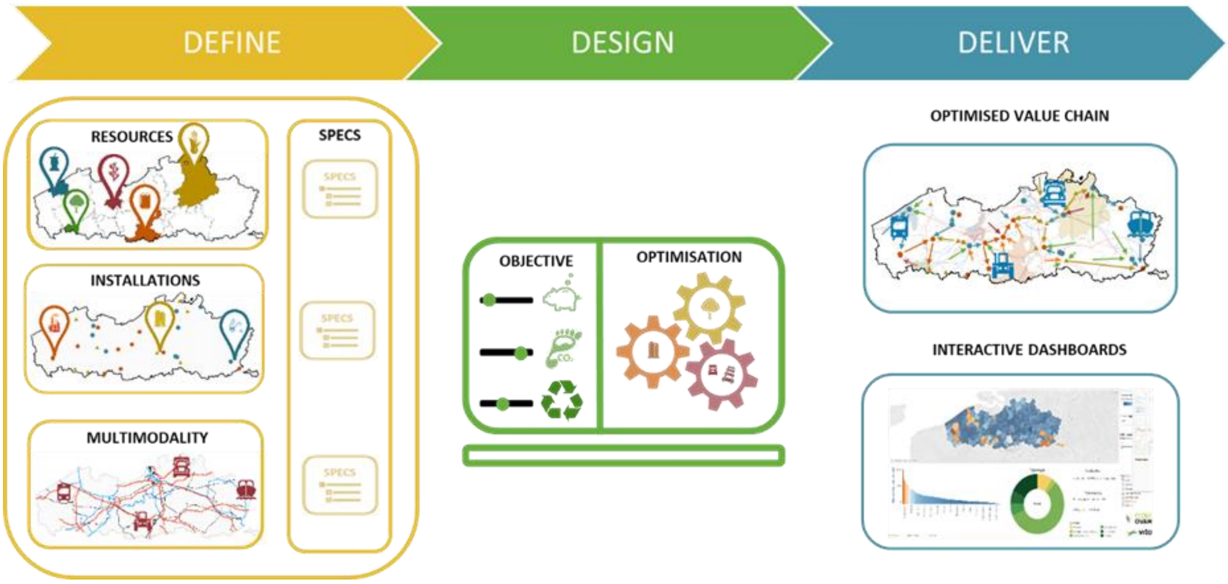

Figure 3: MooV methodology – Define, design & deliver.

[3] https://moov.vito.be *MooV – is a multi-objective mixed integer linear programming model developed by VITO – and the result of further development of the OPTIMASS-model, described in "Design and management of biomass-for-bioenergy value chains – Towards a comprehensive spatio-temporal optimisation approach" (De Meyer, A., 2015).*

4 De Meyer A.; Guisson R. MooV – a flexible decision support system for the strategic design of supply chain networks (submitted)

2.3 DEFINE – The grass mobilisation case

When developing new mobilisation strategies numerous decision options are possible, leading to various scenarios. This section sets the scene for the grass case, defining all activities and its characteristics and requirements or limitations as well as how activities are interconnected.

2.3.1 Case requirements

2.3.1.1 Flexibility

The assessment of mobilisation strategies needs to cope with numerous decision options, such as quality of the grass or processing options. So, flexibility in the MooV assessment is key to be able to define the different, relevant scenarios and calculate the impact of these changes on the scenarios. MooV includes the following grass case activities and related changeable characteristics:

- Products: feedstock typology and potential, intermediate and end-products typology
- Harvest: harvesting types, costs, capacities, effect on the quality of grass cuttings;
- Pre-treatment: treatment types, costs, capacities, effect on quality of grass cuttings;
- Storage: storage types, costs, capacities, storage effects on grass quality;
- End-processing: processing types, required quality, capacities;
- Transport modes: type, capacity, cost, bulk densities, fresh matter vs. dry matter.

Section 2.3.2. gives a more detailed description of these characteristics.

2.3.1.2 Planning & time context

As grass is a feedstock following seasonal growth cycles the planning horizon and period are key time parameters for the assessment of mobilisation strategies. The **planning horizon** reflects the total period for which feedstock supply will be analysed and optimised (Figure 4). Since grass along road sides and within nature reserves is managed in yearly cycles, the planning horizon is set to **1 year**.

The **planning period** is the shortest time span within the planning horizon at which time related decisions can be made – the planning period is set to **2 weeks**. This allows to model the harvested amount of grass on a two-weekly basis and as such correctly reflect peaks in harvested volumes. Consequently, this cascades to the long-term storage facilities which need to buffer these peaks to balance against the demand side which requires a continuous year-round supply (e.g. composting, AD-landfill, materials) as well as the short-term storage locations which can only buffer the grass for a maximum of 2 weeks. As a surplus, time-dependent changes in grass characteristics throughout the year could be considered (e.g. moisture content, biogas production potential, nutritional value…).

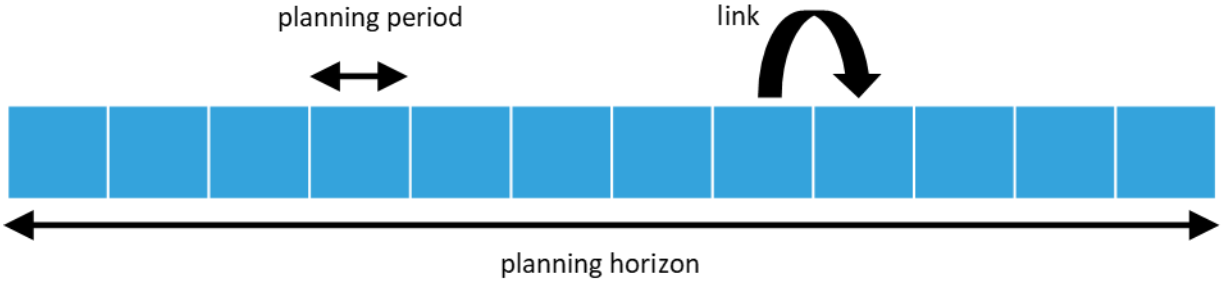

Figure 4: Difference between planning horizon and planning period.

2.3.1.3 Mobilisation objective

For this study the objective is to assess how grass is best **mobilised at least costs** to fulfil a specific demand-side. So, the assessment is **demand-side driven.** The MooV model is set to calculate the minimal mobilisation cost over the supply chain – from the origin of harvest over pre-treatment and storage up to the gate of the end-processor[5]. And this for all grass from road verges and nature reserves in Flanders.

The **total mobilisation cost** is calculated as the sum of 3 components (Figure 5):

1) The **costs related to harvest**: the costs for harvesting as well as the transport of the grass cuttings from the harvesting site to the closest short-term storage.
2) The **costs related to storage**: the costs for long-term storage as well as eventual pre-treatment activities to maintain grass quality during storage.
3) The **costs related to transport:** the costs for transport from i) the short-term storage to long-term storage sites, ii) from short-term storage to end-processors (e.g. digestate transport from landfill-AD to composting[6]), iii) from long-term storage to end-processing (and back) and iv) between end-processors.

Figure 5 shows the composition of the total cost – broken down over its components. The mobilisation cost will be assessed for five different scenarios. These scenarios are explained in detail in section 2.5.1 and following.

---

[5] *Costs for pre-processing are considered excluded from the mobilisation cost as these costs are very specific and inherent to the type of end-use.*

[6] *See scenario 2.5.4 where digestate is transported from landfill-AD to composting sites for further processing*

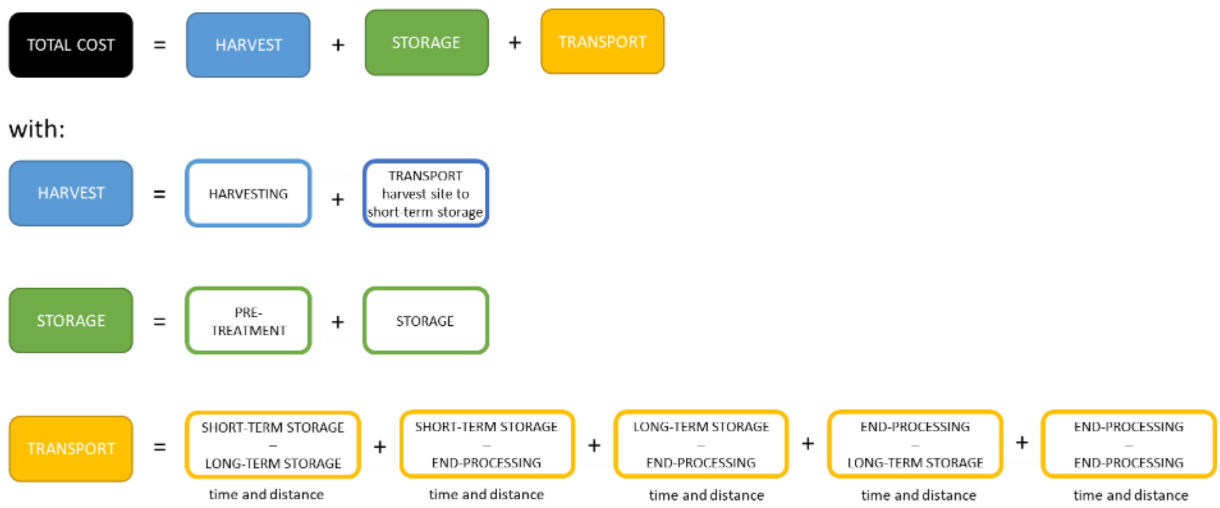

Figure 5: Components of the total mobilisation cost included in the MooV model.

Additionally, the MooV model calculates for each scenario the **total transport distance** (km) and the **number of transport movements** needed to mobilise the grass from the harvest locations to the end-processors (Figure 6).

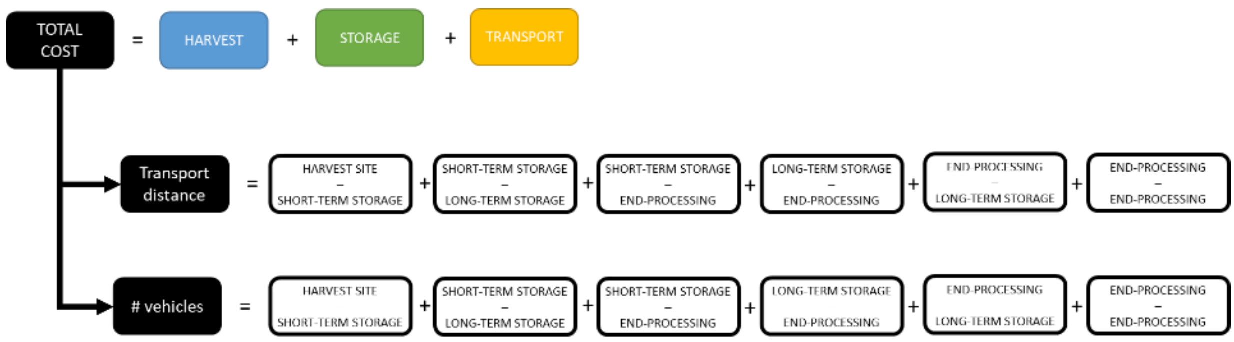

Figure 6: Other KPI's calculated by the MooV model after minimising the total cost.

2.3.2 Feedstock and activities

Now the overall study objective is set, this section details on all activities that take part in the mobilisation of grass cuttings. Besides the origin of the grass cuttings (e.g. nature reserves vs litter-rich roadsides), different activities (or processes) influence the quality and characteristics of the grass cuttings. The harvest type as well as pre-treatment activities will determine how the grass can be further stored, transported and end-processed. An activity upstream in the chain affects the possibilities for end-processing and vice-versa the envisioned end-product may restrict the preceding upstream activities. Four main activities are distinguished: (1) harvesting, (2) storage and treatment, (3) end-processing and (4) transport.

2.3.2.1 Feedstock

2.3.2.1.1 Location & acreage

The supply chain starts at the point of harvest. The grass cuttings at the time of harvest are considered the starting feedstock. Based on origin, 3 feedstock types are defined:

- *NAT grass*: grass from nature reserve grasslands (owned/managed by Natuurpunt vzw and the Agency for nature and forests of the Flemish Government – ANB).
- *AWV grass*: grass from highway and regional road verges (owned/managed by the Flemish Agency for Road and Traffic – AWV).
- *MUN grass*: grass from municipal road verges (assumed to be owned/managed by municipalities).

The **location and acreage** of the *nature reserves* as well as *road side verges* are essential information to model the logistics in the supply chain.

- For ***nature reserve grasslands***, a GIS-map was obtained from Natuurpunt and ANB.
    - For Natuurpunt the mapped acreage is circa 3.580 ha.
    - For ANB the mapped acreage is circa 11.450 ha.

    In total the grassland in nature reserve is circa **15.050 ha**.
- For the *location and acreage of* ***road grass verges***, ideally a GIS-map was available with the location, length (and width/surface) and type of the verges. Such a map for Flanders does not exist. To mitigate this lack of data, VITO has developed a SQL-code to derive this information from the GIS-map 'Grootschalig Referentie Bestand – GRB'.

  Building on that SQL-code, following methodology was followed (Table 1):

    1. VERGE MAP of FLANDERS: The location of all road verges from the GRB-map has been captured using the specifically developed SQL-code which is based on the layers 'wvb' ("wegverbinding" or road connection), 'wbn' ("wegbaan" or road way) and 'wgo' ("wegopdeling" or road layout) of the GRB and the different road typologies as defined in the GRB.
    2. ADD OWNER: Distinction has been made between roads owned by; i) the Flemish Agency for Road and Traffic (AWV); differentiated between highways and main regional roads and ii) the municipalities - being all remaining local roads. The total acreage of these verges has been calculated, leading to a theoretical acreage of circa 50.500 ha.
    3. EXCLUDE CITY CENTRE AREAS: This with the rational that these surfaces are virtually completely built-up or paved with the consequence that grassy verges are marginal on these verges. This exclusion is not performed on the verges along highways because highways are mostly accompanied by grassy verges, even when passing through or along a city centre.
    4. EXCLUDE DRIVEWAYS: A fixed driveway width was excluded for each address point defined in the GRB, as also driveways are considered paved. This correction of the theoretical surface leads to a technical surface of circa 25.250 ha.

5. ADDITIONAL CORRECTION for regional and community verges[7]: This to correct for verges which have been paved, planted (e.g. hedges…) or mowed by citizens (e.g. front yard gardens). As no scientific literature for a correction factor is available for Flanders, it was assumed that 45%[8] of remaining verges were not grass covered. This correction led to the technical corrected surface **14.550 ha**.

Notwithstanding the methodology and the resulting GIS-map of Flemish road side verges can be subjected to criticism, specifically when drilling down to parcel level, it is the best map available for Flanders to our knowledge. The method provides a solid idea of the location and acreage of verges at a higher geographic level, which is the level relevant to define strategic mobilisation strategies.

Table 1: Road verge grass acreage (ha).

	AWV grass	*MUN grass*	*Total*
Theoretical	11.500	39.000	50.500
Technical	6.250	19.000	25.250
Technical (corr.)	**4.250**	**10.300**	**14.550**

Combining both surfaces from nature reserves (15.050 ha) and road verges (14.550 ha) amounts to **a total of 29.600 ha of grass acreage** within the study scope. The corresponding locations are shown in Figure 7.

The total grass acreage sums to 29.600 ha distributed over nature reserves (15.050 ha or 50%), municipal road verges (10.300 ha or 35%) and highway & regional road verges (4.250 ha or 15%).

[7] *Note that highways were excluded from this correction.*
[8] *Note variations on this factor can be modeled as well.*

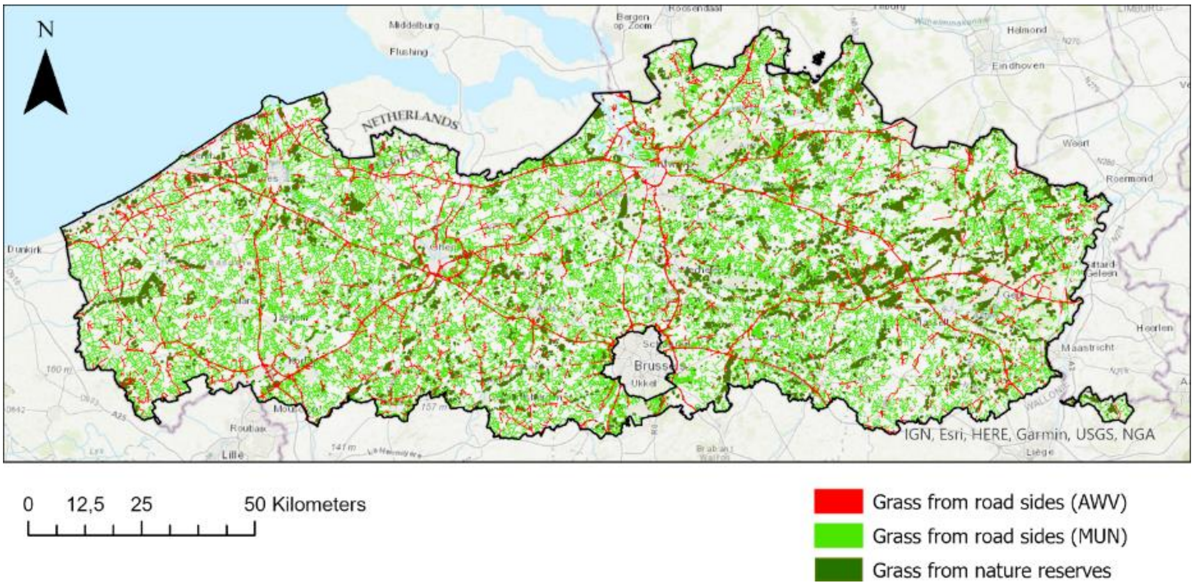

Figure 7: Map of Flanders –grass acreage in nature reserves and on road verges (MooV-VITO).

2.3.2.1.2 Quantity

In addition to differentiation by location and ownership, the feedstock types can be differentiated by harvested quantity and corresponding quality (Table 2). The harvested **quantity** (volume/mass) is important in view of mobilisation; it defines the number of harvester movements, the capacity of (temporary) short-term storage sites and the required throughput pace towards end-processors.

The number of cuts and the time of harvest have an important impact on the harvested quantity. Notwithstanding variations, the general harvest procedure adopted in this study is to cut twice a year[9], once in summer and once in autumn.

Table 2 shows the theoretical as well as the technical grass quantities per hectare harvested from a double cut. The technical potential is considered 70% of the theoretical potential[10]. This correction is to compensate for acreage that cannot be harvested completely, due to obstacles or topography. The technical harvestable quantity ranges between 11-19 ton/ha fresh matter depending on feedstock type.

Table 2: Harvestable quantities per hectare.

Feedstock type	**Theoretical Quantity[11]** (tonne/ha fresh)			***Technical Quantity*** *(tonne/ha fresh)*		
	Summer	*Autumn*	*Total*	*Summer*	*Autumn*	***Total***
NAT grass	9,0	6,7	15,7	6,3	4,7	**11,0**
AWV grass	13,8	9,8	23,6	9,7	6,9	**16,6**

[9] *In past years growth season lasted longer – due to extended summer periods – leading to regular cases of three cuttings (oral communication from contractors).*

[10] *Van Meerbeek et al. (2015) and Caron et al. (2002) concluded that the surface area of a roadside cannot be completely harvested due to obstacles or topography. They assumed that 30% of the roadside area is not harvestable. The Grasgoed study adopted the same reduction factor of 30% for nature reserve grasslands.*

[11] *Theoretical biomass potential*

MUN grass	16,0	10,6	26,6	11,2	7,4	**18,6**

Combining results from Table 1 and Table 2 shows the estimated total technical/harvestable grass potential from road verges and nature reserves in Flanders (Table 3). The total harvestable grass from road verges and nature reserves in Flanders amounts to circa **427.000 tonnes fresh matter or 141.000 tonnes dry matter** each year. Looking only at road verges, the harvestable potential is circa 262.000 tonnes per year (191.600 tonnes per year + 70.550 tonnes per year). For the AWV, the 70.550 tonnes per year is distributed over; highway (42% - 30.000 tonnes per year) and regional roads (58% - 40.550 tonnes per year).

Table 3: Harvestable grass feedstock in Flanders.

Feedstock type	***Quantity*** *(technical)* *(tonne/ha fresh)*	**Surface** *(technical (corr.))* *(ha)*	***Total Quantity*** *(technical)* *(tonne fresh)*	*(tonne dry)*[12]
NAT grass	11,0	15.050	165.550	54.600
AWV grass	16,6	4.250	70.550	23.300
MUN grass	18,6	10.300	191.600	64.500
Total[13]		**30.000**	**427.000**	**141.000**

Following earlier studies (Graskracht and Bermgras), circa 149.000 tonnes is yearly harvested from road verges,[14] which is dominantly processed via composting. OVAM communicated that circa 82.000 tonnes of grass were composted in 2020. It is assumed that this grass mainly comes from road verges and in much lesser from nature reserves, as nature grass is also used as feed. These – being it rough - assumptions would lead to the conclusion that from the technical harvestable verge grass potential (100%) about 57% is harvested while 43% is not. From the harvested grass (100%) about 55% is composted while 45% is exported or not treated.

[12] *Dry matter content of 33%*

[13] *Rounded * 1000*

[14] *https://www.ovam.be/sites/default/files/atoms/files/Actieplan-duurzaam-beheer-biomassareststromen-2015-2020-DEF%2BERRATUM.pdf*

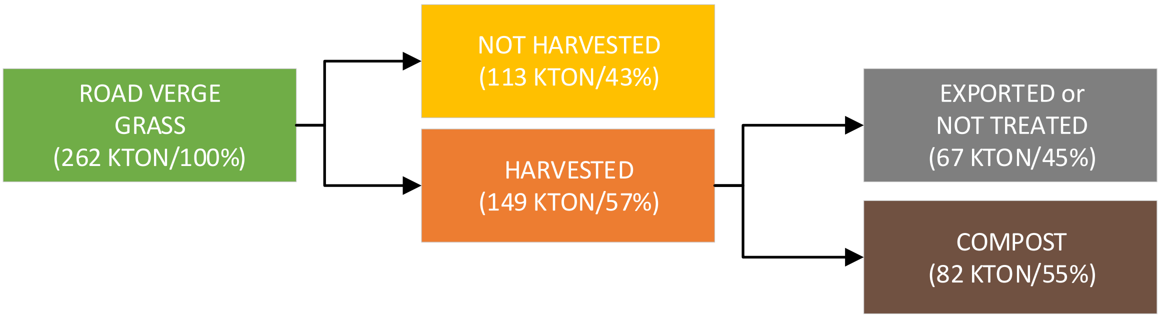

Figure 8: Road verge grass AS-IS flow in Flanders.

2.3.2.1.3 Quality

Besides the quantity, also the **quality** of the harvested grass is important in view of acceptance criteria for downstream processing (composting, landfill-AD, materials…). From quality viewpoint, the presence of litter (plastics, glass, …) and contamination (heavy metals) are points of attention.

Litter

Litter can cause problems to attain quality compost or digestate as well as to process the grass into fibre materials. Table 4 shows, while the trend is declining, that in 2020 still 1.750 tonnes of litter was collected from highways and regional roads. For municipal verges no generic data was found on litter.

Table 4: Road side litter collected from highway and regional roads (tonnes) [15].

	2015	2016	2017	2018	2019	2020
ANTWERP	579	643	584	435	560	485
FLEMISH-BRABANT	1.244	1.161	937	568	470	450
WEST-FLANDERS	676	625	407	382	451	235
EAST-FLANDERS	279	309	266	227	196	355
LIMBURG	306	216	165	189	257	223
FLANDERS	**3.084**	**2.954**	**2.359**	**1.801**	**1.934**	**1.749**

For grass from nature reserves the risk of litter is assumed to be low due to its origin. For highways Table 4 shows that littering is a serious point of attention. However, highway verges are relatively wide vis-à-vis municipal verges. Therefore, for highway verges it is assumed that littering is more concentrated to the first meters adjacent to the road, while surfaces further away from the road side are less littered. The risk of litter is therefore set to medium.

It should be noted that recently the Bermstroom project[16] commissioned a litter and heavy metal analysis of grass cuttings from AWV (regional & highway), nature (ANB) and waterway (Vlaamse Waterweg)[17]. The results showed litter problems for virtually all –

[15] *https://wegenenverkeer.be/natuur-en-milieu/milieu/zwerfvuil*

[16] *https://www.innovatieveoverheidsopdrachten.be/projecten/bermgras-als-grondstof-voor-de-productie-van-papier*

[17] Verduyn (innovatieveoverheidsopdrachten.be)

however limited in number - addressed highway verges. For this study scope the litter problem for highways is acknowledged – however the rationale is kept that litter is concentrated to the first meters while areas further away from the road side are less littered. This opens debate on whether it is reasonable and/or feasible to organise source-separated harvest of parts of bigger verge areas in view of mobilisation strategies towards higher value end-products (e.g. biomaterials).

Litter risk in municipal verges is marked high. While no reliable and uniform data for these verges is available, initiatives on municipal level to fight littering are numerous and underpin the litter risk.

The litter risk will be used in the next sections where grass mobilisation scenarios are defined. For some scenarios high-risk grass will be excluded for processing towards fibre and biomaterials.

Table 5: Feedstock litter risk.

Feedstock type	***Risk*** *(litter)*
NAT grass	Low
AWV grass	Medium
MUN grass	High

Contamination

Next to litter, potential heavy metal **contamination** of grass cuttings is a concern as well. The results from heavy metal analysis of grass cuttings commissioned by the Bermstroom project showed – on average[18] -no exceedance in heavy metal concentrations vis-a-vis the norms set by the compost quality mark 'Keurcompost'[19]. In view of mobilisation strategies heavy metal contamination is hence not considered a constraint for end-processing.

However, from a circular viewpoint it is noted that 'if dangerous and harmful substances can be extracted from the cycle, we must still avoid their diffusion into the environment' - See section 3.3- Use as safe sink

2.3.2.2 Harvest

While variations in harvest typology and methodology exist, the most common harvest types considered are flail mowing and rotary mowing. In nature reserves, rotary mowers are used since it is more nature friendly. However, swath drying, and baling operations are generally needed before the grass can be transported to a storage or end-processing site; leading to higher harvest and collection costs. Road verges are generally harvested with a flail mower, however with additional safety cars when mowing is performed along highways or regional roads; leading to higher harvest and collection costs as well.

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[18] *Notwithstanding outliers – which were reported as well*

[19] Verduyn (innovatieveoverheidsopdrachten.be)

Following the blue cost component in Figure 5, Table 6 shows the differentiation in harvest types with reference to the harvest and collection cost, the bulk storage capacity of the harvester and the cost for transport to-and-from the harvest site and the short-term storage.

Table 6: Main characteristics of the harvest types.

Feedstock type	Harvest type	Harvest & collection cost[20] *(€/tonne)*	Harvest capacity[20] *(tonne)*	Transport cost *(€/km)*
NAT grass	Rotary mower + baler	24	25	1,6
AWV grass	Flail mower + safety cars	37	9,3	1,1
MUN grass	Flail mower	15	9,3	0,8

2.3.2.3 Storage and pre-treatment

After harvesting, the grass cuttings are generally unloaded at short-term storage sites, where the cuttings are temporary stored in open air for 1-2 weeks. From these sites larger trucks transport the grass to long-term storage or end-processing sites. So, the short-term sites allow to improve logistics through a more efficient transhipment of grass between harvesters and transport trucks. Note that no treatment occurs at this short-term storage site. The following short-term storage sites are considered:

- The short-term sites of Natuurpunt (only available in the Province of Limburg, accepting grass from nature reserves.
- The short-term sites from AWV, accepting verge grass from highways and regional roads managed by AWV.
- The recycling centres, accepting verge grass from municipal roads as well as grass from nature reserves.

Figure 9 shows the location of the short-term storage sites and are assumed to accept grass only from respective owners, so e.g. grass from AWV road verges can only be stored at AWV sites. This implies that after harvest the cuttings are always transported to the nearest short-term storage location.

[20] *Derived from communication with experts and contractors and literature such as Graskracht (2012), Gras-to-Gas (2017). The harvest capacity is the mass the harvest type can load in one time. (xxx)*

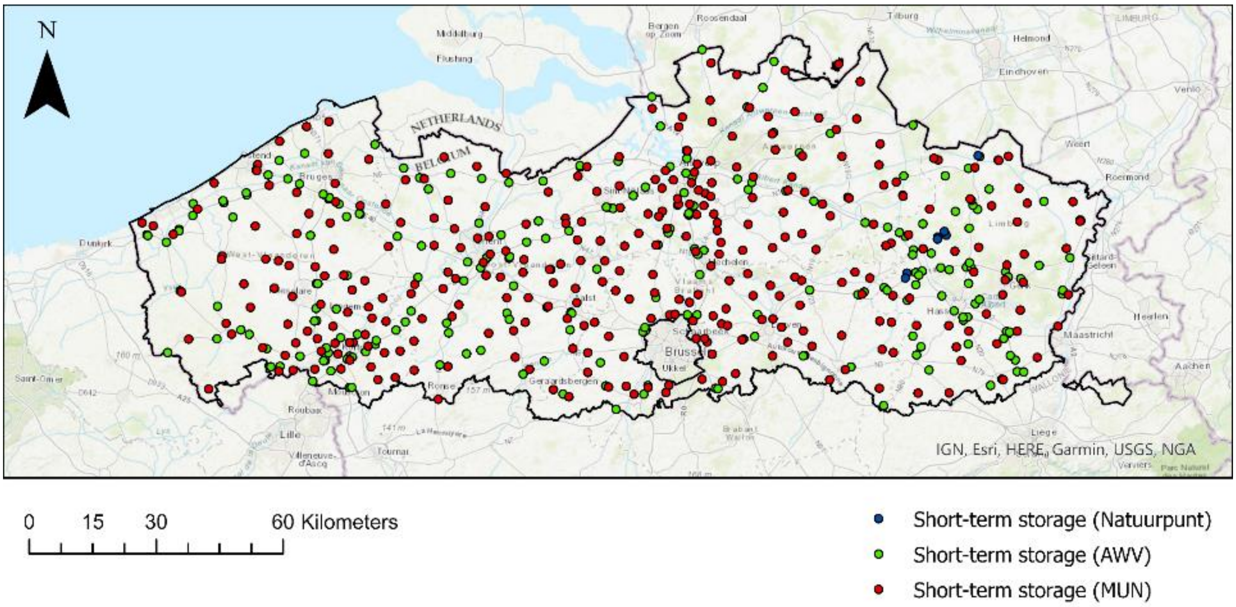

Figure 9: Short-term storage sites as considered in the MooV assessment.

Long-term storage sites are required to buffer the imbalance between seasonal harvesting peaks vis-a-vis the year-round constant demand from processors. From short-term storage sites grass is transported to a long-term storage site. For the scenario analysis the long-term storage sites are assumed to be located at the site of end-processing facilities (see next section) (Figure 10).

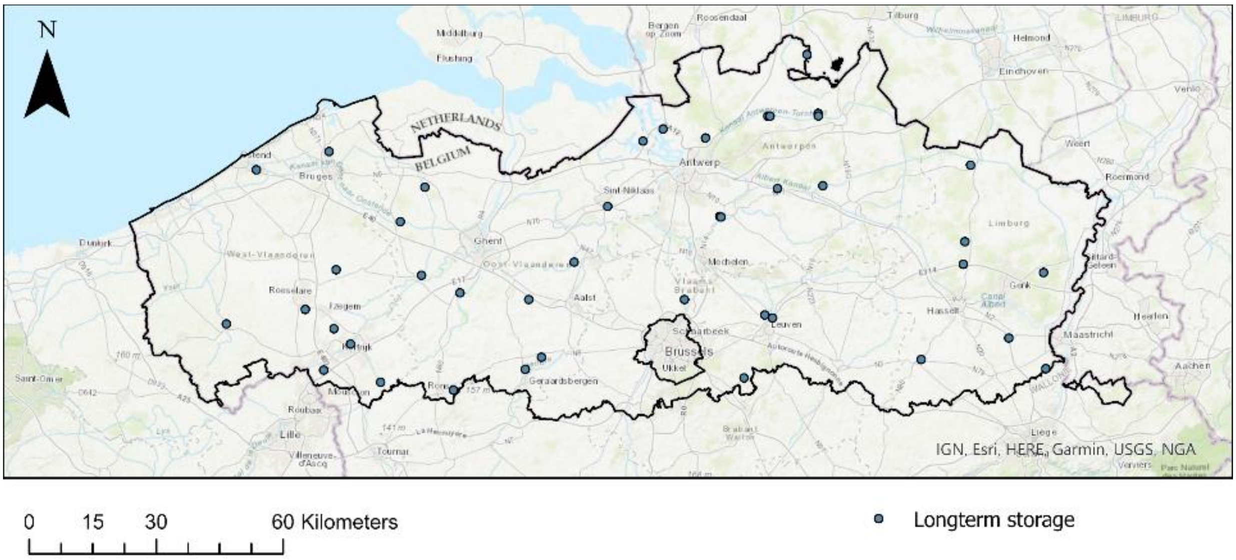

Figure 10: Long-term storage sites as considered in the MooV assessment.

At long-term storages grass is pre-treated and stored to maintain grass quality at an acceptable degree; and to allow processors to take in feedstock at a constant rate while avoiding the need for oversized processing facilities. To maintain quality, nature grass is stored as bales while the verge grass is ensiled.

Some remarks:

- Baling is performed at the harvest location. Therefore, the baling costs were already included in the harvest and collection cost to avoid double counting, baling cost in Table 7 equals zero.
- The quality evaluation of digestate from landfill-AD is still in research phase. Therefore, the required treatment of digestate prior to composting is not yet known. A drying and litter removal step seems however realistic and is therefore considered in the analysis.

Following the green cost component in Figure 5, Table 7 shows the cost for storage and pre-treatment differentiated by feedstock type.

Table 7: Main characteristics of the pre-treatment types.

Pre-treatment type	**Cost** *(€/tonne)*	**Feedstock type**
Baling	0	NAT grass
Ensilaging	5,3	AWV and MUN grass
Digestate treatment	20	Digestate

2.3.2.4 End-processing and end-products

As earlier stated, the assessment of the grass mobilisation strategy is demand-side driven, or in other words; the end-products create a 'pull' for grass and the mobilisation strategy is to provide this grass at the lowest overall mobilisation cost.

Various grass-based end-products are possible. For the study scope major current end-uses (feed, compost and to lesser extent biogas) have been selected as well as emerging end-uses with potential to increase in the (near) future (such as biomaterials).

- *Feed*
  As current practice, a part of nature reserve grass is used as animal feed.
- *Compost*

  Composting of grass is always performed in a mix with other green waste. All existing composting sites are included in the analysis. Figure 11 distinguishes between green waste and VFG-waste (vegetable, fruit and garden waste) composting sites.
- *Biogas & digestate*

  Landfill-anaerobic digestion (landfill-AD) is investigated in the Interreg project Grassification.[21] This is a robust process analogue to landfill-gas winning. Grass cuttings are ensiled underground in anaerobic conditions and the produced biogas is tapped. As the remaining digestate is considered a waste product it requires further downstream processing towards compost. Figure 11 shows all existing landfills in Flanders. Within the scope of this study these sites are considered potential sites to start landfill-AD activity.

[21] Grassification | VITO

Note that while landfill-AD is considered; agricultural digesters are excluded. As the Grassification project and other previous projects concluded the support base for accepting grass cuttings is very low in agri-AD for both technical and legislative reasons.

- *Biomaterials*

  Notwithstanding the potential of grass proteins for feed or other applications; for the scope of this study the grass fibres are considered a resource for biomaterials. Many options are possible for the applications of grass fibres, which are in different stages of development and/or commercialisation. Three potentially promising applications are selected; grass fibres for insulation materials (cf. Gramitherm), grass fibres for paper production (cf. Stora Enso – currently working with recycled paper) and grass fibres for composite materials (cf. Circular Matters).

Note that costs for end-processing are not considered as mobilisation costs as these costs are inherent to the end-processing. However, all upstream costs - i.e. harvest, storage, pre-treatment and transport – are included. So, the total mobilisation cost includes all **costs 'delivered at-the-gate'** of the respective end-processor.

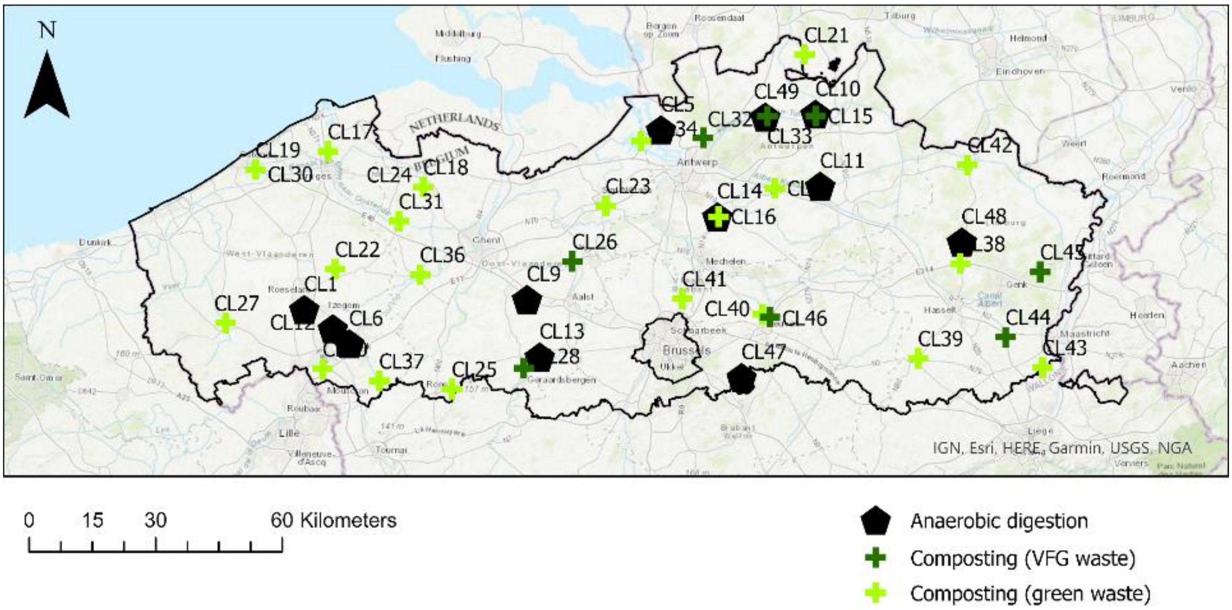

Figure 11: Composting and landfill-AD sites considered in Flanders with assumed long-term storage option.

2.3.2.5 Transport

The grass cuttings from roadsides as well as nature reserves are transported by road. Figure 12 shows the Flemish road network considered, including all highway, regional and municipal roads.

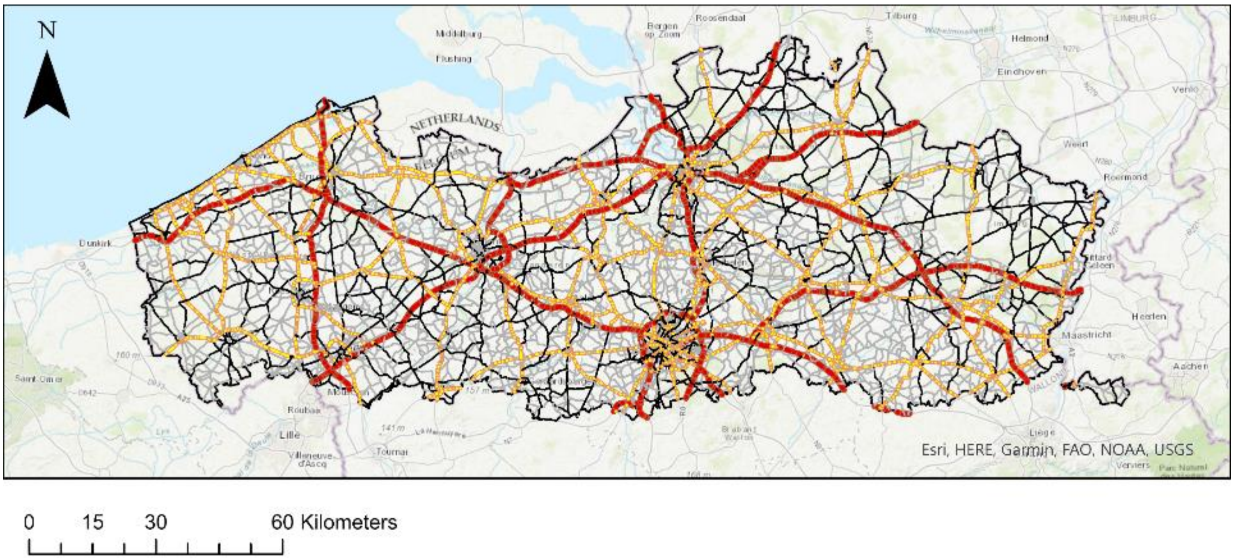

Figure 12: Transport network in Flanders.

Transport from harvest location to short-term storage occurs by the harvester / tractor combination, while transport from short-term storage to long-term storage is organised by truck. Following the yellow cost component in Figure 5, Table 8 shows the transport characteristics for harvester and truck.

Table 8: Characteristics of transport types.

Transport type	Cost transport (€/km)	Cost transport (€/h)	Cost transload (€/h)	Load capacity (tonne)
Harvest – NAT grass	1,6	-	included in harvest cost	25
Harvest – AWV grass	1,1	-	included in harvest cost	9,3
Harvest – MUN grass	0,8	-	included in harvest cost	9,2
Truck[22]	0,96	27	27	28

This concludes all cost components (harvest, storage and transport) – allowing to calculate mobilisation costs in the scenario analysis of section 2.5.

[22] https://vil.be/wp-content/uploads/2017/09/Nacatrans-slotevent-presentatie-Michael-Van-Leeuwen-ELC.pdf

2.3.3 Supply chain diagram

2.3.3.1 Process flow diagram

The previous section discusses harvest, storage, processing and transport as individual entities. However, from a mobilisation strategy perspective these entities need to be logically interconnected into a process flow. Figure 13 shows the process flow diagram (PFD) with all activities (rectangle), products (diamond) and their interconnecting transports (connectors). The PFDs serve as blueprint for the mobilisation strategies to be analysed.

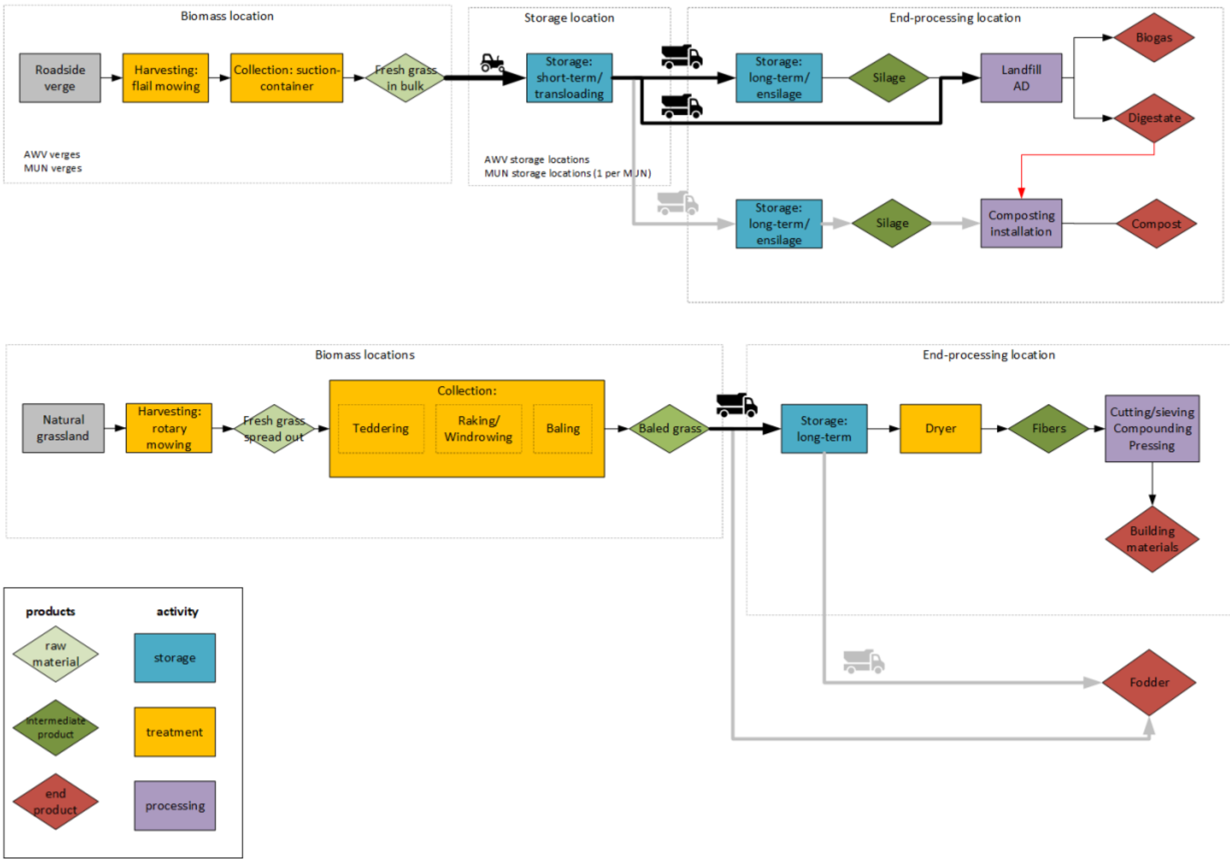

Figure 13: Process flow blueprints for the mobilisation strategies.

2.3.3.2 Network configuration

Note that the PFD only provides information on the process flow but gives no information on the location of activities. This geographical context needs to be added as well. Obviously, the physical location of the activities and products throughout the supply chain is key to define an optimal mobilisation strategy. Following the logic of section 2.3.2, four main activity types are differentiated as physical locations:

- Harvest locations (Figure 7);
- Short-term storage locations (Figure 9);
- Pre-treatment and long-term storage locations (Figure 10); and
- End-processing locations (Figure 11).

Additionally, all relevant transport connections between locations are defined to establish a network configuration (Figure 14). The following connections are considered:

- From a harvest location to a short-term storage;
- From a short-term storage directly to a processing facility where primary feedstock is immediately processed;
- From a short-term storage to a long-term storage where pre-processing takes place;
- From a long-term storage to end-processing;
- From end-processing to long-term storage (specifically for digestate);
- Between end-processing facilities (specifically for digestate).

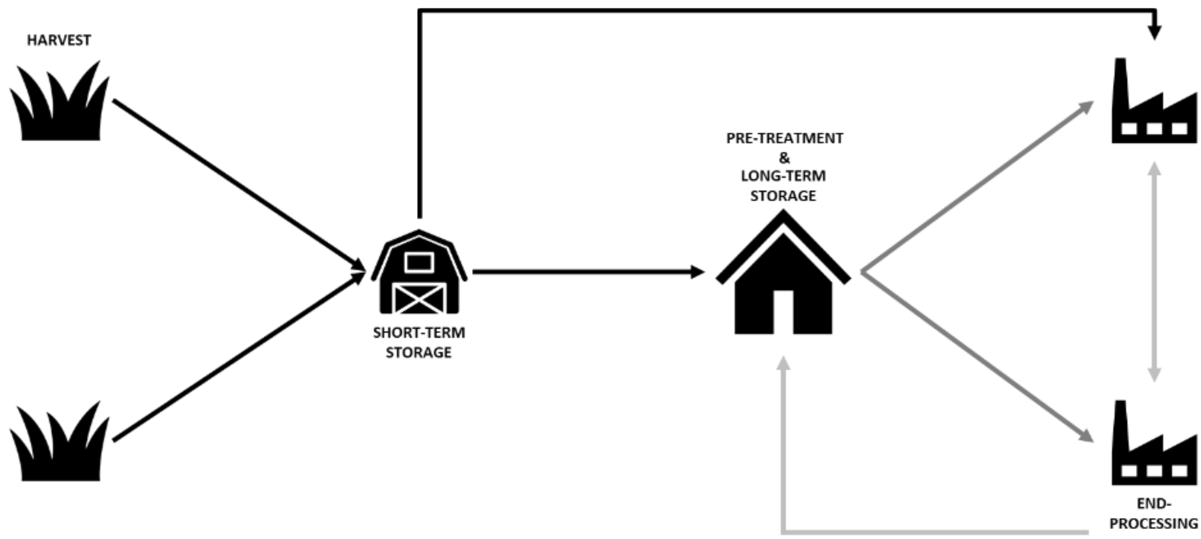

Figure 14: Network configuration options to be considered (black arrow = primary feedstock, dark grey arrow = intermediate product, light grey arrow = digestate[23]).

With the network configuration the definition of the grass mobilisation case is now completed and ready for transcription into the optimisation model.

2.4 DESIGN – The grass MooV model

2.4.1 MooV – a core/shell configuration

For the definition of grass mobilisation strategies, the MooV optimisation model is used. MooV is a supply chain optimisation service specifically developed for complex supply chain questions. The MooV model is built-up in a **core/shell configuration**. The core captures all universal supply chain logics that characterise supply chain activities, how activities effect product characteristics and how activities are interconnected by transport modes. The shell is customised to capture the specifics of the case at hand. The model is defined in Python and solved with Gurobi 9.0[24].

[23] *Note that digestate needs a composting step as final processing*
[24] *https://www.gurobi.com/*

For this study all specifics defined in section 2.3 have been transcripted into the customised shell code of the MooV model. Such specifics include amongst others:

- The addition of parameters related to describing the specific relationships between harvesting location and closest short-term storage location;
- The addition of parameters defining the demand of a specific end-processing facility considering location, type and moment in the year.

The parameters and their values are collected via partners and/or literature review. The advantage of such a shell-approach is that case-specific data can be easily added, changed or removed without having to modify the core configuration of the model. This approach allows for the flexibility to perform a variety of scenario-analyses; or to swiftly use the same model later to assess comparable cases in the future.

2.4.2 Mobilisation objective & constraints

To assess mobilisation strategies for grass cuttings in Flanders, MooV approaches the problem as a multi-stage capacitated facility location planning problem[25] in which at each site or activity the grass characteristics can change due to harvesting, storage, pre-processing and processing operations. Next the problem is translated to mathematical linear relationships - i.e. a model - in which the goal is to find the optimal mobilisation strategy at least cost (the objective) while fulfilling case-specific requirements (the constraints)[26].

The goal is to find the optimal mobilisation strategy to meet a specific demand for grass feedstock at least cost - while fulfilling case-specific requirements.

2.4.2.1 Objective function(s)

The objective function is a combination of mathematical equations dictating that the mobilisation costs must be minimised while meeting a set of constraints and relationships between the decision variables[27]. Each combination of decision variables is a potential solution. However, only the combinations that meet the constraints are feasible. With solver techniques the optimal combination is calculated.

[25] *Melkote, S., and Daskin, M. Capacitated facility location/network design problems. European Journal of Operational Research 129 (2001), 481–495.*

[26] *The MILP model is an extension of the model described in DE MEYER, A., CATTRYSSE, D., VAN ORSHOVEN, J. (2015). A generic mathematical model to optimise strategic and tactical decisions in biomass based supply chains (OPTIMASS). European Journal of Operational Research, 245 (1), 247 - 264.*

[27] *Alternatively, next to costs also environmental (e.g. emissions) or social (e.g. jobs) objectives can be minimised or maximised.*

So, the main objective is to minimise the **total mobilisation cost** which includes:

- Cost for harvesting[28]
- Cost for pre-treatment
- Cost for long-term storage
- Cost for transport

Additionally, the **total transport distance** and **the total vehicle movements** are calculated.

2.4.2.2 Constraints

The constraints reflect the limitations and conditions under which the grass supply chain operates. These constraints are sourced from previous projects[29] and expert knowledge.[30] The most important constraints are listed below.

- **Physical constraints** (e.g. capacity, feedstock quality or origin) imposing limitations on the allowable combinations between feedstock and activities, between activities mutually, and on the allowed activities at the primary feedstock locations, storage locations and end-processing locations.
  - Example 1: for scenario TO-BE 4 (see section 2.5) – only grass from nature reserves is allowed for the biomaterials. This constraint links the feedstock quality with the end-product; as litter risk for nature reserve grass is low – while sensitivity towards litter for biomaterials is high.
  - Example 2: flail mowing is constrained (not allowed) as a harvest option for nature reserve grassland. So, while from least-cost perspective, flail mowing would be preferential - as it is cheaper than rotary mowing - still nature reserves will be rotary mowed due to the enforced constraint.
- **Product conversion constraints** defining the conversion of a product into another product due to an activity (harvesting, pre-processing, storage or end-processing);
  - Example: when grass is stored and ensilaged, it changes from fresh grass into silage including a change in moisture content, bulk density, etc.
- **Network flow constraints** define the mass (and volume) flows between i) harvest location and end-processing location, ii) between harvest location and storage location and iii) between storage location and end-processing location (Figure 14). An additional flow occurs between end-processing locations. This is the case for digestate from landfill-AD (end-processing 1) which is moved to composting (end-processing 2). This movement is necessary as digestate from landfill-AD cannot be directly applied and requires further processing.
- **Long-term storage constraints** as grass is a degradable product, proper long-term storage maintains its quality to meet the end-product requirements. So, when not immediately processed after harvest, a constraint dictates that, road side cuttings must be ensiled, and nature grass must be baled.

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[28] *These costs parameters where described in Section 3.2*
[29] *Non-limitative: Grasgoed, Graskracht, Grassification.*
[30] *Note these constraints can be easily changed in case new insights emerge.*

2.5 DELIVER – The mobilisation results

Now the grass case is correctly defined (Section 2.3) and the MooV model is designed for the case optimisation accordingly (Section 2.4), this section describes the different mobilisation scenarios and their results.

2.5.1 Overview

2.5.1.1 Mobilisation scenarios

The AS IS scenario reflects the current situation for processing grass cuttings, i.e. green composting and processing of a part of nature grass towards feed. This scenario sets the baseline for total mobilisation cost and other KPIs (total mileage and vehicle movements).

The TO BE scenarios, in the following sections, investigate potential future scenarios. Each scenario differs in i) type of end-processes, ii) the capacity of the end-processes and/or iii) the allowed feedstock quality for the end-process. This differentiation allows to test the impact on mobilisation cost of each scenario. Table 9 shows the overview of the investigated mobilisation scenarios which are further detailed in the next sections.

Table 9: Overview of investigated mobilisation scenarios[31].

		END – PROCESSING				
		Compost (Green)	Compost (VFG)	Landfill digestion	Feed	Material applications
SCENARIO	AS IS	✓ (17%)	✗	✗	✓	✗
	TO BE 1	✓ (30%)	✓ (10%)	✗	✓	✗
	TO BE 2	✓ (30%)	✓ (10%)	✓	✓	✗
	TO BE 3	✓ (20%)	✓ (10%)	✗	✓	✓
	TO BE 4	✓ (20%)	✓ (10%)	✗	✗	✓ (NAT)
	TO BE 5	✓ (20%)	✓ (10%)	✗	✗	✓ (NAT+HW)

[31] *% = the proportion of grass cuttings in the total input of the composting facility*

2.5.1.2 KPIs – Key Performance Indicators

In the sections below the KPIs are 'cost', 'mileage' and 'vehicle movements' can be found in the result tables. The indicators are to be interpreted as follows:

- ***Cost:*** *expresses the total mobilisation cost - including harvest, storage and transport (Figure 5)*
- ***Mileage:*** *expresses the total travel distance to deliver the harvested grass at the gate of the end-processor. The mileage includes i) travel from harvesting site to the closest short-term storage, ii) from short-term storage to long-term storage or end-processors and iii) from long-term storage to end-processing.*
- ***Vehicle movements:*** *expresses the number of transport movements (by tractor or truck) to mobilise the grass from the harvest locations to the end-processors*
- ***Used NAT / AWV / MUN (%):*** *expresses the percentage of the technical harvestable potential being mobilised – from NAT, AWV, MUN verges respectively*

2.5.2 AS IS scenario – Composting

This scenario starts from the total technical harvestable grass quantity of 427.000 tonnes fresh matter per year (Table 6) of which 262.000 tonnes verge grass and 165.000 tonnes nature grass.

The AS IS scenario reflects the dominant current practice (Figure 15). This means, verge grass being mainly composted at green composting sites while nature reserve grass is either used as feed or composted at green composting sites.

For nature reserve grass it is assumed that circa 60% or 95.000 tonnes is being directly used as feed each year.[32] [33]

About 82.000 tonnes of grass cuttings are green composted[34]. As the total green composting capacity is circa 492.000 tonnes per year [35], the grass input equals 17% the total green composting capacity. This results in 250.000 tonnes of cuttings left unharvested, unused, or exported.

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[32] *Source: Natuurpunt (2020)*

[33] *Action Plan Biomass(residual)streams (2015-2020) – grass cuttings from nature reserves often finds an application as feed*

[34] *Source: OVAM (2020)*

[35] *Source: OVAM (2020)*

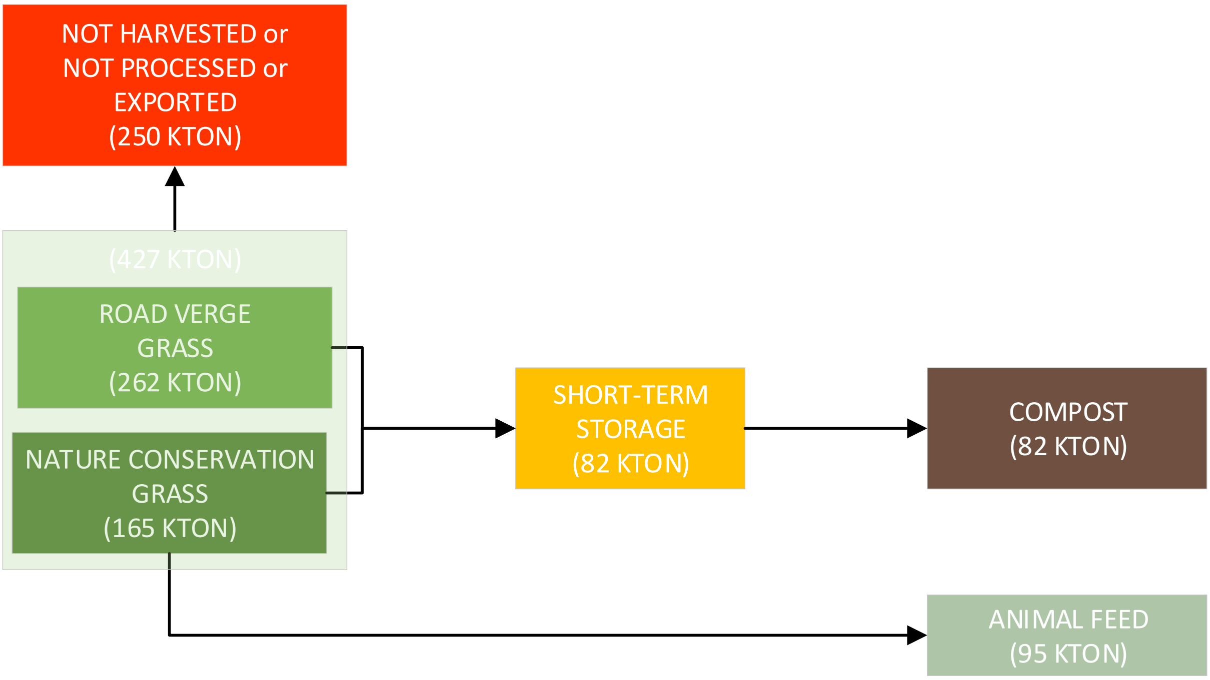

Figure 15: AS IS SCENARIO: Process flow diagram and technical potential.

Note that the AS IS scenario can only be assessed from the assumption that current mobilisation is optimally organised (i.e. *best practice*) while the *actual practice* is most probably sub-optimally organised.

- For the *best case* it is assumed that the grass is mobilised at minimal cost to meet the demand from the green composting sites. This means that;
  - i) the model choses municipal verge grass to feed composting sites, as it comes at the lowest harvest cost and is abundantly available; and
  - ii) that verges nearest to the respective composting sites are being harvested first, as this comes at the lowest transport cost.

However, these *best practice* assumptions – and thus the baseline costs - most probably reflect a more positive situation than actual practice.

- For the *actual case* no information is available. It can however be expected that not always verges are harvested at lowest cost and that not always the verges nearest to the composting sites are being harvested. As such it is likely that the *best case* AS IS scenario underestimates the mobilisation cost vis-à-vis the *actual case*.

Figure 16 shows the cost optimal supply chain configuration map of the AS IS scenario with the sourcing area for 82.000 tonnes grass (grey), the selected optimal short-term storage sites (red) and the green composting installations (green). Bird flight lines indicate transport routes (black interconnectors), however transport distances have been calculated via the actual road network.

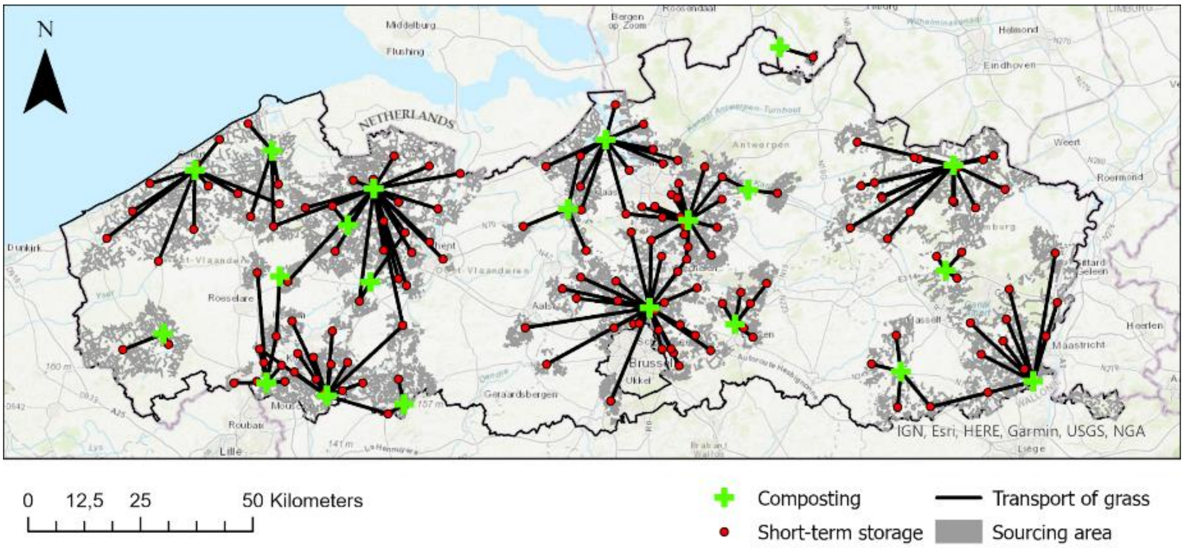

Figure 16: AS IS SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the AS IS scenario are summarised in Table 10. These results are the baseline reference to be benchmarked with the TO BE scenarios (see section 2.5.3 - 2.5.7). To be able to compare the scenarios, the 3 KPI's (Section 2.3.1.3) are expressed per tonne of harvested (and mobilised) grass per year:

- The minimised mobilisation cost is **50 € per tonne of harvested grass**, to meet the demand of the green composting facilities;
- In the AS IS situation, the minimised mileage is **1,9 km per tonne of harvested grass**;
- The mobilisation requires **0,21 vehicle movements per tonne of harvested grass**.
- From the cost perspective, the origin of the grass (NAT / AWV / MUN) mainly impacts the harvesting costs (Table 6). In the AS IS scenario only verge grass from municipal roads is harvested and transported to the green composting sites because flail mowing (without safety cars) is preferential - as it is cheaper than rotary mowing (Table 6) – and MUN grass is abundantly available (191.000 tonnes available vs. 82.000 tonnes demand (or 43% is used)).

Table 10: AS IS SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	50	+ 0
Mileage (km)	1,9	+ 0
Vehicle movements (#)	0,21	+ 0
Used NAT / AWV / MUN (%)	57 / 0 / 43	+ 0 / + 0 / + 0

2.5.3 TO BE 1 scenario - Increased composting

In the TO BE 1 scenario, the demand for grass cuttings by green composting is increased to 30 % or 171.000 tonnes of grass per year. In addition, the demand from garden, fruit and vegetable waste (GFV) composting sites is set to 10% of their capacity or about 23.000 tonnes (Figure 17). In total composting sites take in 194.000 tonnes of grass.

Note that for this scenario, long-term storage is foreseen to buffer a constant year-round supply to the composting facilities. If not, to attain an overall yearly percentage of 30%, composting sites would need to take in peaks way above 30% during harvest season – as no grass is available during winter season - which is not feasible for composting sites.

Nature grass remains being used for feed at a 57% ratio or 95.000 tonnes.

This results in a remaining 138.000 tonnes of grass which is unharvested, unused, or exported.

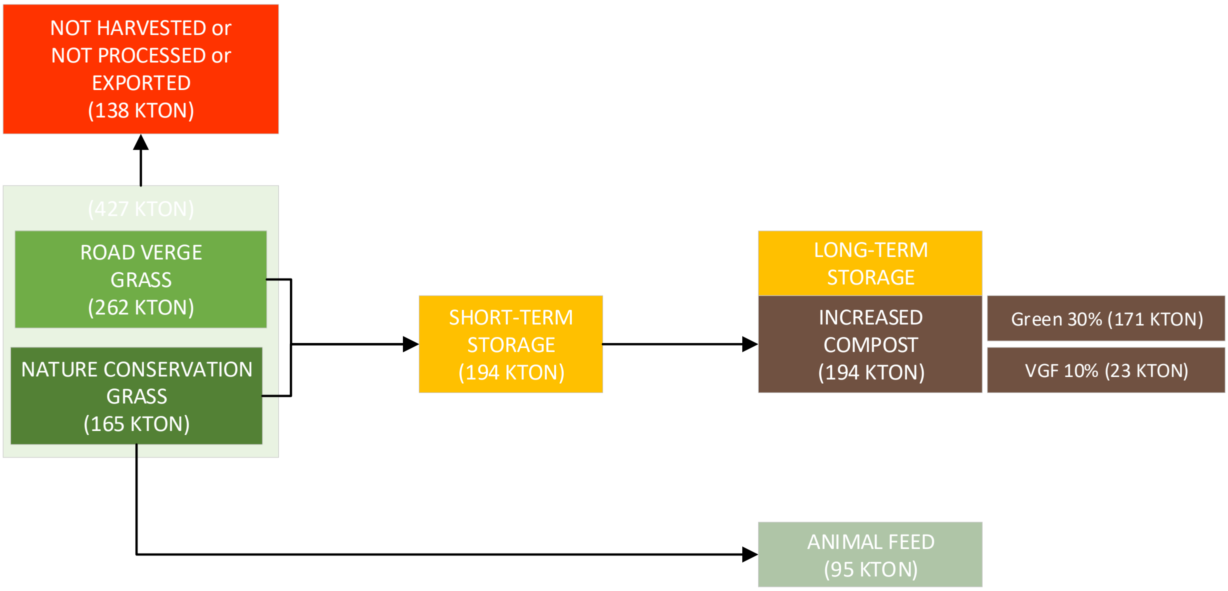

Figure 17: TO BE 1 SCENARIO: Process flow diagram and technical potential.

Figure 18 shows the cost optimal supply chain configuration of the TO-BE 1 scenario with the sourcing area for the 194.000 tonnes grass (grey), the optimal short-term storage sites (municipal - red dots and AWV - green dots), the composting installations (green - light green cross and VFG - dark green cross). Bird flight lines indicate transport routes (black interconnectors), however transport distances have been calculated via the actual road network. Note that the sourcing areas have increased significantly to meet increased demand.

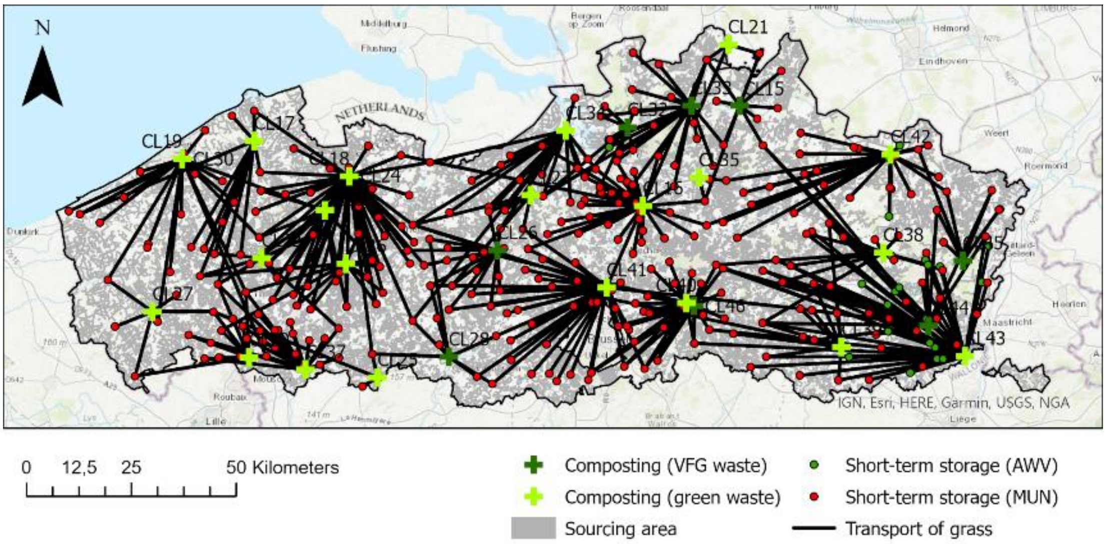

Figure 18: TO BE 1 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 1 situation are summarised in Table 11:

- The minimised mobilisation cost is **51 € per tonne of harvested grass**, to meet the increased demand at the composting facilities, or a marginal increase with 3% in comparison to the AS IS scenario;
- In the TO BE 1 situation, the mileage counts up to an average of **2,8 km per tonne of harvested grass** or an increase with 43% in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 18, showing that the sourcing area covers the whole region of Flanders;
- The mobilisation requires **0,22 vehicle movements per tonne of harvested grass** or a marginal increase with 0,3% in comparison to the AS IS scenario.
- In this scenario **most verge grass from municipal roads** has been harvested (99%) complemented by verge grass from AWV to meet the demand at the gate of the composting facilities. As feedstock type, grass from municipal roads is preferred as it is abundantly available and cheapest to harvest.

Table 11: TO BE 1 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	51	+ 3 %
Mileage (km)	2,8	+ 43 %
Vehicle movements (#)	0,22	+ 0,3 %
Used NAT / AWV / MUN (%)	57 / 5 / 99	+ 0 % / + 5 % / + 57 %

2.5.4 TO BE 2 scenario – Increased composting / landfill-AD

This scenario builds on the TO BE 1 scenario. The increased intake of grass by composting installations is kept at 30% for green compost and 10% for VGF compost[36]; with a demand of 194.000 tonnes per year. Nature grass remains being used for feed at 57% or 95.000 tonnes per year.

However, the TO BE 2 scenario envisions all existing landfills operating as grass landfill-AD sites. This technology is under investigation in the Interreg-project Grassification for the Vanheede landfill in West-Flanders.

This scenario adds all 12 existing landfill sites as potential landfill-AD sites with a grass intake calculated proportional to the Vanheede case. The total intake sums 110.000 tonnes per year, which is converted to circa 20.000 tonnes biogas and 90.000 tonnes digestate per year. The digestate must be further processed into compost before it can be used as soil improver.

From perspective of the composting sites this means they only need to take in 104.000 tonnes of fresh cut grass, as 90.000 tonnes digestate needs to be composted as well (Figure 19).

This results in 118.000 tonnes of grass cuttings left unharvested, unused or exported per year.

Also, in this scenario, long-term storage is needed at the composting facilities to ensure the availability of year-round grass cuttings. At the landfill-AD sites no long-term storage is needed. Grass is directly digested after harvest to ensure highest biogas levels; hence no long-term storage activities are needed.

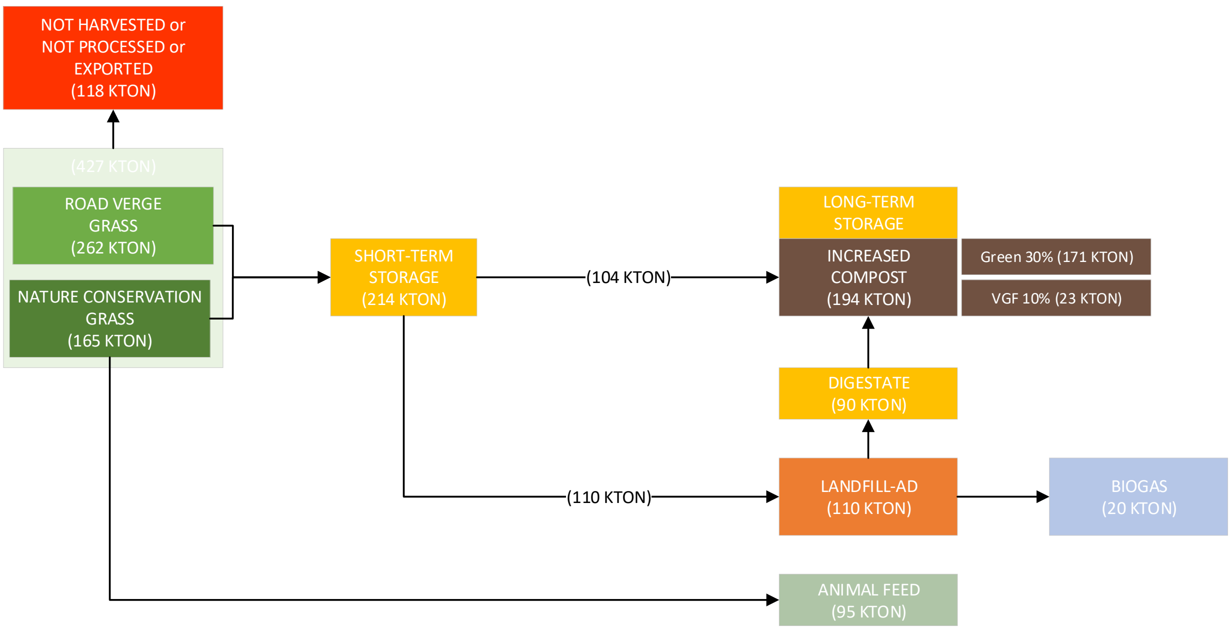

Figure 19: TO BE 2 SCENARIO: Process flow diagram and theoretical potential.

[36] *Full scale tests indicate even up to 25% of VGF waste can be replaced with verge grass. (source: OVAM -Action Plan Sustainable management of biomass streams 2015-2020)*

Figure 20 shows the cost optimal supply chain configuration of the TO-BE 2 scenario with the sourcing area for the 214.000 tonnes grass (grey), the landfill-AD's (black), the optimal short-term storage sites (municipal – red dots and AWV – green dots) and the composting installations (green – light green cross and VFG – dark green cross)

Bird flight lines indicate transport of fresh grass to composting and landfill-AD sites (black interconnectors) and digestate transport form landfill-AD sites to composting sites (green connectors). This time the sourcing area increased slightly vis-à-vis scenario TO BE 1 as demand increased with 20.000 tonnes. Note that digestate is transported over longer distances to be processed into compost.

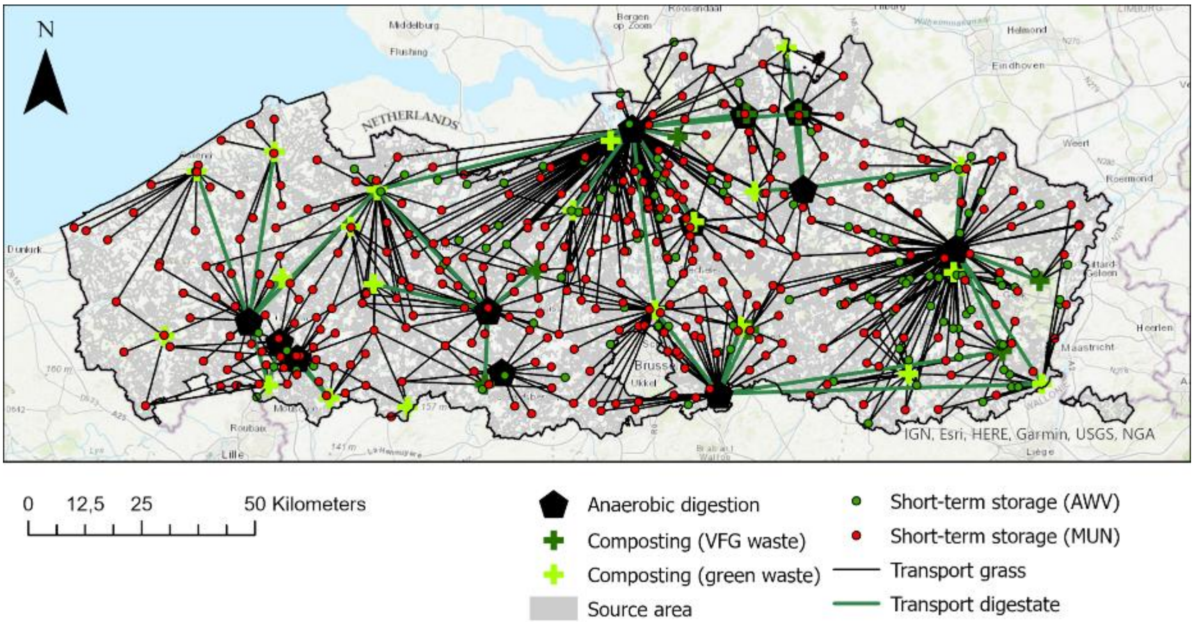

Figure 20: TO BE 2 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 2 scenario are summarised in Table 12, focussing on the KPI's for the mobilisation of the grass, excluding the activities related to digestate:

- The minimised mobilisation cost is **45 € per tonne of harvested grass**. This is a decrease with 9 % in comparison to the AS IS scenario. This is directly related to the increased grass processing capacity at time of harvesting (thanks to landfill-ADs) which reduces the need for storage and treatment of fresh grass. In addition, transport of grass from short-term storage to end-processing site occurs more efficiently (~ reduced number of vehicle movements);
- In the TO BE 2 situation, the mileage counts up to an average of **2,6 km per tonne of harvested grass** or an increase with 37 % in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 20, showing that the sourcing area covers the whole region of Flanders;
- The mobilisation requires **0,20 vehicle movements per tonne of harvested grass** or a decrease with 7 % in comparison to the AS IS scenario. The reduction can only be assigned to the transport movements from short-term storage to end-processing sites and long-term sites, indicating an increase in the efficiency of truck transport (i.e. increase in load factor).

- Also, in this scenario **most verge grass from municipal roads** has been harvested (99%) complemented by verge grass from AWV to meet the demand at the gate of the composting facilities. Again, the preferred grass type is grass from municipal roads as it is abundantly available at cheapest harvest cost.

Table 12: TO BE 2 SCENARIO: Summary of the MooV result (fresh grass).

KPIs	Per tonne harvested grass	Compared to AS IS
Cost (€)	45	- 9 %
Mileage (km)	2,6	+ 37 %
Vehicle movements (#)	0,20	- 7 %
Used NAT / AWV / MUN (%)	57/ 37 / 99	+ 0 % / + 37 % / + 57 %

Within this TO BE2 scenario, the digestate, produced at the landfill-AD sites, must be further processed into compost at the composting facilities before it can be used as soil improver. The mobilisation of the digestate (green connectors in Figure 20) also comes at a cost (Table 13), i.e. 35 € per tonne digestate. The digestate is transported to the closest composting site, considering its available capacity. This limits the mileage to 1,2 km per tonne digested to be transported, requiring 0,07 movements per tonne digestate.

Table 13: TO BE 2 SCENARIO: Summary of the MooV result (digestate).

KPIs	Per tonne digestate
Cost (€)	35
Mileage (km)	1,2
Vehicle movements (#)	0,07

Considering the total cost for mobilisation of fresh grass and digestate (Figure 21), the **TO BE 2 scenario reduces the total mobilisation cost with 15% in comparison to the AS IS scenario**. This reduction is explained by:

- the reduced harvesting costs per tonne demand, since digestate is used to meet a part of the demand at the composting sites;
- the increased grass processing capacity at time of harvesting reducing the need for storage and treatment of fresh grass; and
- transport of fresh grass from short-term storage to end-processing site occurs more efficiently.

These cost reduction overcompensate the additional costs for mobilising the digestate.

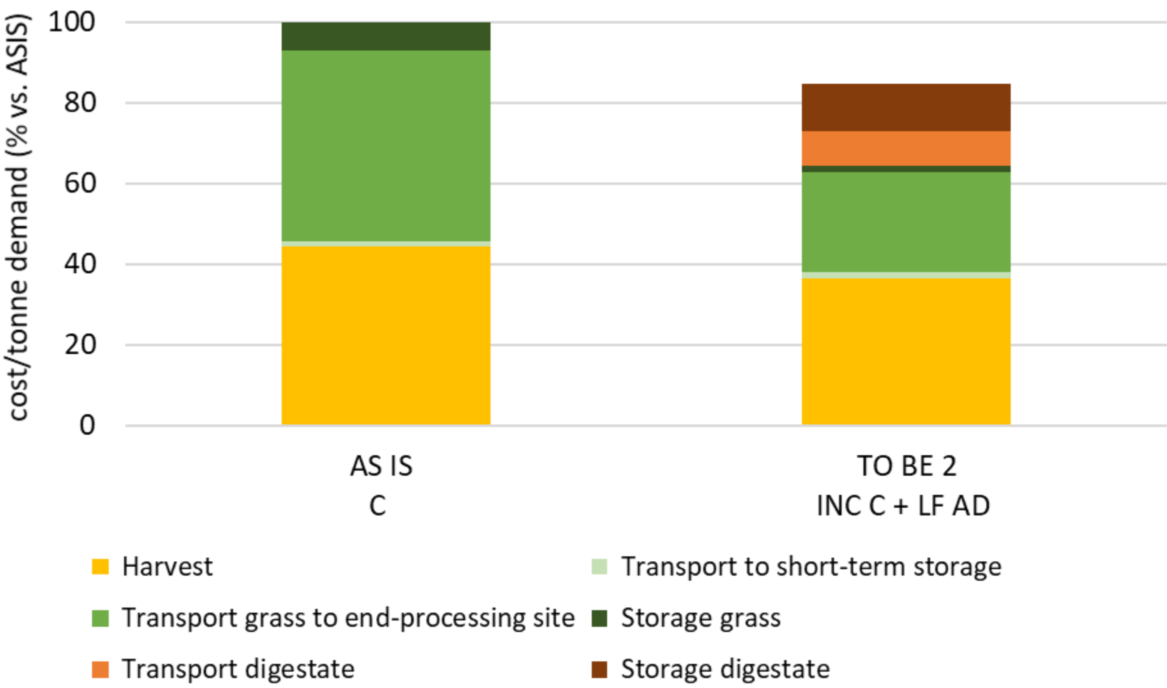

Figure 21: TO BE 3 SCENARIO: Comparison of total cost (mobilisation of grass and digestate) per tonne demand at the gate of the end-processing sites.

2.5.5 TO BE 3 scenario – Increased composting / biomaterials

As for the previous scenarios, also this scenario assumes increased grass composting. However, green composting demand is reduced from 30% to 20% (or 114.000 tonnes per year) which is only a slight increase vis-a vis the AS-IS scenario of 17%. For VGF composting the input was kept at 10% or 23.000 tonnes per year; leading to a total annual demand of 137.000 tonnes. Nature grass remains being used for feed at 95.000 tonnes per year.

However, freed up potential by reducing green composting demand is now used for biomaterials. This scenario is in line with the ambition of the *Flemish Action Plan Sustainable management of biomass streams 2021-2025* to increase grass processing towards materials.

A variety of biomaterials is possible. Notwithstanding the relevance of any other biomaterials, the following biomaterials have been selected for this scenario:

- grass fibres for insulation materials (cf. Gramitherm[37]);
- grass fibres for paper production (cf. Stora Enso – currently working with recycled paper);
- grass fibres for composite materials (cf. Circular Matters).

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[37] Note: the referenced companies were contacted to capture realistic orders of magnitude on processing scale for such applications. However, data do not reflect individual company data, nor company ambitions. Data reflect a generic interpretation of what could be a realistic scale for such applications.

Table 14 shows the total fresh grass demand for the aforementioned biomaterials. The total demand sums to 188.000 tonnes per year divided over 91.000 tonnes for insulation material, 82.000 tonnes for paper production and 15.000 to produce extruded composite materials. The production capacity shows the total tonnes of end-product for one site. The column 'grass fibres' expresses the (assumed) percentage of grass fibres used in each material. Combination of production capacity and fibre percentage leads to the dry matter demand, considering a dry matter content of 33%.

Given their scale it was opted to allow only one insulation and one paper production site. Since demand from composite materials is proportionately relatively low; the scenario allows for five such sites. This set-up allows for biomaterial production in co-existence with composting. Obviously, this is only one of numerous potential set-ups, variations are possible as well.

For the location of the biomaterial sites, commercial scale sites do not yet exist to our knowledge. Their locations were chosen with the following rational;

- Biomassaplein (Houthalen) for the insulation material as this site has the ambition to become a collection point of biomass streams;
- Stora-Enso Langerbrugge for paper as this site already processes recycled paper;
- Flemish Province capitals (5) for composites; as currently one site is operational in Leuven and the scale of these sites allows for a production site on provincial level at least.

Table 14: Capacity & demand from biomaterials.

	Production capacity per site	***Grass fibres***	***Demand per site***		***Number of sites***	***Demand total***
	tonne/y	*%*	*tonne DM/y*	*tonne FM/y*	*#*	*tonne FM/y*
Insulation	50.000	60%	30.000	91.000	1	**91.000**
(Recycled) paper	540.000	5%[38]	27.000	82.000	1	**82.000**
Composite[39]	5.000	20%	1.000	3.000	5	**15.000**

Given demand for compost, feed and biomaterials, virtually all harvestable grass is processed in Flanders, with a marginal leftover of 7.000 tonnes. (Figure 22).

In this scenario, long-term storage is needed at compost as well as the biomaterial sites to ensure continuous feedstock availability.

This scenario disregards the fact that biomaterial processing is sensitive to litter contamination. While verge grass is more likely to be littered, either it will be costlier to clean to an acceptable quality or, if cleaning would proof to costly, grass from verges would need to be excluded from biomaterial applications. Such a scenario will be investigated in the next sections (2.5.6 and 2.5.7).

[38] Personal assumption

[39] e.g. extruded materials such as 3D-printing or panels

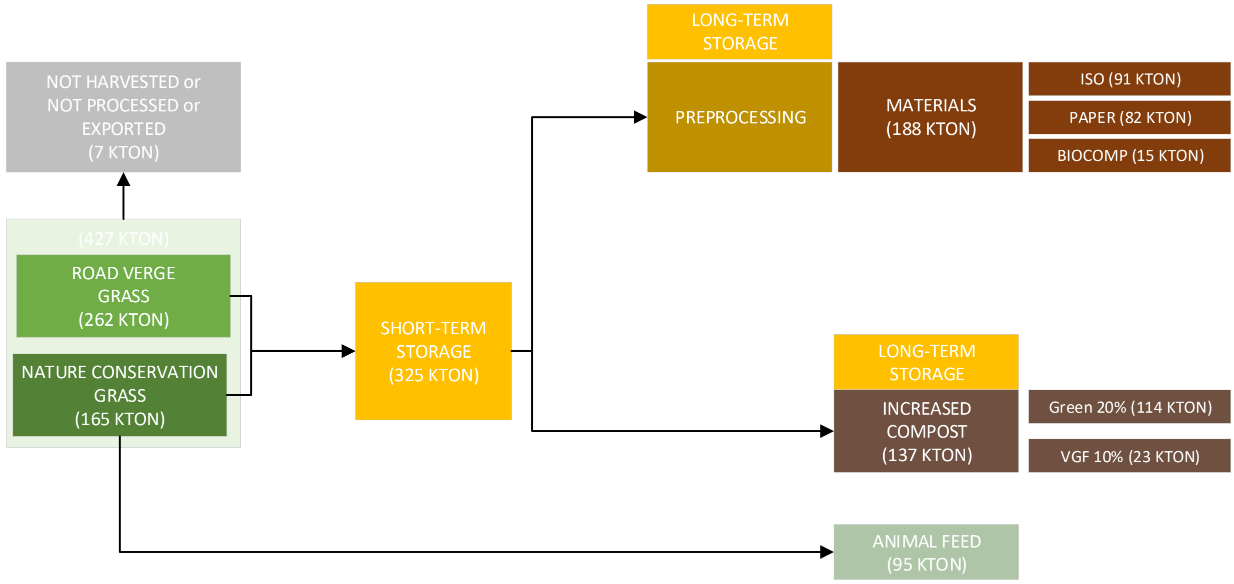

Figure 22: TO BE 3 SCENARIO: Process flow diagram and theoretical potential.

Figure 23 shows the cost optimal supply chain configuration of the TO-BE 3 scenario with the sourcing area for the 325.000 tonnes grass (grey), the optimal short-term storage sites (municipal - red dots and AWV - green dots), the composting installations (light green cross) and the biomaterial sites (yellow). Again, bird flight lines indicate transport routes (black interconnectors), while actual transport distances have been calculated via the actual road network.

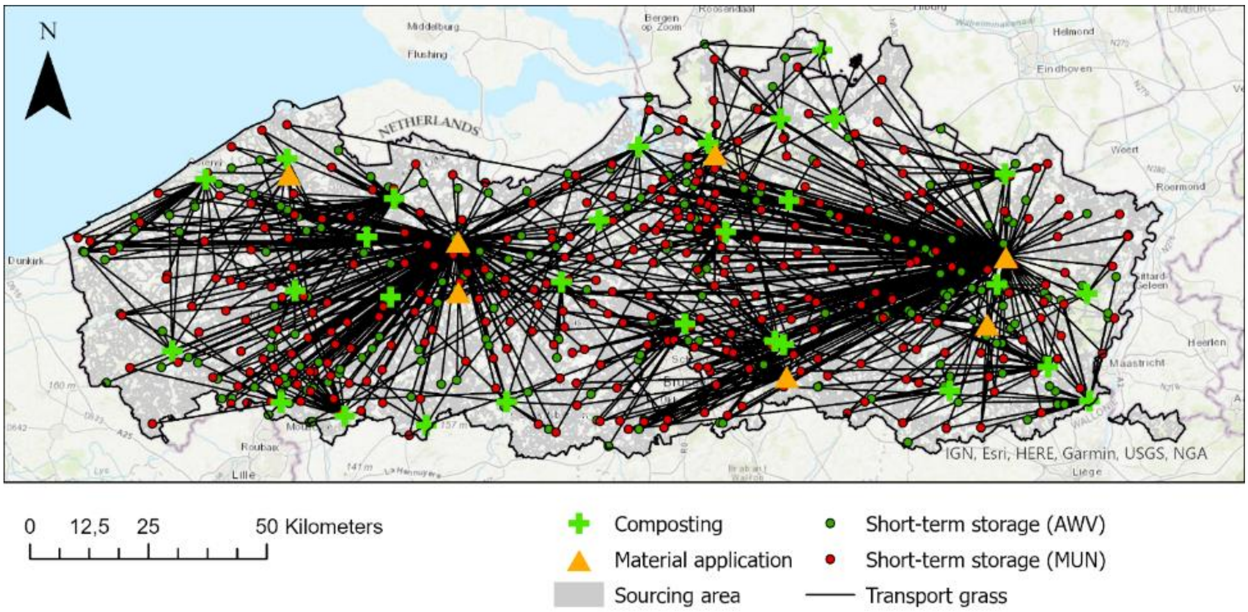

Figure 23: TO BE 3 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 3 scenario are summarised in Table 15:

- The minimised mobilisation cost is **71 € per tonne of harvested grass**. This is an increase with 43 % in comparison to the AS IS scenario. This significant increase is directly related to the fact that virtually all harvestable grass must be processed in Flanders, given the demand for compost, feed and biomaterials. This increase is mainly attributable to the increased harvesting costs since nature grass and verge grass from AWV must be harvested as well, against higher cost per tonne in comparison to harvesting verge grass from municipal roads (Table 6);
- In the TO BE 3 situation, the mileage counts up to an average of **3,7 km per tonne of harvested grass** or an increase with 93 % in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 23, showing that the sourcing area covers the whole region of Flanders. On the other hand, grass is transported over large distances towards Biomassaplein (i.e. insulation) and Stora-Enso (recycled paper) to meet the high demand for grass clippings (Table 14);
- The mobilisation requires **0,21 vehicle movements per tonne of harvested grass** or a status quo (decrease with 0,2 %) in comparison to the AS IS scenario;
- Given demand for compost, feed and biomaterials, virtually all harvestable grass is processed in Flanders, with a marginal leftover of 7.000 tonnes (of nature grass). Verge grass from municipal roads is still the preferred grass type due to the lower harvesting costs. Verge grass from AWV is preferred over nature grass since nature grass is more fragmented and the constraint that within a region about 57% of the nature grass must be used for feed.

Table 15: TO BE 3 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	Compared to AS IS
Cost (€)	71	+ 43 %
Mileage (km)	3,7	+ 93 %
Vehicle movements (#)	0,21	- 0,2 %
Used NAT / AWV / MUN (%)	89 / 99 / 100	+ 32 % / + 99% / + 57 %

2.5.6 TO BE 4 scenario – Increased composting / biomaterials only with nature grass / no feed

This scenario builds on the previous one, but with further restrictions. Still, increased grass composting is assumed; with 20% of green composting (or 114.000 tonnes per year) and 10% of VGF composting (or 23.000 tonnes per year). This leads to a total demand of 137.000 tonnes per year at the composting sites. The demand for grass fibres for biomaterial applications is kept at the same level as TO BE scenario 3, being 188.000 tonnes of fresh grass per year, which reflects a commercial production scale (Table 14).

However ongoing and past grass refinery projects, such as Grassification and Graskracht, reported that material applications have a strong preference for high quality grass. Specifically, for biomaterial applications litter is to be avoided; and if it should be present, needs to be removed in pre-treatment steps. However, these steps come at an additional cost. As material applications are currently entering the market it is assumed that these applications will initially hold a strong preference for grass with minimal risk of being littered. Table 5 assumed that grass from nature reserves holds the lowest risk for littering[40]. Following this rational only grass from nature reserves is allowed for biomaterials in this scenario.

Under previous scenarios a 57 % feed rate, or 95.000 tonnes per year, has been assumed for nature grass out of the 165.550 tonnes per year in total. This would leave only 70.550 tonnes available for biomaterial production – clearly not meeting the demand of 188.000 tonnes per year.

As the nutritional value of nature grass is assumed rather low and the production of biomaterials is higher ranked on the cascading hierarchy, for this scenario the nature grass is prioritised for biomaterial production at the expense of feed application.

This opens the potential for biomaterials from nature grass to the full 165.550 tonnes fresh matter per year which roughly matches the 188.000 tonnes of demand for biomaterial applications. The remaining deficit of 23.000 tonnes per year is assumed to be imported nature grass areas from neighbouring regions.

Note that as road verge grass is not accepted for biomaterials, due to its higher litter risk. As the demand from composting (137.000 tonnes per year) is lower than the road grass offer (262.000 tonnes per year); circa 125.000 tonnes per year will be left not harvested, not processed or exported.

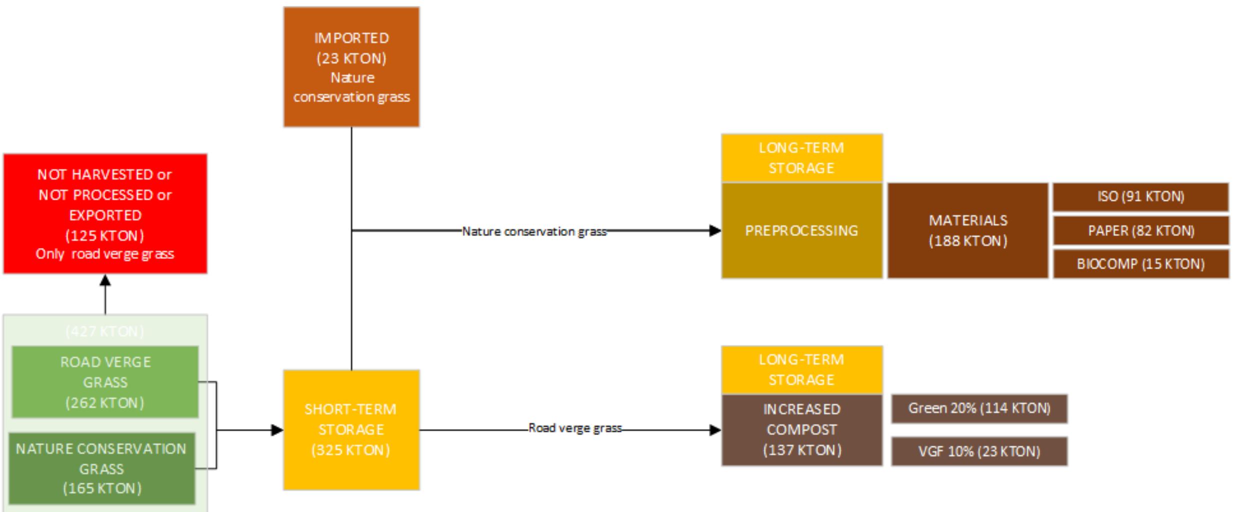

Figure 24: TO BE 4 SCENARIO: Process flow diagram and theoretical potential.

[40] This scenario is in line with the Flemish Action Plan Sustainable management of biomass streams 2021-2025 which sets the ambition to 'in 2025 at least 30.000 ton nature reserve grass cuttings (fresh matter) is treated towards material applications (next to composting).

Figure 25 shows the map of the TO-BE 4 scenario with the sourcing area for a total of 302.000 tonnes grass (grey), the optimal short-term storage sites (municipal – red dots), the composting installations (green – light green cross and VFG – dark green cross) and the biomaterial sites (yellow).

The imported 23.000 tonnes were divided over all biomaterial producers pro-rata their respective capacities. Since this study focuses on the mobilisation of grass in Flanders, the KPI's related to the imported grass are excluded from the assessment.

Identical to scenario TO BE 3, the following locations for biomaterial sites have been chosen: Biomassaplein (Houthalen) for the insulation material, Stora-Enso (Langerbrugge) for paper and the Flemish Province capitals (5) for composites.

Bird flight lines indicate transport routes (black interconnectors), however transport distances have been calculated via the actual road network.

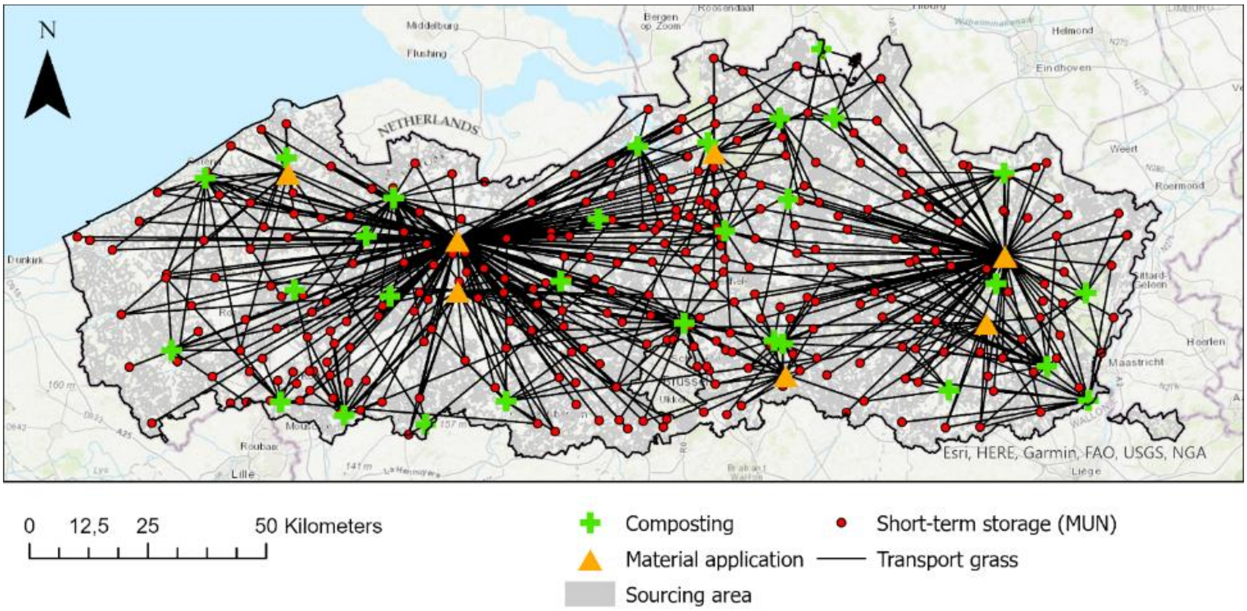

Figure 25: TO BE 4 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 4 situation are summarised in Table 16:

- The minimised mobilisation cost is **58 € per tonne of harvested grass**, to meet the increased demand at the composting facilities, or an increase with 17% in comparison to the AS IS scenario. The increase mainly relates to higher harvesting costs to harvest grass from nature reserves and highways (for biomaterial application) in comparison to the harvesting of verge grass from municipal roads (for composting). Additionally, the transport costs for transport between short-term storages and end-processing facilities is higher since more grass is required for the biomaterial applications: insulation (Biomassaplein in Houthalen) and recycled paper (Stora-Enso in Langerbrugge));
- In the TO BE 4 situation, the mileage counts up to an average of **3,1 km per tonne of harvested grass** or an increase with 63% in comparison to the AS IS scenario. This increase is also reflected in Figure 25, showing the longer distance transports towards Biomassaplein in Houthalen (insulation) and Stora-Enso in Langerbrugge (recycled paper);

- The mobilisation requires **0,16 vehicle movements per tonne of harvested grass** or a decrease with 24% in comparison to the AS IS scenario. This decrease can be completely attributed to a reduction in movements related to the harvesting activity due to the higher loading capacity for harvest in nature reserves (Table 6);
- In this scenario **all grass of nature reserves** has been harvested for processing towards biomaterials, complemented by verge grass from municipal roads to meet the demand at the gate of the composting facilities. Note that AWV short-term storage sites are not used in this scenario. Verge grass is not allowed for bio-material production but is available for composting. However composting sites will attract grass at minimal mobilisation cost. As mobilisation cost for AWV verge grass is highest (Table 6), municipal verge grass is preferred and sufficiently available.

Table 16: TO BE 4 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	Compared to AS IS
Cost (€)	58	+ 17 %
Mileage (km)	3,1	+ 63 %
Vehicle movements (#)	0,16	- 24 %
Used NAT / AWV / MUN (%)	100 / 0 / 71	+ 43 % / + 0% / + 28 %

2.5.7 TO BE 5 scenario – Increased composting / biomaterials only with nature & highway grass / no feed

Also, this scenario assumes increased grass composting; with 20% of green composting capacity (or 114.000 tonnes per year) and 10% of VGF composting (or 23.000 tonnes per year). This leads to a total demand of 137.000 tonnes per year. Also, in this scenario nature grass is preferred for biomaterials in view of low litter risk; and biomaterials production is preferred over feed application. The biomaterial demand for grass fibres is kept at the same level as TO BE scenario 3 and 4, being 188.000 tonnes fresh matter in total (Table 14).

To mediate the nature grass shortage of the TO BE 4 scenario, which led to limited import, this time also grass from highway verges – with a medium litter risk (Table 6) – is assumed acceptable for biomaterials[41]. This opens an additional highway potential of 30.000 tonnes for processing towards biomaterials. This potential compensates for the import need of 23.000 tonnes in the TO BE 4 scenario. While no import is needed in this scenario also less grass is left not harvested, not processed or exported vis-à-vis scenario TO BE 4 (102.000 tonnes).

[41] Note that, for highway verges it was assumed that littering is more concentrated to the first meters adjacent to the road, while surfaces further away from the road side are less littered.

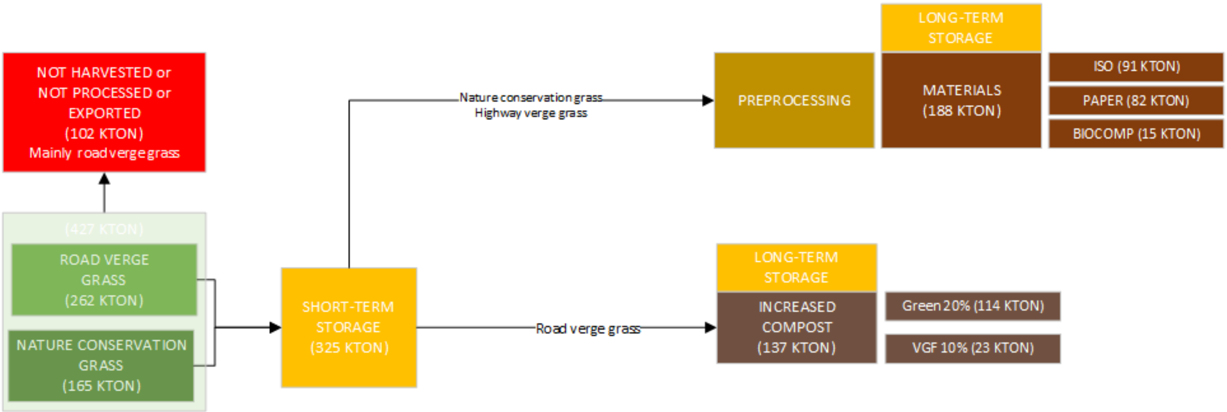

Figure 26: TO BE 5 SCENARIO: Process flow diagram and theoretical potential.

Figure 27 shows the map of the TO BE 5 scenario with the sourcing area for the 325.000 tonnes grass (grey), the optimal short-term storage sites (municipal - red dots and AWV - green dots), the composting installations (green - light green cross and VFG - dark green cross) and the biomaterial sites (yellow).

Opposite to scenario TO BE 4, this scenario allows for highway grass processing into bio-materials, so AWV short-term storage sites are opened again.

Like scenario TO BE 3 and TO BE 4, the following locations for biomaterial sites have been chosen: Biomassaplein (Houthalen) for the insulation material, Stora-Enso (Langerbrugge) for recycled paper and the Flemish Province capitals (5) for composites.

Bird flight lines indicate transport routes (black interconnectors), however transport distances have been calculated via the actual road network.

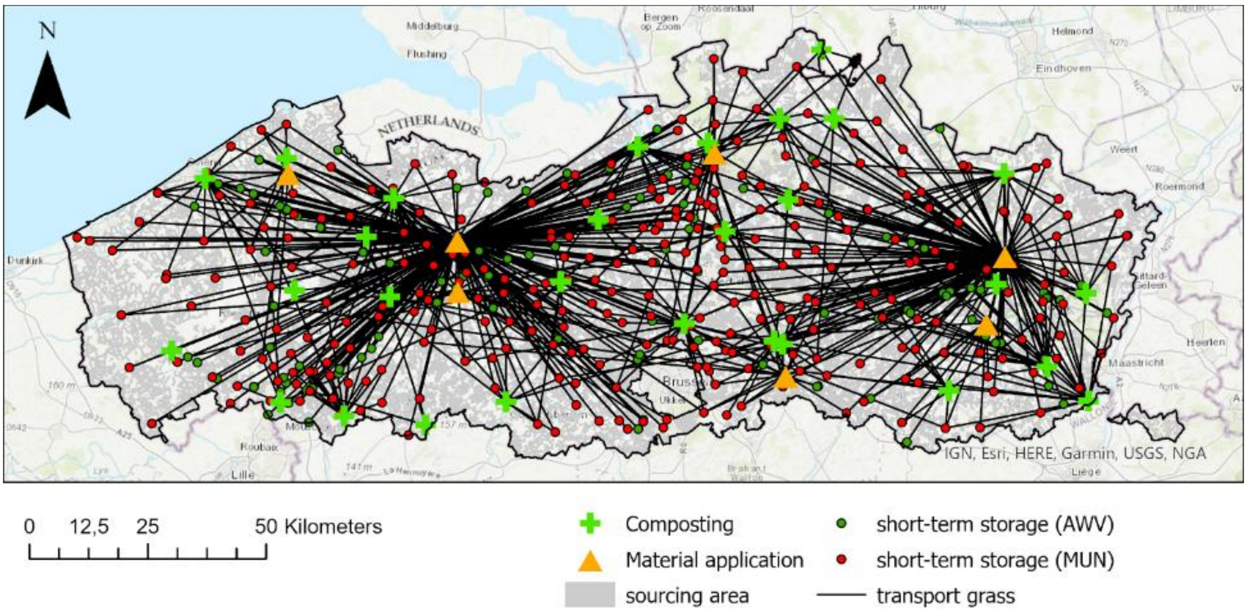

Figure 27: TO BE 5 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 5 situation are summarised in Table 17:

- The minimised mobilisation cost is **60 € per tonne of harvested grass**, to meet the increased demand at the composting facilities, or an increase with 20% in comparison to the AS IS scenario. The increase mainly relates to higher harvesting costs to harvest grass from nature reserves and highways (for biomaterial application) in comparison to the harvesting of verge grass from municipal roads (for composting). Additionally, the transport costs for transport between short-term storages and end-processing facilities is higher since more grass is required for the biomaterial applications: insulation (Biomassaplein in Houthalen) and recycled paper (Stora-Enso in Langerbrugge));
- In the TO BE 5 situation, the mileage counts up to an average of **2,9 km per tonne of harvested grass** or an increase with 50% in comparison to the AS IS scenario. This increase is also reflected in Figure 27, showing the long distance transports towards Biomassaplein in Houthalen (insulation) and Stora-Enso in Langerbrugge (recycled paper);
- The mobilisation requires **0,17 vehicle movements per tonne of harvested grass** or a decrease with 22% in comparison to the AS IS scenario. This decrease can be completely attributed to a reduction in movements related to the harvesting activity due to the higher loading capacity for harvest in nature reserves (Table 6);
- In this scenario **all grass of nature reserves as well as most verge grass from highways** has been harvested for processing towards biomaterials. This is complemented by verge grass from municipal roads to meet the demand at the gate of the composting facilities.

Table 17: TO BE 5 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	Compared to AS IS
Cost (€)	60	+ 20 %
Mileage (km)	2,9	+ 50 %
Vehicle movements (#)	0,17	- 22 %
Used NAT / AWV / MUN (%)	99 / 33 / 71	+ 42 % / + 33 % / + 28 %

2.5.8 The impact of different mobilisation strategies

In previous sections, each TO BE scenario has been compared to the AS IS scenario. To analyse the impact of the different mobilisation strategies, this section focusses on the comparison between TO BE scenarios mutually:

- Comparing the results of AS IS, TO BE 1 and TO BE 3 allows to define the impact of end-processing demand (Section 2.5.8.1);
- Comparing the results of TO BE 2 and TO BE 3 allows to define the impact of the "re-use of grass" as digestate (Section 2.5.8.2);
- Comparing the results of TO BE 3, TO BE 4 and TO BE 5 allows to analyse the impact of grass origin requirements at the end-processing site (Section 2.5.8.3).

In each section, the impact is defined for the 3 KPIs: grass mobilisation cost, mileage and number of transport movements.

2.5.8.1 Impact of end-processing demand

In the AS IS scenario, 82.000 tonnes of grass are processed in green composting facilities each year. This grass demand has been raised to 195.000 tonnes per year in TO BE 1 and to 325.000 tonnes per year in TO BE 3. Within these scenarios, the same constraints are considered which implies that these scenarios can be compared 1-on-1.

As mentioned previously, verge grass from municipal roads is preferred as it is abundantly available and cheapest to harvest (Figure 28 – left). When all harvestable grass from municipal roads has been depleted, verge grass from AWV is added in first order (TO BE 1) and nature grass in second order (TO BE 3).

Where only verge grass from municipal roads is mobilised (AS IS vs TO BE 1), the impact on the cost per tonne harvested grass is rather small (Figure 28 – right). However, when grass from AWV and nature reserves are mobilised as well, to meet demand (TO BE 3), the increase in cost per tonne is significant (>40%). This is mainly due to the higher harvest cost for nature and AWV grass vis-a-vis municipal grass. Note that these costs could/should be compensated through higher revenues at the gate – if higher quality grass is attained.

In addition to the increased harvesting costs, transport costs between short-term storage and end-processing sites also rise per tonne harvested grass. This because as demand increases, a larger sourcing area is needed, resulting in higher travel distances between storage sites and end-processing sites (Figure 29 - left).

The number of transport movements per tonne remains unchanged which indicates that the load factor is similar in all scenarios and the impact of increased demand on the load factor is limited. This is mainly due to the fragmented availability of grass clippings.

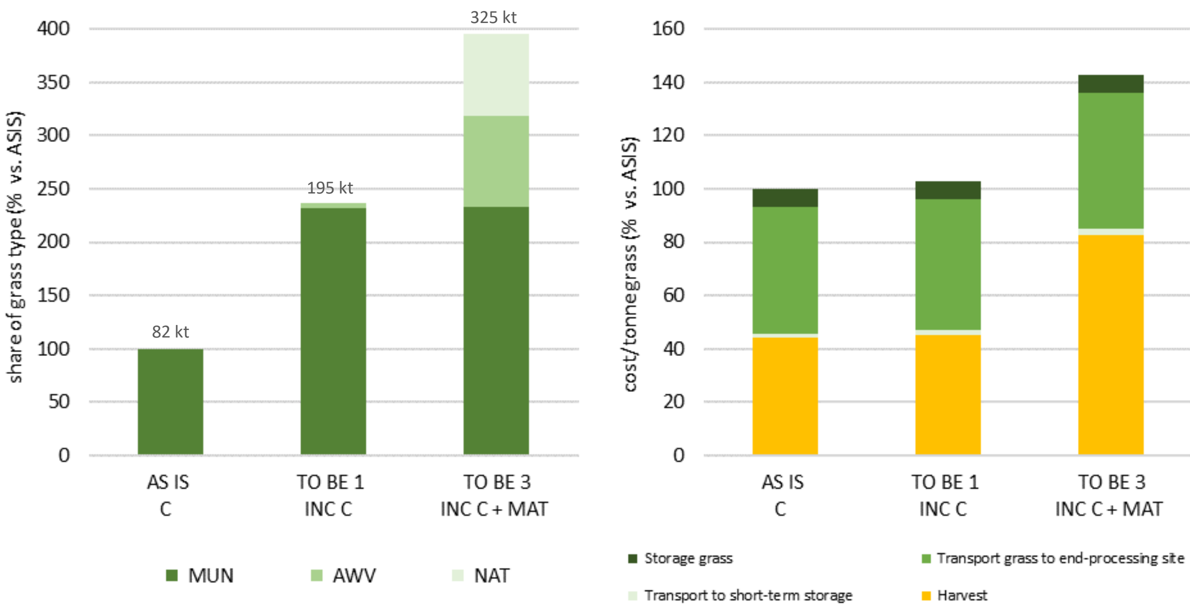

Figure 28: Impact of end-processing demand (left) on the cost per tonne mobilised grass (right) (as % vs. AS IS).

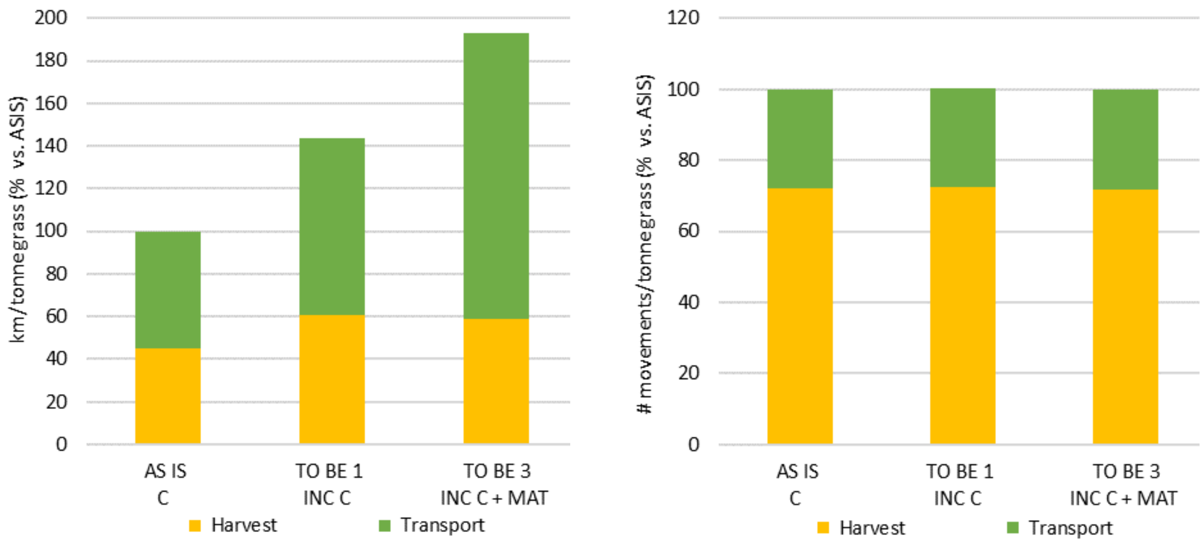

Figure 29: Impact of end-processing demand on the mileage (left) and transport movements (right) per tonne mobilised grass (as % vs. AS IS).

2.5.8.2 Impact of 'reuse' of grass clippings

In the TO BE 1 scenario, grass is only used once for processing into compost at the composting sites. However, in the TO BE 2 scenario, grass can be used twice (or 'reused'): for the production of biogas at the landfill-AD as well as the processing of digestate into compost. Within these scenarios, the same constraints are considered which implies that these scenarios can be compared 1-on-1.

Within TO BE 1 and TO BE 2 similar quantities of verge grass from municipal roads and AWV have been harvested (Figure 30 - left). Since the harvest cost per tonne remains similar (yellow), the reduction in total cost is mainly attributed to a reduced transport cost between short-term storage and end-processing sites, combined with a smaller reduction of the storage cost to overcome seasonal peaks (Figure 30 - right). These reductions are directly related to the increased grass processing capacity at time of harvesting (thanks to landfill-ADs) which reduces the need for storage and treatment of fresh grass. In addition, transport of grass from short-term storage to end-processing site occurs more efficiently (~ reduced number of vehicle movements (Figure 31 - right)).

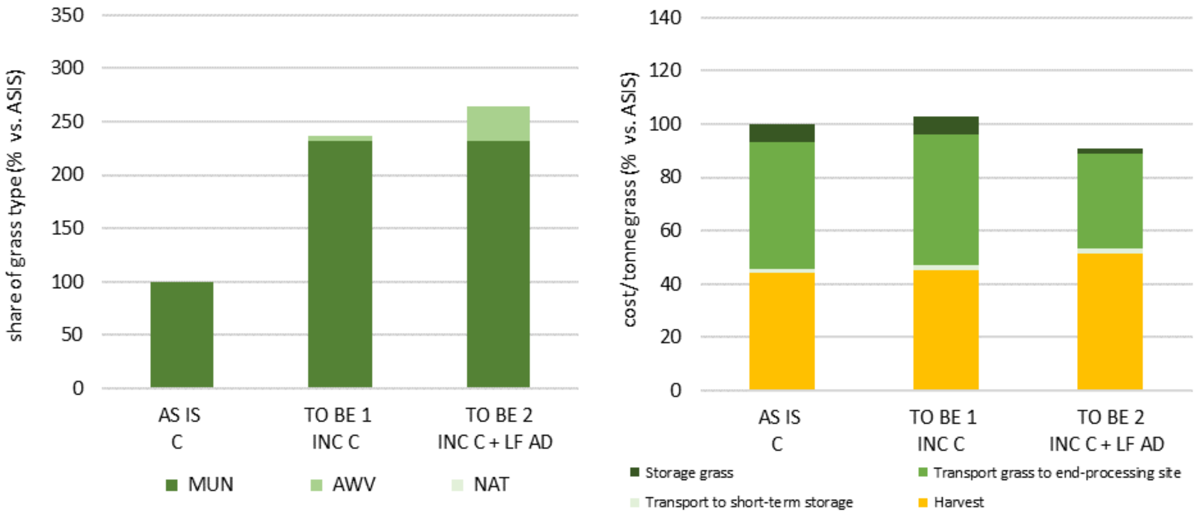

Figure 30: Impact of 'reuse' of grass clippings on the cost per tonne mobilised grass (right) (as % vs. AS IS).

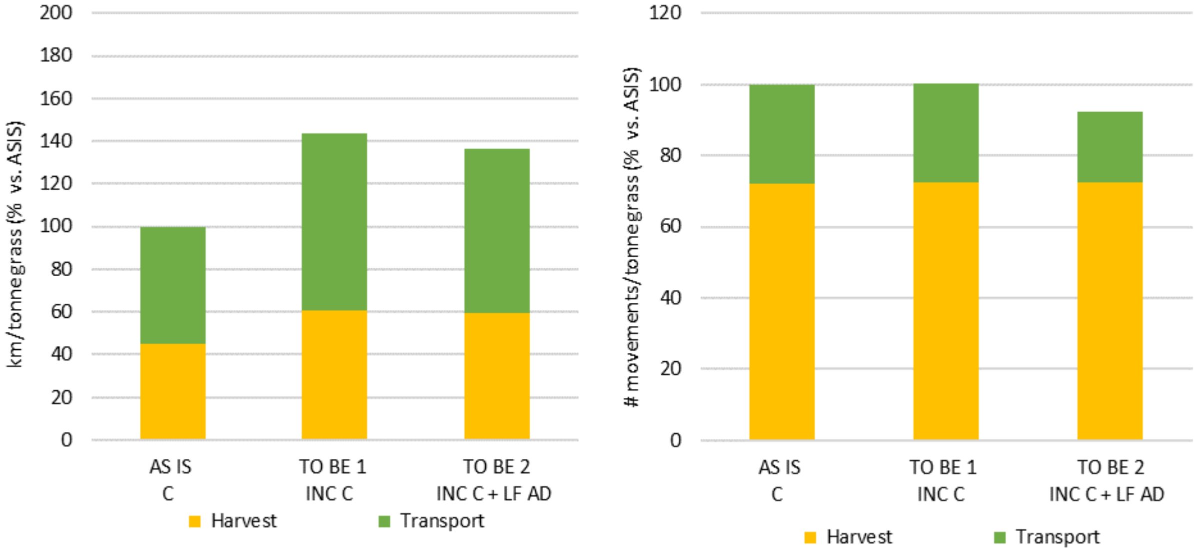

Figure 31: Impact of 'reuse' of grass clippings on the mileage (left) and transport movements (right) (as % vs. AS IS).

2.5.8.3 Impact of grass origin/quality requirements at the gate

To analyse the impact of grass origin requirements at the gate, the KPIs of TO BE 3, TO BE 4 and TO BE 5 are compared which are constrained by origin/quality which can be processed towards biomaterials (Figure 32 - left):

- TO BE 3: no constraints –grass from AWV, municipal roads and nature reserves can all be used for biomaterials as well as composting;
- TO BE 4: only nature grass can be used for biomaterials and verge grass (MUN-AWV) for composting;
- TO BE 5: nature grass and grass from highways (AWV) can be used for biomaterials and verge grass from regional roads (AWV) and municipal roads (MUN) for composting.

The grass demand is similar between these scenarios which allows to compare the results 1-on-1. However, it must be noted that in the TO BE 3; 95.000 tonnes of nature grass are used for feed which reduces the availability of nature grass for biomaterials and forces the usage of verge grass from AWV. In TO BE 4 and TO BE 5, nature grass is favoured for biomaterial production at the expense of feed application.

For all KPIs, TO BE 3 results in the highest value which is mainly due to the requirement that all grass (verge grass as well as nature grass) must be harvested to meet the demand for composting, material applications and feed applications. This results in high harvesting costs (Figure 32), a higher number of harvest movements and larger distances travelled between harvesting sites and short-term storage sites (Figure 33).

Without the condition of 95.000 tonnes attributed to feed, more grass is available (TO BE 4 and TO BE 5) and the mobilisation cost is reduced. Nature grass is used for biomaterials and grass from municipal roads for composting.

Compared with the AS IS scenario transport increases in the TO BE scenarios (green) (Figure 33 - left), indicating grass is sourced from a larger area (mainly towards Biomassaplein for insulation and Stora-Enso for paper recycling).

Comparison between TO BE scenarios shows a lower mobilisation cost occurs when not all grass is spoken for (TO BE 4 and TO BE 5) in such cases grass can be more easily be delivered than when all grass has a destination (TO BE 3). Further finetuning scenarios allows to define trade-off tipping points between mobilisation cost increase vs. increased local valorisation of local feedstock.

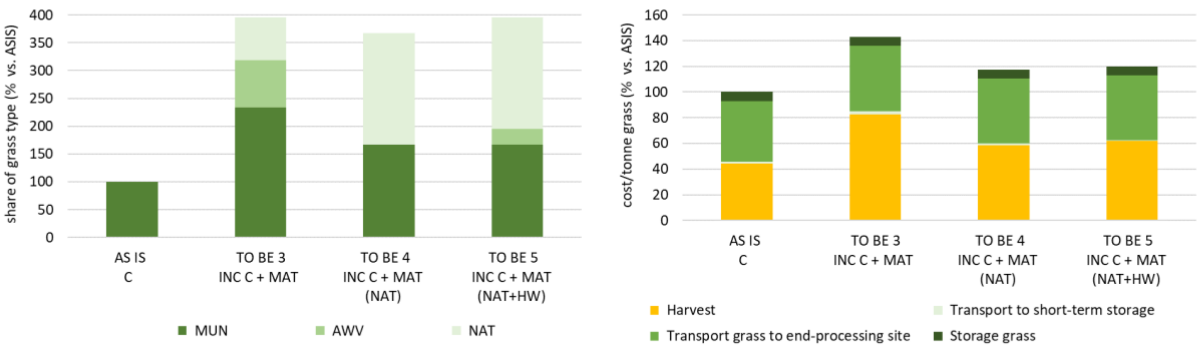

Figure 32: Impact of grass origin requirements (left) on the cost per tonne mobilised grass (right) (as % vs. AS IS).

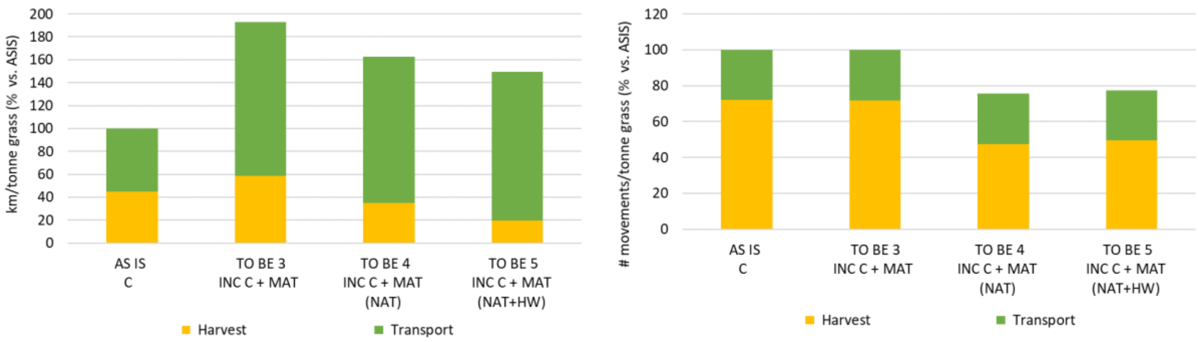

Figure 33: Impact of grass origin requirements on the mileage (left) and transport movements (right) (as % vs. AS IS).

3 A Circular Perspective

Authors: Nelen D., Cuypers D. (VITO)

Disclaimer: It is important to note that this chapter only considers the objective of making the greatest possible contribution to the ***circular economy. Therefore, the cost or economic feasibility of the pursuit of an optimal feedstock*** quality of the ***cutting for*** a ***specific application*** was in no way considered***.***

3.1 Objectives of the circular economy

The **first objective** of this report is to define the potential contribution of grass from roadsides and nature reserves to the objectives of the (local) circular economy with indication of the challenges to be addressed. This section is based on expert knowledge and literature and focusses on the objective of making the greatest possible contribution to the circular biobased economy.

Numerous definitions of the concept of circular economy have been proposed in recent years, with different interpretations of the design, priorities and corresponding objectives.[42] As part of this study, we look at the potential of grass cuttings of road sides and nature reserves to contribute to a circular economy, defined as follows:

The circular economy is an economic system in which products and materials are kept at their maximum value and functionality. The starting point is to look at everything from the point of view of products rather than materials, and the goal is to create closed cycles within which the complexity and functionality of a product is maintained for as long as possible instead of breaking down a product into the basic materials after each cycle of use.

Source: https://vito.be/nl/circulaire-economie/wat-een-circulaire-economie

Grass cuttings from roadsides (or verge grass) are rarely a product, but in certain cases offer the possibility of being used as a raw material to manufacture products, in particular animal feed. However, since production of grass is not the objective of the roadside, verge grass has the status of **waste**. This means that the recipient of verge grass must be authorised for the processing of waste and that legislation on the cross-border transport of waste must be respected when disposed abroad.[43]

[42] Kirchherr J. Reike, D., Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. Resources, Conservation and Recycling, Volume 127, 2017, Pages 221-232, ISSN 0921-3449, https://doi.org/10.1016/j.resconrec.2017.09.005.

[43] https://www.ovam.be/wetgeving-evoa

For grass cuttings from nature reserves (or nature grass), the status is less obvious. Such grass is not considered waste and can be used as **fodder** in the same way as grass from cultivated grassland. In this case, it must also comply with the corresponding product specifications (e.g. do not contain poisonous plants, contain the highest possible energy value and content of intestinally digestible proteins, as low as possible raw ash content).[44] In this case, no further contribution is expected from the corresponding mowing management to a circular economy. In other cases, it is considered a waste.

The circular aspects of the marketing opportunity as 'product' animal feed are not further elaborated within this chapter. The nature reserve and roadside manager should, from the circular perspective, in the case of application as animal feed, ensure that the greatest possible feed grass yield per metre is achieved with the lowest possible use of resources, which is of course difficult to reconcile with the management objectives of roadside and nature management.

We are now looking at the various possible options to ensure that waste products ‘verge grass’ and ‘nature grass’ make a maximum contribution to the circular economy:

Option 1: Use of verge grass and nature grass with a waste status, as secondary raw materials

In a circular economy, waste should preferably be recycled or used as an energy source. Recycling waste as a secondary raw material avoids the use of primary raw materials, materials, parts or products. In some cases, recycling unfortunately leads to low-grade applications, which result in an incomplete substitution, which still requires primary raw materials and materials to fully realize the intended functionality. At worst, recycling even increases the total production volume or total energy supply. In such cases, we speak of a −avoidable − rebound effect[45]. This option, whereby as many secondary raw materials of the highest possible quality are obtained from cuttings, is considered in section 3.2.

Option 2: Use of verge grass and nature grass with a waste status, in the service of clean and safe cycles

An adequate waste management always ensures that substances that are harmful to humans or the environment cannot end up in new material cycles, but on the contrary are concentrated and isolated in a shielded and safe environment. Obvious examples of waste streams for which such “safe sinks” must be provided are waste asbestos-containing products (insulation, corrugated sheets) or PCB-containing refrigerated fluids. This option, whereby the verge grass is disposed of and further processed to avoid the spread of harmful substances in the environment or in new material cycles, is discussed in section 3.3.

Both options are legitimate in the circular economy: (1) substitution or (2) concentration and seclusion. That choice must always be linked to the degree of pollution. In a circular economy, it is by no means appropriate to destroy (relatively) clean cuttings that can be used as a raw

[44] https://www.grasgoed.eu/wp-content/uploads/2018/02/Presentatie-3-Willy-Verbeke.pdf

[45] Zink, T., & Geyer, R. (2017). Circular economy rebound. Journal of Industrial Ecology, 21(3), 593-602.

material, nor to contaminate otherwise clean cycles with nanoplastics, heavy metals or any other substance that can be harmful for human health or the environment.

In section 3.4, the extent is analysed to which a waste-based product effectively replaces a product produced from primary raw materials. The analysis covers the diverse products that can be obtained from the processing of the different available qualities of grass cuttings. Thereto, the substitution potential of grass cuttings-based compost, digestate, biogas, fuel and other products is briefly discussed in separate subsections. Those products that replace measurable volumes of primary resources, and thus effectively avoid their extraction from nature, will contribute to the main circular economy objective of increased sustainability.

Section 3.5summarizes the findings from the previous sections and looks in more detail to those quality differences in the supply of grass cuttings that may affect their suitability to be converted into virgin-grade products. This allows the owner of the waste grass to choose the destination that best fits the cuttings' quality. Finally, reference is made to the primary resource intensity associated to those products that can be replaced by products made of available supply qualities of grass cuttings. The more resource intensive the avoided primary product, the more relevant the contribution of the equivalent grass cuttings product.

3.2 Use as secondary raw materials

3.2.1 Waste management in a circular economy

The sustainability gains resulting from the application of circular strategies are always linked to **avoiding the use of primary raw materials**, including fossil energy carriers. After all, the extraction and processing of primary raw materials is often energy and material intensive and can be accompanied by significant environmental damage. The repair, reuse and recycling of waste products and materials often leads to less environmental damage.

The quality of the products or secondary raw materials produced from verge grass or nature grass with a waste status will depend to a large extent on the quality of the grass cuttings supplied. The larger the quality differences with the primary product or raw material to be substituted, the less the grass cuttings will contribute to a circular economy.

To the extent that a reused product or a secondary raw material effectively substitutes for primary production, the environmental benefit is defined by the difference between adverse impacts of the recycling or processing processes on the one hand, and the avoided effects of primary production on the other hand. If the quality of the secondary raw material does not allow, or only partially, to replace a primary product or a primary raw material, the corresponding environmental gains are not realised.[45] Therefore, the quality aspects of the supply are first analysed below.

3.2.2 Quality aspects for material applications

3.2.2.1 Raw material for compost production

Verge grass and nature grass can be composted. About 82.000 tonnes of verge grass is processed on green composting plants in Flanders[46]. Composting of verge grass is described as a very robust technique, where the tolerance for lesser quality is higher than for energy or material application[47]. Composting is always performed in a certain mixing relationship with other green waste. It is not clear which is the optimal degree of mixing to ensure the quality of the compost produced, but there are advices in this regard.

3.2.2.2 Raw material for digestion

→ Digestate products from digestion

The following solid and liquid **materials** can be produced from the co-digestion of verge grass or nature grass[48]:

- Raw digestate;
- Thin fraction of digestate;
- Thick fraction of digestate;
- Effluent after biological purification of thin fraction digestate;
- Concentrate after filtration thin fraction digestate;
- Thermally dried digestate;
- Biothermal dried manure;
- Biothermal dried organic soil improver.

The quality of the grass cuttings supplied for digestion is of great importance. This also applies to the quality of the other organic waste fractions that go along with the digester. Variations in the origin (location, mowing type, storage) of the grass cuttings will have a great effect on that quality.

Presence of litter

The amount of litter present in verges, and therefore in verge grass, is largely determined by the nature and location of the roadside and can therefore be estimated to a certain extent in advance. Mowing of verges along roads with intensive traffic probably have a higher litter load than, for example, difficult-to-access verges. Verge grass that is too contaminated is not eligible

[46] OVAM (2019). Personal communication.
[47] OVAM (2009). Integrated processing possibilities (including energetic valorisation) of roadside mower.
[48] https://www.vlaco.be/digestaat-gebruiken/wat-is-digestaat/eindproducten-van-de-vergisting

for digestion and digestate production[49], nor does it lead to the corresponding environmental gains as envisaged in a circular economy.

A distinction can still be made according to the digestion process with which the supplied grass cuttings will be processed. yard waste will be less problematic, from a technical point of view, in dry digesters, in which no sink or float layers are formed[50]. However, we assume here that the final impact of litter on the quality of the digestate produced is not different in dry and wet processes.

Methods for removing litter are available[50]. This requires additional operations, transport and the presence of specific installations such as a star sieve, drum sieve, wind shifter or ballistic separator. These operations can be used for both pre- and post-digestion.

__Presence of sand__

The presence of sand in the verge grass is influenced by:

- The local soil type in the roadside strip:[51]on lighter, sandy soils, more soil will also be included in the grass cuttings;[52]
- The mowing method. When using a flail mower, more soil is carried with the grass cuttings to the processing plant, which disadvantages any subsequent silage and digestion process. This is due to the introduction of butyric acid bacteria present in the soil and making the pH decrease favourable to the process less efficient. With a rotary mower, less soil is picked up.[50]

In practice, verge grass or nature grass is never fermented as a single stream, but together with, for example, manure, maize and/or organic waste. The addition of a limited amount of grass, even in a wet digester, does not change the quality of the digestate[50].

Verge grass of low-litter roadsides, or grass cuttings that, after additional operations, meet the maximum degree of visual contamination, derived from heavier soils and mowed with rotary mowers, will produce the highest quality of digestate products, and thus the greatest environmental benefit. The process itself will be more efficient in a dry digester.

[49] '*Material with too many impurities (soil, plastic) should be refused. The input flows may contain a maximum of 3 % (w/w) of visual contamination.*' (From: Inverde, red. Verbeke. (2012). Graskracht, final report. Inverde

[50] Inverde, red. Verbeke. (2012). Graskracht, final report.

[51] For the development of a valuable roadside, the starting situation is important. In road works, as much material of local origin as possible is later reused for the 'new' verges. Nutrient-rich cultivated or compost is not suitable as a cover material. It contains too many nutrients, which will greatly dominate unwanted shaggy herbs and the local flowering aspect of the berm will be lost. Finishing a new roadside with local soil is preferable: plant species that belong in the area will quickly colonize the bare berm. (From: https://www.natuurpunt.be/pagina/dossier-bermen)

[52] BIOGAS-E NON-PROFIT ORGANISATION (2019). Unused biomass: Municipal roadside mower, Deliverable D2.1, WP 2: Scenario analysis based on technical description, IWT-Project: IWT 150411 - 2015/6094 – ADBR/KW – TransBio.

→ **Biogas from digestion**

In relation to the biogas production and methane content of the biogas, the effect of the soil type, grassland type or dominant plant species appears to be very limited. Inverde (2012)[50] defined that the biogas yield of verge grass is relatively low, but fairly constant regardless of the vegetation type, soil or mowing period. The presence of sand and litter, with metal objects, for example, can significantly complicate the digestion process, especially in the wet processes, but does not affect the efficiency and quality of the formed biogas. Here too, we assume that verge grass represents only a limited share of the total volume of material supplied for digestion. The biogas potential of verge grass is between 80 to 200 m^3/tonne[52].

Fibrousness and fibre length of the grass cuttings

The higher the lignin content, the less biogas and methane are formed. The lignin content translates into a higher fibrousness of the grass cuttings, which negatively affects the degradability. On the other hand, the fibre length is probably also important. In addition, shortening and bruising make it easier to release cell juices and sugars for the micro-organisms involved in the digestion process. Variations in the origin of the verge grass that have a major effect on fibrousness and fibre length are:

- The mowing method. After rotary mowing, the grass could not be sufficiently reduced, which will require additional chopping to increase the quality of the grass for the digestion process;
- The storage method. When storing verge grass in the form of pressed bales, pre-treatments are necessary to make the cuttings suitable for digestion. After all, the bales must be loosened in advance, and the grass must also be reduced here. In certain cases, the moisture content of the baled grass may be too low, so that less biogas will be formed;
- The mowing period. Later in the mowing season, the proportion of cellulose, lignin and protein increases but the proportion of hemicellulose and fat decreases. However, this would not result in significant differences in biogas yield or methane volume. [50]

Ash content

Rotary mowed grass produces a larger volume of ashes than flailed grass, especially in the wet digester. This is probably an indirect consequence of the less pronounced uptake of soil of rotary mowing as compared with flail mowing.

3.2.3 Quality aspects for other applications

Verge grass and nature grass with a waste status can be used as raw materials in processes such as radiolysis, torrefaction and integrated hydro-pyrolysis. In **radiolysis,** microwave irradiation is used to produce carbon, asphalt, liquid hydrocarbon, organic acids, methane gas and/or hydrogen from an organic material. Nano-cellulose can also be made via radiolysis.[53]

Torrefaction produces a coal-like fuel. The use of this technique with verge grass as a raw material is still being investigated[54].

Integrated hydro-pyrolysis and hydro-conversion is a thermochemical technique that allows to produce gasoline and diesel from biomass. Integrated hydro-pyrolysis would be a robust technique applied to heterogeneous feedstocks, such as non-recyclable plastic waste, B wood, sludge processing and verge grass.[55]

Further research can provide more clarity about the cutting properties that could contribute to a higher efficiency or a better quality of one or more end products of radiolysis, (hydro)pyrolysis and torrefaction.

3.2.4 Quality aspects for energy applications of verge grass

Verge grass can be burned, converting the **calorific value** into heat and/or electricity. In this case, the quality of the waste is determined by the calorific value, and thus the moisture content of the grass cuttings. Litter is co-incinerated and therefore does not constitute a technical restriction on incineration.

Presence of soil and litter

- The presence of soil and non-combustible fractions in the litter, such as metals, do increase the ash content.[56]

Moisture content

- The storage method. Verge grass exposed to humid weather conditions for a number of days will first have to dry before it can make a positive energetic contribution in an incinerator;
- Cutting period. Given the intended energy yield, it is appropriate that the grass cuttings contain the highest possible dry matter content at the lowest possible ash rest[56].

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[53] Kuzina, S. I., Shilova, I. A., Ivanov, V. F., Nikol'skii, S. N., & Mikhailov, A. I. (2013). Influence of radiolysis on the yield of nanocellulose from plant biomass. High energy chemistry, 47(4), 192-197.
[54] Bee, P., Jaap Kiel, J. (2020). Techno-economic assessment of biomass upgrading by washing and torrefaction. Biomass and Bioenergy, Volume 142, 2020, 105751, ISSN 0961-9534, https://doi.org/10.1016/j.biombioe.2020.105751.
[55] OVAM (2019). Processing scenarios Flemish Household Waste & Similar Industrial Waste 2020-2030
[56] OVAM (2009). Integrated processing possibilities (including energetic valorisation) of roadside mower.

3.3 Use as safe sink

The policy priority for the management of waste in a circular economy is to avoid the spread of substances harmful to humans and the environment. The reintroduction of harmful substances into successive material cycles should also be avoided, such as the mixing of asbestos fibres from waste cement sheets in secondary building granules, or cadmium in plastic tubes with recycled PVC.

If such dangerous and harmful substances can be extracted from the cycle, we must still avoid their diffusion into the environment by neutralising or concentrating them and safely isolate them. By using adapted landfill techniques and/or existing final processing techniques of residues from thermal processes with energy recovery, heavy metals, organic compounds and other undesirable components can be derived to so-called **'final safe sinks'.**[57]

So, in this section we are looking at verge grass from a completely different perspective vis-a-vis the previous sections. After all, the roadside and its vegetation present the ability to efficiently retain and concentrate contaminants generated on and along the roads. This property significantly reduces the mass flow that is discharged from the immediate vicinity of the road to the ground and surface water.[58] Verge grass −and the soil it grows on – will now become a collector **material** of harmful and/or undesirable substances that could contaminate the environment or new material cycles or interfere with recycling processes.

Unwanted materials in verge grass

- **Litter**. Litter can be removed manually from the roadside. However, due to its heterogeneous composition, the collected litter will be unsuitable to be used as a feedstock for recycling processes. The litter is therefore always disposed of to incinerators. For verges with high litter load, the contaminated grass cuttings can be disposed of to an incinerator, using the calorific value from the litter, separating ferrous metals and recovering non-ferrous metals from the resulting soil ash;
- **Metals**. Wear and tear of brake pads, tyres and the road surface contribute significantly to the total pollution caused by road transport. The corresponding particles are transported to road verges by the **rain** or contribute to the **(fine) dust concentrations** above the road surface. Braking, tyres and road pavement accounted for 73% of total PM_{10} emissions from road transport in the UK in 2016, and 60% of $PM_{2.5}$ emissions. Tyre wear mainly increases zinc **emissions**, while the dust from the road surface is rich in aluminium, calcium and magnesium. Brake dust contains **barium, copper** and **antimony.** It is assumed that only 5% of the material from tyre wear forms particulate matter (PM_{10}), while the rest does not remain in air, but settles in the immediate vicinity. Some of the (fine) dust will end up on the roadside vegetation, and some will be deposited on the bottom surface. In addition to

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[57] Kingin the. MorfL.s. Vyzinkarova, D., Brunner, P. (2019). Cycles and sinks: two key elements of a circular economy. J Mater Cycles Waste Manag 21, 1–9, https://doi.org/10.1007/s10163-018-0786-6.

[58] Aljazzar, T., Cooker B. (2016). Monitoring of Contaminant Input into Roadside Soil from Road Runoff and Airborne Deposition, Transportation Research Procedia, Volume 14, 2016, Pages 2714-2723, ISSN 2352-1465, https://doi.org/10.1016/j.trpro.2016.05.451

the aforementioned metals, we also find higher concentrations of titanium, iron and **vanadium** on the roadside, mainly from brake wear. [59] In Germany, Aljazzar & Kocher (2016)[17] observed a decreasing pattern of zinc, **lead** and copper concentrations58 soils with increasing distance to the roadside. The concentration of vanadium at 1 m distance from the road side was double the concentration at 2.5 m distance from the road, after which the concentration remained constant. The concentration of **cobalt, nickel** and **chromium** showed a slight decrease with increasing distance to the road side, while the concentration of other heavy metals at 1 m distance was four to five times higher than their concentration at 10 m distance. The concentrations of zinc, lead and copper near the roadside were substantially **higher than the precautionary values** of the German Federal Soil Protection and Pollution Regulation (BBodSchV) of the Ministry of the Environment. Their concentrations decreased after 2 m, but remained above the precautionary values, even at greater distances from the road. Nickel and cobalt concentrations were already below precautionary values and also decreased with increasing distance to the road side.

For mowings from busy road verges, combustion and the subsequent bottom ash treatment certainly offers a 'safe final sink' for the metals

3.4 Products based on verge grass and nature grass

3.4.1 Quality aspects of products and services in a circular economy

In a circular economy, it is decisive to adopt a **product perspective.** [60] In contrast to the **materials perspective** where in a context of waste management the corresponding waste hierarchy is considered, now the most sustainable processing of the entire waste product is considered. In general, a waste product is subjected to a series of processes, resulting in reusable parts, recyclable material fractions, usable minerals, polymer-rich fractions, combustible residues… which in turn can be further separated and purified into secondary raw materials, and on the other hand give rise to waste for final processing.

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[59] DEFRA (2019). Non-Exhaust Emissions from Road Traffic, Air Quality Expert Group, London. (Available Op: https://uk-air.defra.gov.uk/assets/documents/reports/cat09/1907101151_20190709_Non_Exhaust_Emissions_typeset_Final.pdf)

[60] EEA - European Environment Agency (2017). Circular by Design - Products in the Circular Economy. EEA Report, No. 6/2017. https://doi.org/10.2800/860754

The **environmental benefits** from these waste treatment processes are mainly determined by the extent to which new products, parts, materials or primary raw materials are substituted. In some, specific cases, where the **substitution potential** is very low, the net environmental impact of recycling may even be negative, leading to a net loss in some environmental categories.[45]

In a circular economy, we do not use a material - but a product perspective. From such a product perspective, we strive for an optimal distribution of the entire product composition over the different possible output categories of waste treatment; such as reusable parts, secondary raw materials, and combustible and landfillable residues.

*In this way, all strategies in the waste hierarchy are applied to the same waste product that is subject to successive processing processes, in order to achieve the highest possible **aggregated** environmental benefit.*

Material products are used for the sake of their **functionality.** In a circular economy, these products are designed in such a way that their functionality can be maintained or restored for as long as possible. If the product is in use, no raw materials need to be used to replace it. When a product can no longer be reused or repaired, the product parts or materials that make up the product must be as usable as possible in new products, with the same or with a different functionality, in closed or open cycles respectively.

In the manufacturing of **products from waste,** the use of primary raw materials is often limited to filling the net energy needs of the separation, sorting and recycling processes. To estimate the environmental contribution of the product made from waste, we therefore look at the extent to which that waste-based product effectively replaces a product from primary raw materials.

The isolation of hazardous substances and other undesirable materials from material cycles, and the provision of a safe final destination for the excluded materials, are essential services in a circular production and consumption system. These services lead to so-called *'clean material cycles'.* However, such non-toxic and non-hazardous material cycles are not self-evident in a world of globally circulating material sources –at least not without disrupting the supply chain – and require sustained conscious efforts. [61] The more harmful substances can be removed from the environment and given an appropriate final destination, the greater the contribution will be to the circular economy.

3.4.2 Substitution potential of material products

The main material products (as opposed to energy products) that are produced as a result of the processing of grass cuttings, are **compost** and various **digestate-based** products from the co-digestion with other organics streams. Grass cuttings are processed into compost in garden

[61] Johansson, N., Velis, C., Corvellec, H. (2020). Towards clean material cycles: Is there a policy conflict between circular economy and non-toxic environment? Waste Management & Research. 2020;38(7):705-707. doi:10.1177/0734242X20934251

waste composting plants, and to a much lesser extent in vegetables, fruit and green waste composting installations. The relatively recent introduction of stricter hygiene conditions makes it very difficult for co-digestion plants to ferment verge grass[50]. To be able to use the composted digestate or compost as a raw material, fertilizer or soil improver, the processing plant must have an inspection certificate from VLACO.

The digestate from a dry digestion is immediately usable for composting. The digestate from wet digestion has a low dry matter content, which requires a separation step that gives rise to a thick and a thin fraction (see Figure 34).

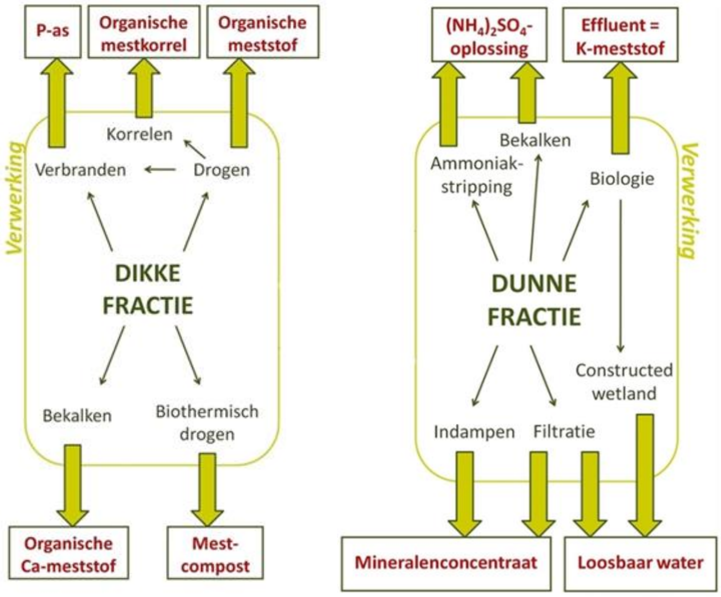

Figure 34: Examples of finished products (in red) from the processing of digestion products[62]

However, both in composting and digestion plants, verge grass is only added to a limited extent to another feedstock of biomass (waste) with a different composition and origin. In theory, verge grass or nature grass with a waste status can be added to the digestion process of biomass from **energy crops**, i.e. as a substitute for primary biomass. In practice, however, this rarely or never happens. Verge grass will therefore virtually always replace another organic-biological waste stream as a source of carbon, structure material and/or nutrients.

3.4.3 Substitution potential of biogas

Biogas is produced from both wet and dry digestion processes. The energy yield per tonne is then 6,9 GJ at a co-digestion with a gas yield of 330 Nm^3 per tonne to 3,4 GJ in an all-digester with a gas gradient of 150 Nm^3. [63] The biogas produced can be converted into heat and/or electricity on site, or can be transported via a pipeline to a so-called combined heat and power system (CHP). The biogas from verge grass or nature grass replaces other fuels and energy

[62] https://www.vcm-mestverwerking.be/nl/kenniscentrum/4800/verwerking-dikke-fractie; https://www.vcm-mestverwerking.be/nl/kenniscentrum/4794/verwerking-dunne-fractie

[63] Brinkmann Consultancy (2014). Biogas from grass – an underused potential, A study of opportunities for grass digestion. Netherlands Enterprise Agency (RVO)Utrecht.

sources, renewable or not. Only when fossil sources are avoided by biogas, it counts as a contribution to the circular economy. Determining the proportion of avoided primary, fossil carbon is often done based on the local, regional or national energy mix. The emission of CO_2 from the combustion of biogas is usually assumed to be climate-neutral, because previously the same amount of carbon was absorbed from the air by the grass.

Biogas can also be further purified by removing hydrogen sulphide, water, particles and CO_2, leaving **methane gas,** with an interesting calorific value for various applications. Biomethane can be used, for example, as a transport fuel, as a substitute for fossil Compressed Nature Gas (CNG) or Liquified Nature Gas (LNG). On the other hand, the methane can also be distributed via networks of gas pipelines to industrial or household customers.[64]

3.4.4 Substitution potential as fuel

The combustion value of verge grass is between 5,4 and 7,4 MJ/tonne of dry matter with a moisture content between 50 and 70 %[56]. When incineration with energy recovery, verge grass does not replace primary raw materials, but other waste. However, due to the high nitrogen and chlorine content, the quality of verge grass as feedstock is lower than, for example, household waste, due to the adverse effect on the quality of the flue gases and corrosion in the combustion boiler respectively. In this sense, verge grass is therefore a less **qualitatively desirable substitute for other waste streams**, and therefore this application does not contribute to a circular economy. But as a safe-sink, so from a different point of view, it does (see 3.2.4).

3.4.5 Substitution potential of other uses

Radiolysis, torrefaction and integrated hydro-pyrolysis and hydro-conversion of verge grass or nature grass with a waste status are more likely to be in a research phase. These processes can lead to a whole range of secondary products, of which the final quality, and the corresponding **substitution potential,** must be analysed individually for each case.

3.5 Potential of verge grass and nature grass for a circular economy

3.5.1 Circular potential according to the quality of the supplied grass feedstock

For all applications, the potential amount of grass cuttings that can be produced per square meter will be higher when a rotary mower is used, followed by additional operations. The mowing method therefore influences the efficiency with which the feedstock −to be interpreted here as 'raw material'− is produced. Based on Table 18, for each possible application, it can be further determined how quality specifications of the produced grass cuttings offered for

[64] Fagerström, A., Al Seadi, T., Cape, S., Briseid, T, (2018). The role of Anaerobic Digestion and Biogas in the Circular Economy. Murphy, J.D. (Ed.) IEA Bioenergy Task 37, 2018: 8

processing will impact the quality and/or the volume per unit of feedstock of the secondary raw materials produced from the cuttings.

Table 18: Overview of parameters that determine feedstock quality for different uses of verge grass and nature grass with a waste status

Feedstock quality	**Compost**	**Digestate Dry digestion**	**Digestate Wet digestion**	**Biogas**	**Other applications**	**Energy**	**Safe sink**
Presence of litter	Yellow	Red	Red	Yellow	Yellow	Yellow	Green
Presence of sand	Yellow	Red	Red	Red	Yellow	Red	Yellow
Fibrousness of the grass cuttings	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow
Ash content	Yellow	Yellow	Yellow	Red	Yellow	Yellow	Yellow
Moisture content of the grass cuttings	Yellow	Yellow	Yellow	Green	Yellow	Red	Yellow
Presence of harmful substances	Red	Red	Red	Red	Yellow	Yellow	Green

Legend colours: Yellow = quality parameter without, or with not well-known impact on application; Red = quality parameter with negative impact; green = quality parameter with positive impact.

3.5.1.1 Presence of litter

Litter consists of both compostable and non-compostable[65]components. The non-compostable components do not affect the parameters considered in the quality standards of the compost from green composting [66], but are usually removed from the supply before or during the composting process. In particular, the possible residual presence of small **plastic chips** in verge grass or other green waste for composting is currently a cause for concern. In the Netherlands, the Organic Residues Association (BVOR) has therefore distinguished different standards for l such as glass and plastic in their “Keurcompost” quality mark for three years. [67]

[65] http://echteheld.nl/zwerfafval/747/samenstelling

[66] OVAM (2019) General Regulations of certification for the biological processing of organic-organic waste into raw material (fertiliser or soil-enhancing means). Issue January 2019

[67] https://www.plasticsoupfoundation.org/2018/09/plasticsoep-op-land-landbouwcompost-is-vervuild-met-plastic/

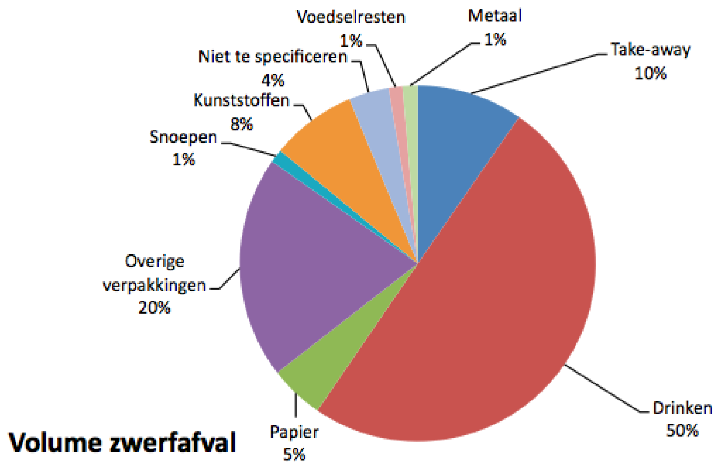

Figure 35: Composition of litter in the Netherlands by volume percentage

The pollution rate of roadside grass will depend heavily on the location and type of the roadside - see also section 2.3.2.1.3 on quality aspects.

Combination of the safe sink concept with the developed MooV model can mitigate dispersion risks of roadside pollution, while other processors of the remaining cuttings obtained from less polluted verges or areas will benefit from higher average quality feedstock. Verges with high litter risk could be mapped and grass from these verges could be dedicatedly diverted to safe sink locations.

3.5.1.2 Presence of sand

Compost is a soil improver and not a fertilizer. The possible presence of sand does not negatively affect the quality of the compost.

However, the presence of sand in the supply does affect the quality of **digestate**, in a negative sense. This quality is determined by the presence of, for example, nutrients (nitrogen and phosphorus) and organic carbon that get into the soil when the digestate or digestate products are applied in agriculture and horticulture. This way, the soil particles increase the specific weight of the digestate, but do not contribute to the ability to improve soil properties.

Like litter, the soil carried with it makes processing more difficult, especially in wet processes. Furthermore, the presence of certain soil bacteria may also make the digestion process less efficient, but it is not clear whether they also have an effect on the quality of the digestate or the digestate yield.

In energy applications, the presence of sand increases the specific weight of the feedstock without any contribution in terms of calorific value. Unburnt soil will also contribute to the ash volume that remains after combustion. Sand thus reduces the yield in heat or electricity per unit of weight.

The content of sand will be higher in grass cuttings from lighter, sandy verges or soils, and when mowed with a flail mower.

Adding soil texture to the mapped grass areas (Figure 7) could help differentiate feedstock quality and make links with harvest management (mowing vs. flailing) in view of production of better feedstock quality for biogas, digestate or energy production.

3.5.1.3 Fibrousness and fibre length

Increased fibrousness of the grass cuttings has a negative effect on the efficiency and quality of the biogas formed during digestion.

The fibrousness will be higher in grass cuttings obtained by rotary mowing, and/or when the grass was pressed into bales before collection for further processing.

To avoid fibrousness-related loss of yield and quality of cuttings meant for biogas production, an additional chopping can be provided. This requires additional operations, which, however, allow to limit, or even avoid, the impact of fibrousness and fibre length on the quality and quantity of biogas produced.

3.5.1.4 Ash content

When roadside grass feedstock is processed for biogas production, the presence of soil in digestion will lead to a higher ash content, and thus to a lower conversion efficiency per unit of weight.

The ash content for digestion is higher for grass cuttings from flail mowers, and from lighter, sandy verges.

3.5.1.5 Moisture content

In the digestion process, water functions as a means of transport for the nutrients of the bacteria and stimulates the necessary chemical-biological reactions.[68] Higher moisture content of the feedstock has therefore a positive impact when cuttings are used for biogas production. However, in a combustion process, valuable energy is lost during the evaporation of the water present. When energy production is the planned destination of grass cuttings, cuttings with the lowest possible moisture content should looked for.

The moisture content of nature and verge grass is higher when not pressed into bales, and when the mown grass was exposed to humid weather conditions.

[68] Organisation for Sustainable Energy Flanders (2006). Digestion - Converting biomass into an energy-rich gas.

3.5.1.6 Presence of harmful substances

In a circular economy, it is of the highest importance to prevent harmful or undesirable substances from entering the environment, or to be used again in new material and product cycles. Where the verge grass and the soil and litter carried along during mowing contain a significant amount of harmful substances, care should be taken to ensure that they are given a **safe, final destination.** This can be done, for example, by removing the verge grass, with soil and litter, to an incinerator. Depending on the load of harmful substances, this can be a grate furnace, or a drum oven for hazardous waste.

When we consider the verge grass to be a 'collector' of harmful substances, unlike the use of verge grass as an energy source, the possible energy recovery is not a priority in the processing, but instead keeping product and material chains clean and safe is.

Verge grass from heavily polluted roadsides along busy roads, which was mowed with flail mower, with high concentrations of heavy metals in the grass cuttings or in the carried soil, is best diverted to a safe final destination.

3.5.2 Circular potential according to the substituted product or material

Table 19: Potential of verge grass and nature grass according to the substituted product

Product from secondary raw material	Substituted (primary) product	Contribution to circularity
Compost	Other organic-organic waste	
Compost	Peat	
Digestate	Other organic-biological waste	
Biogas	Other organic-biological waste	
Biogas	Fossil energy carriers	
Biogas	Energy crops	
Other applications	Primary raw materials	
Energy	Household waste	
Safe sink		

In Flanders, **compost** is produced from organic waste streams. The compost is almost exclusively used to improve or maintain soil properties of gardens, gardens and agricultural land. To be used as a peat substitute in professional potting soil substrates, compost from waste has less suitable chemical, physical and biological properties. However, research shows that a mixture of up to 20% compost in the total composition of universal hobby potting soil does not significantly affect its quality. Only by limiting the input material to pure pruning wood and applying a number of additional mechanical operations during the composting process, a mixture of up to 40% is possible. [69]

Only if the verge grass or nature grass does not contribute to additional volumes of compost, but on the contrary could be used as an effective peat substitute in potting soil, without loss of quality, a positive contribution to the circular economy is realized.

The production of **digestate** is always an inevitable by-product of the digestion of organic waste streams and manure in Flanders, with a view to biogas production. Carbon and nutrients from verge grass or nature grass will always either replace the same elements from other waste streams, or –as is often the case for compost– generate an additional raw material use and consumption, on top of the existing.

The production of **biogas** from verge grass or nature grass can certainly avoid the use of fossil fuels, or the production of biogas from specially grown energy crops. However, in practice it is very difficult to prove such substitution or to demonstrate a quantitative reduction in consumption of fossil fuels. It is then possible that the energy from biogas from verge grass or nature grass simply increases the total energy supply, and therefore no existing energy production is avoided.

There are examples of **alternative applications** of verge grass or nature grass, where a whole range of primary raw materials could be avoided. For example, verge grass can be used as a raw material to produce paper.[70] In such applications, it is always possible to consider on a case-by-case basis which and how many primary raw materials or products are being substituted.

Verge grass used as an **energy source** in a waste incinerator will replace household waste, but with a lower energy efficiency.

Avoiding the spread of **harmful substances** in the environment or in material or product cycles by securing **safe sinks** is essential to achieve a circular economy.

[69] https://www.vlaco.be/kenniscentrum/onderzoeksprojecten/dupoco-onderzoek-naar-duurzame-potgrond
[70] https://www.decaprint.nl/partner-voor-duurzaam-drukwerk-en-papier

4 Conclusions

4.1 Mobilisation strategies

Accurate definition of mobilisation strategies, and by extension circular biobased policy making as a whole, requires solid, historic and empiric datasets. Notwithstanding earlier efforts have been undertaken within projects or other initiatives, a sufficiently accurate dataset was not available. Such accuracy includes covering the Flemish area as a whole with reference to location, acreage and ownership.

The same is true for (potential) locations of short-term and long-term storage as well as processing locations and capacities. However, the main issue for these activities was not so much the absence of data but rather the fragmentation of data over different stakeholders and related privacy issues.

For this study intensive data acquisition and processing has been accomplished to centralise both grass feedstock as supply chain activities such as storage and end-processing. Such data acquisition is very time and labour intensive. Assumptions made have been underpinned to the extent possible. However, these could be further refined with preceding future insights.

Conclusion 1: Solid data is important to (scientifically) underpin policy making and strategic planning of a circular bioeconomy. Current data is too often incomplete, inaccurate, fragmented,…

- *with a risk of data quality being insufficient to make adequate policy decisions and/or frame action plans;*
- *leading to the need for recurring intensive (and often parallel) data-gathering efforts*

Recommendation 1: Continue to strengthen a holistic and coordinated (big) data centralization with regard to a circular bioeconomy.

Conclusion 2: The resulting grass map of road verges and nature reserves and related processing activities with differentiation to location, acreage, ownership, capacity and production is currently the best available for Flanders.

Recommendation 2: Use the map to further capitalised on i) by further completion (e.g. adding waterway verges, or other biomass(residual)streams or ii) by challenging the map's fit for purpose in view of data centralization (see recommendation 1).

The analysed scenarios reflect scenarios which are deemed accomplishable or realistic in a near-term future and which are in line with current policy roadmaps and action plans. As the model has been developed, variations on these scenarios can be readily assessed – under the condition of data availability.

The technical harvestable grass potential indicates that established (composting/feed) as well as more innovative (biomaterials) applications of grass can co-exist. Even more, they can mutually benefit from cooperation with regard to storage ownership, location and capacity. Next to the location of existing end-processing sites, the location of new sites has been chosen with a justifiable rational. However, when in near future additional sites are planned or considered, scenarios can be re-run with these new locations to assess the impact of such sites on the mobilisation strategy (and its KPIs) – including the effect on the sourced areas.

Conclusion 3: The MooV scenarios show that the assessed grass potential allows for the co-existence of established (compost, digesting, feed) and near-future (biomaterials) commercial-scale end-processing sites. Source separation of feedstock qualities shows enough feedstock is available for higher end biomaterials.

Recommendation 3: Use the developed model to assess the impact of alternative grass mobilization strategies.

This assessment is strategic in nature - scoping the Flemish territory as a whole. Divert individual study cases is possible, but requires further finetuning to capture case specifics (case-by-case assessments).

The studied scenarios are demand driven (pull scenario) – meaning the demand was forced to be met at least cost.

The mobilisation cost includes harvest, storage and transport up-to the processor's gate. Note that gate-fee costs are not accounted for, as these costs are inherent to the processor and the processing type (currently mainly composting).

The study results give a good reference of the optimised mobilisation cost for society as a whole as well as for future end-processors to match these costs with their business models. It is clear that scenarios with stricter safety regulation, higher quality requirements or larger sourcing area lead to higher mobilisation costs. However, these higher costs can be mitigated by processor's higher willingness to pay - or accept at a lower gate fee – in return for higher quality feedstock. This willingness is depending on a lot of variables (e.g. quality parameters, scale, product-type, …) but can be assessed in a case-by-case approach to test alternative scenarios.

Conclusion 4: As grass processing currently comes at a societal cost – management mainly occurs due to regulation/obligation or environmental development goals. With increased demand, feedstock differentiation (e.g. by origin) or need for higher grass qualities; mobilisation costs tend to increase. The scenarios show a mobilization cost in the range of 45-70 € per tonne fresh. The higher end of the range reflects scenarios with higher demand for mass and quality; but could be compensated by higher willingness to pay better feedstock quality.

Recommendation 4: Use study results to test the feasibility of current and future biomass mobilisation strategies of local biomass resources in a circular bioeconomy. For further detailing a case-by-case approach is advisable.

Next to cost minimisation other criteria can be incorporated as well, such as environmental or circular impact. Based on current results only part of the environmental impact can be deducted from the transport (mileage) to mobilise the grass feedstock, however this can be refined. Equally circularity parameters can be adopted as well.

Mobilisation scenario TO BE 2 already indicates the relevance of multiple use of feedstock. If grass cuttings can be used 'twice', i.e. for the production of biogas as well as the processing of digestate into compost (TO BE 2), the cost per tonne capacity significantly decreases. The cost per tonne harvested grass increases due to large costs related to transport and treatment of digestate.

Conclusion 5: The study results address economic optimisation; however environmental or circular optimisation can be addressed as well. Multiple feedstock use already shows the interaction between economic and circular benefits.

Recommendation 5: Investigate further how circularity can be incorporated in optimization modelling.

Comparison between TO BE scenarios shows a lower mobilisation cost occurs when not all grass is spoken for (TO BE 4 and TO BE 5). In such cases, grass can be more easily be delivered than when all grass has a destination (TO BE 3). Further finetuning of scenarios allows to define trade-off tipping points between mobilisation cost increase vs. increased local valorisation of local feedstock. Additionally, policy deployment scenarios on future grass mobilisation can be assessed towards increase or decrease of societal mobilisation costs.

Conclusion 6: Trade-off tipping points between mobilisation cost increase vs. increased local valorisation of local feedstock could be defined – and deployment scenarios can be tested on their expected increase/decrease of societal mobilisation cost.

Recommendation 6: This study sets the scene and developed the base-model to make such assessments. Further detailing of assumptions and constraints will benefit result accuracy.

4.2 Circular Perspective

Disclaimer: It is important to note that this chapter only considers the objective of making the greatest possible contribution to the ***circular economy. Therefore, the cost or economic feasibility of the pursuit of an optimal feedstock*** quality of the ***cutting for*** a ***specific application*** was in no way considered***.***

The processing of verge grass and nature grass with a waste status can make a positive contribution to the development of a more circular economy. Table 19 indicates in which cases a product from verge grass or nature grass with a waste status can replace a product from primary raw materials, without significant loss of quality. Thereto it is necessary to demonstrate, for each application, that the product resulting from the processing of grass cuttings not only leads to an increased supply in a given product category, but also effectively avoids a pre-existing primary application.

Where a particular application has been chosen, Table 18 indicates the quality characteristics that can be controlled to ensure that the supplied mowing has optimal properties for that application.

An example is the production of compost from verge grass or nature grass with a waste status. To contribute to a circular economy, the grass must replace peat in potting soil, without loss of quality (see Table 19). It is then a matter of looking for a supply of verge grass that contains as few harmful substances as possible (see Table 18). The identification of a supply with particular characteristics and qualities can be facilitated by displaying the risk factors for the presence of, for example, high concentrations of heavy metals on a map, thus enabling the quantification of the potential supply of roadside or nature grass for the replacement of peat.

Conclusion 7: Increasing the knowledge on the quantities, characteristics and qualities of grass cuttings that can be made available for mobilisation, allows to properly identify, for each distinguishable and relevant quality parameter, the corresponding processing option(s) that produce(s) the secondary resource(s) with the highest potential to substitute for its primary equivalent(s). By selecting for each quality or grade the best circular fit, the sum of the environmental gains from converting the different qualities of grass feedstock into different secondary resources, will be higher than when all qualities were processed into a single type of product without acknowledging for feedstock quality.

Recommendation 7: This study sets the scene and developed the base-model to make it possible to distinguish and display cuttings feedstock qualities, thus facilitating the selection of the most circular processing option in each case. Further detailing of assumptions and constraints will allow to provide the most circular solution for a particular feedstock quality, and to optimize roadside management in function of the available and targeted processing options.

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