Grassification

MooV – Mobilisation strategies for verge grass in the 2 SEAS region

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WP3 – Value chain assessment

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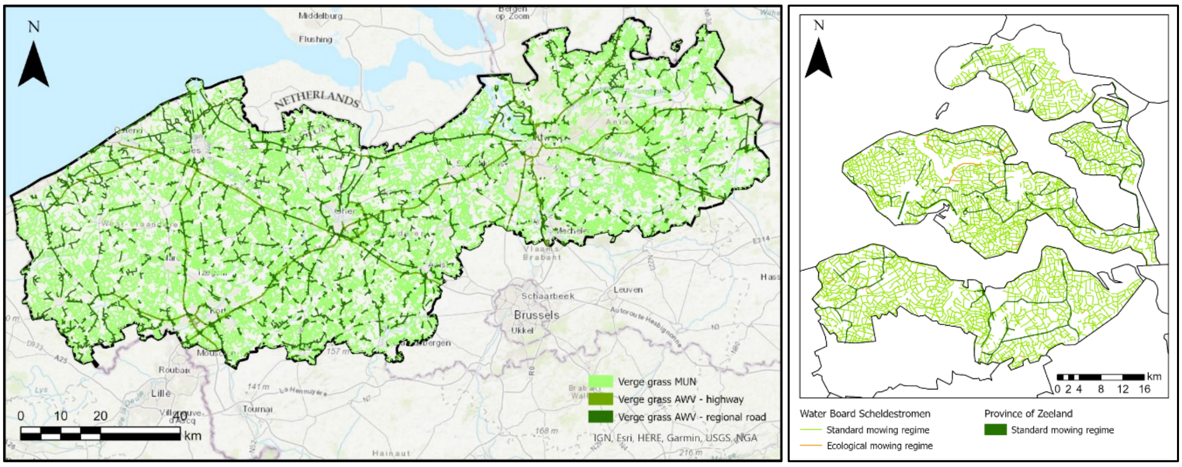
Introduction

Grass on roadsides verges grows back seasonally. Depending on the region/country a “cut-and-collect” or “cut-and-leave” management is applied depending on legislation, road safety rules and/or biodiversity goals. In any case, cutting, collecting and/or processing of roadside grass comes at a significant societal cost.

The European Union sets ambitious goals for further deployment of grass clippings in a circular bio-based economy. Investigating different mobilisation strategies - in which established as well as new grass-based value chains co-exist - is key to assess the impact and realism of these ambitions since the sustainable and cost-efficient management of verge grass remains a challenge. A well-founded value chain analysis increases grass mobilisation rates and reduces risks and costs.

MooV – VITO’s supply chain optimisation model - is used to analyse different mobilisation scenarios in search of the best value chain configuration from harvest over pre-treatment and storage to the end-processor’s site. Within “Grassification, a detailed assessment is performed for two regions; i) the provinces Antwerp, West Flanders and East Flanders (BE) and ii) the province of Zeeland (NL).



Mapped roadside verges in Belgium (left) and the Netherlands (right).

The following scenarios are investigated:

- for the provinces Antwerp, West Flanders and East Flanders (cut and collect management);

AS IS (current)	green composting
TO BE 1 (future)	increased demand by green composting
TO BE 2 (future)	increased demand by green composting and VGF- composting (vegetable/fruit/garden waste).
TO BE 3 (future)	increased demand by green composting and a dry digester added at each VGF-composting
TO BE 4 (future)	increased demand by green composting and VGF-composting and a biomaterial production added for each province.
TO BE 5 (future)	increased demand by green composting and VGF- composting and a biomaterial production at each large-scale composting site

- for the province of Zeeland (cut and leave management);

AS IS (current)	one cut - no collection
TO BE 1 (future)	one cut - increased collection (50%)
TO BE 2 (future)	one cut - increased collection (100%)
TO BE 3 (future)	two cuts - increased collection (100%)

Methodology

The assessment of mobilisation strategies requires to cope with numerous variables, such as the grass quality, the available processing options and specific characteristics and cutting regimes of a region. So, flexibility in the MooV assessment is key to correctly define and investigate all relevant scenarios and calculate the impact of changing variables on the mobilisation cost. The following variables are modelled:

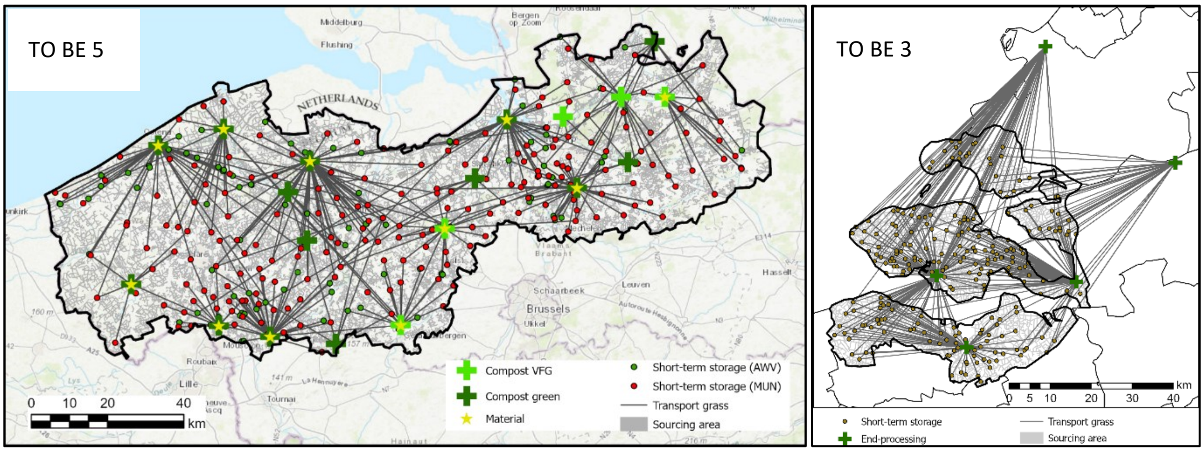
- Products: feedstock typology and potential, intermediate and end-products typology;
- Harvest: harvesting types (flail/rotary), costs (safety cars), capacities, quality;
- Pre-treatment: treatment types, costs, capacities;
- Storage: storage types, costs, capacities, storage effects on grass quality;
- End-processing: processing types, required quality, capacities;
- Transport modes: type, capacity, cost, bulk densities, fresh matter vs. dry matter;
- Time: seasonal growth cycles, long- and short-term storage.

The objective for each scenario is to mobilise the required grass throughout the supply chain at least costs while fulfilling the demand from the end-processors (i.e. composting, digesting and/or biomaterial production). The total mobilisation cost is calculated as the sum of costs related to harvest, pre-treatment/storage and transport by road (i.e. tractor-harvester combination, truck and/or safety cars). Next to the cost, the total transport distance (km) and the number of transport movements are calculated for each scenario.

Results

The technical harvestable quantity ranges between 16-19 ton/ha fresh matter depending on feedstock type. For the three Flemish provinces, the yearly harvestable potential is circa 190.000 tonnes fresh grass. The area represents about 66% of the roads in Flanders. The total is divided over municipal roads (73%), regional roads (16%) and highways (11%). For the Province of Zeeland, the potential is circa 42.300 tonnes if two cuts per year would be organised. Current practice is to cut once a year, resulting in a harvestable potential of 25.300 tonnes per year. However, this cut is dominantly left on the road verges without collection.

Based on the data gathered and the assumptions defined in the DEMO's, an average (optimal) mobilisation cost of between 50 € and 60 € per tonne harvested grass was calculated. Note that this average cost depends on the road density, the density of the storage network and proximity of end-processors. Specifically, when grass is collected in the vicinity of the end-processing facility, mobilisation costs drop below 40 €. Optimising the sourcing area helps to reduce mobilization costs. The quality of the grass constraints the allowed end-processing type. The quality can be influenced by choice of road type (e.g. with minimal amount of litter), mowing type (e.g. flail vs. cut), harvest moment and manner of long-term storage.



Example of an optimal supply chain configuration in a specific mobilization scenario (Belgium (left) and the Netherlands (right)).

Main conclusions

The mobilisation cost is influenced by the quantity, quality and location of the available grass.

Optimising the sourcing area helps to reduce mobilization costs.

On average a mobilisation cost of 55€ per tonne fresh grass seems realistic. If grass is strategically collected in the vicinity of the end-processing sites, the cost can drop below 40€.

The mobilisation mileage averages around 2-2,5 km/tonne fresh grass. If processing sites are strategically located, an increase in processing demand does not lead to an increase of mileage per tonne.

Future scenarios show enough grass potential for the co-existence of established (composting, digesting) and emerging commercial-scale end-processing sites (biomaterials).

Trade-offs between mobilisation cost increase (as a result of increased sourcing) vs. revenue increase (as a result of higher added-value products e.g. biomaterials) could be defined.

The mapped road side verges and related processing sites with differentiation to location, acreage, ownership, capacity, yield and requirements is the best available for Flanders.

GRASSIFICATION consortium

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www.interreg2seas.eu/en/grassification

Chapter 1.

D3.2.1 - Design and development of the supply chain optimisation model

1.1 Context

Grass on roadsides verges grows back seasonally. When this grass needs to be cut, collected and processed – it comes at a significant societal cost. Organisation of these activities is often complex due to the variety of management measures, the different actors involved and the variable and heterogeneous quantity and quality of the grass clippings. Hence within Europe, a significant part of the grass clippings is not (locally) processed because it is simply not cut, left on the verge after cutting or exported. When clippings 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 components (protein extraction), which are getting attention in research and (early) commercial development. The European Union sets some ambitious goals for further deployment of grass clippings in a circular bio-based economy. Investigating different mobilisation strategies - in which established as well as new grass-based value chains co-exist - is key to assess the impact and realism of these ambitions since the sustainable and cost-efficient management of verge grass remains a challenge[1].

This report investigates the feasibility of current and future grass mobilisation strategies assessing harvest, pre-treatment, storage and transport costs. A detailed assessment is performed for 2 regions in the Interreg 2 SEAS region; Flanders (BE) and Zeeland (NL), considering aforementioned key elements such as - different roadside management measures, different actors in the chain, centralised storage and different processing options (low value vs. high value products).

Figure 1 shows the main activities in grass processing chains (from left-to-right): growth & harvesting, pre-treatment, 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.

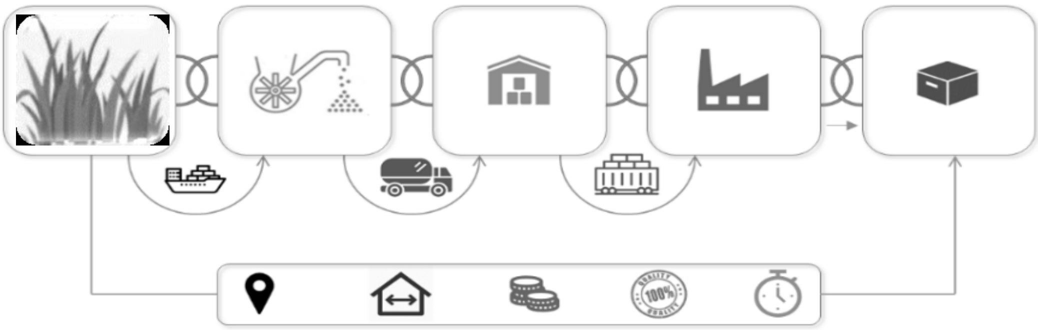

Figure 1: Main activities & key conditions in a grass supply chain considered by MooV.

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

1.2 Methodology

To address the complexity of a grass mobilisation strategy, VITO's MooV model[2,3] has been used. MooV is a supply chain optimisation model that analyses different grass mobilisation 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.

MooV is designed to be flexible for application on any type of activity, product, condition or objective without the need to question the system's fundamental logics, nor the need for major additional model developments for each individual case. The MooV system is a smart merger of proprietary linear programming code and Python-based advanced (geo-)data analytics, and professional software packages such as GUROBI Optimizer and ESRI ArcGisPro.

However, the heart of the flexibility lies in the design of the MooV model as a central core enveloped by a shell[3]. 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 2 shows the three main steps of the MooV methodology.

- Define-phase: defining the case specifics, and gathering and processing data in the MooV-database (Chapter 1.2);
- Design-phase: scripting the case specifics into the MooV-shell by linear programming (Chapter 1.3);
- Deliver-phase: running the MooV-model for various scenarios and analysing the results (Chapter 2 and 3).

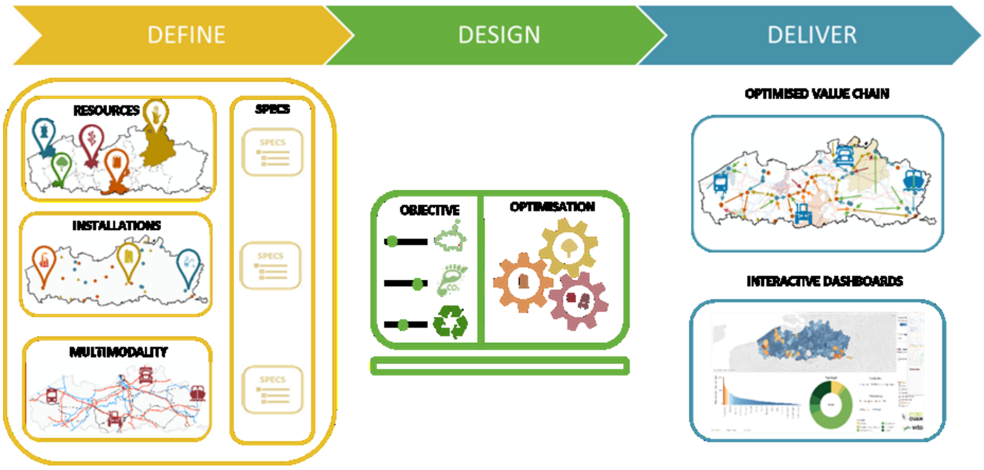

Figure 2: MooV methodology – Define, design & deliver.

[2] https://moov.vito.be MooV – is a service developed by VITO – and the result of further development of the OPTIMASS-MILP model, described in "Design and management of biomass-for-bioenergy value chains – Towards a comprehensive spatio-temporal optimisation approach" (De Meyer, A., 2015).
[3] De Meyer A.; Guisson R. MooV – a flexible decision support system for the strategic design of supply chain networks (submitted to 'Descion Support Systems' (Elsevier))

1.3 Defining the supply chain

When developing new mobilisation strategies numerous decision options are possible, leading to various scenarios. This chapter defines the grass mobilisation cases with all its activities and related characteristics, requirements or limitations, as well as how activities are interconnected. These cases are analysed to investigate potential future scenarios by varying:

i) the implemented roadside management strategy;
ii) the capacity of the end-processes;
iii) the type of end-products and/or
iv) the allowed feedstock quality for the end-process.

Two cases have been defined for which a detailed MooV assessment is performed: (1) the Grassification region of Flanders (BE) and (2) Zeeland (NL) (Figure 3). These regions have been selected by and based on the partners involved in the Grassification project in combination with the availability of required data. The MooV model is designed with flexibility in mind (Section 1.3.1.1), allowing swift application to the other regions (within or outside the Interreg 2SEAS area).

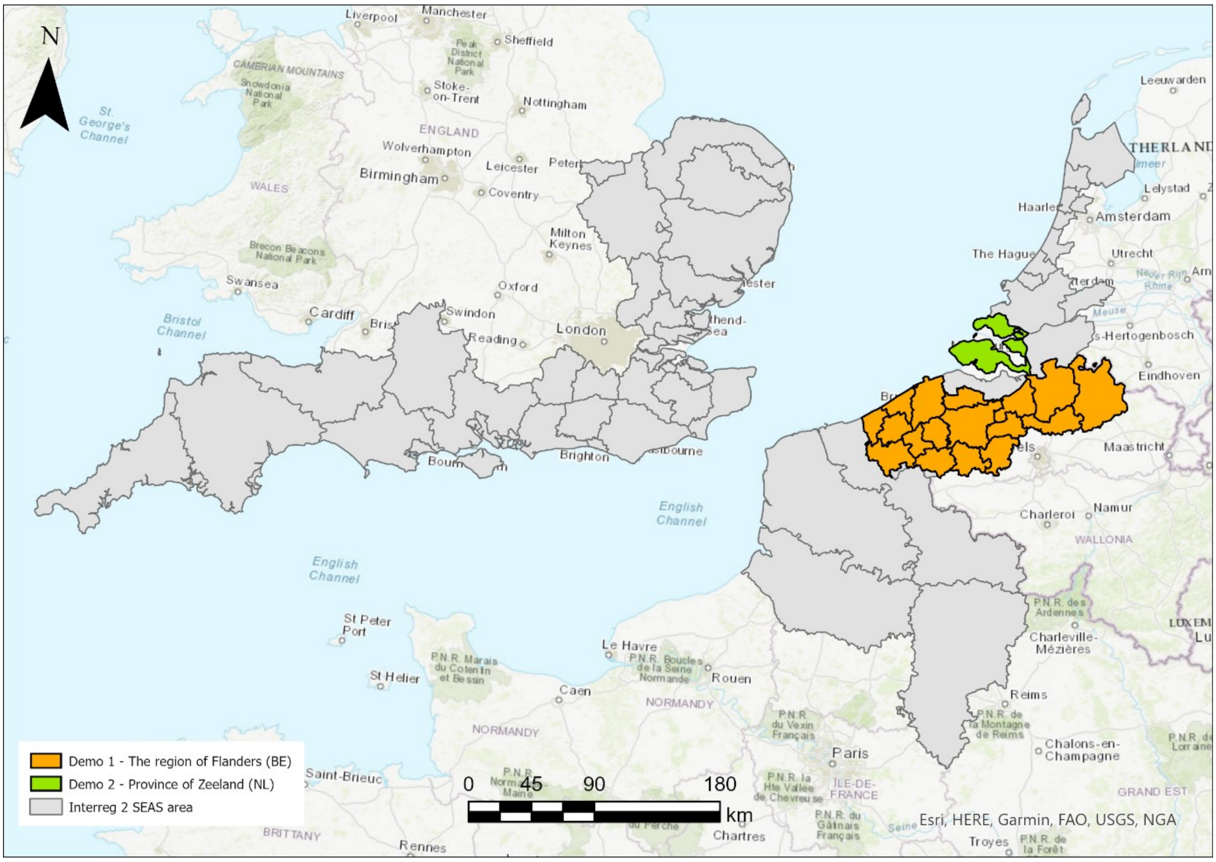

Figure 3: Area of the Interreg2SEAS Programme with indication of the DEMO study areas for the detailed MooV assessment.

1.3.1 *Model requirements*

1.3.1.1 Flexibility

The assessment of mobilisation strategies needs to cope with numerous variables, such as the grass quality and the available processing options. So, flexibility in the MooV assessment is key to be able to correctly define and assess all relevant scenarios and calculate the impact of changing variables on the mobilisation cost. MooV includes the following grass mobilisation activities and related characteristics:

- Products: feedstock typology and potential, intermediate and end-products typology;
- Harvest: harvesting types, costs, capacities, effect on the quality of grass clippings;
- Pre-treatment: treatment types, costs, capacities, effect on quality of grass clippings;
- 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 1.3.2. gives a more detailed description of these characteristics.

In terms of geographic context, the MooV Grassification model is applicable to different regions. Within the project scope the same model has been applied to the region of Flanders (BE) as well as Zeeland (NL) (Figure 3) to define the **optimal value chain configuration** in terms of locations, capacities and transport modes.[4] The model can be easily applied to other regions as well.

1.3.1.2 Time context

As grass is a feedstock following seasonal growth cycles, the time context is a 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 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, as well as the storage facilities needed to buffer these peaks.

Storage facilities are differentiated between long- and short-term. Short-term storage locations are smaller sites, on or near the roadside, where clippings can be stored for a maximum of 2 weeks; while long-term storage concerns larger sites to store bulk grass clippings for months.

Storage sites are needed to balance peaks in supply (harvest season) with the demand side which requires a continuous year-round supply (e.g. composting, dry digestion, materials).

By considering the time context, time-dependent changes in grass characteristics such as moisture content, biogas production potential, nutritional value, deterioration can be considered in the model.

[4] Note that the cases cover a geographic region in the respective countries – but do not cover the countries as a whole – see **Error! Reference source not found.**.

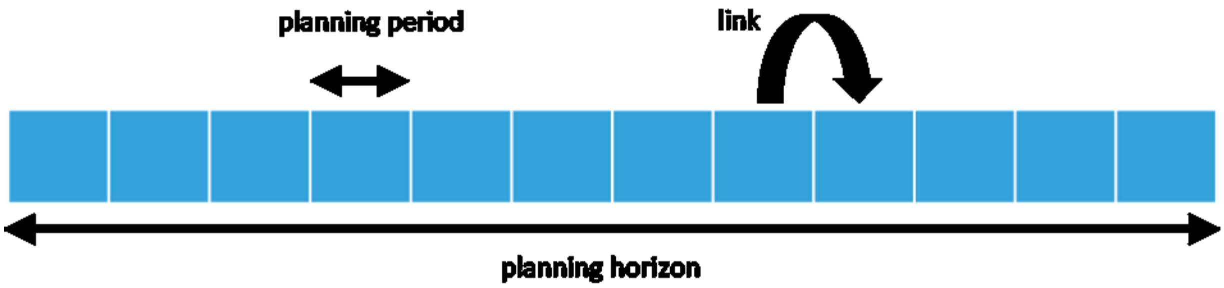

Figure 4: Difference between planning horizon (1 year) and planning period (2 weeks).

1.3.1.3 Supply chain cost objective

The objective is to assess how grass clippings are best **mobilised throughout the supply chain at least costs** to fulfil a specific demand from end-processing facilities. So, in this case the assessment is **demand-side driven (i.e. pull).** The Grassification model calculates the minimal mobilisation cost over the supply chain – from harvest over pre-treatment and storage up to the gate of the end-processor. And this for all grass from road verges in the considered area (Figure 3).

Note that for now pre-processing costs; such as litter removal washing; are excluded from the mobilization cost as these costs are inherent to the quality requirements of the specific type of end-processor[5].

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 clippings 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;
    iii. from long-term storage to end-processing (and back) and
    iv. between end-processors (e.g. digestate transport from landfill-AD to composting[6]).

Figure 5 shows the total cost broken down over its components. The mobilisation cost will be assessed for different scenarios which are explained in detail in section 2.1.1 and following.

Next to the cost, the **total transport distance** (km) and the **number of transport movements** needed is calculated for each scenario (Figure 6).

[5] The pre-processing needs per end-processor remained undefined in the project course – however the costs could be easily adopted to the MooV-model once pre-processing needs are defined.
[6] See scenario 0 where digestate is transported from landfill-AD to composting sites for further processing.

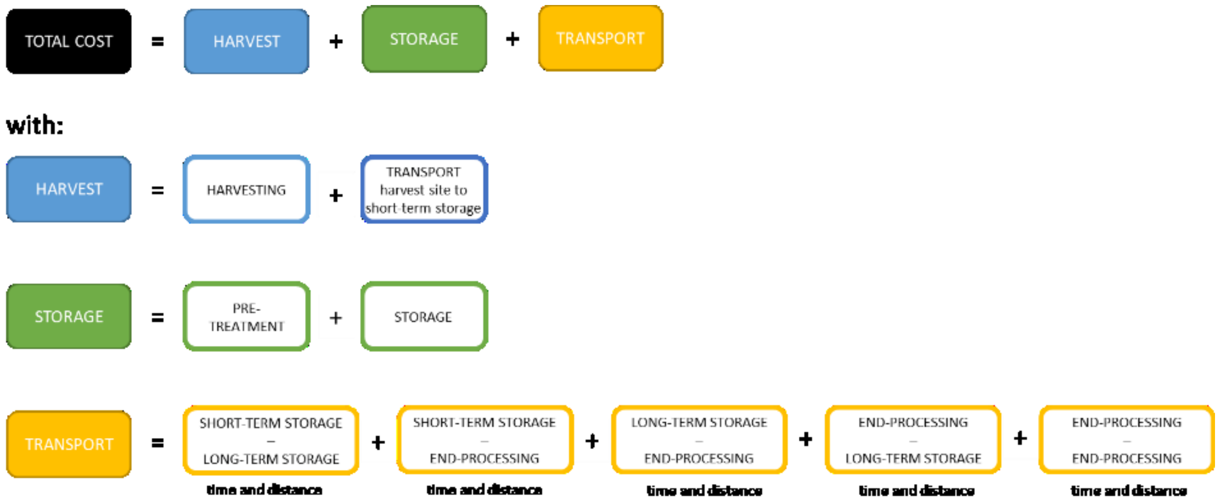

Figure 5: Components of the total mobilisation cost included in the MooV model.

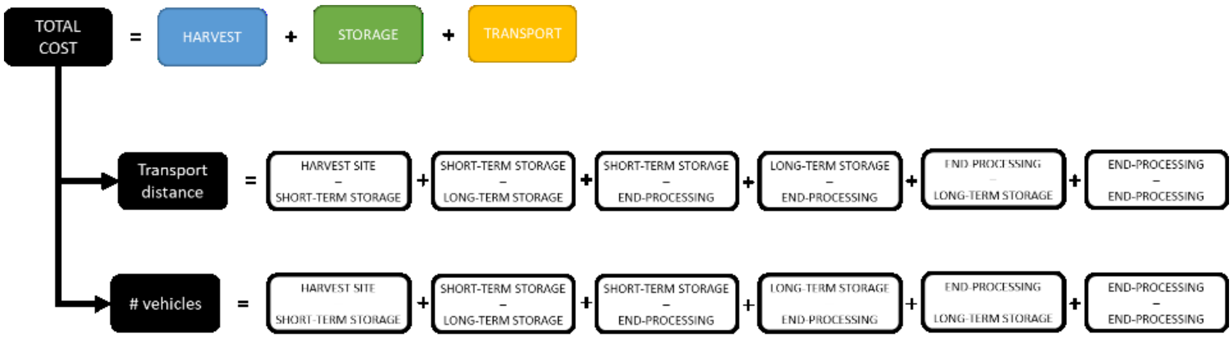

Figure 6: Other KPI's calculated by the MooV model after minimising the total cost.

1.3.2 Feedstock and activities

Now the supply chain objective is set, this section details on all activities that take part in the mobilisation of grass clippings in the 2 demo cases; the region of Flanders (BE) and Zeeland (NL).

Next to the origin of the grass (municipal roadsides vs. highway roadsides) also the different activities in the supply chain influence the quality and characteristics of the grass product. 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.

1.3.2.1 Feedstock

1.3.2.1.1 Ownership & road type - location & acreage

The supply chain starts at the point of harvest. The grass clippings at the time of harvest are considered the starting feedstock. The feedstock types for the two demos are differentiated by **ownership and road type**.

- DEMO 1: In Flanders, regional roads and highways are managed by the Flemish Agency for Road and Traffic (AWV) and local roads are managed by the municipalities. Three feedstock types are defined:
  - *AWV-RR grass*: grass from regional road verges (RR), owned/managed by the Flemish Agency for Road and Traffic – AWV;
  - *AWV-HW grass*: grass from highway road verges (HW), owned/managed by the Flemish Agency for Road and Traffic – AWV;
  - *MUN grass*: grass from municipal (local) road verges, assumed to be owned/managed by municipalities;
- DEMO 2: In Zeeland, road verges are managed by 5 different parties: 1) the province of Zeeland, managing the main roads, 2) Rijkswaterstaat, taking care of the A58 and the N57, N61, N63, 3) North Sea Port, covering the port area from Vlissingen and Terneuzen, 4) nv Westerscheldetunnel and 5) Water Board Scheldestromen, taking care of the other Zeeland roads. Based on the availability of data, 2 feedstock types are distinguished (covering about 93 % of the road network in Zeeland):
  - *PZ grass:* grass from the larger provincial road verges, managed by the Province of Zeeland;
  - *WSS grass:* grass from the smaller local road verges, managed by Water Board Scheldestromen.

The **location and acreage** of the *road side verges* are essential information to model the logistic needs of the supply chain. For the location and acreage of road grass verges, ideally a GIS-map is available with the location, length (and width/surface) and type of the verges.

- DEMO 1: For Flanders, such a map did not exist. To mitigate this lack of data, VITO has derived this information based on the GRB (large-scale reference database) which contains up-to-date and detailed data on buildings, lots, roads, waterways, rail, and public artwork. The methodology as well as the result is described in section 1.3.4;

- DEMO 2: For Zeeland, the Province of Zeeland as well as Water Board Scheldestromen delivered a polygon-map with indication of mowing regime (# clippings) on their road verges. These data can be used to derive the location and acreage of the road grass verges as well as an estimation of the currently harvested quantity.

1.3.2.1.2 Quantity

In addition to differentiation by location and ownership, the feedstock types can be differentiated by harvested quantity and corresponding quality (Table 1). The harvested **quantity** (volume/mass) is important in view of mobilisation; it defines the number of harvester movements, the needed capacity for short-term storage sites and the required throughput pace to end-processors.

The number of cuts and the time of harvest have an important impact on the harvested quantity and quality of the grass. Notwithstanding variations[7], the general harvest procedure adopted in this study is to cut twice a year for safety reasons[8]. Several EU member-states impose a "cut-and-collect" regime, where the grass clippings have to be collected to improve biodiversity of the roadside verges[8].

- DEMO 1: In Flanders mowing of road verges occurs between the 15th of June and the 15th of October as regulated by the Bermdecreet (Roadside Act)[9]. However, exemptions are made regularly for reasons of road safety;

- DEMO 2: In Zeeland the main mowing regime is to cut once or twice a year while leaving the clippings on site. Removal of the clippings only occurs in about 25% of the area to improve biodiversity (i.e. ecological management)[10]. To assess the current (AS-IS) situation in the Netherlands, the data about the mowing regimes, obtained from the Province of Zeeland and Water Board Scheldestromen are used.

Figure 7 shows the grass growth cycle and the impact of harvest.

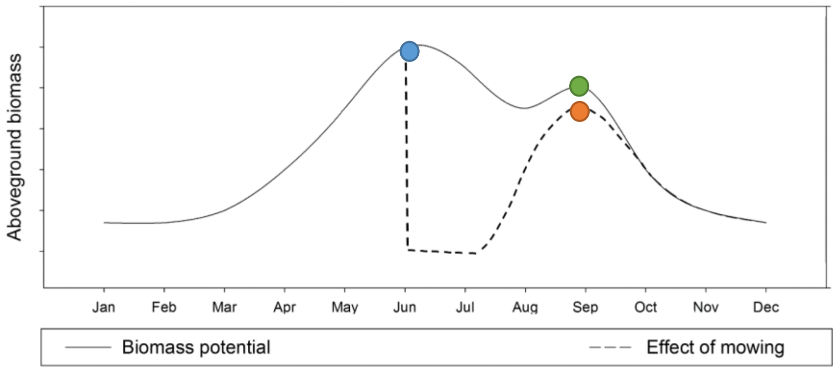

Figure 7: Indicative growth year cycle of grass with the effect of harvest (based on [11]). Coloured dots indicate the harvesting times (blue = single cut in summer, green = single cut autumn, blue-orange = double cut in summer and autumn).

Table 1 shows the theoretical as well as the technical grass quantities per hectare harvested from a double cut (summer and autumn cut). The technical potential is considered 70% of the theoretical potential[12]. This correction is to compensate for acreage that cannot be harvested completely, due to obstacles or topography. The technical harvestable quantity ranges between 16-19 ton/ha fresh matter depending on feedstock type.

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[7] In past years growth seasons (2018-2020) lasted longer leading to regular cases of three clippings (oral communication from contractors).

[8] Noordijk J, Delille K, Schaffers AP, Sýkora KV. Optimizing grassland management for flower-visiting insects in roadside verges. 2009. Biological Conservation 142 (10), 2097-2103

[9] https://navigator.emis.vito.be/mijn-navigator?woId=261

[10] Provincie Zeeland, Natuurrapportage Zeeland (2019)

[11] De Becker, P. Hoofdstuk 6: Graslanden, ruigten en natuurbeheer (Chapter 6: Grassland, brushwood and nature management. In Natuurbeheer (Leuven, 2004), M. Hermy, G. De Blust, and M. Slootmaekers, Eds., Uitg. Davidsfonds i.s.m. Argus vzw, Natuurpunt vzw and IN, pp. 190–219.

[12] 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.

Table 1: Harvestable quantities per hectare.

	Feedstock type	Theoretical quantity[13] (tonne/ha fresh)			Technical quantity[12] (tonne/ha fresh)		
		Summer	*Autumn*	*Total*	*Summer*	*Autumn*	***Total***
DEMO 1	**AWV-RR grass**	13,8	9,8	23,6	9,7	6,9	**16,6**
	AWV-HW grass	13,8	9,8	23,6	9,7	6,9	**16,6**
	MUN grass	16,0	10,6	26,6	11,2	7,4	**18,6**
DEMO 2	**PZ grass**	13,8	9,8	23,6	9,7	6,9	**16,6**
	WSS grass	16,0	10,6	26,6	11,2	7,4	**18,6**

1.3.2.1.3 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…) (see 1.3.2.4). From quality viewpoint, the presence of litter (plastics, glass, …), contamination (heavy metals) and soil/sand are points of attention.

1.3.2.1.3.1 Litter

Litter can cause problems to attain quality compost or digestate as well as to process the grass into fibre materials. Table 2 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. In 2015, cleaning litter along the Flemish public roads costed about € 60 million, or about € 10 per person. Although these figures are specifically for Flanders, roadside litter is a general phenomenon all over Europe.

Table 2: Roadside litter collected from highway and regional roads in Flanders (tonnes) [14].

	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

Since conclusive quantitative data is not available, the risk for litter in harvested clippings is considered in a qualitative manner; being low, medium or high.

[13] Theoretical biomass potential – derived from Van Meerbeek, Ottoy, De Meyer, Van Schaeybroeck, Van Orshoven Muys, Hermy (2015) The bioenergy potential of conservation areas and roadsides for biogas in an urbanized region. Applied Energy (154), 742-751.
[14] https://wegenenverkeer.be/natuur-en-milieu/milieu/zwerfvuil

For grass from highways, Table 2 indeed 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[15] commissioned a litter and heavy metal analysis of grass clippings from the Flemish Agency for Road and Traffic - AWV (regional & highway), nature reserves (Agency for Nature and Forests of the Flemish Government - ANB) and waterway (De Vlaamse Waterweg nv)[16]. The results showed litter problems for virtually all – however limited in number - addressed highway verges.*
>
> *For this study the litter problem for highways is acknowledged – however the rational 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 for local road verges (MUN grass (DEMO 1) as well as WSS grass (DEMO 2)) is marked high. While no reliable and uniform data for these verges is available, initiatives on local level to fight littering are numerous and underpin the litter risk.

The litter risk will be a qualitative exclusion criterion for certain processing options, e.g. for some scenarios clippings with high-risk will be excluded for processing towards fibre and biomaterials as these are more sensitive towards litter.

Table 3: Feedstock litter risk.

	Feedstock type	**Quality** *(litter)*
DEMO 1	AWV - HW grass	Low
	AWV - RR grass	Medium
	MUN grass	High
DEMO 2	PZ grass	Medium
	WSS grass	High

1.3.2.1.3.2 Contamination

Next to litter, potential heavy metal **contamination** of grass clippings is a concern as well. The results from heavy metal analysis of grass clippings commissioned by the Bermstroom project showed – on average[17] - no exceedance in heavy metal concentrations vis-a-vis the norms set by the compost quality mark 'Keurcompost'[16]. In view of mobilisation strategies heavy metal contamination is hence not considered an exclusion constraint for end-processing. The rationale behind this consideration is that notwithstanding potential exceptions, the test results showed no problems related to heavy metal concentrations on average.

[15] https://www.innovatieveoverheidsopdrachten.be/projecten/bermgras-als-grondstof-voor-de-productie-van-papier
[16] Verduyn (innovatieveoverheidsopdrachten.be)
[17] Notwithstanding outliers – which have been reported as well

1.3.2.2 Harvest

While variations in harvest typology and methodology exist, in Flanders (DEMO 1) as well as in Zeeland (DEMO 2), road verges are generally harvested with a flail mower. It is assumed that additional safety cars are required when mowing is performed along highways and main roads; leading to higher harvest and collection costs than local roads.

In Zeeland (DEMO 2), the Water Board Scheldestromen (WSS) more and more focusses on ecological roadside management performed with a rotary mower and removal of grass clippings. Since the Water Board Scheldestromen provided their intended management at parcel level, distinction could be made between verges under ecological management (WSS^E) and verges under 'non-ecological' management (WSS).

Table 4 shows the differentiation in harvest types with reference to the combined harvest-and-collection cost, the capacity of the harvester and the transport cost to the short-term storage (back-and-forth)[18].

Table 4: Main characteristics of the harvest types.

	Feedstock type	Harvest type	Harvest & collection cost[19] (€/tonne)	Harvest capacity[19] (tonne)	Transport cost (€/km)
DEMO 1	AWV grass	Flail mower + safety cars	37	9,3	1,1
	MUN grass	Flail mower	15	9,3	0,8
DEMO 2	PZ	Flail mower + safety cars	37	9,3	1,1
	WSS	Flail mower	15	9,3	0,8
	WSS^E	Rotary mower	19	25	1,6

1.3.2.3 Storage and pre-treatment

After harvesting, the harvester generally unloads at a **short-term storage** sites, where the clippings are temporary stored in open air for 1-2 weeks without any additional handling. From these sites larger trucks transport the grass to long-term storage or end-processing sites. As such, short-term storage allows to reduce transport by buffering clippings between harvesters (with lower capacity) and transport trucks (with higher capacity).

- In Flanders (DEMO 1), the following short-term storage sites are considered:
    - The short-term sites from AWV, accepting verge grass from highways and regional roads managed by AWV;
    - The recycling centres, assumed accepting verge grass from municipal roads.

For Zeeland (DEMO 2), the contacted experts and policy advisors did not have data or information on the short-term storage of verge grass. Therefore, verge grass is assumed to be temporarily stored at one of the 250 points randomly distributed along the A58 and the N57, N61, N63 (managed by province of Zeeland) and the roads managed by Water Board Scheldestromen (or 1 point per 45 km approximately). However, during the process of random distribution of the points, the density of verge grass availability is considered based on the data obtained from the province of Zeeland and Water Board Scheldestromen.

[18] Note: this cost equals the blue cost component in Figure 5

[19] Derived from communication with experts and contractors and literature such as Graskracht (2012), Gras-to-Gas (2017)

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 14).

At long-term storages grass is **pre-treated** and stored to maintain grass quality at an acceptable degree; and to allow end-processors to take in feedstock at a constant rate while avoiding the need for oversized processing facilities. Within both DEMO cases, fresh grass is assumed to be ensiled, except when anaerobic digestion is envisioned.

The quality evaluation of digestate from landfill-AD is still in research phase. Therefore, the required pre-treatment actions to align the quality of the digestate to the specifications for composting are unknown. 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 5 shows the cost for storage and pre-treatment differentiated by feedstock type.

Table 5: Main characteristics of the pre-treatment types.

Pre-treatment type	**Cost** *(€/tonne)*	**Feedstock type**
Ensilaging	5,3	Fresh grass
Digestate pre-treatment (drying and litter removal)	20,0	Digestate

1.3.2.4 End-processing and end-products

As earlier stated, the assessment of the grass mobilisation strategy is demand-side driven, 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. In relation to the Grassification project, the DEMO cases compare current end-uses (feed, compost and to lesser extent biogas) as well as emerging end-uses where grass fibres are used for biomaterials.

- *Compost*
  Composting of grass is performed in a mix with other green waste. Distinction (in DEMO 1) can be made between green waste and VFG-waste (vegetable, fruit and garden waste) composting sites.
- *Biogas & digestate*

  Within the Grassification project, landfill-anaerobic digestion (landfill-AD) is investigated. This is a robust process analogue to landfill-gas winning. Grass clippings 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. Within the scope of this study, existing landfills are considered potential sites to start such a landfill-AD activity.

  Note that in the mobilisation analysis, agricultural digesters (agri-AD) are excluded as a processing option. The Grassification project as well as other previous projects concluded the support base for accepting grass clippings is very low in agri-AD for both technical and legislative reasons.

Alternatively, dry digestion is included in one scenario since the action plan 'Sustainable management of biomass (residual) streams 2015 -2020' favours the processing of roadside clippings in a dry digester with post-composting of digestate at the VGF composting sites.[20] Through this methodology, the VGF waste is first valorised energetically through biogas production and secondly as soil improver during composting.

- *Biomaterials*

  Notwithstanding the potential of grass proteins for feed or other applications; for the scope of this mobilisation study only 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. In correspondence with the Grassification objectives, grass fibres for composite materials (cf. Circular Matters) has been selected as a promising application.

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.

1.3.2.5 Transport

The grass clippings from roadsides are transported by road. Transport from harvest location to short-term storage is serviced by the harvester-combination, while transport from short-term to long-term storage is organised by truck. Following the yellow cost component in Figure 5, Table 6 shows the transport characteristics for harvester and truck. Figure 8 shows the road network considered in both demo cases, including all highway, regional and local roads.

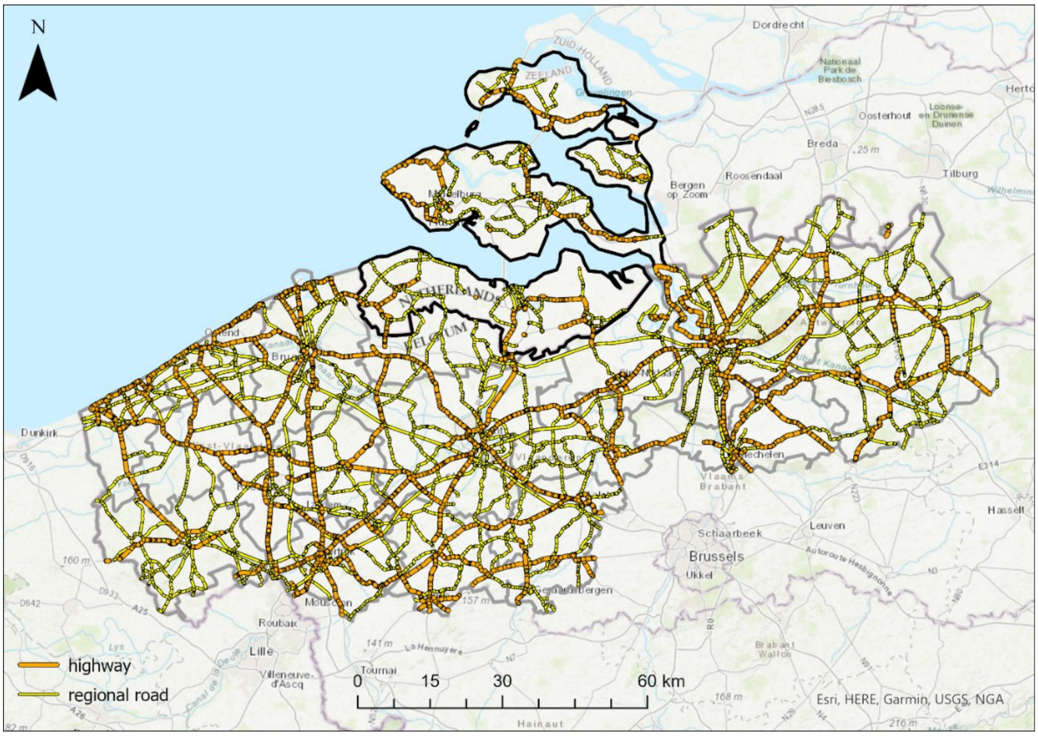

Figure 8: Transport network in Flanders (DEMO 1–grey border) and Zeeland (DEMO 2–black border).

[20] https://www.biogas-e.be/sites/default/files/2019-07/D2_2%20Onbenutte%20biomassa%20gemeentelijk%20berm%20en%20grasmaaisel_0.pdf

Table 6: Characteristics of transport types.

	Transport type	Cost transport *(€/km)*	Cost transport *(€/h)*	Cost transload *(€/h)*	Load capacity *(tonne)*
DEM	Harvest – AWV grass	1,1	-	in harvest cost	9,3
	Harvest – MUN grass	0,8	-	in harvest cost	9,2
	Truck[21]	0,96	27	27	28
DEM	Harvest – PZ grass	1,1	-	in harvest cost	9,3
	Harvest – WSS grass	0,8	-	in harvest cost	9,2
	Truck[21]	0,96	27	27	28

This concludes all cost components as depicted in Figure 5 (harvest, storage and transport). This allows to calculate mobilisation costs in the scenario analysis (Chapter 2 and 2.2).

1.3.3 Supply chain diagram

1.3.3.1 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 9 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. DEMO 1 mainly focusses on defining the impact of decisions related to end-processing (end of the supply chain), while DEMO 2 focusses on defining the impact of decisions on roadside management (start of the supply chain).

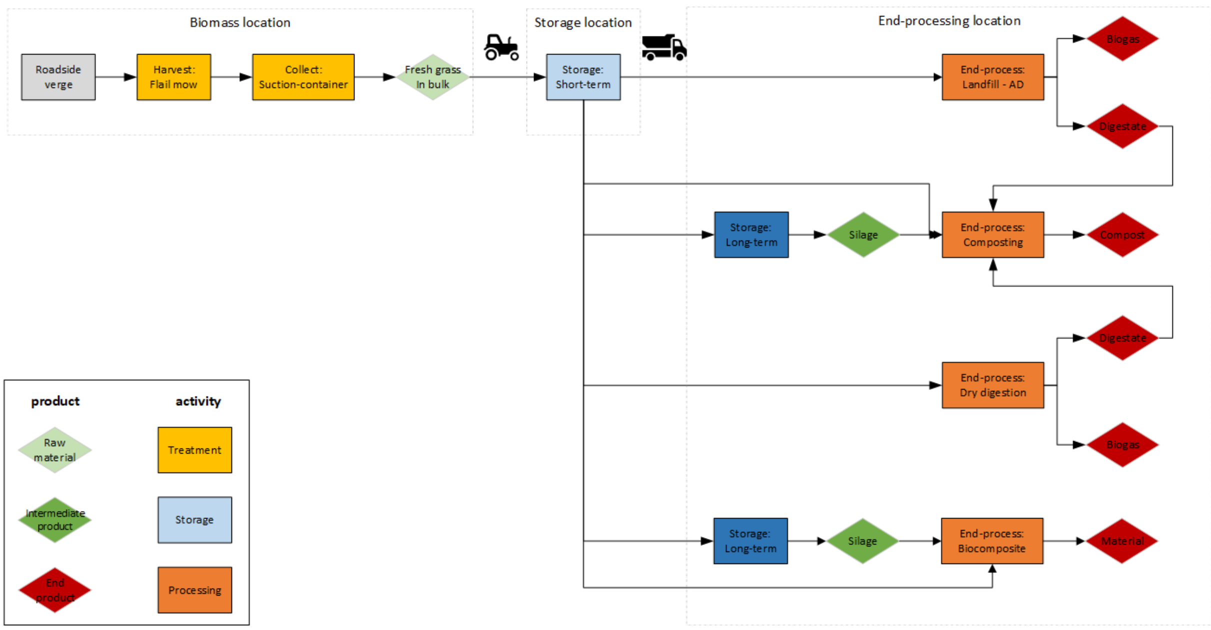

Figure 9: Process flow blueprints for the mobilisation strategies in DEMO 1 – Flanders (BE).

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

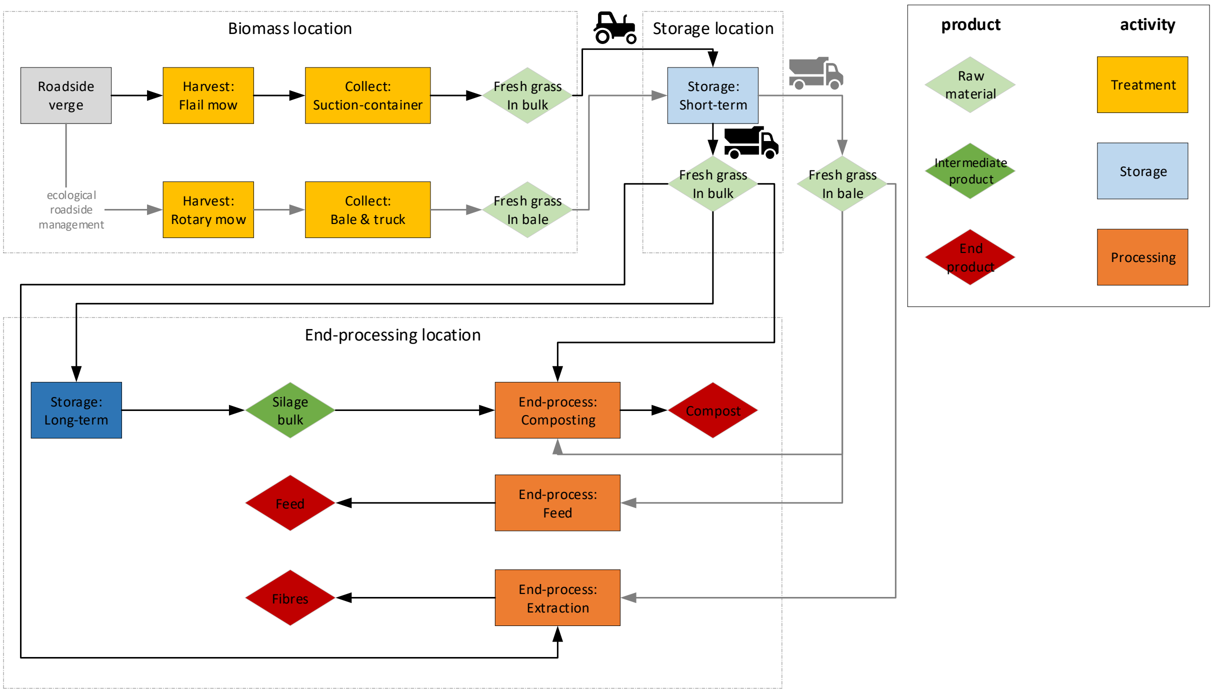

Figure 10: Process flow blueprints for the mobilisation strategies in DEMO 2 – Zeeland (NL).

1.3.3.2 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 1.3.2, four main activity types are differentiated as geographic locations:

- Harvest locations (Figure 12);
- Short-term storage locations (Figure 13);
- Pre-treatment and long-term storage locations (Figure 14);
- End-processing locations (Figure 15).

Additionally, all relevant transport connections between locations are defined to establish a network configuration (Figure 11). 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).

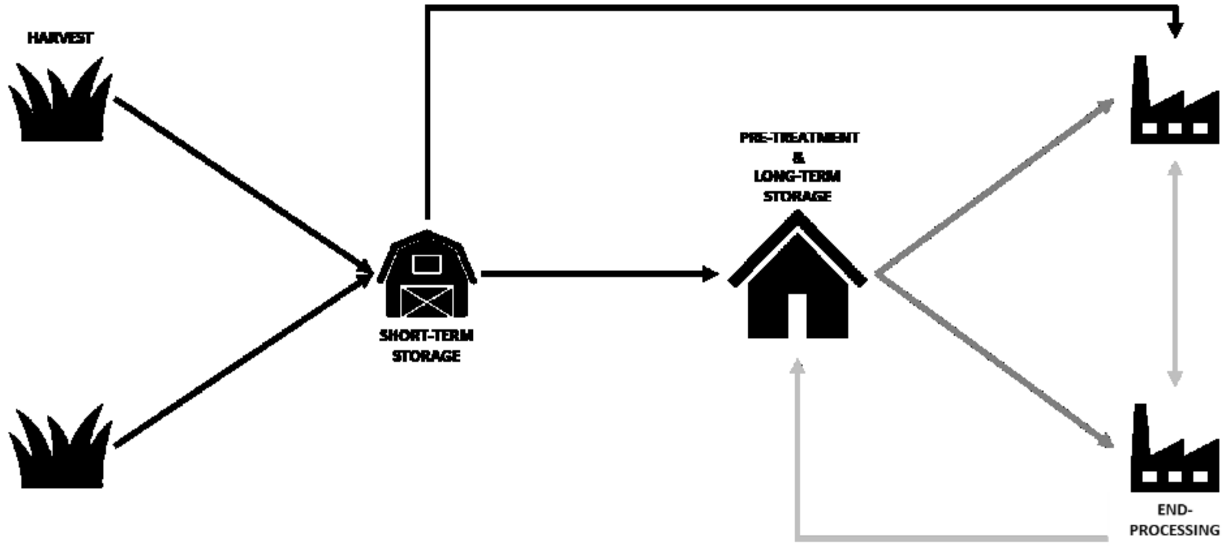

Figure 11: Network configuration options to be considered (black arrow = primary feedstock, dark grey arrow = intermediate product, light grey arrow = digestate[22]).

1.3.4 Geographic context

1.3.4.1 DEMO 1: Grassification region – Flanders (BE)

1.3.4.1.1 Feedstock

As mentioned previously, the **location and acreage** of the *road side verges* are essential information to model the logistics in the supply chain. For DEMO1 (Flanders), no such map existed with data on location, length (and width/surface) and type of the verges. Additionally only segmented information was available on which verges are actually harvested. To mitigate this lack of data, VITO has developed a SQL-code to derive this information from the GIS-map '*G*rootschalig Referentie Bestand – GRB'.

Building on that SQL-code, the methodology below has been followed to create a grass verges map of Flanders (Table 7):

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 35.690 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;

[22] Note that digestate needs a composting step as final processing.

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 18.085 ha;
5. ADDITIONAL CORRECTION for regional and community verges[23]: 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%[24] of remaining verges were not grass covered. This correction led to the technical corrected verge surface **10.510 ha**. The corresponding locations are shown in Figure 12. These locations were assumed to be verges which needed to be harvested by a cut-and-collect campaign.

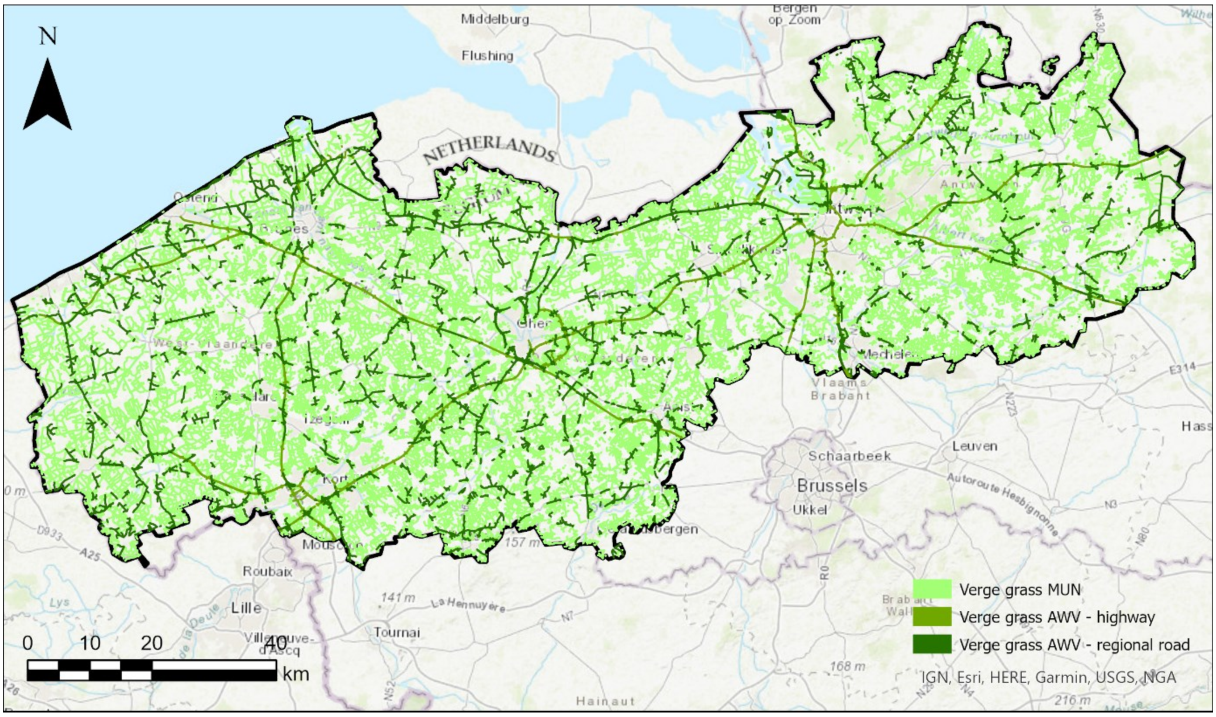

Figure 12: Map of the Grassification region in Flanders –grass acreage on road verges (MooV-VITO).

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, nonetheless 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.

The now attained acreage and location of verges combined with the harvestable quantity (Table 1) results in a harvestable potential of 190.000 tonnes fresh clippings per year in the DEMO1 region (Table 8). The DEMO 1 region concerns 3 provinces of Flanders, i.e. Antwerp, West Flanders and East Flanders and entails about 66% of the roads in Flanders.

[23] Note that highways were excluded from this correction.
[24] Note variations on this factor can be modeled as well.

Table 7: Road verge grass acreage in demo 1 (Flanders) (ha).

	AWV grass RR	AWV grass HW	MUN grass	Total
Theoretical (1-2)	7.305	1.255	27.130	35.690
Excl. driveways and city centres (3-4[25])	3.370	1.255	13.460	18.085
Additional correction (5[26])	**1.855**	**1.255**	**7.400**	**10.510**

Table 8: Harvestable quantities in demo 1 (Flanders) (rounded at 100).

Feedstock type	Theoretical quantity (tonne/year fresh)			Technical quantity (tonne/year fresh)		
	Summer	*Autumn*	*Total*	*Summer*	*Autumn*	***Total***
AWV-RR grass	25.600	18.100	43.700	18.000	12.600	**30.600**
AWV-HW grass	17.300	12.300	29.600	12.200	8.500	**20.700**
MUN grass	118.400	78.500	196.900	83.000	54.800	**137.800**
Total	161.300	108.900	270.200	113.200	75.900	**189.100**

1.3.4.1.2 Storage and pre-treatment

Figure 13 shows the location of the short-term storage sites which are assumed to only accept clippings from their respective owners, e.g. clippings from AWV verges can only be stored at AWV storage sites. This implies that it is assumed that after harvest the clippings are transported to the nearest short-term storage of their respective owner.

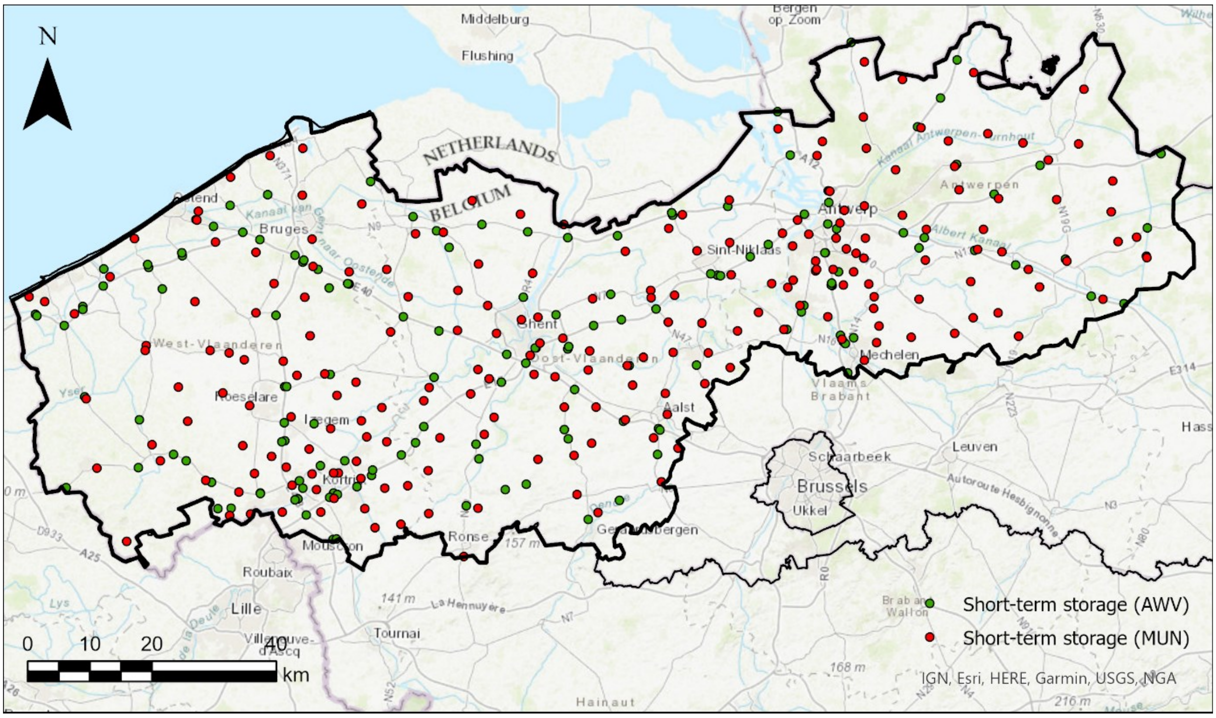

Figure 13: Short-term storage sites as considered in the MooV assessment.

[25] Correction 3 and 4
[26] Correction 5

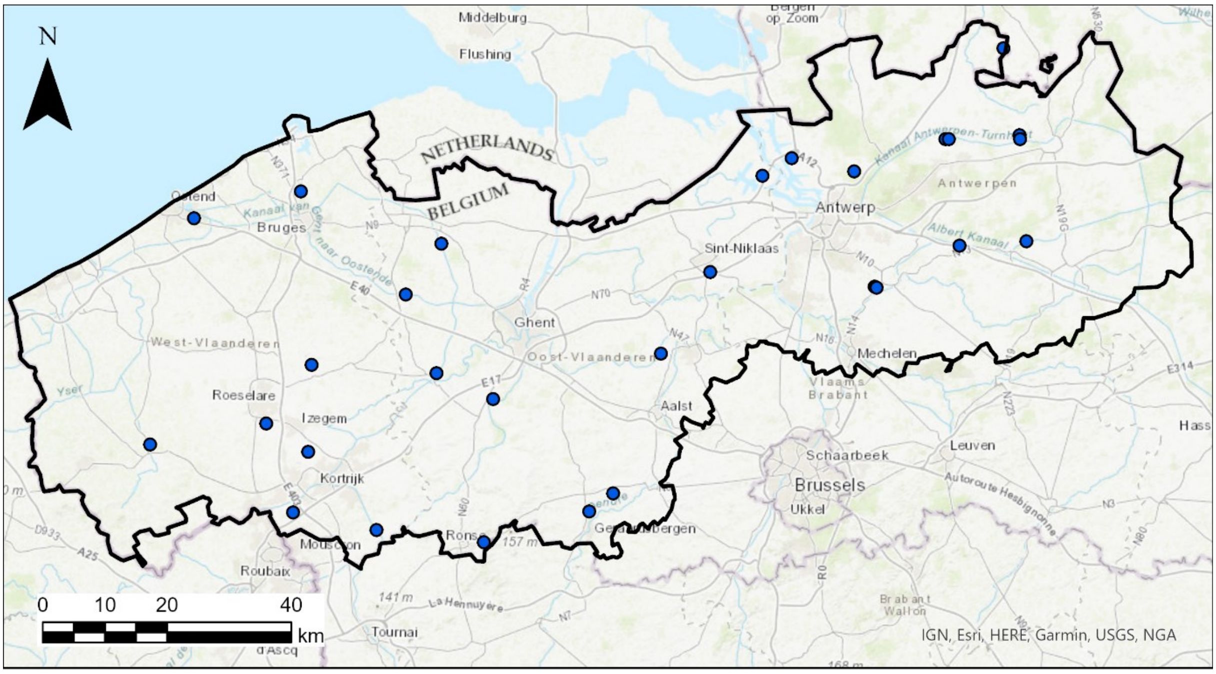

Figure 14: Long-term storage sites as considered in the MooV assessment for demo 1 (Flanders).

1.3.4.1.3 End-processing

Figure 15 shows the location of the potential end-processing sites:

- All existing composting sites distinguished between green waste and VFG-waste (vegetable, fruit and garden waste) composting sites;
- All existing landfills as potential location to start landfill anaerobic digestion (landfill-AD);
- For the location of the biomaterial sites, commercial scale sites do not yet exist to our knowledge. As potential location, it is assumed that each province locates 1 biomaterial site, as currently one site is operational (at limited scale) in Leuven (cf. Circular Matters).

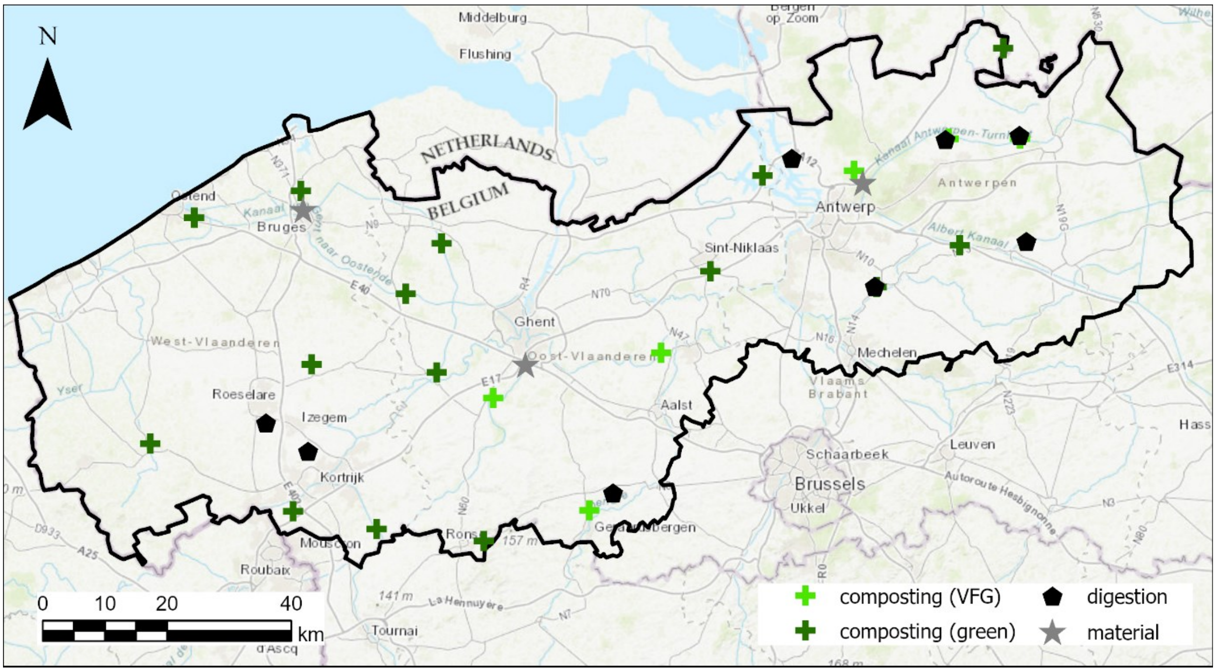

Figure 15: End-processing sites considered in demo 1 (Flanders).

1.3.4.2 DEMO 2: Grassification region – Zeeland (NL)

1.3.4.2.1 Feedstock

In Zeeland, road side verges are managed by 5 different parties: 1) the province of Zeeland, managing the larger through roads, 2) Rijkswaterstaat, taking care of the A58 and the N57, N61, N63, 3) North Sea Port, covering the port area from Vlissingen and Terneuzen, 4) nv Westerscheldetunnel and 5) Water Board Scheldestromen, taking care of the other Zeeland's roads (Table 9).

Table 9: Estimated road verge grass acreage (ha) in Zeeland [27].

Manager	Length (km)	Area (ha)	Ha per km	Share total (based on km)
Water Board Scheldestromen	4.000	1.600	0,4	85 %
Province of Zeeland	400	500	1,3	8 %
Rijkswaterstaat	175	600	3,4	3 %
North Sea Port	130	220	1,7	3 %
NV Westerscheldetunnel	15	67	4,5	1 %
Total	**4.720**	**2.987**	**0,63**	**100 %**

From the Water Board Scheldestromen (85% share) as well as the province of Zeeland (8% share), detailed GIS maps have been obtained with indication of location, area and roadside management on their road side verges in 2018 (Figure 16). Together, the province of Zeeland and the Water Board Scheldestromen cover about 93 % of the road verges which gives already a very good estimation of verge grass availability in the region.

In general, the road side verges in the Netherlands are flailed once a year, after which the clippings are left behind on the verge, resulting in a rough, species-poor verge. Within their dataset, Water Board Scheldestroom indicated the verges under an ecological mowing regime, meaning that the verges are mown with a rotary mower and the clippings are collected for feed (Figure 16).

Table 10 summarizes the acreage of road side verges within the datasets from the Water Board Scheldestromen and the Province of Zeeland. In comparison to Table 9, based on (27), the acreage deducted from the data provided by the Province of Zeeland (Table 10) is higher because this dataset assumes a road verge width of 2 meter.

Table 10: Road verge grass acreage in the demo 2 scenarios (dataset 2018) (ha).

	PZ grass	*WSS grass*	*Total*
Standard mowing regime	800	1.540	**2.340**
Ecological mowing regime	0	20	**20**

[27] Provincie Zeeland, Natuurrapportage Zeeland, 2019

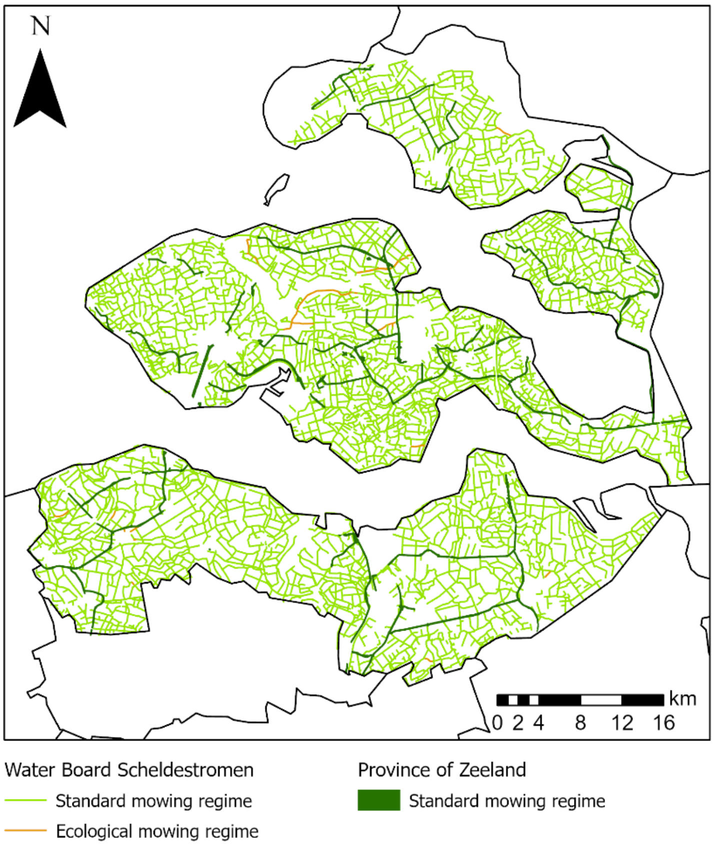

Figure 16: Map of the DEMO 2 region – grass acreage on road verges managed by the Province of Zeeland and the Water Board Scheldestromen.

In combination with the harvestable quantity (tonne per ha), defined in Table 1, this would result in a harvestable potential of 42.300 tonnes per year in Zeeland if two cuts per year would take place (Table 11). However, in the current (AS IS) situation, the standard mowing regime is to only cut once a year, resulting in a harvestable potential of 25.300 tonnes per year.

Table 11: Potential harvestable quantities in the demo 2 region (rounded at 100).

Feedstock type	**Theoretical quantity** (tonne/year fresh)			**Technical quantity** (tonne/year fresh)		
	Summer	*Autumn*	*Total*	*Summer*	*Autumn*	***Total***
PZ grass	11.000	7.800	18.800	7.800	5.500	**13.300**
WSS grass	25.000	16.500	41.500	17.500	11.500	**29.000**
Total	36.000	24.300	60.300	25.300	17.000	**42.300**

1.3.4.2.2 Storage and pre-treatment

Figure 17 shows the location of the randomly allocated short-term storage sites and are assumed to accept all verge grass clippings. So, after harvest the clippings are always transported to the nearest short-term storage location as a cross-dock location from which trucks go back and forth to long-term storage sites (Figure 18) or end-processing sites (Figure 19).

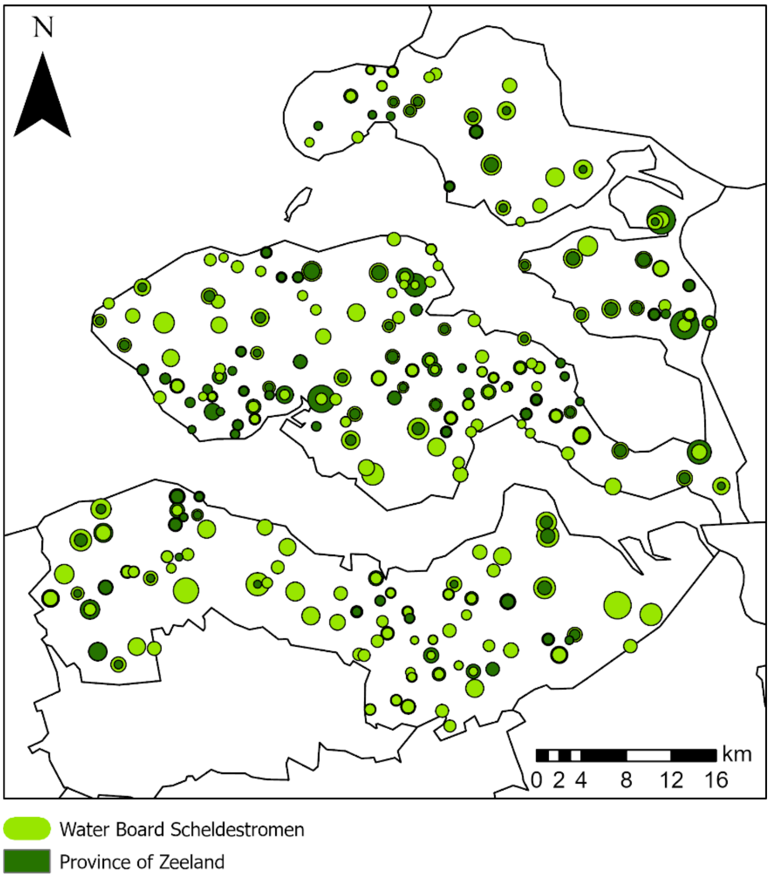

Figure 17: Short-term storage sites as considered in the MooV assessment for DEMO 2.

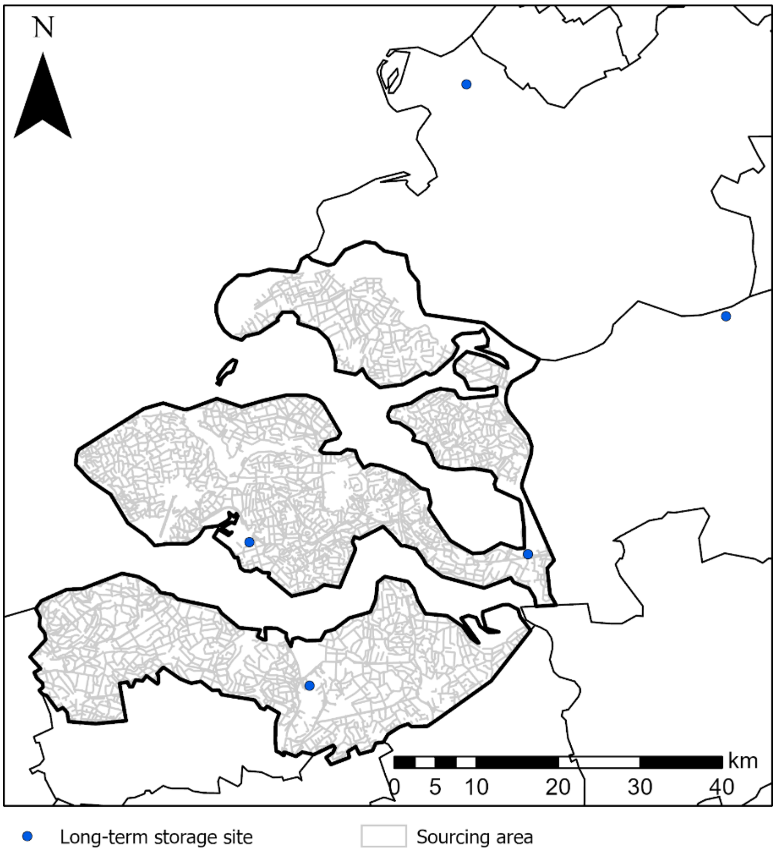

Figure 18: Long-term storage sites as considered in the MooV assessment for DEMO 2.

1.3.4.2.3 End-processing

Figure 19 shows the location of the potential end-processing sites. In DEMO 2, the objective is to investigate the impact of different roadside management strategies. Therefore, potential end-processing locations are limited to the (5) composting facilities in and near Zeeland (i.e. Indaver, Den Ouden and Sagro). Grass clippings can be composted or pre-treated into storable fibres for biomaterial production. It is expected that these composting sites have or attract the needed pre-treatment equipment to pre-process the verge grass into storable fibres for biomaterial production during harvesting months, eliminating the need for long-term storage capacity for the cuttings.

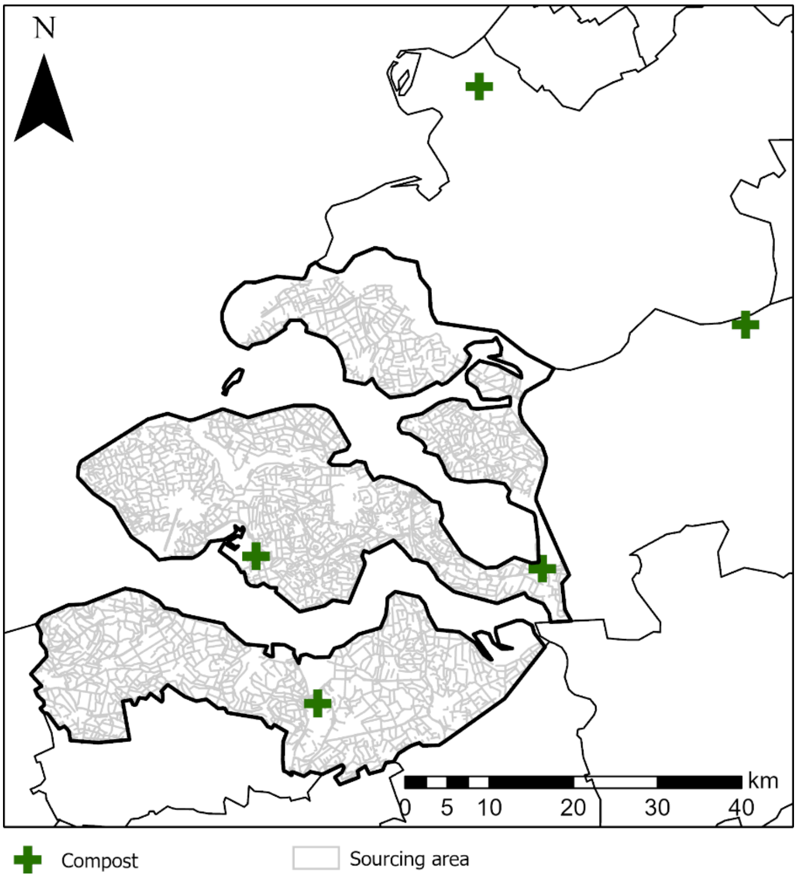

Figure 19: End-processing sites considered in DEMO 2.

This concludes the complete definition of all Grassification supply chain specifics. The next session discusses the design of the supply chain optimisation model based on these specifics.

1.4 Designing the supply chain optimisation model

1.4.1 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.

For this study all specifics defined in section 1.3 have been transcribed into the customised **shell** 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 were 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.

1.4.2 Mobilisation objective & constraints

To assess mobilisation strategies for grass clippings in Flanders, MooV approaches the problem as a multi-stage capacitated facility location planning problem[28] 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 best mobilisation strategy to meet a specific demand for grass feedstock at least cost (the objective) while fulfilling case-specific requirements (the constraints)[29].

1.4.2.1 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[30]. 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.

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

[29] The MILP model is an elaborated 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.

[30] 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[31];
- Cost for pre-treatment and long-term storage;
- Cost for transport.

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

1.4.2.2 Constraints

The constraints reflect the limitations and conditions under which the grass supply chain operates. These constraints are sourced from previous projects[32] and expert knowledge.[33] The most important constraints are listed below.

- **Physical constraints** (e.g. capacity, feedstock quality or origin) imposing limitations on the allowable combinations between clippings and processing options, between processing options mutually, and on the allowed processes at the harvest, storage and end-processing locations.
    - Example 1: for scenario TO-BE 3 in DEMO 1 (see section 2.1.3.5) – only grass from highways is allowed for the biomaterials. This constraint links the feedstock quality with the end-product. It indeed is assumed that litter risk for highways is relatively low after the first 2 meters – while sensitivity towards litter for biomaterials is high.
- **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 and end-processing sites, ii) between harvest and storage sites and iii) between storage and end-processing sites (Figure 11). An additional flow can occur between end-processing sites mutually. This is the case for digestate from landfill-AD sites (end-processing 1) which is transported to compost sites (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 clippings are 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, roadside clippings must be ensiled.

For the Grassification project a MooV shell has been customised to capture all supply chain specifics (section 1.3) as well as the objective function and constraints (section 1.4.2). The customised supply chain optimisation model is now ready to be tested and validated (Chapter 2).

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

Chapter 2.
D3.2.2 - Testing and Validation of the Supply Chain Optimisation Model

Now the grass supply chain is correctly defined and supply chain optimisation model is designed accordingly (Chapter 1), this chapter describes the different mobilisation scenarios and their results for the respective demos; DEMO 1 (Flanders) and DEMO 2 (Zeeland).

2.1 DEMO 1 - Mobilisation strategies for verge grass in Belgium

Within DEMO 1 the main objective is to investigate the impact of variation in end-processing on the mobilisation cost.

2.1.1 Overview

2.1.1.1 Mobilisation scenarios

The AS IS scenario reflects the current situation for processing verge grass clippings in Flanders, i.e. green composting. This scenario sets the baseline for the total mobilisation cost and the related mileage and number of vehicle movements.

In the TO BE scenarios potential future scenarios for verge grass processing in Flanders are investigated. 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 12 shows the overview of the six investigated mobilisation scenarios. The detailed description of the scenarios is found in the following sections.

Table 12: Overview of investigated mobilisation scenarios for Flanders [34].

		END - PROCESSING				
		Compost (Green)	Compost (VFG)	Landfill digestion	Dry digestion	Material applications
SCENARIO	AS IS	✓ (17%)	✗	✗	✗	✗
	TO BE 1	✓ (30%)	✓ (10%)	✗	✗	✗
	TO BE 2	✓ (30%)	✓ (10%)	✓	✗	✗
	TO BE 3	✓ (30%)	✓ (20%)	✗	✓	✗
	TO BE 4	✓ (30%)	✓ (10%)	✗	✗	✓ @ province
	TO BE 5	✓ (30%)	✓ (10%)	✗	✗	✓ @ compost

[34] % = the proportion of grass clippings in the total input of the composting facility

In addition, a case for one specific landfill-anaerobic digestion (landfill-AD) was investigated i.e. the landfill site of Vanheede in Roeselare. This required a detailed analysis of the mobilization costs this specific digester (section 2.3).

Finally, the supply chain model was used to analyse the sensitivity of the mobilisation cost with respect to the grass origin by road type (AWV-HW, AWV-RR, MUN), the availability of grass and the service area (section 2.3.3).

2.1.1.2 KPIs – Key Performance Indicators

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

- ***Cost:*** *expresses the mobilisation cost per tonne - including harvest, storage and transport up to the gate of the end-processor (Figure 5);*
- ***Mileage:*** *expresses the travel distance per tonne*[35] *to deliver the clippings 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 movement:*** *expresses the number of transport movements (by tractor or truck) per tonne*[36] *to mobilise the grass from the harvest locations to the end-processors;*
- ***Used AWV / MUN (%):*** *expresses the percentage of the technical harvestable potential being mobilised – from AWV and MUN verges respectively.*

2.1.2 *Availability of verge grass*

In the region of Flanders, DEMO 1 area consists of the provinces Eastern Flanders, Western Flanders and Antwerp. Combining results from Table 7 and Table 1 shows the estimated total technical/harvestable grass potential from road verges in the DEMO (Table 13).

The total harvestable grass from road verges in the area amounts to circa **189.000 tonnes fresh matter or 63.000 tonnes dry matter** each year. The total is divided over municipal roads (73%), AWV regional roads (16%) and AWV highways (11%).

Table 13: DEMO 1 harvestable grass feedstock.

Feedstock type	Quantity (technical) (tonne/ha fresh)	Surface (technical (corr.)) (ha)	Total Quantity (technical) (tonne fresh)	(tonne dry)[37]
AWV – RR	16,6	1.855	30.605	10.100
AWV - HW	16,6	1.255	20.735	6.845
MUN	18,6	7.400	137.820	45.480
Total[38]	**-**	**10.510**	**189.160**	**62.450**

[35] If a truck transports 5 tonnes over 10 km, the mileage is 2 km per tonne.
[36] If a truck transports 5 tonnes with 1 movement, the vehicle movement is 0.2
[37] Dry matter content of 33%
[38] Rounded * 1000

As a reflection on the grass availability the results from Table 13 were combined with results from earlier studies (Graskracht and Bermgras). These studies concluded circa 149.000 tonnes is yearly harvested from road verges for the whole of Flanders.[39] These clippings are predominantly processed via composting. OVAM communicated that circa 82.000 tonnes of grass have been composted in Flanders (2020). It is assumed that this grass mainly comes from road verges and to much lesser extent from nature reserves, as nature grass is also used as feed.

As the DEMO 1 area is limited to 3 provinces of Flanders (Antwerp, West Flanders and East Flanders) representing about 66% of the Flemish roads[40] this results in about 99.000 tonnes yearly harvested from road verges[41]. Starting from a technical potential of 189.000 tonnes (100%). These assumptions would conclude 99.000 tonnes (52%) are harvested while 90.000 (48%) is not. From the harvested grass (100%) about 54.000 tonnes[42] (55%) are composted while 45.000 tonnes (45%) is exported or not treated.

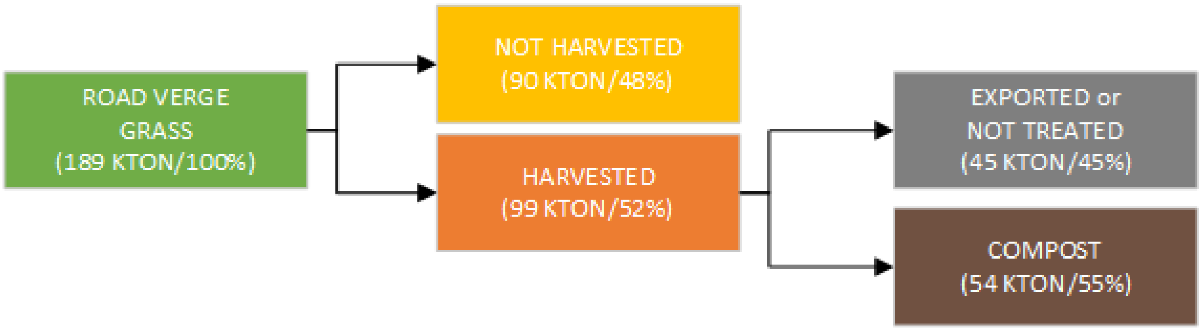

Figure 20: DEMO 1: Road verge grass AS-IS flow.

2.1.3 *Scenario analysis*

2.1.3.1 AS IS scenario – Composting

This scenario starts from 189.000 tonnes (fresh) that is technically harvestable every year (Table 4).

The AS IS scenario reflects the dominant current practice (Figure 21). This means, verge grass being mainly composted at green composting sites.

About 54.000 tonnes of verge grass clippings are green composted.[43] As the total green composting capacity within the region is circa 318.000 tonnes per year,[43] grass clippings would represent 17% of the total capacity. This results in 136.000 tonnes of clippings left unharvested, unused, or exported.

[39] https://www.ovam.be/sites/default/files/atoms/files/Actieplan-duurzaam-beheer-biomassareststromen-2015-2020-DEF%2BERRATUM.pdf
[40] https://www.seniorennet.be/Pages/Auto/wegenpatrimonium_vlaanderen_cijfers.php
[41] Being 66% of 149.000 tonnes defined in Graskracht and Bermgras).
[42] Being 66% of 82.000 communicated by OVAM (2020)
[43] Source: OVAM (2020)

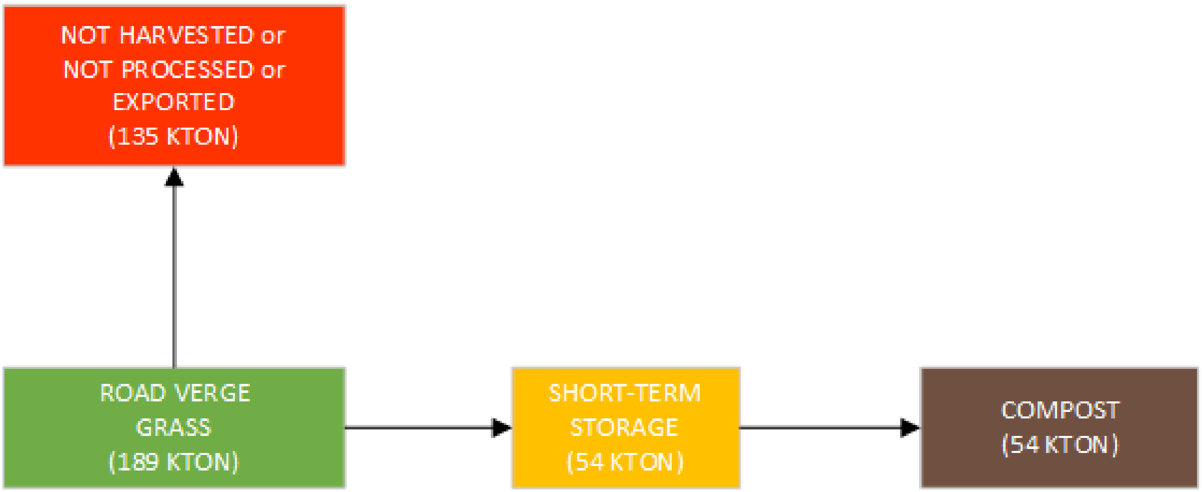

Figure 21: DEMO 1: AS IS SCENARIO: Process flow diagram and technical potential.

Note that the AS IS scenario can only be assessed under the assumption that current mobilisation would be optimally organised (i.e. *best practice*). It is likely that this is not the case and that current *actual practice* is operating sub-optimally. It can be expected that in *actual practice* not always verges are harvested at lowest cost nor that the verges nearest to the composting sites are being harvested first. As such it is likely that the *best practice* baseline cost calculated for the AS IS scenario underestimates the mobilisation cost vis-à-vis the *actual case*. However, empiric data from the actual practice are not available.

For the *best practice* 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 the 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.

Figure 22 shows the cost optimal supply chain configuration map of the AS IS scenario with the sourcing area to supply 54.000 tonnes clippings(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.

The results of the AS IS scenario are summarised in Table 14. These results are the baseline costs to be benchmarked with the TO BE scenarios (see section 2.1.3.2 - 2.1.3.5). To be able to compare the scenarios, the 3 KPI's (Section 1.3.1.3) are expressed <u>per tonne of harvested (and mobilised) grass per year</u>:

- The minimised mobilisation cost is **49,5 € per tonne of harvested grass**, to meet the demand of the green composting facilities;
- In the AS IS situation, the minimised mileage is **1,6 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 (AWV / MUN) mainly impacts the harvesting costs (Table 4). 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 4) – and MUN grass is abundantly available (137.820 tonnes available vs. 54.000 tonnes demand (or 39% is used)).

Table 14: DEMO 1: AS IS SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	49,5	0%
Mileage (km)	1,6	0%
Vehicle movements (#)	0,21	0%
Used AWV / MUN (%)	0 / 39	0 / 0

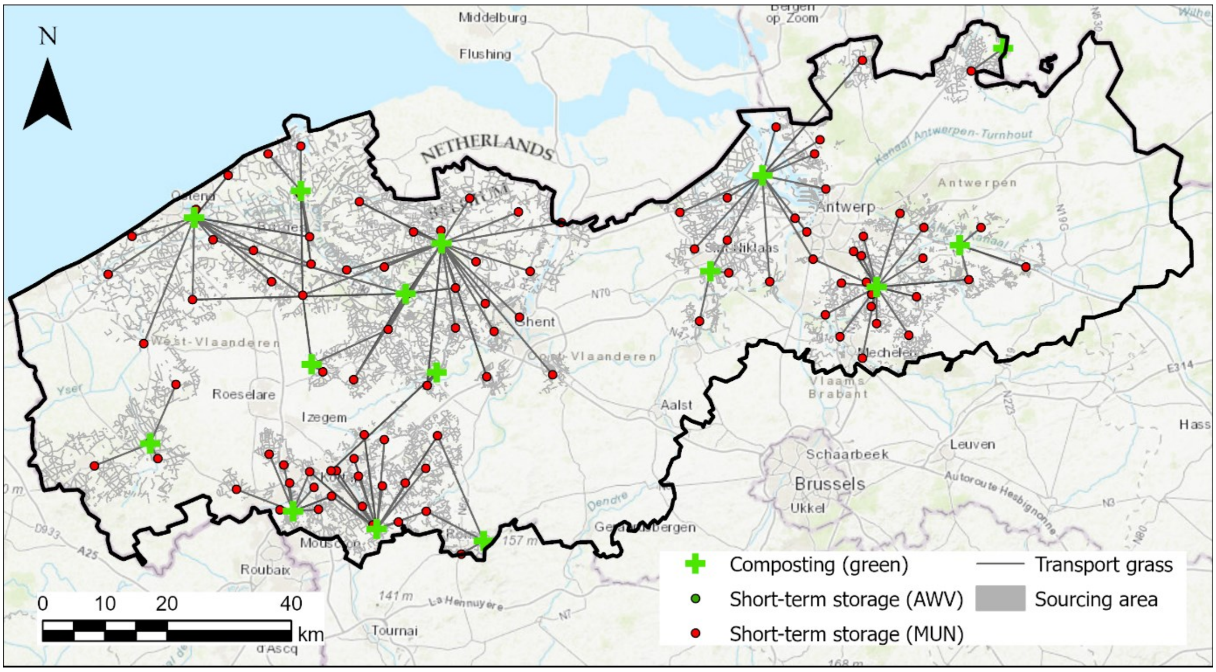

Figure 22: DEMO 1 - AS IS SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

2.1.3.2 TO BE 1 scenario - Increased composting

In the TO BE 1 scenario, the demand for grass clippings by **green composting is increased from 17% (AS IS) to 30 %** of the total capacity or 97.000 tonnes of grass per year. In addition, the demand from **garden, fruit and vegetable waste (VGF) composting sites is set to 10%** of their capacity or 28.000 tonnes per year (Figure 23). In total, the composting sites would take in 125.000 tonnes. This results in a remaining 65.000 tonnes of grass which is unharvested, unused, or exported.

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% (which is not feasible) during harvest season – as no grass is available during winter season.

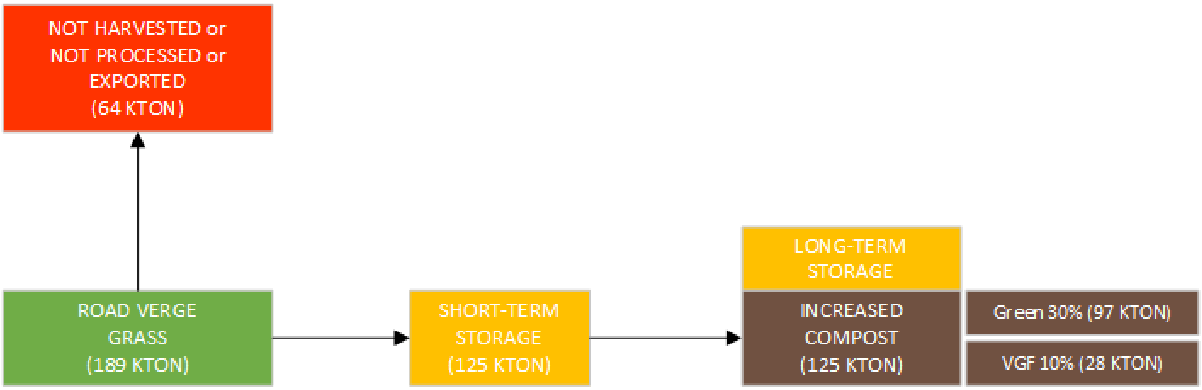

Figure 23: DEMO 1: TO BE 1 SCENARIO: Process flow diagram and technical potential.

Figure 24 shows the cost optimal supply chain configuration of the TO-BE 1 scenario with the sourcing area for the 125.000 tonnes grass (grey), the optimal short-term storage sites (municipal - red dots and AWV - green dots), the composting installations (green - light green cross and VGF - dark green cross). Bird flight lines indicate transport routes; however, transport distances have been calculated via the actual road network. The sourcing areas have increased significantly to meet the demand.

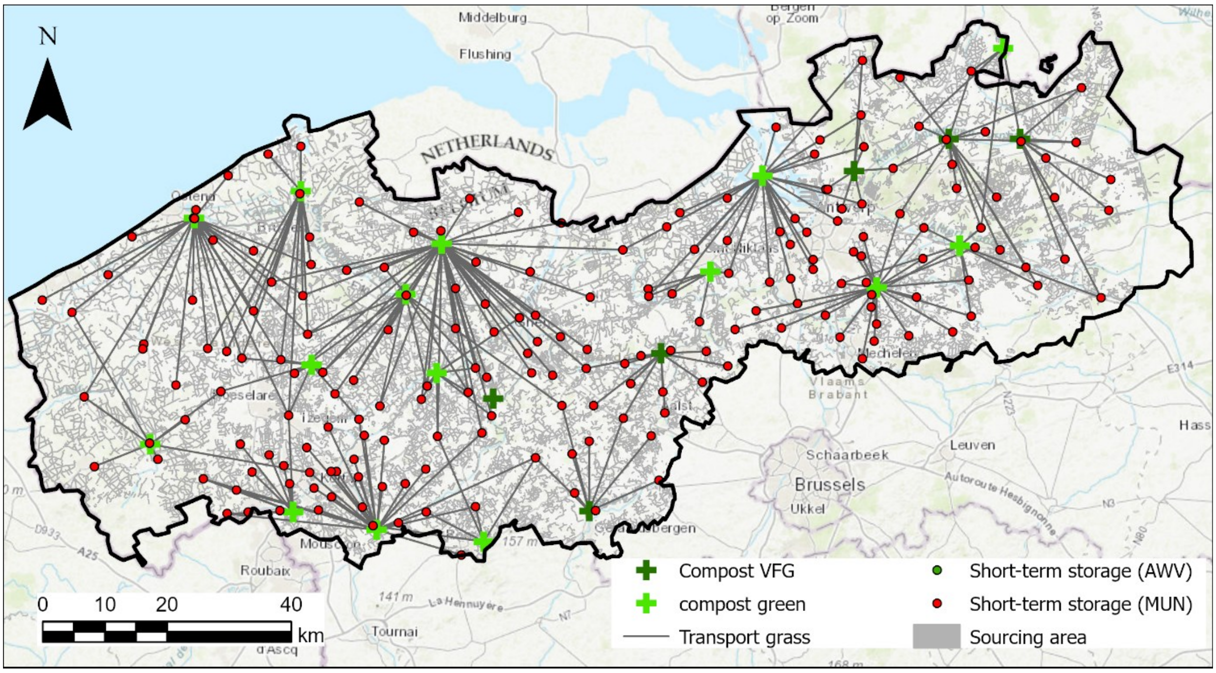

Figure 24: DEMO 1: TO BE 1 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 1 situation are summarised in Table 15:

- 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 0,9% in comparison to the AS IS scenario;
- In the TO BE 1 situation, the mileage counts to an average of **2,1 km per tonne of harvested grass** or an increase with 31% in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 24;
- The mobilisation requires **0,21 vehicle movements per tonne of harvested grass** which equals the AS IS scenario;
- In this scenario, **most verge grass from municipal roads** has been harvested (91%) to meet the demand at the gate of the composting facilities. As feedstock type, grass from municipal roads remains preferred as it is sufficiently available and cheaper to harvest.

Table 15: DEMO 1: TO BE 1 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	51,0	+0,9 %
Mileage (km)	2,1	+31 %
Vehicle movements (#)	0,21	+0%
Used AWV / MUN (%)	0 / 91	0 / +52%

2.1.3.3 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**[44]; with a demand of 125.000 tonnes per year. However, the TO BE 2 scenario **additionally includes all existing landfills operating within the region as grass landfill-AD sites**.

This scenario adds the 8 existing landfill sites as potential landfill-AD sites with a grass intake calculated proportional to the Vanheede case (Section 2.3))[45], i.e. a fresh grass demand at each site of 4.500 tonnes in the summer as well as in the autumn mowing season. The intake for all AD-landfill sites would than sum 76.000 tonnes per year, which is converted to circa 16.000 tonnes biogas and 60.000 tonnes digestate per year. The digestate must be further processed into compost before it can be used as soil improver.

For the composting sites this means they would only need 65.000 tonnes of fresh clippings to meet their total demand of 125.000 tonnes, as 60.000 tonnes of digestate needs to be composted as well (Figure 25).

This results in 49.000 tonnes of grass clippings left unharvested, unused or exported per year.

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[44] 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)

[45] The AD-landfill technology is under investigation in the Interreg-project Grassification at the Vanheede site in Roeselare. The mobilization costs for this specific location were also calculated and are presented in section **Error! Reference source not found.**.

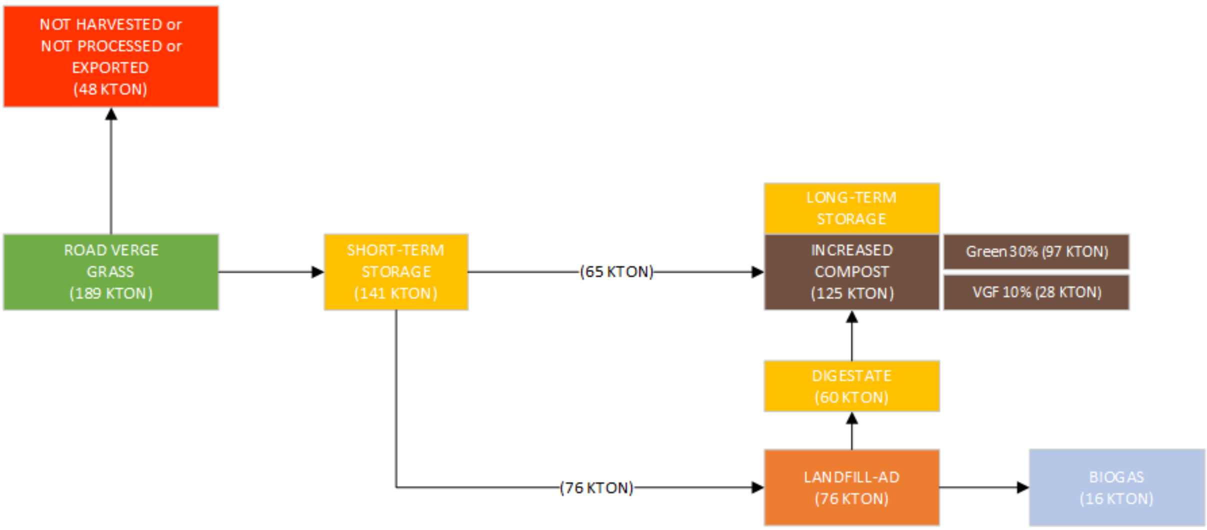


Figure 25: DEMO 1: TO BE 2 SCENARIO: Process flow diagram and theoretical potential.

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

Figure 26 shows the cost optimal supply chain configuration of the TO-BE 2 scenario with the sourcing area for the 141.000 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 VGF – 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 16.000 tonnes. Note that digestate is transported over longer distances from landfill AD sites to be processed at composting sites.

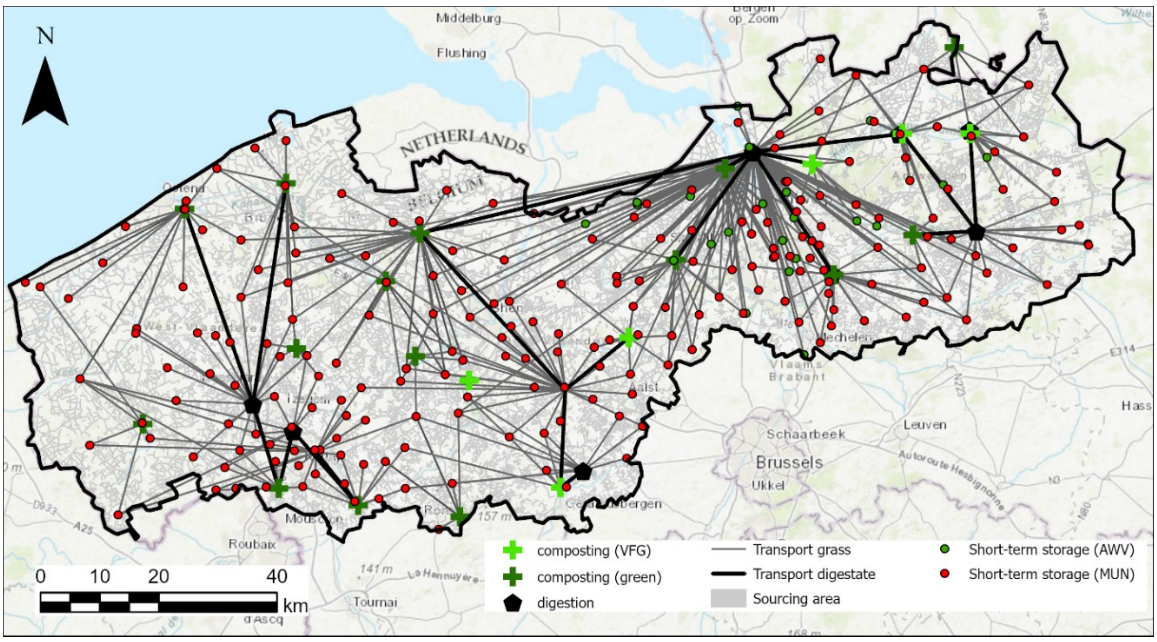


Figure 26: DEMO 1: TO BE 2 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 2 scenario are summarised in Table 16, focussing on the KPI's for the mobilisation of the grass, excluding the activities related to digestate which are discussed in Table 17:

- The minimised mobilisation cost is **42 € per tonne of harvested grass**. This is a decrease with 15 % in comparison to the AS IS scenario. This is directly related to the increased grass processing capacity at harvest time (thanks to landfill-ADs) which reduces the need for storage and treatment of fresh grass. Due to the increased number of end-processing locations, 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 to an average of **2,4 km per tonne of harvested grass** or an increase with 48 % in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 26, showing that practically the complete area is sourced;
- The mobilisation requires **0,20 vehicle movements per tonne of harvested grass** or a decrease with 8 % 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 (97%) complemented with verge grass from AWV to meet the demand of the composting facilities. Again, the preferred grass type is grass from municipal roads as it is abundantly available at lower harvest cost.

Table 16: DEMO 1: TO BE 2 SCENARIO: Summary of the MooV result (fresh grass).

KPIs	Per tonne harvested grass	Compared to AS IS
Cost (€)	42	-15 %
Mileage (km)	2,4	+ 48 %
Vehicle movements (#)	0,20	- 8 %
Used AWV / MUN (%)	3 / 97	+3% / + 58%

So, within the TO BE2 scenario, part of the harvested grass is transported directly to composting facilities while the other part is delivered at the landfill ADs. The landfill-AD digestate 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 26) also comes at a cost (Table 17), 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 **0,1 movements per tonne digestate**.

Table 17: DEMO 1: TO BE 2 SCENARIO: Summary of the MooV result (digestate).

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

Considering the total cost for mobilisation of fresh grass and digestate (Figure 27), the **TO BE 2 scenario reduces the total mobilisation cost with 20% 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.

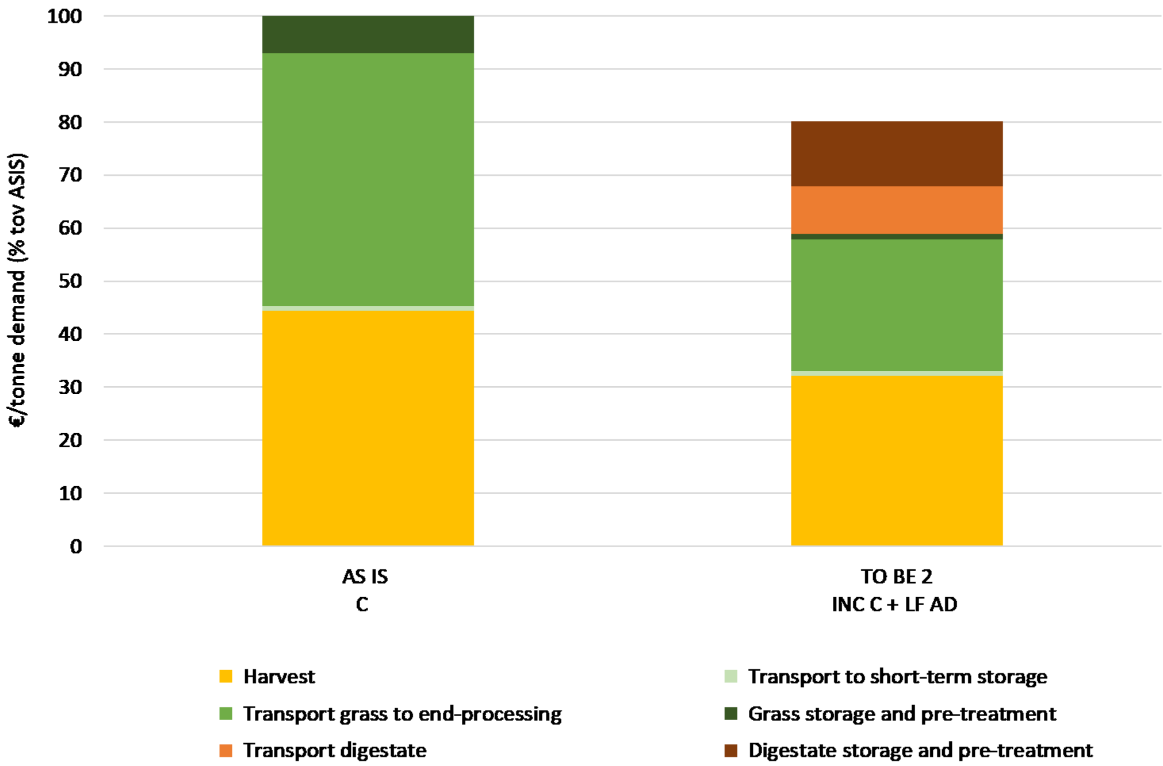


Figure 27: DEMO 1: TO BE 2 SCENARIO: Comparison of total cost (mobilisation of grass and digestate) per tonne demand at the gate of the end-processing sites.

2.1.3.4 TO BE 3 scenario – Increased composting / dry digestion

This scenario elaborates on the action plan 'Sustainable management of biomass (residual) streams 2015 -2020' which favours the processing of roadside clippings in a dry digester with post-composting of digestate at the VGF composting sites. [46] Through this methodology, the VGF waste is first valorised energetically and secondly as soil improver during composting.

[46] https://www.biogas-e.be/sites/default/files/2019-07/D2_2%20Onbenutte%20biomassa%20gemeentelijk%20berm%20en%20grasmaaisel_0.pdf

This scenario builds on the TO BE 1 scenario. The increased intake of grass by composting installations is kept at **30% for green compost** (or 97.000 tonnes per year). In addition, **a dry digester is added at each of the VGF composting sites**, with similar capacity (on average 40.000 tonnes). Considering that roadside clippings can be mixed up to 25% in a VGF digester without adverse effects on biogas production or digestate quality[47,46,48], the fresh grass demand at the VGF sites, is set to 25% of their capacity. This sums to a total of 48.000 tonnes per year, which is converted to circa 10.000 tonnes biogas and 38.000 tonnes digestate per year (Figure 28). The digestate is further processed into compost within the adjacent VGF composting facility before it can be used as soil improver, which takes about 20% of the total capacity of the VGF composting facilities.

In total, the composting sites take in 145.000 tonnes of grass per year, resulting in a remaining 44.000 tonnes of grass which is unharvested, unused, or exported.

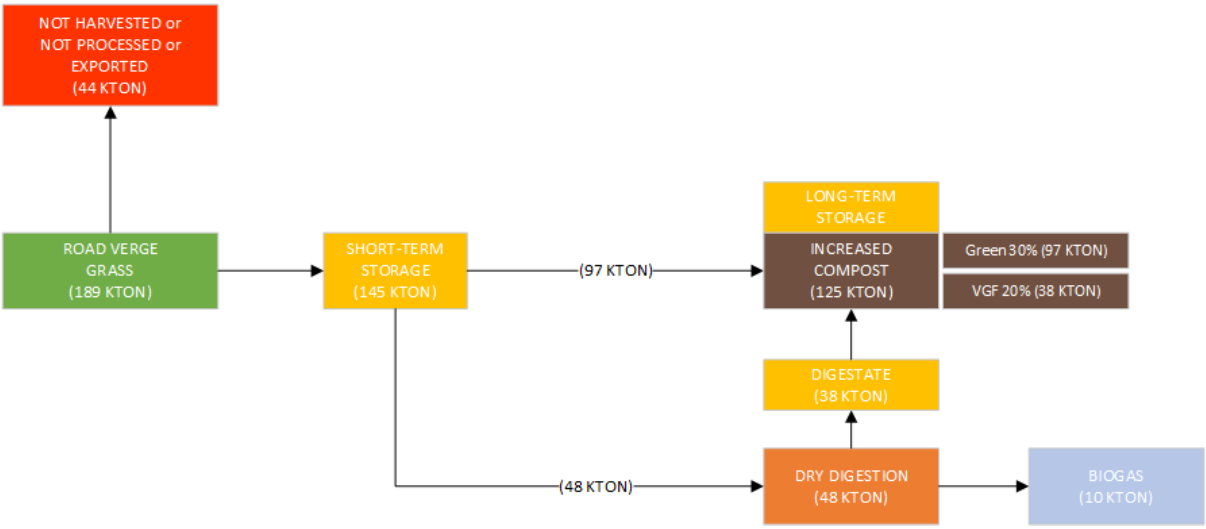


Figure 28: DEMO 1: TO BE 3 SCENARIO: Process flow diagram and theoretical potential.

Also, in this scenario, long-term storage is needed at the composting facilities to ensure the availability of year-round grass clippings.

Figure 29 shows the cost optimal supply chain configuration of the TO-BE 3 scenario with the sourcing area for the 145.000 tonnes grass (grey), the optimal short-term storage sites (municipal – red dots and AWV – green dots) and the VGF-composting installations (dark green cross).

Bird flight lines indicate transport of fresh grass (black interconnectors). This time the sourcing area increased slightly vis-à-vis scenario TO BE 1 as demand increased with only 20.000 tonnes. Note that digestate is on-site processed in the adjacent VGF composting facility, and therefore no additional transport movements are required.

[47] https://www.ovam.be/sites/default/files/atoms/files/Graskracht.pdf

[48] 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)

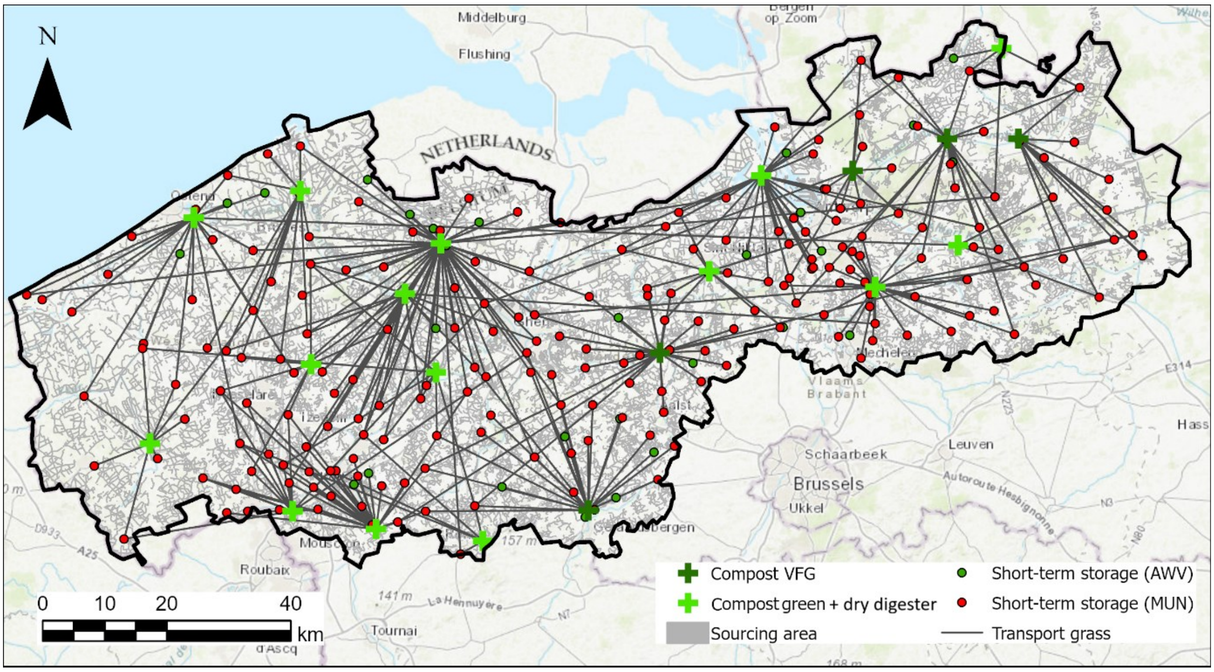


Figure 29: DEMO 1: TO BE 3 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 3 situation are summarised in Table 18:

- The minimised mobilisation cost is **52 € per tonne of harvested grass**, or an increase with 4% in comparison to the AS IS scenario. This increase is mainly related to an increase in harvesting costs and transport costs from short-term storage to end-processing site due to the larger sourcing area;
- In the TO BE 3 situation, the mileage counts to an average of **2,2 km per tonne of harvested grass** or an increase with 34% in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 29, showing most of the sourcing area is cut;
- The mobilisation requires **0,22 vehicle movements per tonne of harvested grass** equals the AS IS scenario.
- In this scenario, **most verge grass from municipal roads** has been harvested (94%) to meet the demand at the gate of the facilities. As feedstock type, grass from municipal roads is cheaper to harvest. However, 6% is being harvest from AWV roads as well. This because the remaining 6% municipal verges have such high transport costs (are so far away), that it becomes more interesting to harvest local AWV road sides (despite the higher harvest costs) instead.

Table 18: DEMO 1: TO BE 3 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	51,7	+5%
Mileage (km)	2,2	+34%
Vehicle movements (#)	0,22	+0,8%
Used AWV / MUN (%)	6 / 94	+6% / +55%

2.1.3.5 TO BE 4 scenario – Increased composting / biomaterials @ provincial level

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 biomaterials. Although a variety of biomaterials is possible this scenario focusses on the use of grass fibres for composite materials (cf. Circular Matters).

As for the previous scenarios, also this scenario assumes increased grass composting. The increased intake of grass by composting installations is kept at **30% for green compost and 10% for VGF compost** with a demand of 125.000 tonnes per year. **In addition, 1 biomaterial production facility is assumed in each province (3 in total) of the Grassification area, with each a verge grass demand of 3.000 tonnes (fresh) grass per year**. Obviously, this is only one of numerous potential set-ups, variations are possible as well.

Table 19 shows the total fresh grass demand for the aforementioned biomaterials. The total demand sums to 9.000 tonnes fresh grass per year to produce extruded composite materials. The production capacity shows the total tonnes of end-product (fibres + other composites material) for one site. The column 'fibres' expresses the assumed percentage of grass fibres used in the biomaterial. Combination of production capacity and fibre percentage leads to the dry matter demand, considering a dry matter content of 33%.

Table 19: DEMO 1: TO BE 4 SCENARIO: Capacity & demand from biomaterials.

	Production capacity per site	***Fibres***	***Demand per site***		***Number of sites***	***Demand total***
	tonne/y	*%*	*tonne DM/y*	*tonne FM/y*	*#*	*tonne FM/y*
Biomaterial[49]	5.000	20%	1.000	3.000	3	**9.000**

In total, this scenario processes 134.000 tonnes of grass per year, resulting in a remaining 55.000 tonnes of grass which is unharvested, unused, or exported (Figure 30). In this scenario, long-term storage is needed at compost as well as the biomaterial sites to ensure continuous feedstock availability.

Figure 31 shows the cost optimal supply chain configuration of the TO-BE 4 scenario with a sourcing area for 134.000 tonnes grass (grey), the optimal short-term storage sites, the composting installations (green cross) and the biomaterial sites (star). Again, bird flight lines indicate transport routes (black interconnectors), while actual transport distances have been calculated via the actual road network.

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

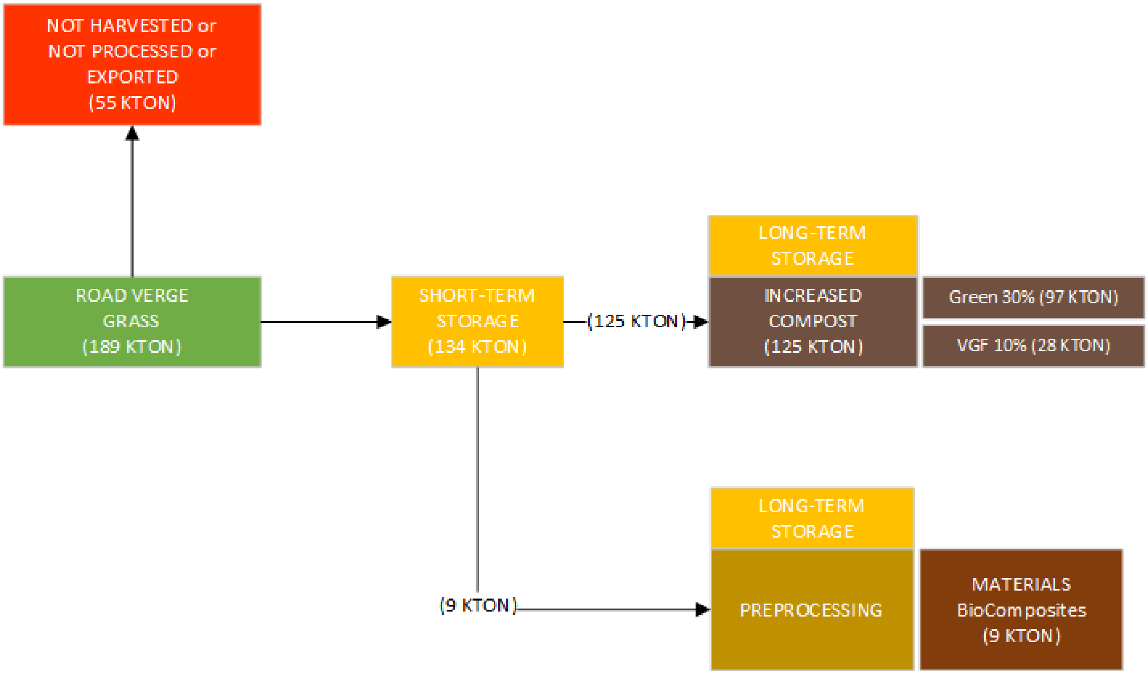


Figure 30: DEMO 1: TO BE 4 SCENARIO: Process flow diagram and theoretical potential.

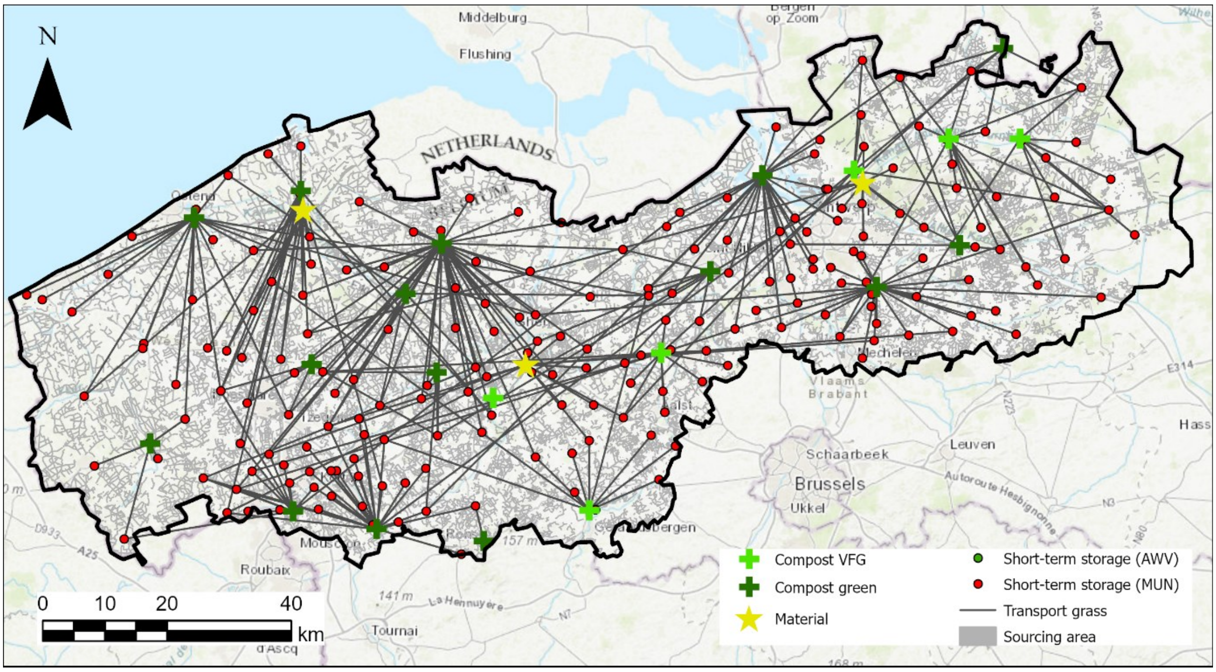


Figure 31: DEMO 1: TO BE 4 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 4 situation are summarised in Table 20:

- The minimised mobilisation cost is **50 € per tonne of harvested grass**, or a marginal increase with 1% in comparison to the AS IS scenario;
- In the TO BE 4 situation, the mileage counts up to an average of **2,2 km per tonne of harvested grass** or an increase with 36% in comparison to the AS IS scenario – due to a larger sourcing area. This increase is also reflected in Figure 31, showing that the sourcing area covers the Grassification region of Flanders;
- The mobilisation requires **0,21 vehicle movements per tonne of harvested grass** equals the AS IS scenario.
- In this scenario, **most verge grass from municipal roads** has been harvested (97%) to meet the demand at the gate of the composting facilities. As feedstock type, grass from municipal roads is preferred over AWV grass as it is cheaper to harvest.

Table 20: DEMO 1: TO BE 4 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	50,0	+1%
Mileage (km)	2,2	+36%
Vehicle movements (#)	0,21	+0%
Used AWV / MUN (%)	0 / 97	+ / 58%

2.1.3.6 TO BE 5 scenario – Increased composting / biomaterial @composting sites

As for the previous scenarios, also this scenario investigates end-processing towards compost in combination with biomaterials. The increased intake of grass by composting installations is kept at **30% for green compost and 10% for VGF compost** with a demand of 125.000 tonnes per year. In addition, **a biomaterial facility is situated at each composting site with a capacity larger than 10.000 tonnes per year** (i.e. 13). Each biomaterial site has a verge grass demand of 3.000 tonnes (fresh) grass per year. It is assumed that these composting sites already have (to a certain extent) or will attract the needed pre-treatment equipment to pre-process the verge grass into storable fibres for biomaterial production during harvesting months, excluding the need for long-term storage.

In total, this scenario processes 164.000 tonnes of grass per year, resulting in a remaining 25.000 tonnes of grass which is unharvested, unused, or exported (Figure 32).

Figure 33 shows the cost optimal supply chain configuration of the TO-BE 5 scenario with the sourcing area for the 164.000 tonnes grass (grey), the optimal short-term storage sites, the composting installations (green cross) and the biomaterial sites (yellow star). Again, bird flight lines indicate transport routes (black interconnectors), while actual transport distances have been calculated via the actual road network.

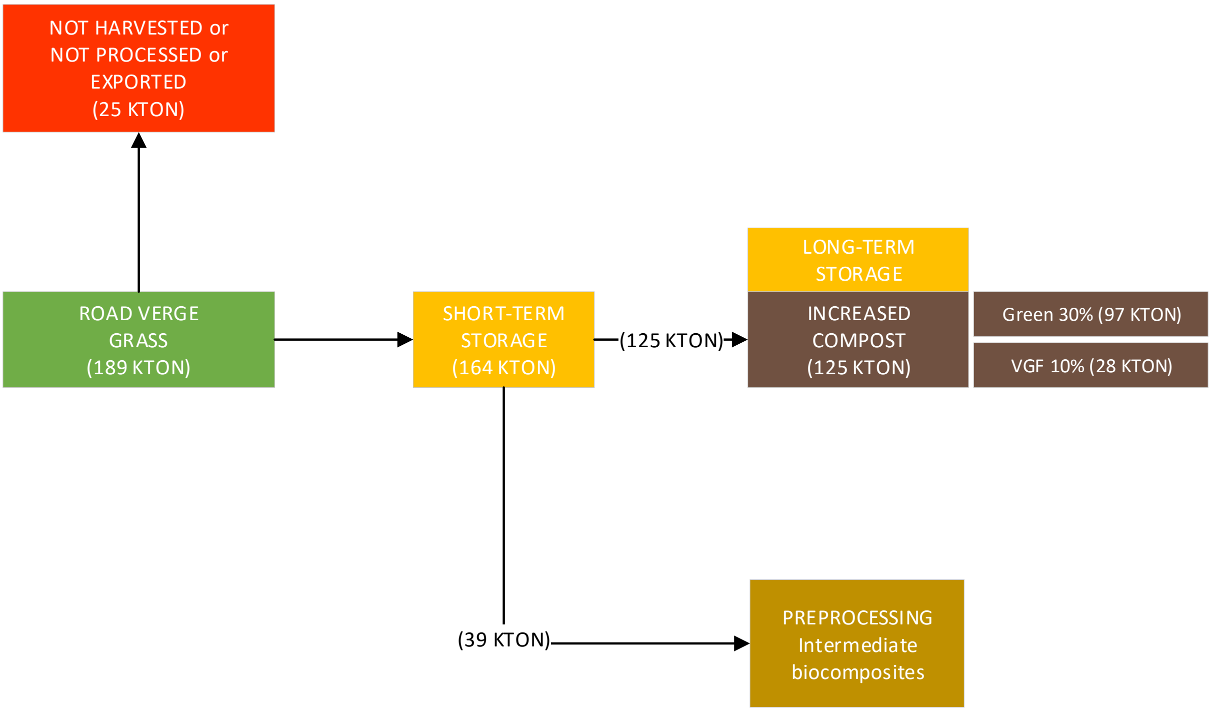


Figure 32: DEMO 1: TO BE 5 SCENARIO: Process flow diagram and theoretical potential.

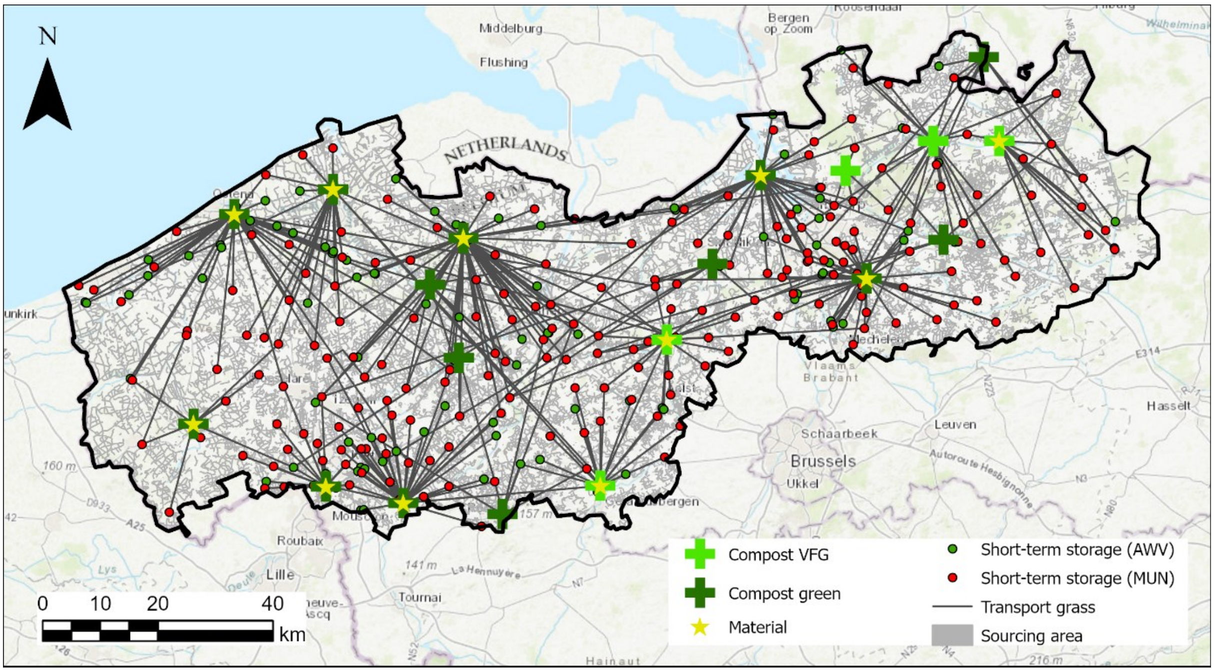


Figure 33: DEMO 1: TO BE 5 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

The results of the MooV analysis of the TO BE 5 situation are summarised in Table 21:

- The minimised mobilisation cost is **52 € per tonne of harvested grass**, or an increase with 6% in comparison to the AS IS scenario;
- In the TO BE 5 situation, the mileage counts up to an average of **2,1 km per tonne of harvested grass** or an increase with 33% in comparison to the AS IS scenario – due to a broader sourcing area. This increase is also reflected in Figure 33, showing that the sourcing area covers the Grassification region of Flanders;
- The mobilisation requires **0,21 vehicle movements per tonne of harvested grass** equals the AS IS scenario.
- In this scenario, **most verge grass from municipal roads** has been harvested (99%) to meet the demand at the gate of the composting facilities. As feedstock type first all grass from municipal roads is preferred as it is cheaper to harvest. However, to meet the demand of 164.000 tonnes, additionally 57% of AWV road verges needs to be harvested as well.

Table 21: DEMO 1: TO BE 5 SCENARIO: Summary of the MooV result.

KPIs	Per tonne harvested grass	vs. AS IS (%)
Cost (€)	52,4	+6%
Mileage (km)	2,1	+33%
Vehicle movements (#)	0,21	+0%
Used AWV / MUN (%)	57 / 99	+57 / +60%

2.1.4 Comparison 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 to be able to define:

- the impact of the end-processing demand (Section 2.1.4.1);
- the impact of the “re-use of grass” as digestate (Section 2.1.4.2);
- the impact of grass origin requirements at the end-processing site (Section 2.1.4.3);
- the impact of centralisation.

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

2.1.4.1 Impact of end-processing demand

AS IS: In this scenario, 54.000 tonnes of grass are processed in green composting facilities each year.

TO BE 1: The grass demand is raised to 125.000 tonnes per year due to an assumed increase of grass composting.

TO BE 1B: In this variant – the impact of end-processing demand is tested by adding the constraint that all grass (189.000 tonnes per year) must be processed in the composting facilities. Opposite to the TO BE 1 scenario, which is a ‘pull’ scenario where a predefined demand from composting installations needs to be fulfilled; the TO BE 1B scenario is a ‘push’ scenario, which dictates that all grass must be harvested and processed. As such, the TO BE 1B scenario reflects a continuation of the current practice of cut-and-collect in Flanders, however this time dictating all grass (189.000 tonnes) needs to be collected; while the AS IS scenario assumes only 52.000 tonnes being collected.

Two aspects can be derived from comparison of these results (Figure 34-Figure 35):

1) Comparison between the AS IS scenario and the TO BE 1 scenario:
In both scenarios, verge grass from municipal roads is abundantly available and no grass from AWV verges is needed to fulfil the demand. As mentioned previously, verge grass from municipal roads is preferred as it is cheaper to harvest. The small increase in mobilization costs (+0,9%) is directly related to the increase in mileage (and related costs) for transport between short-term storages and end-processing sites. This because as demand increases, a larger sourcing area is needed, and higher travel distances towards end-processing sites.
2) Comparison between the TO BE 1 and the TO BE 1B scenario:
When only municipal grass is mobilised (AS IS & TO BE 1), the impact on the cost per tonne is rather small. However, when all grass – i.e. including AWV grass - must be mobilised (TO BE 1B), the cost increase in cost per tonne is more pronounced (+10%). This is mainly due to the higher harvest cost for AWV grass. Note that these higher costs are slightly compensated by a more efficient transport from short-term storage sites to end-processing sites. The number of transport movements per tonne remains unchanged which indicates that the load factor is rather 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.

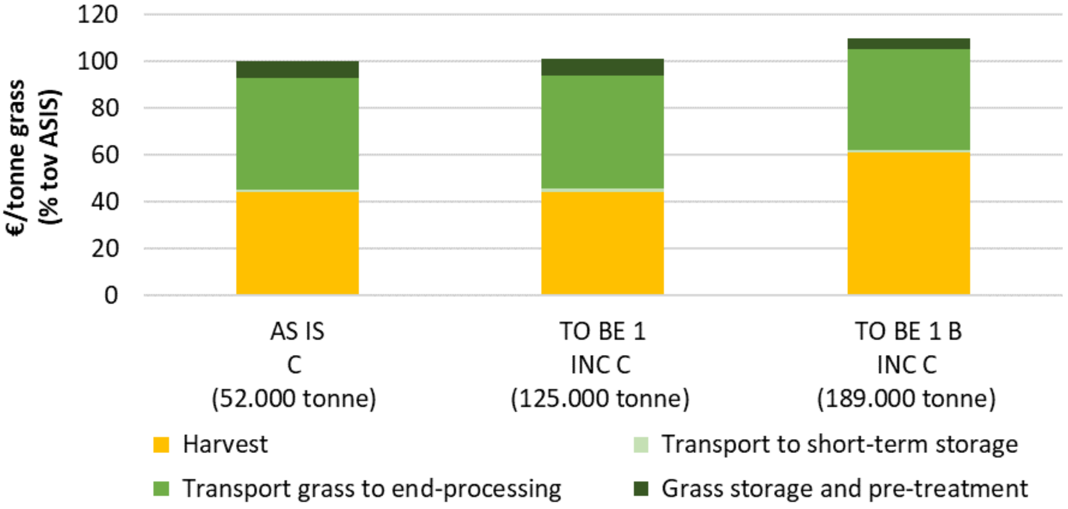
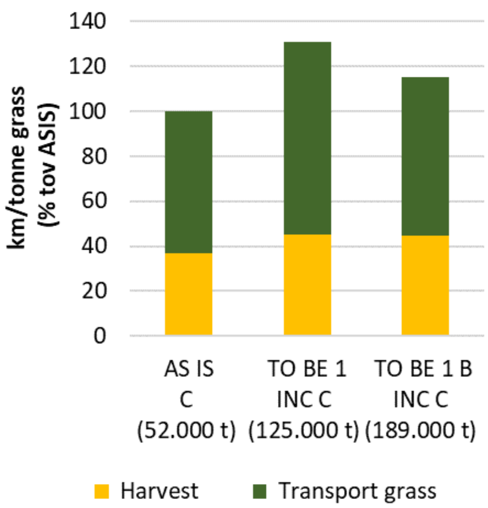


Figure 34: DEMO 1: Impact of end-processing demand on the cost per tonne mobilised grass (as % vs. AS IS).



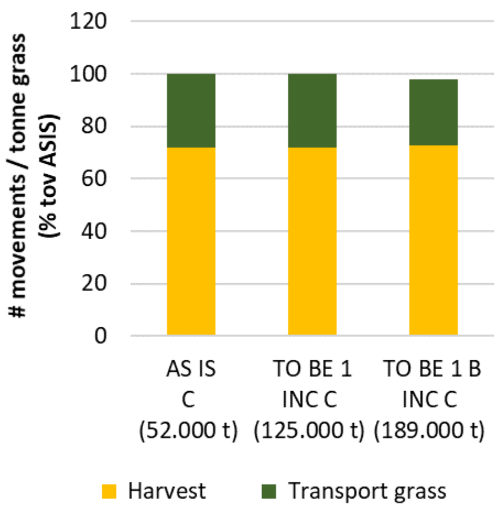


Figure 35: DEMO 1: Impact of end-processing demand on the mileage (left) and transport movements (right) per tonne mobilised grass (as % vs. AS IS).

2.1.4.2 *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 and TO BE 3 scenario, grass can be used twice (or 'reused'): for the production of biogas at the digester (landfill anaerobic digester or dry digester) 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 2 and TO BE 3 similar quantities of verge grass from municipal roads and AWV have been harvested, resulting in similar harvesting costs (yellow). In **TO BE 2, the scenario including landfill anaerobic digestion** (LF AD), the reduction in mobilisation cost (Figure 36 - left) is mainly attributed to a reduced transport cost between short-term storage and end-processing sites, and to lesser extent to a reduction in storage costs to overcome seasonal peaks. 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 37 - right)).

This reduction in mobilization costs is not observed in **the scenario including dry digestion at VGF composting facilities** (DD) (TO BE 3) (Figure 37 - left) due to the year-round demand at the dry digester. In correspondence to section 2.1.4.1, the minimal increase in mobilization costs (+0,5%) is directly related to the increase in mileage (and related costs) for transport between short-term storages and end-processing sites because a larger sourcing area is needed to fulfil the demand.

However, when comparing the total cost per tonne demand (Figure 37 – right), the 'reuse' of grass clippings for the production of biogas as well as the processing of digestate into compost provides a signification reduction in both scenarios (-20% to – 12%). In the TO BE 3 scenario, no additional mobilisation costs are adopted for processing of digestate since it is assumed the dry digester is adjacent to the VGF composting facility where the digestate is processed.

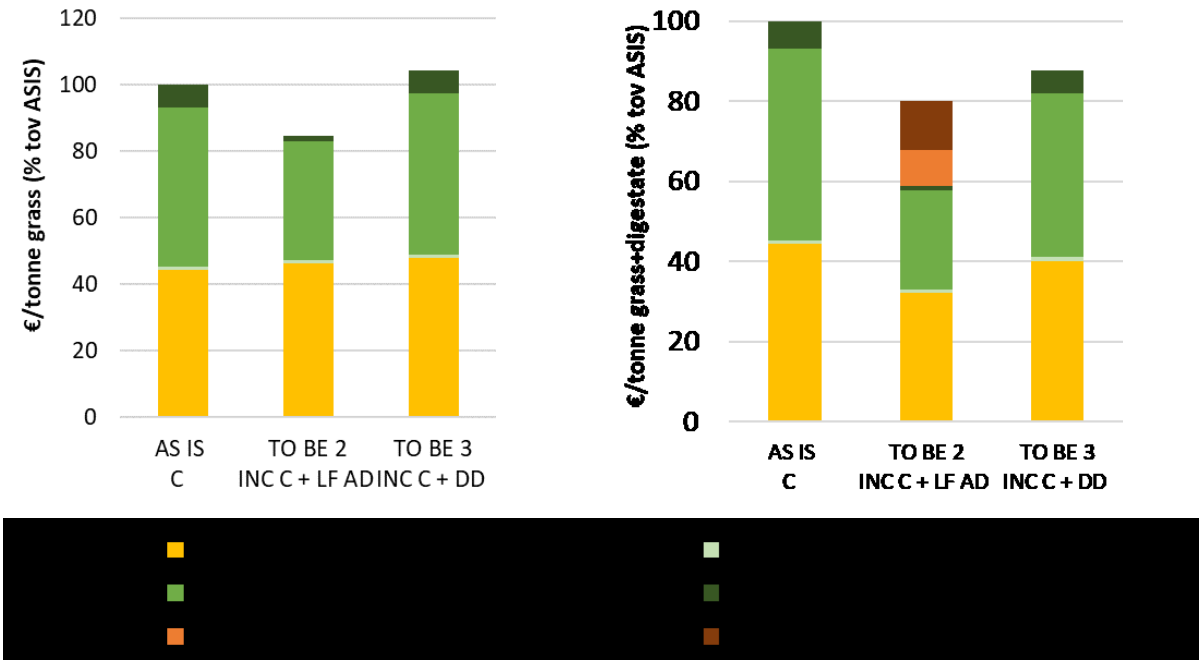


Figure 36: DEMO 1: Impact of 'reuse' of grass clippings on the cost per tonne mobilised grass (left) and total cost per tonne demand (right) (as % vs. AS IS).

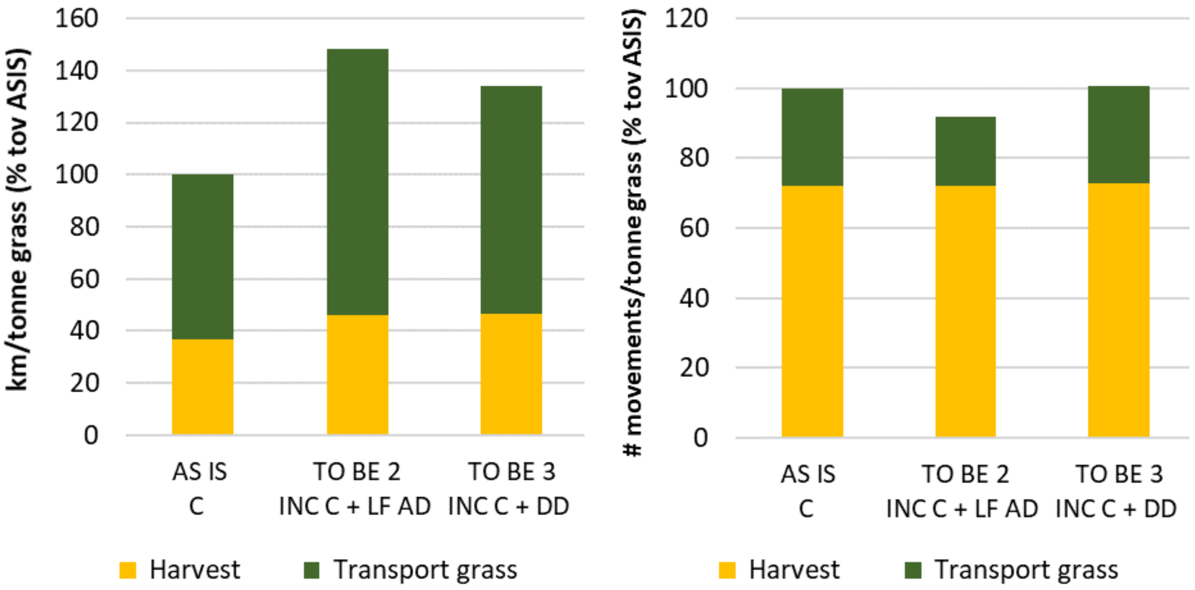


Figure 37: DEMO 1: Impact of 'reuse' of grass clippings on the mileage (left) and transport movements (right) (as % vs. AS IS).

2.1.4.3 Impact of grass origin/quality requirements at the gate

In the TO BE 4 scenario, grass fibres are used for composite materials (section 2.1.3.5). This scenario disregards the fact that biomaterial processing is sensitive to **litter contamination**. As 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 is mimicked by limiting grass for biomaterials application, to grass from highway verges as it has a medium litter risk (Table 3)[50]. To analyse the impact of such a limitation, the KPIs of the TO BE 4 scenario are calculated with and without the limitation of grass from verges with high litter risk being excluded for biomaterial application:

- TO BE 4 A: without constraints – all grass (AWV-RR, AWV-HW and MUN) can be used for biomaterials as well as composting;
- TO BE 4 B: with constraints – only grass from highways (AWV-HW) can be used for biomaterials while verge grass from regional roads (AWV-RR) and municipal roads (MUN) can be used for composting.

Only accepting grass from highway verges, results in an **increase of the total grass mobilization cost of 4%** (from 50 € per tonne to 52 € per tonne mobilised grass), exclusively related to an increase in the harvesting costs (Figure 38).

[50] 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.

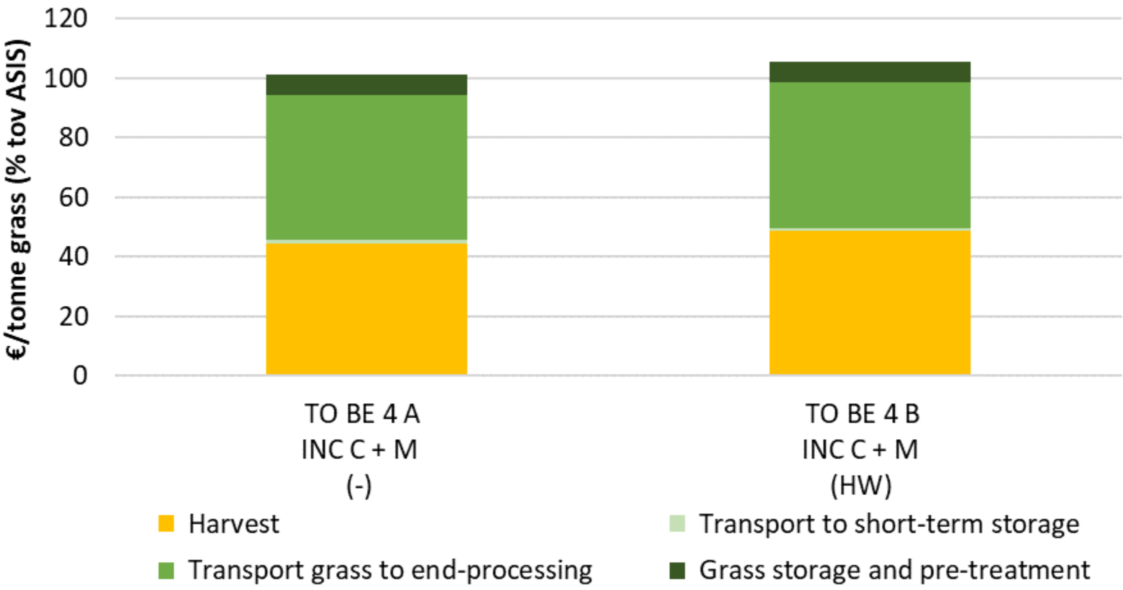


Figure 38: DEMO 1: Comparison of the mobilization cost with and without restriction on origin of grass (as % vs. AS IS).

Although the requirement for grass from highway verges results in higher harvesting costs (Figure 38), a similar number of harvest movements and transport movements (Figure 39). The increase in mobilisation cost can be entirely attributed to the higher harvesting costs for mowing highway verges (due to the need for safety cars). This is also underpinned by the mileage per tonne (Figure 39), which is reduced with about 10% in the scenario only allowing grass from highway verges. The reduction in costs related to the reduced transport distances is entirely outweighed by the increase in harvesting costs.

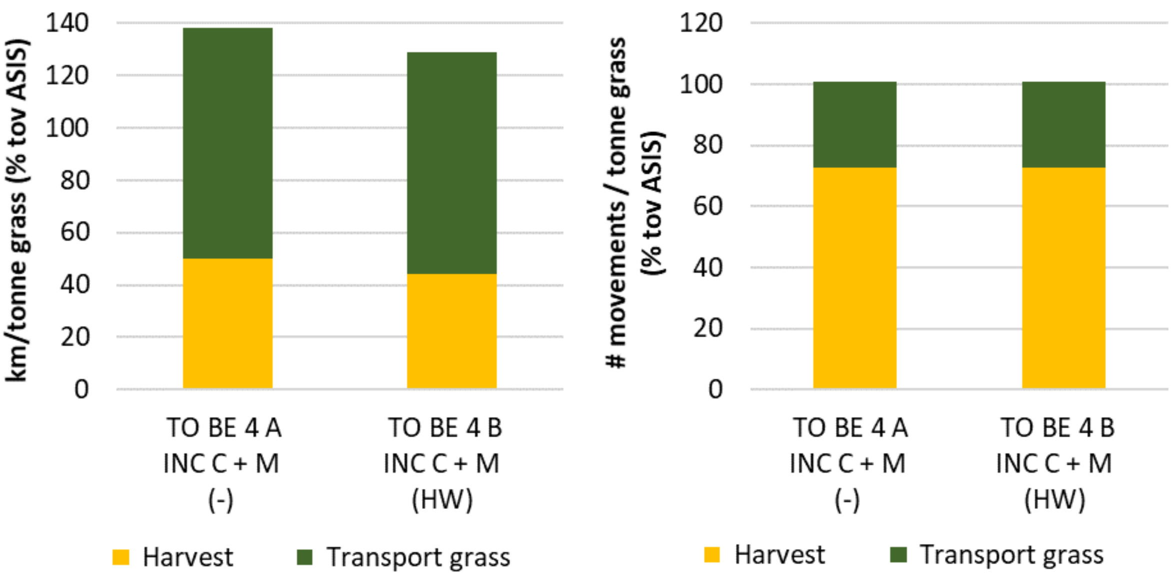


Figure 39: DEMO 1: Impact of grass origin requirements on the mileage per tonne mobilised grass (left) and on the number of movements per tonne mobilised grass (right) (as % vs. AS IS).

2.1.4.4 *Impact of centralisation vs. decentralisation*

To study the impact of (de)centralisation on the grass mobilisation cost (and other KPIs), the model is forced to process all available grass in the Flemish Grassification area (i.e. 189.000 tonne). In comparison to the original TO BE 1 scenario (section 2.1.3.2), this requires an additional processing capacity of 64.000 tonnes fresh grass.

To test the impact of (de)centralisation the additional processing capacity is defined in 2 ways:

- **TO BE 1 B – decentral approach**: increase of the capacity of the available composting sites in TO BE 1 pro rata the total capacity of each site.
- **TO BE 1 C – central approach**: 1 processing facility in the middle of the region (neighbourhood of Ghent) which is able to process 64.000 tonnes of fresh grass per year.

In comparison to the AS IS situation, the grass mobilisation cost in the decentral scenario (TO BE 1 B) increases with 12% (or 55 € per tonne mobilised grass) while in the central scenario (TO BE 1 C) the cost increases with 19% (or 59 € per tonne mobilised grass) (Figure 40) for processing the same quantity of fresh grass. Since the assessment requires that all available grass is harvested, the harvesting cost in both scenarios is equal as is the storage and treatment cost. Therefore, the increase can be entirely attributed to the larger transport distances to be overcome in the centralised (TO BE 1 C) scenario (1,9 km per tonne vs 2.8 km per tonne (or an increase of 150%) (Figure 41).

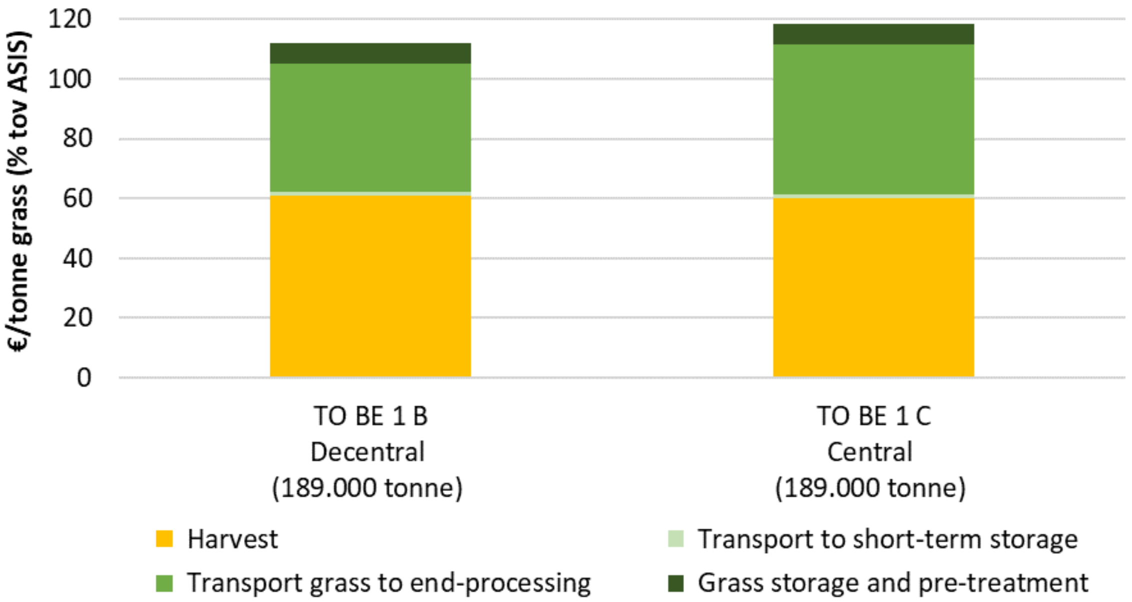
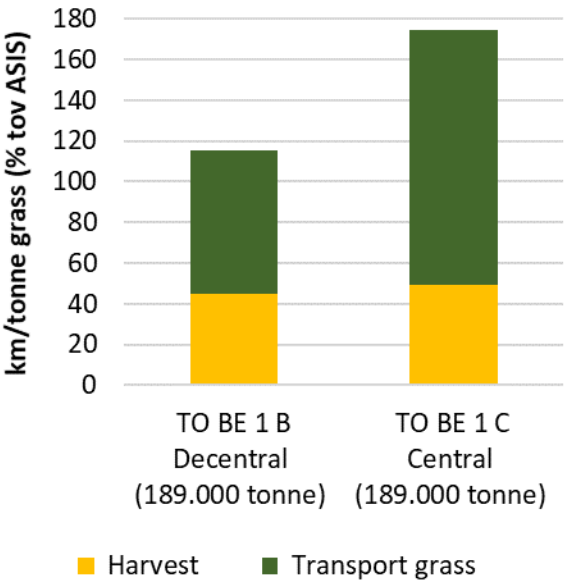


Figure 40: DEMO 1: Comparison of the impact of centralisation on the grass mobilization cost (as % vs. AS IS).



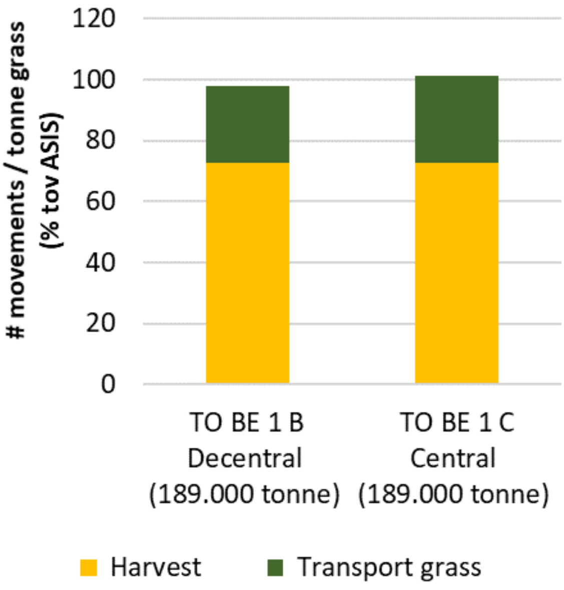


Figure 41: DEMO 1: Comparison of the impact of centralisation on the mileage per tonne mobilised grass (left) and on the number of movements per tonne mobilised grass (right) (as % vs. AS IS).

2.2 DEMO 2 – Roadside management strategies for verge grass in The Netherlands

2.2.1 Overview

2.2.1.1 Roadside management scenarios

The AS IS scenario reflects the current roadside management strategy in The Netherlands. In general, the road side verges in the Netherlands are flailed once a year, after which the clippings are left behind on the verge (opposite to the Flemish cut-&-collect strategy), resulting in a rough, species-poor verge. A marginal number of verges, managed by Water Board Scheldestromen, are under an ecological mowing regime, meaning that the verges are mown with a rotary mower and the clippings are collected for 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 for roadside management in Zeeland. Each scenario differs in i) whether or not clippings are removed, ii) the mowing frequency or iii) the mower type. This differentiation allows to test the impact of the roadside management regime (as well as the impact of grass availability) on mobilisation cost of each scenario. Table 22 gives an overview of the investigated scenarios which are described in the next sections.

Table 22: Overview of investigated roadside management scenarios for Zeeland.

		MOWING REGIME				
		Flail mower	Rotary mower	Leave	Collection	Mowing frequency
SCENARIO	AS IS	✓	✓	✓ (99 %)	✓ (1 %)	Once per year
	TO BE 1	✓	✗	✓ (50 %)	✓ (50 %)	Once per year
	TO BE 2	✓	✗	✗	✓ (100 %)	Once per year
	TO BE 3	✓	✗	✗	✓ (100 %)	Twice per year

2.2.1.2 KPIs – Key Performance Indicators

In the sections below the KPIs are ‘cost’, ‘mileage’ and ‘vehicle movements’ reflected in the result tables of each scenario. The indicators are to be interpreted as follows:

- ***Cost:*** *expresses the total mobilisation cost - including cut, collection, 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.*

2.2.2 *Availability of verge grass*

Combining results from Table 9 and Table 1 shows the estimated total technical/harvestable grass potential from road verges in the region (Table 23). The total harvestable grass from road verges from the 2 major roadside managers in the region, under the general assumption of 2 clippings per year and removal of grass clippings (section 1.3.2), amounts to circa 42.000 tonnes fresh matter or 14.000 tonnes dry matter each year.

As mentioned previously, data are obtained from 2 roadside managers in the region, i.e. the Province of Zeeland (400 km) and the Water Board Scheldestromen (4.000 km). Together, they cover about 93 % of the 4.720 km of roads in Zeeland.

Table 23: DEMO 2: Harvestable grass feedstock in Zeeland.

Feedstock type	**Quantity** *(technical)* *(tonne/ha fresh)*	**Surface** *(ha)*	**Total Quantity**[51] *(technical)* *(tonne fresh)*	*(tonne dry)*[52]
WSS	18,6	1.560	29.000	9.600
PZ	16,6	800	13.300	4.400
Total[53]		**2.360**	**42.300**	**14.000**

Table 23 shows the assumed harvestable grass potential if verges in Zeeland would be cut and collected twice a year (section 1.3.2). However, verges in the Netherlands are predominantly flailed once a year, after which the clippings are left on the verge, resulting in a rough, species-poor verge. Cutting only once reduces the potential to 60% or circa **25.000 tonnes of fresh matter or 7.500 tonnes dry matter each year.**

Furthermore, Water Board Scheldestromen provided data indicating 1% (or circa 250 tonnes) of their verges are under an ecological mowing regime, meaning that the verges are mown with a rotary mower and the clippings are collected for feed.

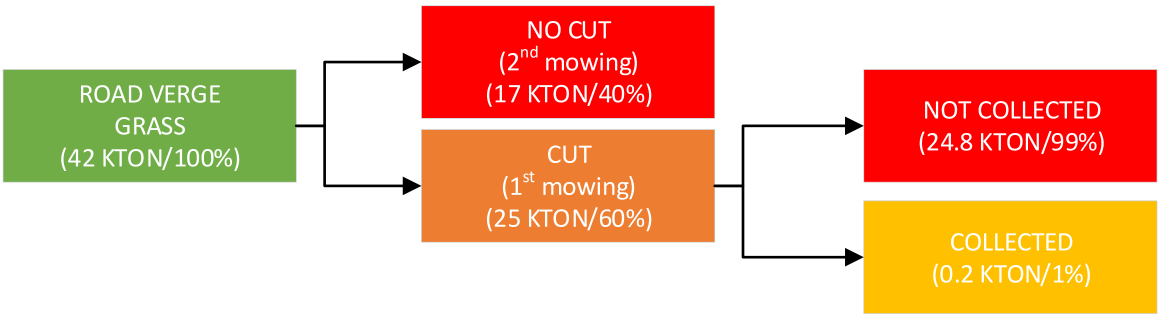


Figure 42: DEMO 2: Road verge grass AS IS flow in Zeeland.

[51] Under the assumption of two cuts
[52] Dry matter content of 33%
[53] Rounded * 1000

2.2.3 *Scenario analysis*

2.2.3.1 *AS IS scenario*

The AS IS scenario reflects the dominant current practice of roadside management (Figure 43). The scenario **assumes one cut per year with a collection of 1% of the cuttings**. Roadsides are flailed once a year predominantly without removal of the clippings. This means an estimated 99% (25.000 tonnes) of the verges are cut with the clippings left on the verges. About 1% (250 tonnes) of the verges is under ecological management of the Water Board Scheldestromen, which are cut with the clippings collected and mainly used for feed. A potential 17.000 tonnes from a second cut is disregarded as it is not current practice.

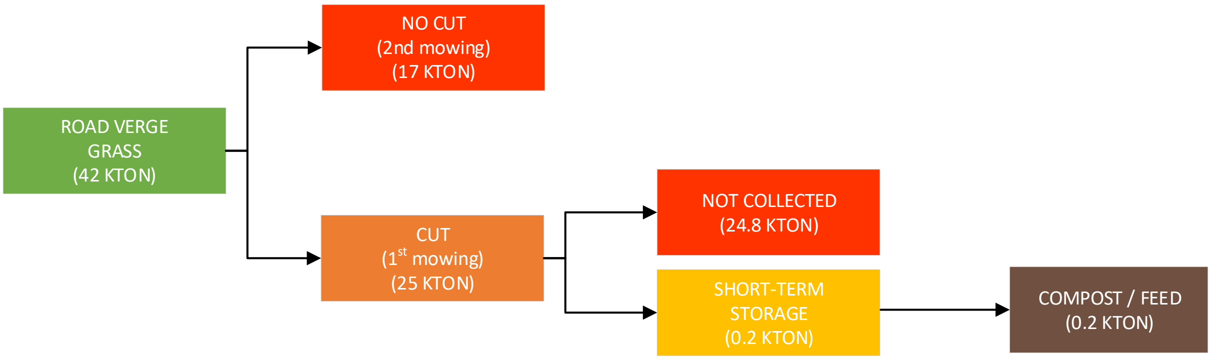


Figure 43: DEMO 2: AS IS SCENARIO: Process flow diagram and technical potential.

Figure 44 shows the cost optimal supply chain configuration map of the AS IS scenario with the sourcing area for 250 tonnes grass (grey), the selected optimal short-term storage sites (red) and the composting installations which are assumed as end-processing destinations (green)[54]. Bird flight lines indicate transport routes (black interconnectors), however transport distances have been calculated via the actual road network.

The results of the AS IS scenario are summarised in Table 24. These results are the baseline reference to be benchmarked with the TO BE scenarios (see section 2.2.3.2 - 2.2.3.4). To be able to compare the scenarios, the 3 KPI's (Section 1.3.1.3) are expressed <u>per tonne of cut (or mown) grass per year differentiated by the grass left on site and grass collected and mobilised towards end-processing:</u>

- On average, the total minimised cost is **120 € per tonne of cut grass.** This total cost can be divided into **32 € per tonne of cut grass** left on site and **88 € per tonne of harvested grass**; i.e. grass cut and mobilised to the end-processing site;
- In the AS IS situation, the minimised mileage is **7 km per tonne of mobilised grass**;
- To only cut (and not collect) the grass and leave it on site, **0,17 vehicle movements per tonne of cut grass** are required while **0,31 vehicle movements per tonne of harvested grass** are needed to cut and mobilise the grass towards end-processing.

[54] Since feed locations are unknown at the moment of the analysis.

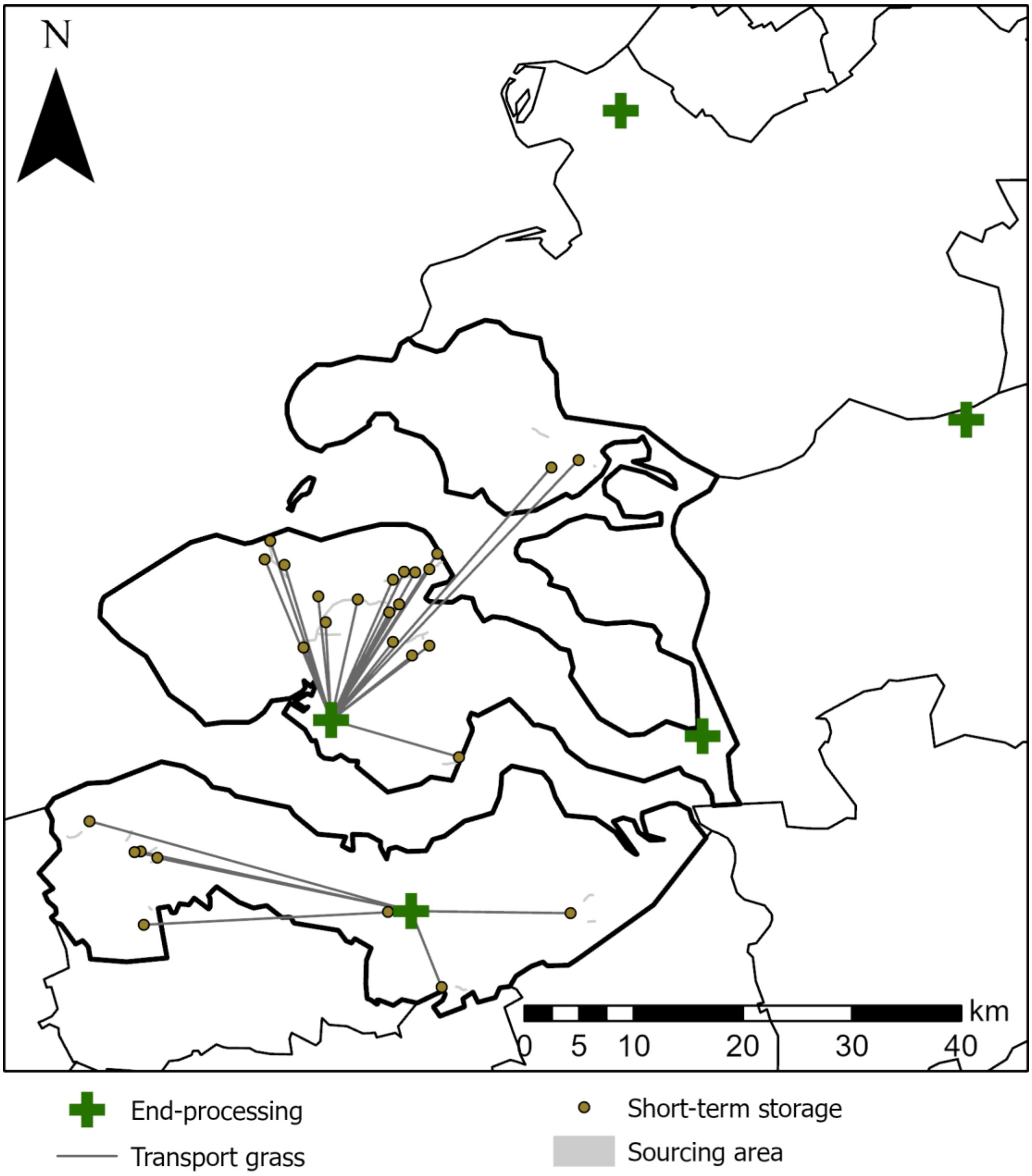


Figure 44 DEMO 2: AS IS SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

Table 24: DEMO 2: AS IS SCENARIO: Summary of the MooV result.

	LEFT ON SITE		MOBILISED	
KPIs	***Per tonne cut grass***	***vs. AS IS (%)***	***Per tonne harvested grass***	***vs. AS IS (%)***
Cost (€)	31,7	+0%	88,0	+0%
Mileage (km)	-	-	7,3	+0%
Vehicle movements (#)	0,17	+0%	0,31	+0%

2.2.3.2 *TO BE 1 scenario*

This scenario builds on the AS IS scenario, still assumes **one cut per year with an increased collection of 50% of the cuttings**, i.e. 12.500 tonnes of grass per year while the other 50% is cut but not collected. This increased availability of grass is distributed to the 3 composting facilities in Zeeland where it is processed into compost or into intermediate fibres for the production off biomaterials. Each site has an allocated maximum fibre processing capacity of 3.000 tonnes (fresh) grass per year and a maximum composting capacity of 6.000 tonnes (fresh) grass per year. A potential 17.000 tonnes from a second cut is disregarded as it is not current practice.

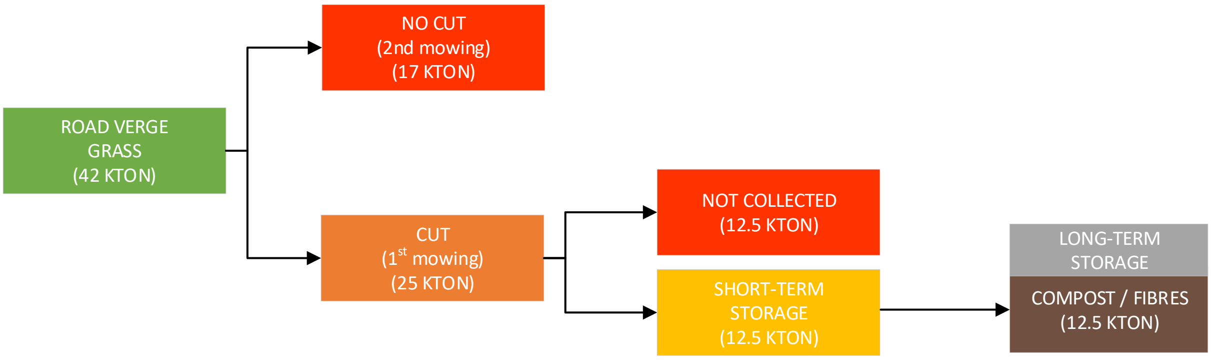


Figure 45: DEMO 2: TO BE 1 SCENARIO: Process flow diagram and theoretical potential.

Figure 46 shows the cost optimal supply chain configuration of the TO BE 1 scenario with the sourcing area for the 12.500 tonnes grass (grey), the optimal short-term storage sites and the composting installations (dark green cross). Bird flight lines indicate transport of fresh grass (black interconnectors).

The results of the MooV analysis of the TO BE 1 situation are summarised in Table 25:

- On average, the total minimised cost is **72 € per tonne of cut grass** or a decrease with 50% in comparison to the AS IS scenario**.** This total cost can be divided into **31 € per tonne of cut grass** left on site and **40 € per tonne of harvested grass;** i.e. grass cut and mobilised to the end-processing site**.** The reduction is attributed to a more efficient usage of the machinery for harvesting and transport of the harvested grass towards the end-processing sites when a larger quantity is demanded (-65%). In addition, the MooV model had the freedom to select the parcels to be harvested in order to minimise the total cost while in the AS IS situation, the parcels under ecological management were a given (Figure 16);
- In the TO BE 1 situation, the mileage counts up to an average of **1,9 km per tonne of mobilised grass** or a decrease with 74% in comparison to the AS IS scenario. Although a wider sourcing area is needed, transport is organised more efficiently and parcels to be harvested are selected by the MooV model in the surroundings of the end-processing sites. This in contrast to the AS IS situation in which the parcels to be harvested (cut and collect) are a given and cannot be freely selected by the MooV model during optimisation.
- The mobilisation requires **0,18 vehicle movements per tonne of harvested** grass (i.e. cut, collected and mobilised), which is a reduction of 41% in comparison to the AS IS scenario. This supports the aforementioned reasoning that the larger volume comes with a more efficient mobilisation of the harvested grass.

  The number of vehicle movements per tonne of cut grass remains more or less equal in comparison to the AS IS situation, i.e. **0,17 vehicle movements per tonne of cut grass.**

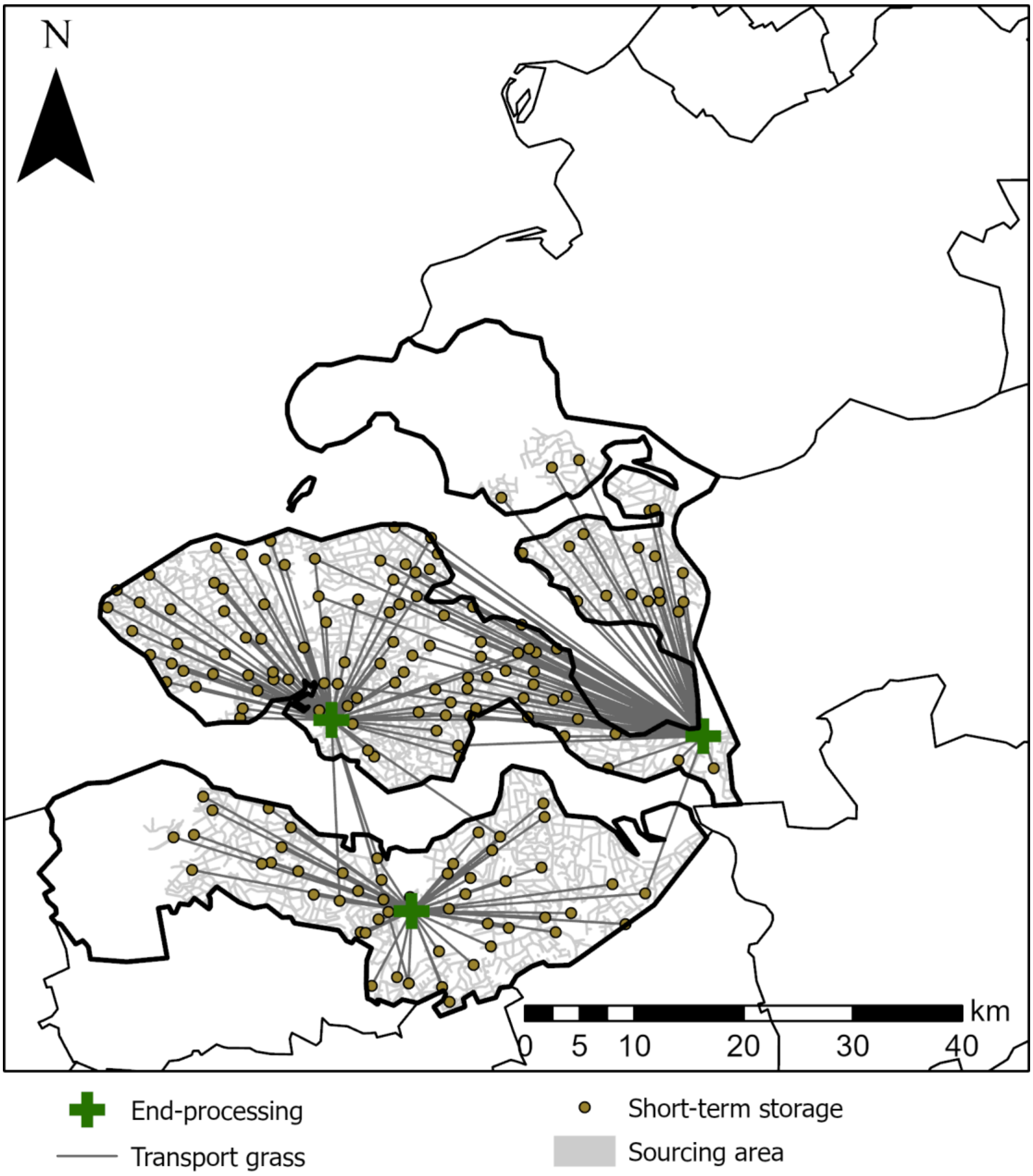


Figure 46: DEMO 2: TO BE 1 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

Table 25: DEMO 2: TO BE 1 SCENARIO: Summary of the MooV result.

	LEFT ON SITE		MOBILISED	
KPIs	***Per tonne cut grass***	***vs. AS IS (%)***	***Per tonne harvested grass***	***vs. AS IS (%)***
Cost (€)	31,3	-1,4%	40,4	-65%
Mileage (km)	-	-	1,9	-74%
Vehicle movements (#)	0,17	-0,4%	0,18	-41%

2.2.3.3 *TO BE 2 scenario*

This scenario builds on the TO BE 1 scenario, **assuming one cut a year with an increased collection of 100% collection of the cuttings**. This increases availability to 25.000 tonnes; which again is distributed to the 5 composting facilities in or close to Zeeland. At the facilities the grass is assumed to be processed into compost or fibres to be used in biomaterials. Each site has a maximum fibre processing capacity of 3.000 tonnes (fresh) grass per year and a maximum composting capacity of 6.000 tonnes (fresh) grass per year.

So, all grass (25.000 tonnes) is collected and transported to the composting sites, meaning no grass is left on the verges. A potential 17.000 tonnes from a second cut is disregarded as it is not current practice.

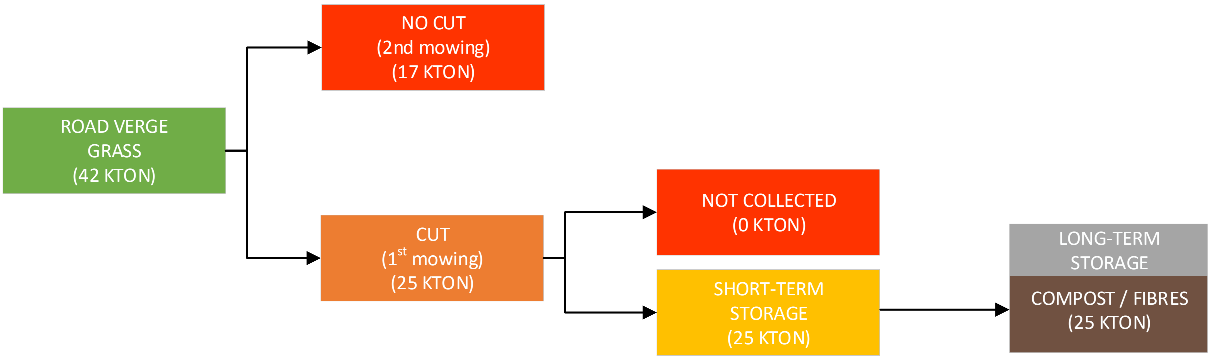


Figure 47: DEMO 2: TO BE 2 SCENARIO: Process flow diagram and theoretical potential.

Figure 48 shows the cost optimal supply chain configuration of the TO BE 2 scenario with the sourcing area for the 25.000 tonnes grass (grey), the optimal short-term storage sites and the composting installations (dark green cross). Bird flight lines indicate transport of fresh grass (black interconnectors).

The results of the MooV analysis of the TO BE 2 situation are summarised in Table 26:

- On average, the total minimised cost is **60 € per tonne of harvested grass** (i.e. cut and collect) or a decrease with 48% in comparison to the AS IS scenario**.** With a higher demand from the processing sites, transport of clippings and machinery use for harvesting can be organised more efficiently.
- In the TO BE 2 situation, the mileage counts up to an average of **2,2 km per tonne of mobilised grass** or a decrease with 70% in comparison to the AS IS scenario. Although a larger sourcing area is needed, transport is organised more efficiently. Harvested verges are attributed by the MooV model to the nearest end-processing sites, reducing transport distances. This in contrast to the AS IS situation in which the parcels to be harvested are a predefined and cannot be altered by the MooV model during optimisation.
- The mobilisation requires **0,22 vehicle movements per tonne of harvested grass**, which is a reduction of 29% in comparison to the AS IS scenario. This supports the reasoning above that the larger volume comes with a more efficient mobilisation of the harvested grass.

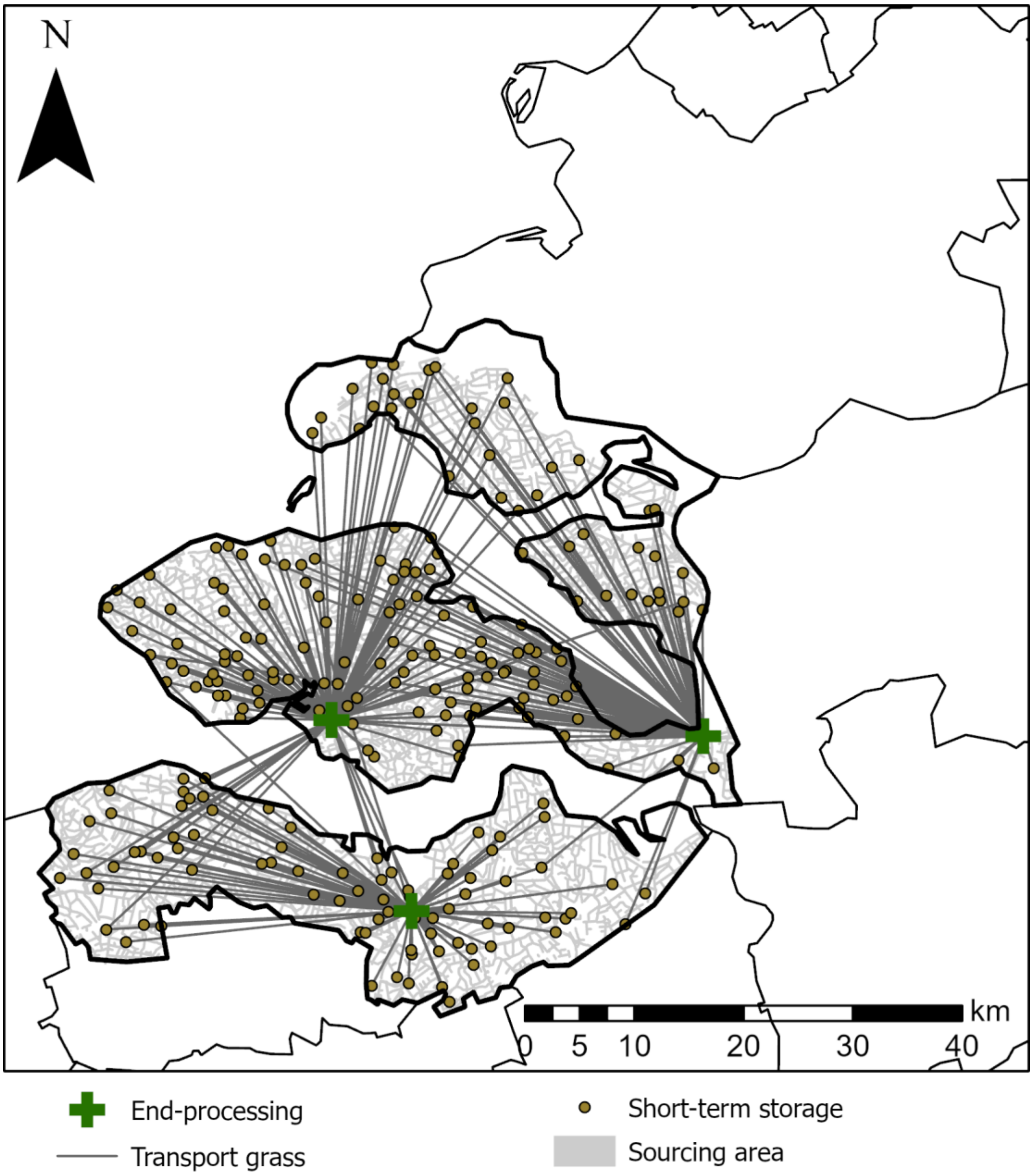


Figure 48: DEMO 2: TO BE 2 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

Table 26: DEMO 2: TO BE 2 SCENARIO: Summary of the MooV result.

	LEFT ON SITE		MOBILISED	
KPIs	***Per tonne cut grass***	***vs. AS IS (%)***	***Per tonne harvested grass***	***vs. AS IS (%)***
Cost (€)	-	-	59,5	-48%
Mileage (km)	-	-	2,2	-70%
Vehicle movements (#)	-	-	0,22	-29%

2.2.3.4 *TO BE 3 scenario*

This final scenario builds on the TO BE 2 scenario, **assuming 2 cuts a year**[55] **with an increased collection of 100% of the clippings**. This increased availability of grass is distributed over the 5 composting facilities in or close to Zeeland where it is processed into compost or processed in intermediate fibres to be used for the production of biomaterials. Each site has a maximum fibre processing capacity of 3.000 tonnes (fresh) grass per year and a maximum composting capacity of 6.000 tonnes (fresh) grass per year.

In total, 42.000 tonnes of grass per year reach the composting sites, meaning that the all grass of the region is mobilised towards the end-processing sites. The seasonal availability of the grass (two cutting peaks) is included in the model, leading to the requirement of long-term storage (and silaging) to match the temporal availability of grass with the year-round demand at the composting site.

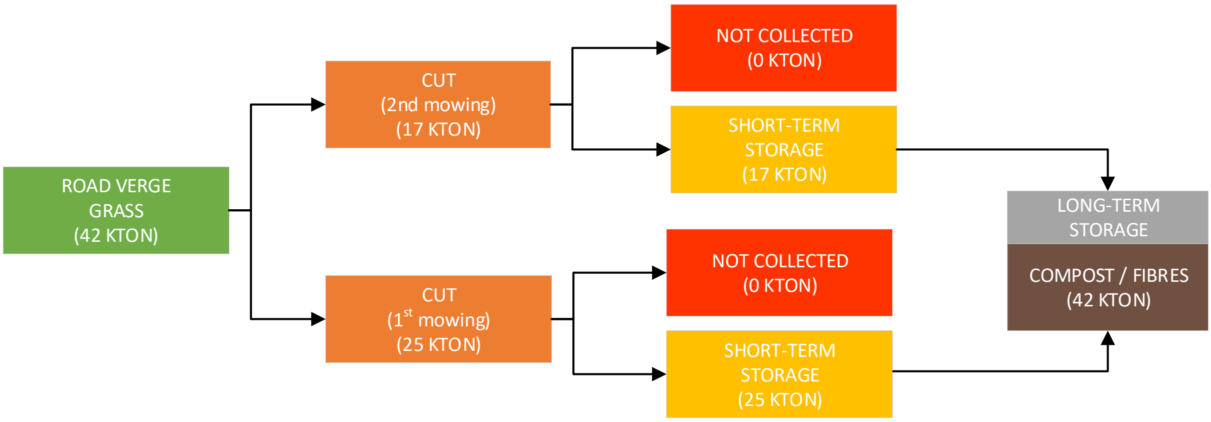


Figure 49: DEMO 2: TO BE 3 SCENARIO: Process flow diagram and theoretical potential.

Figure 50 shows the cost optimal supply chain configuration of the TO BE 3 scenario with the sourcing area for the 42.000 tonnes grass (grey), the optimal short-term storage sites and the composting installations (dark green cross). Bird flight lines indicate transport of fresh grass (black interconnectors).

The results of the MooV analysis of the TO BE 3 situation are summarised in Table 27.

- On average, the total minimised cost is **58 € per tonne of harvested grass** (i.e. cut and collect) or a decrease with 49% in comparison to the AS IS scenario. The reduction is attributed to a more efficient usage of the machinery for harvesting and transport of the harvested grass towards the end-processing sites when a larger quantity is demanded at the processing sites (-49%);
- In the TO BE 3 situation, the mileage counts up to an average of **3,4 km per tonne of mobilised grass** or a decrease with 54% in comparison to the AS IS scenario. Although a broader sourcing area is needed, transport is organised more efficiently and parcels to be harvested are selected by the MooV model in the surroundings of the end-processing sites. This is in contrast with the AS IS situation in which the parcels to be harvested are a given and cannot be altered by the MooV model during optimisation;
- The mobilisation requires **0,22 vehicle movements per tonne of harvested grass**, which is a reduction of 30% in comparison to the AS IS scenario. This supports the reasoning above that the larger volume comes with a more efficient mobilisation of the harvested grass.

[55] e.g. summer and autumn - Figure 7

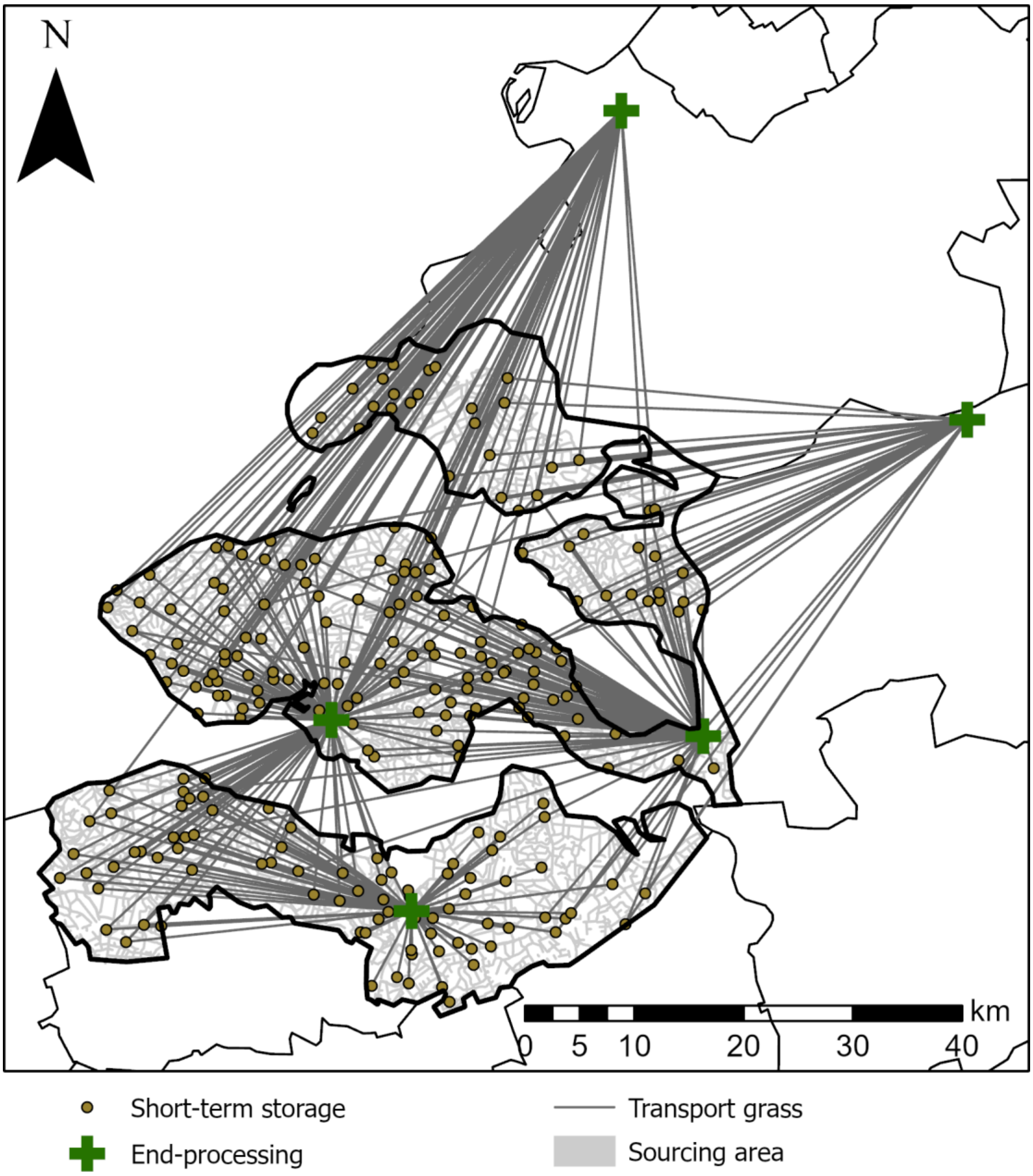


Figure 50: DEMO 2: TO BE 3 SCENARIO: Map of the cost optimal supply chain configuration and sourcing area.

Table 27: DEMO 2: TO BE 3 SCENARIO: Summary of the MooV result.

	LEFT ON SITE		MOBILISED	
KPIs	***Per tonne cut grass***	***vs. AS IS (%)***	***Per tonne harvested grass***	***vs. AS IS (%)***
Cost (€)	-	-	57,9	-49%
Mileage (km)	-	-	3,4	-54%
Vehicle movements (#)	-	-	0,22	-30%

2.2.4 Comparison of different roadside management strategies

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

- the impact of removal of clippings (Section 2.2.4.1);
- the impact of mowing frequency (Section 2.2.4.2).

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

2.2.4.1 Impact of removal of clippings

In the AS IS scenario, 250 tonnes of grass are collected and processed in the composting facilities each year. This grass availability has been raised to 12.500 tonnes per year in TO BE 1 (50% removal) and 25.000 tonnes per year in TO BE 2 (100% removal). Within these scenarios, the same constraints are considered which implies that these scenarios can be compared 1-on-1.

Two aspects can be derived from comparison of these results (Figure 51 - Figure 52):

1) Comparison between the AS IS scenario and the TO BE scenarios:
   Although the total supply chain cost increases in absolute values (TO BE 1: +11% and TO BE 2: +84%), the mobilisation cost per tonne cut grass decreases drastically thanks to the larger volume to be processed (-48% to -55%). Although a broader sourcing area is needed, transport is organised more efficiently and parcels to be harvested are selected by the MooV model in the surroundings of the end-processing sites. This is in contrast with the AS IS situation in which the parcels to be harvested are a given and cannot be altered by the MooV model during optimisation;

2) Comparison between the TO BE 1 and the TO BE 2 scenario:
   The mobilisation costs per tonne cut grass in TO BE 2 is higher than in TO BE 1. This because in TO BE 2, the MooV model is forced to harvest (i.e. cut and collect) and mobilise all grass in the Zeeland region while in TO BE 1 only the 50% most optimally located parcels have been selected by the MooV model. This reflects the larger costs for transport to end-processing and grass storage in TO BE 2. Or in other words, the larger sourcing area results in higher travel distances between storage sites and end-processing sites.

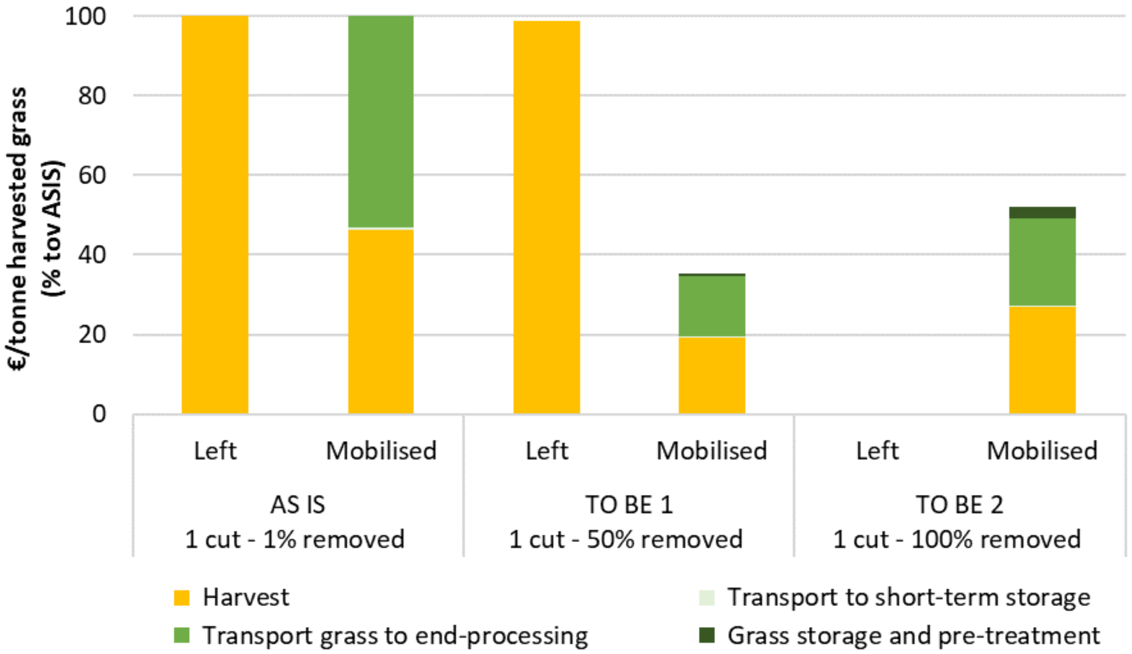


Figure 51: DEMO 2: Impact of removal of grass clippings on the cost per tonne cut grass (as % vs. AS IS).

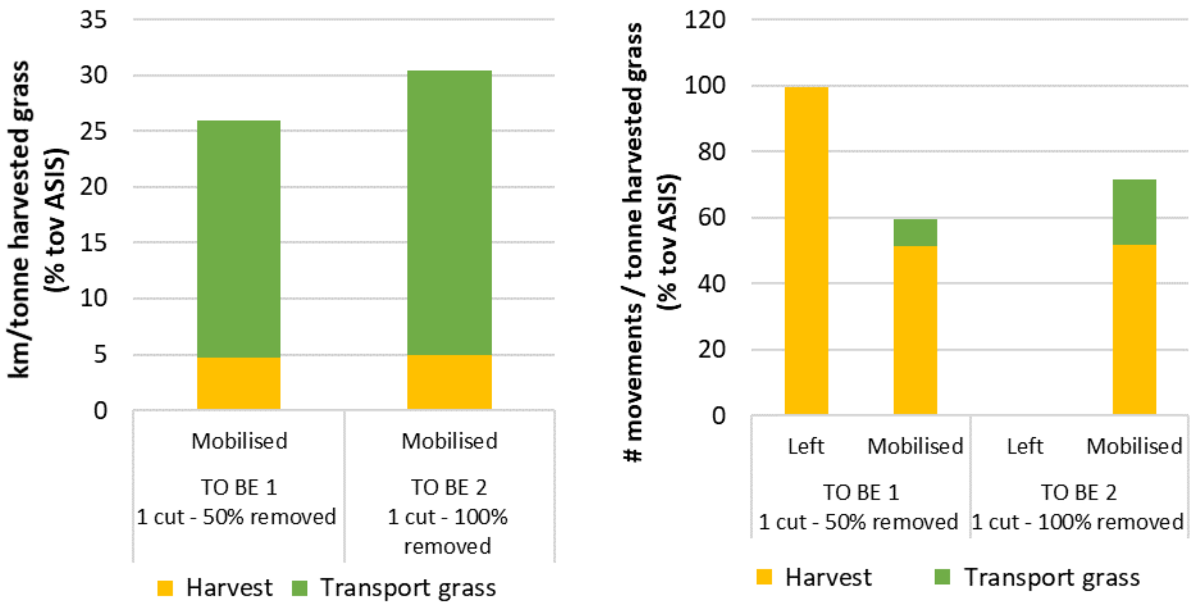


Figure 52: DEMO 2: Impact of removal of grass clippings on the mileage (left) and transport movements (right) per tonne mobilised grass (as % vs. AS IS).

2.2.4.2 Impact of mowing frequency

In the current management situation in the Netherlands, the grass is only mown once a year. Assuming that all grass is mown and collected (TO BE 1), 25.000 tonnes of grass per year is available for end-processing. This availability is increased in TO BE 3 to 42.000 tonnes per year thanks to a second cut in autumn, considering the growth year cycle of grass as defined in Figure 7 Within these scenarios, the same constraints are considered which implies that these scenarios can be compared 1-on-1.

Although in absolute values, a second cut (TO BE 3) increases the total absolute supply chain cost with 70%, the costs per tonne cut grass are marginally lower (i.e. 1,5 € per tonne cut grass) than the costs for a single cut (TO BE 2).

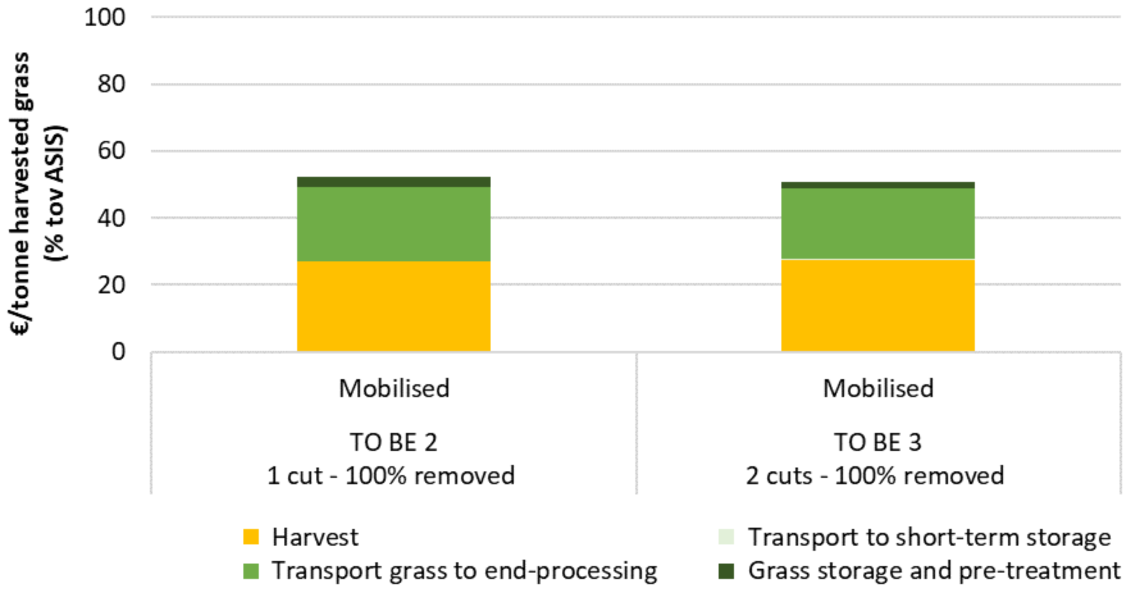


Figure 53: DEMO 2: Impact of mowing frequency on the cost per tonne cut grass (as % vs. AS IS).

2.3 CASE “Vanheede” - Landfill anaerobic digester

2.3.1 Overview

2.3.1.1 Mobilisation scenarios

Within Grassification, landfill-anaerobic digestion (landfill-AD) is investigated. Therefore, this section analysis the sensitivity of the mobilization costs for 1 landfill AD, i.e. the landfill site of Vanheede in Roeselare, in more detail, focussing on:

- Availability of verge grass in the surroundings of the landfill AD;
- Impact of limited sourcing area;
- Impact of grass origin;
- Impact of limited availability.

This analysis of the mobilisation costs is direct input for the techno-economic analysis (TEA) of the landfill digester (D3.1.2. – D3.1.4). In relation to the TEA, this analysis considers a fresh grass demand of 4.500 tonnes during the first mowing period and a fresh grass demand of 4.500 tonnes during the second mowing period; so a yearly demand of 9.000 tonnes. The cuttings delivered at the gate are immediately fed to landfill-AD which eliminates the need for storage.

2.3.1.2 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 AWV / MUN (%):*** *expresses the percentage of the technical harvestable potential being mobilised – from AWV and MUN verges respectively.*

2.3.2 Availability of verge grass

To assess the availability of verge grass in the neighbourhood of the Vanheede landfill, 5 sourcing areas are defined: 0 – 10 km, 0 – 15 km, 0 – 20 km, 0 – 30 km, 0 – 40 km (Figure 54). For instance, the 10 km sourcing area of the Vanheede landfill includes all the grass verges that can be reached within a 10 km driving distance from the landfill.

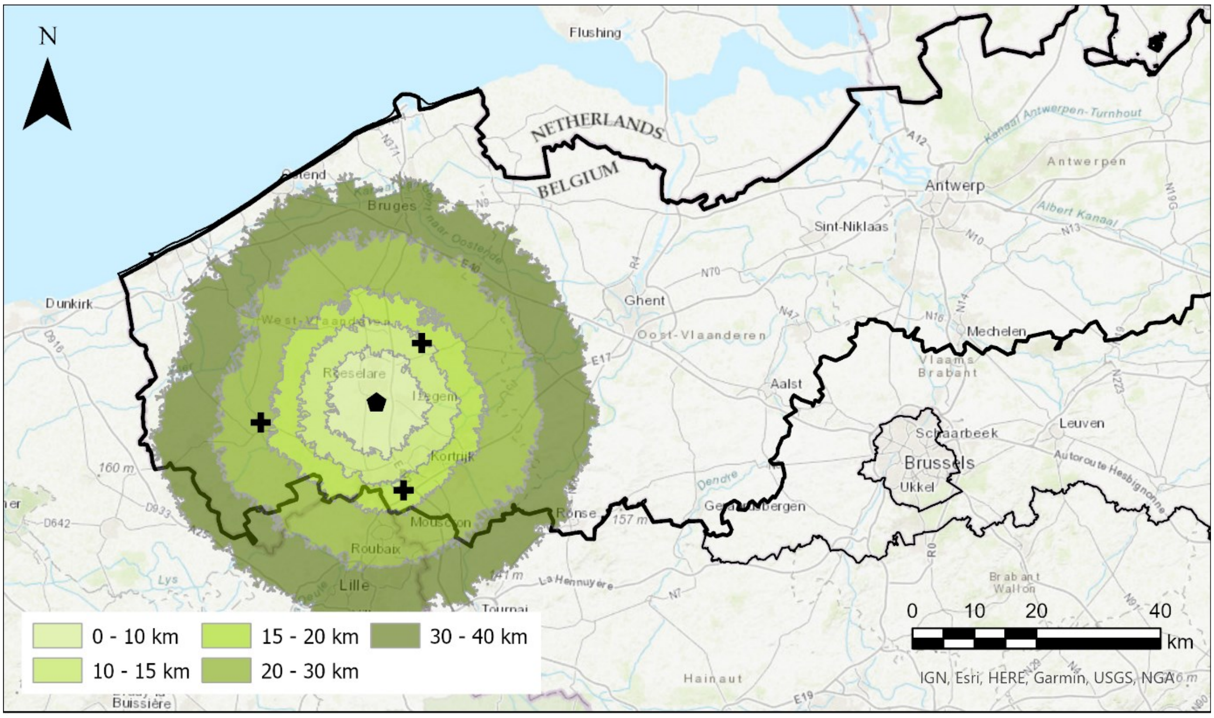


Figure 54: CASE "Vanheede": Sourcing area 0 – 10 km, 10 – 15 km, 15 – 20 km, 20 – 30 km, 30 – 40 km around the landfill of Vanheede (pentagon).

Combination of the verge grass map of Flanders (Figure 12) and the definition of the sourcing areas (Figure 54), gives the acreage of verge grass within each sourcing area (Figure 55). The harvestable verge grass surface in the area surrounding the Vanheede landfill stretches between ca 250 ha in vicinity of the landfill (0-10 km) up to 3.800 ha in the wider surroundings (0-40 km).

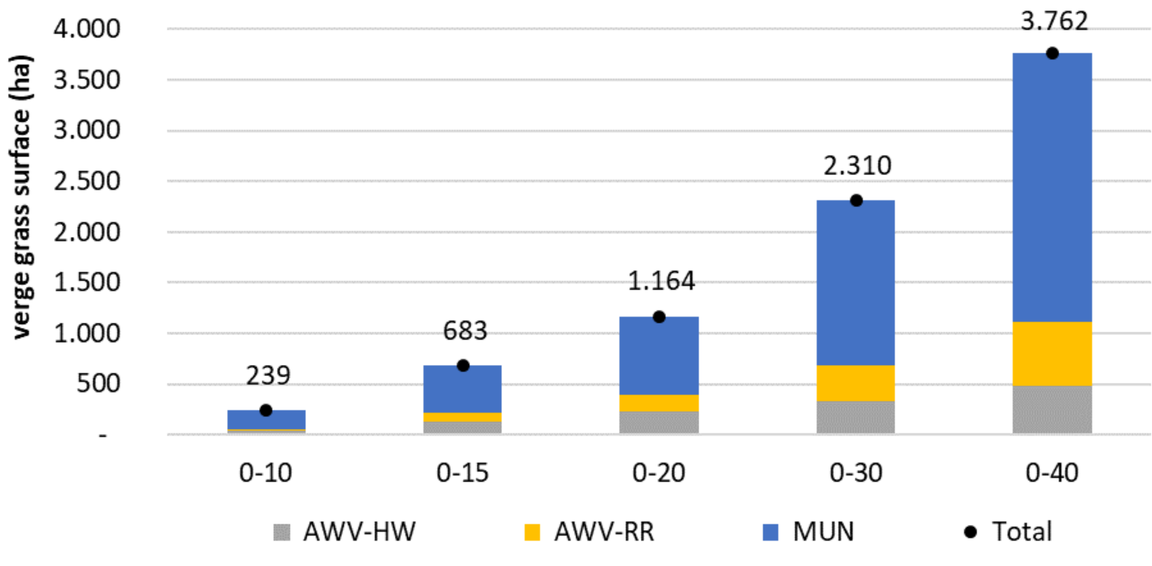


Figure 55: CASE "Vanheede": Harvestable verge grass surface in the area around the Vanheede landfill, considering different sourcing areas (0 – 10 km, 0 – 15 km, 0 – 20 km, 0 – 30 km, 0 – 40 km).

Combining results from Figure 55 and Table 1 defines the estimated total technical/harvestable grass potential from road verges in wider area around the Vanheede landfill (Figure 56). The total harvestable grass from road verges starts at 4.500 tonnes fresh matter per year (1st+2nd mowing combined) in the vicinity of the landfill. In the wider area, the harvestable grass potential rises to 70.000 tonnes per year.

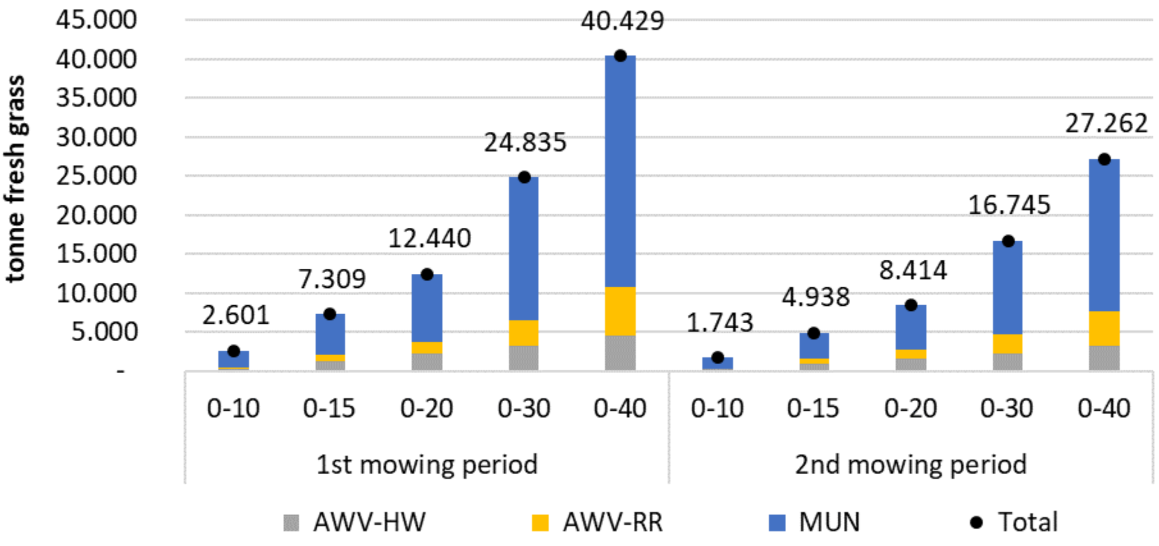


Figure 56: CASE "Vanheede": Harvestable verge grass quantity in the first and second mowing period, in the area around the Vanheede landfill, considering different sourcing areas (0 – 10 km, 0 – 15 km, 0 – 20 km, 0 – 30 km, 0 – 40 km).

2.3.3 Comparison of different mobilisation strategies

2.3.3.1 Impact of sourcing area

The sourcing area limits the availability of grass in quantity as well as in quality (or origin) (Figure 55 and Figure 56).

The availability is most limited in the **smallest sourcing area (0-10 km)**; ca. 2.600 tonne in the 1st mowing period and 1.700 tonne in the 2nd mowing period. So, within this area insufficient grass is available for filling up the digester with 4.500 tonnes per mowing period (Figure 56), resulting in an infeasible solution. To allow feasibility, the digester's capacity has been reduced to 2.500 tonnes within one mowing period. Even at a low demand capacity and in a local harvest range, the grass mobilisation cost per tonne harvested grass is the highest. Main reason is that verge grass from municipal roads as well as highways and regional roads is needed to fulfil the demand. As mentioned previously, harvesting grass along highways and regional roads is costlier due to safety measures (Table 4). Also, transport costs for transport from short-term storage to end-processing is relatively high considering the small sourcing area (max 10 km).

Within the **15km sourcing area**, sufficient verge grass is available to meet the demand of 9.000 tonnes of fresh grass per year. Since more verge grass from municipal roads is available in comparison to the 10 km sourcing area, the mobilisation cost drops with ca 10%, mostly related to the decrease in harvesting costs. However, still some grass from AWV verges is needed to meet the demand. Therefore, the mobilisation cost is higher (+10%) than the 20km sourcing area where the availability of grass from municipal roads is can fully cover the demand.

If all grass can be attributed to the landfill AD (i.e. no competition with surrounding composting facilities or other destinations), the sourcing area of 20 km is sufficient to deliver the required amount of fresh grass at least mobilisation cost (Figure 56).

Within the 20km sourcing area lowest mobilisation costs are realised; meaning the cost interplay between grass availability (enough tonnes), transport costs (distance) and harvest cost (MUN vs. AWV) are at its lowest in this situation.

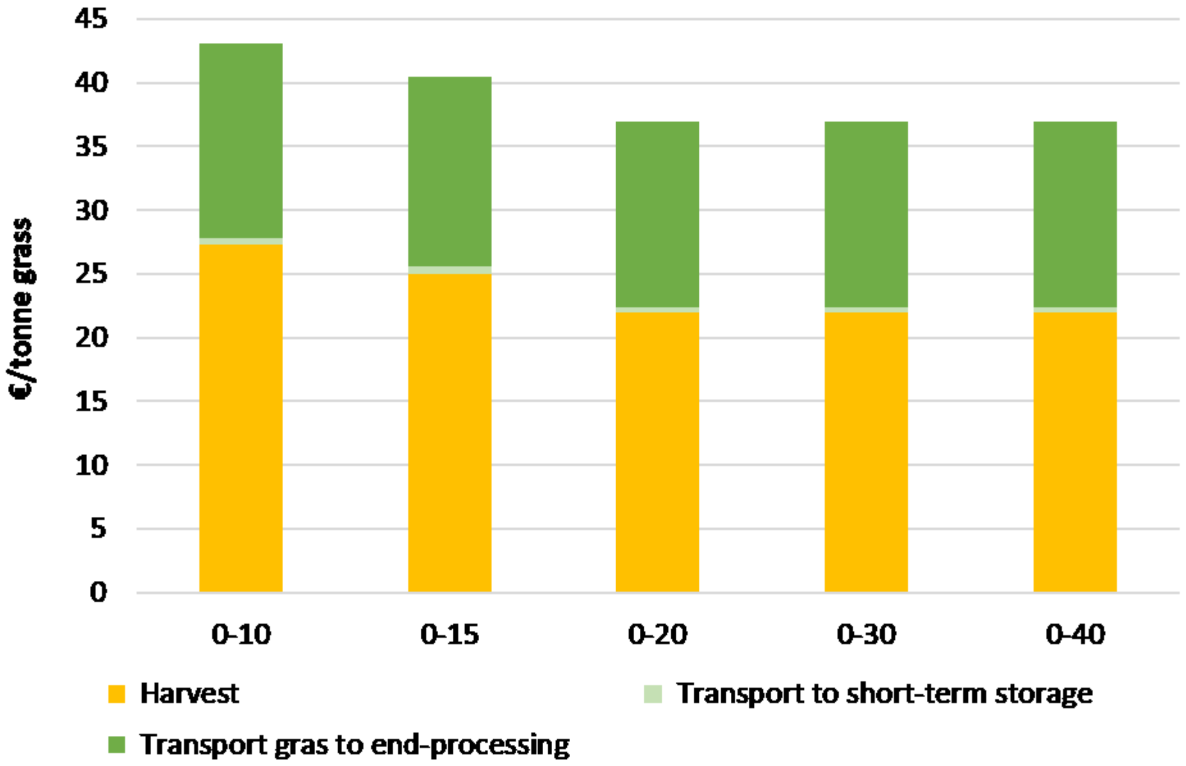


Figure 57: CASE "Vanheede": Impact of a limited sourcing area on the grass mobilisation costs.

2.3.3.2 Impact of grass origin / quality requirements at the gate

To analyse the impact of grass origin requirements at the gate, scenarios are calculated with and without the additional constraint by origin/quality (see 1.3.2.1.3) which can be accepted by the AD-landfill:

- Case A: without constraints – grass from AWV-RR, AWV-HW and municipal roads can all be used;
- Case B: with constraints – only grass from highways (AWV-HW) and grass from regional roads (AWV-RR) can be used;
- Case C: with constraints – only grass from highways (AWV-HW) can be used;
- Case D: with constraints – only grass from municipal roads (MUN) can be used.

With only one operating landfill-AD site, the impact of quality requirements at the gate is large. Only accepting grass from highway verges (whether or not in combination with regional roads), almost **doubles the grass mobilization cost** (from 37 € per tonne to 70 € per tonne mobilised grass). On the one hand, this increase is due to the larger harvesting costs due to safety measures at these roads. On the other hand, transport distance (and related costs) between short-term storages and the end-processing site doubles (AWV-RR and AWV-HW) and triples (AWV-HW) (Figure 58). When limited to the verge grass from AWV (RR and HW), the sourcing area must be enlarged to meet the demand at the gate (Figure 59).

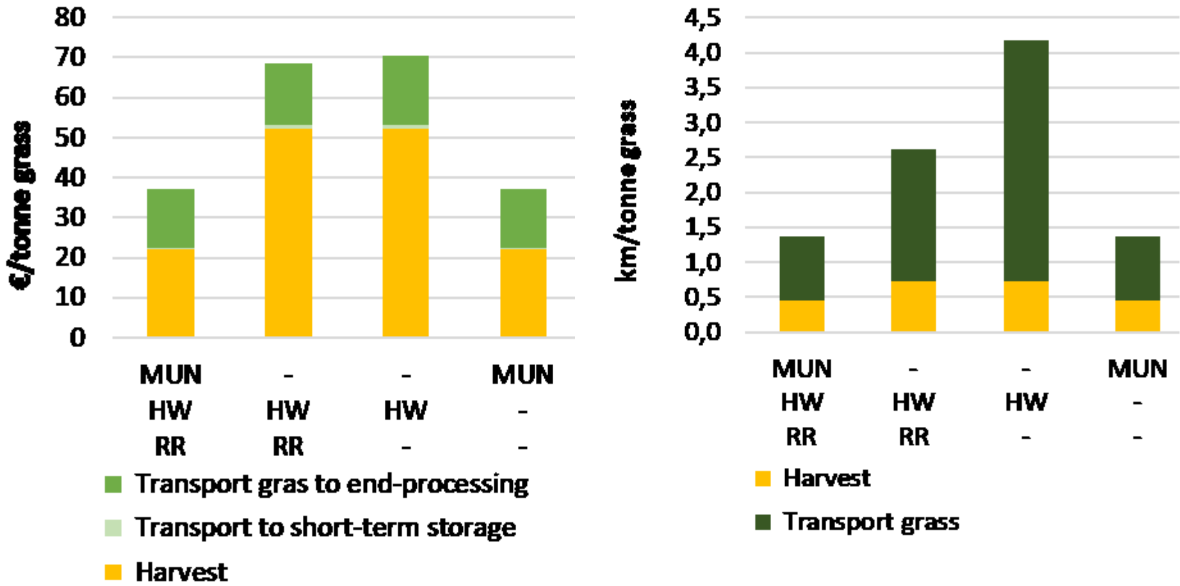


Figure 58: CASE "Vanheede": Impact of verge grass origin on the grass mobilisation costs (left) and the mileage (right).

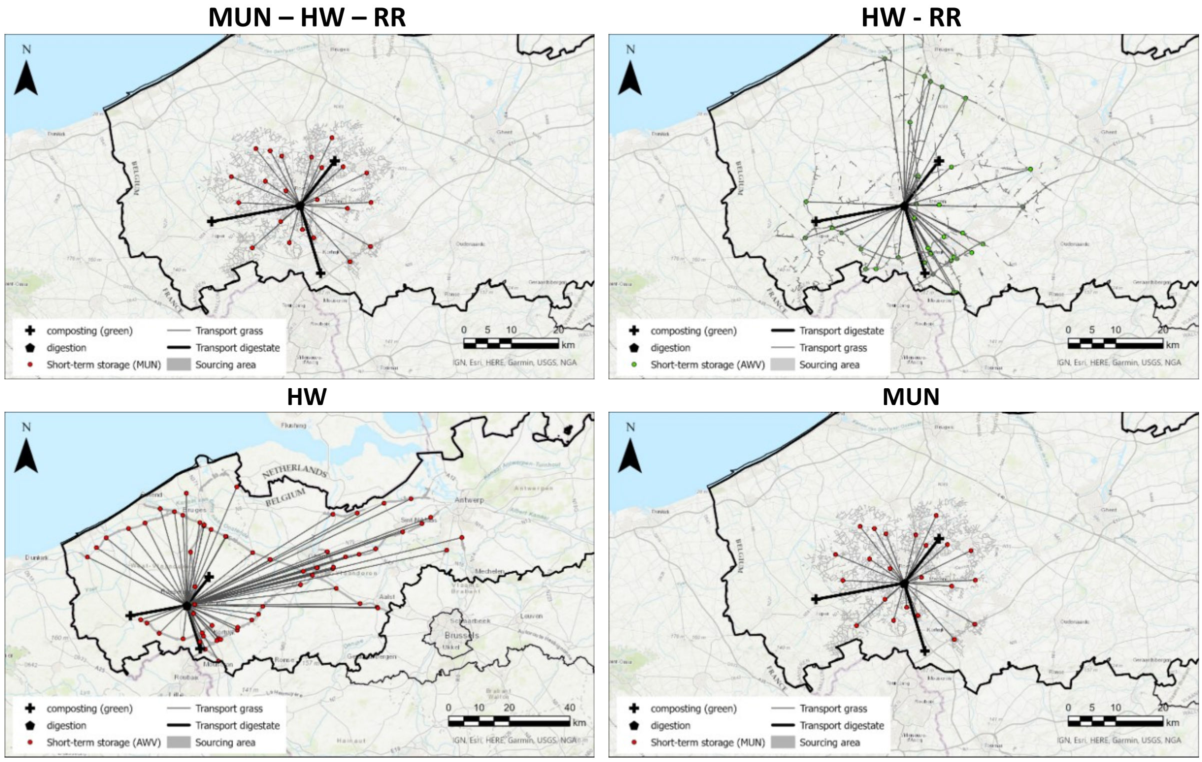


Figure 59: CASE "Vanheede": Map of the cost optimal supply chain configuration and sourcing area considering restrictions on origin of grass.

2.3.3.3 Impact of limited availability

In the previous analysis (sections 2.3.3.1 - 2.3.3.2), it has been assumed that 100 % of the verge grass in the area can be attributed to the landfill digester of Vanheede. In practice, this will not be the situation since contractors might already have another destination for the clippings or competition is in place as e.g. with neighbouring composting sites. This implies that potentially only a fraction of the verge grass is available for the Vanheede landfill. Therefore, this section focusses on the impact of limited availability on the mobilisation cost and the mileage by limiting the quantity of grass that can be delivered to the Vanheede landfill to a fraction of the total available grass (10%, 25%, 33% and 50%).

Since no limitations on sourcing area are in place, larger distances are travelled to deliver as much verge grass from municipal roads as required (Figure 61 – right, Figure 60) to circumvent the need to harvest verge grass from highways or regional roads at higher cost (due to safety measures). Since only verge grass from municipal roads has been harvested, the harvesting cost is stable, and the changes in mobilisation costs can be attributed entirely to changes in transport cost from short-term storage site to end-processing site (Figure 61 – left).

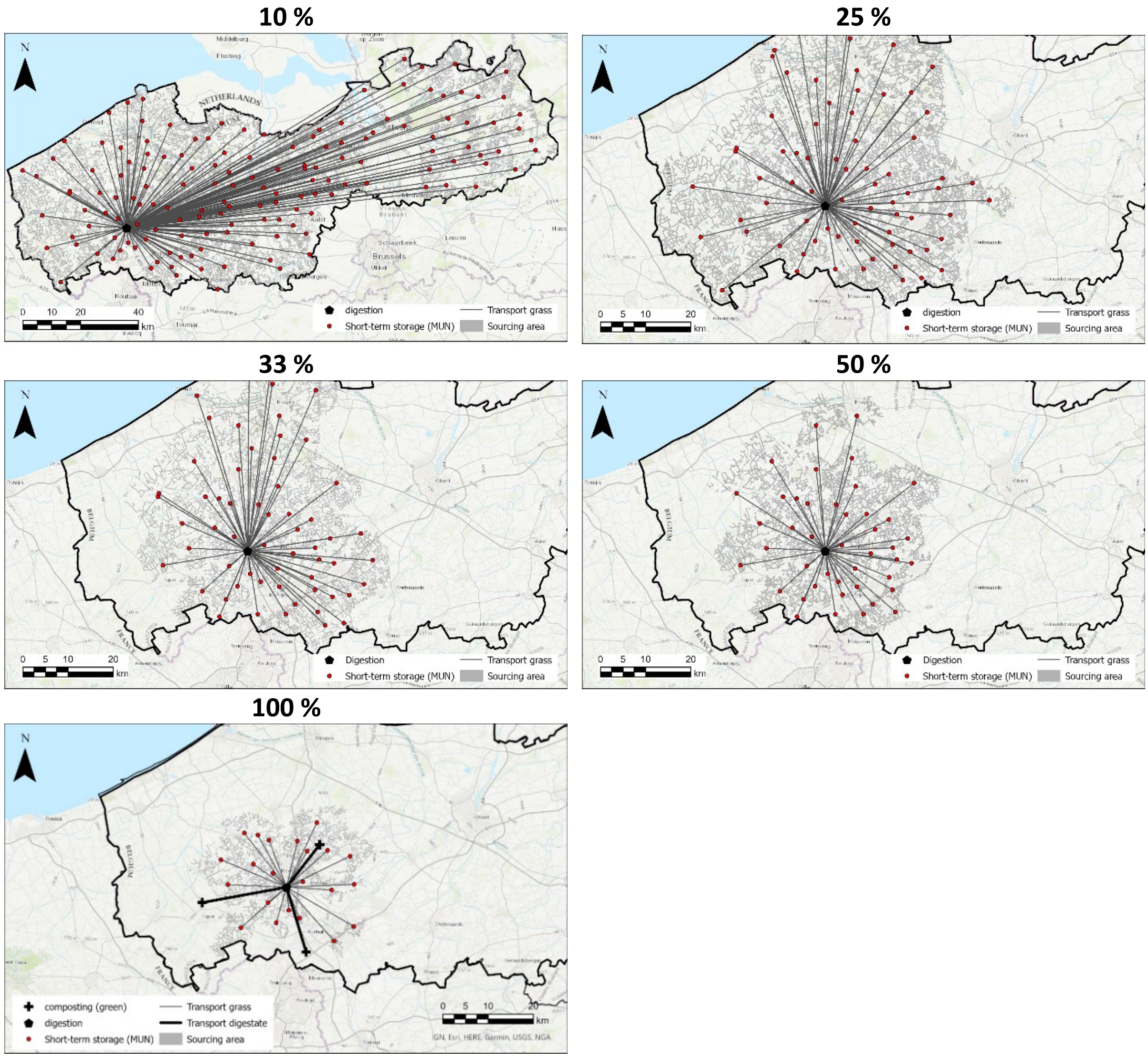


Figure 60: CASE “Vanheede”: Map of the cost optimal supply chain configuration and sourcing area considering restrictions on grass availability.

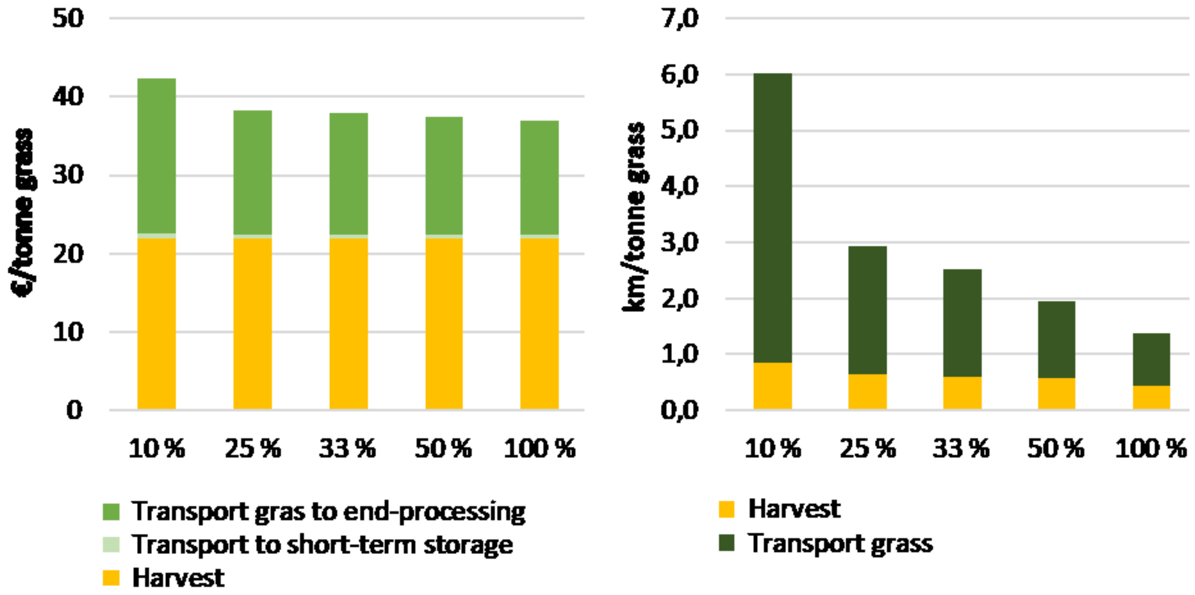


Figure 61: CASE "Vanheede": Impact of limited availability to grass in the area on the grass mobilisation costs (left) and the mileage (right).

Figure 62 shows the expected mobilisation cost vs. a restriction on grass availability in the area. Note that local characteristics (e.g. road density, origin, etc.) impact the results.

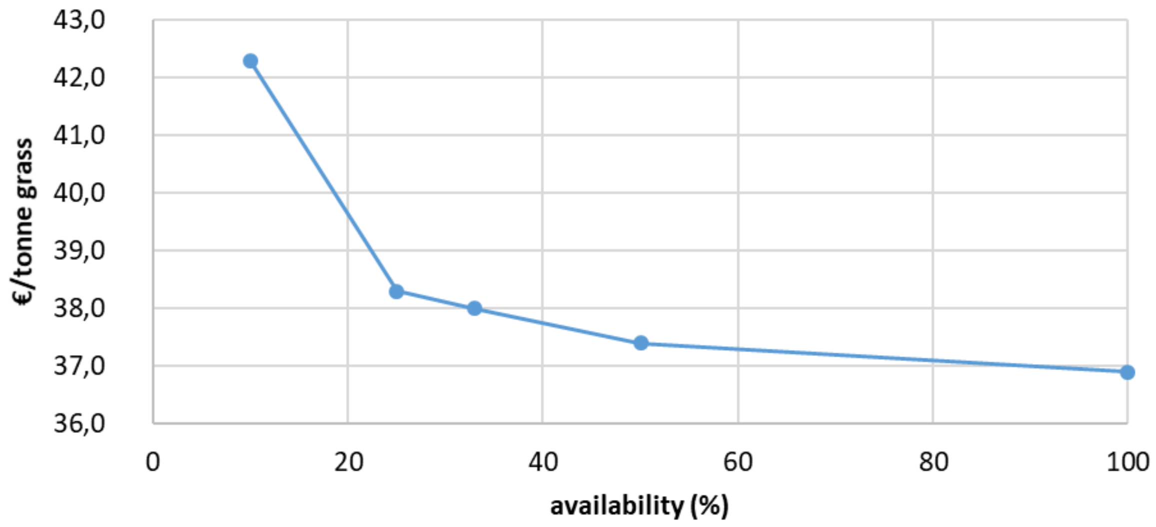


Figure 62: CASE "Vanheede": Relationship between availability of grass and grass mobilisation cost per tonne harvested grass.

Chapter 3.

D3.2.3 - REPORTING ON AND DISSEMINATION OF THE SUPPLY CHAIN OPTIMISATION MODEL

3.1 Conclusions

3.1.1 Towards added value

The European Union sets some ambitious goals for further deployment of grass clippings in a circular bio-based economy. In comparison to composting, feeding and digestion, new alternatives look at higher value applications like bio-material (grass fibres) and feed products (protein extraction). With MooV – VITO's supply chain optimization service - different mobilisation scenarios for grass clippings were tested. The results show the impact of these different scenarios on the cost-efficient management of roadside grass; which remains a challenge to date.

In summary:

- Based on the data gathered and the assumptions defined in the DEMO's, an average (optimal) mobilisation cost of between 50 € and 60 € per tonne harvested grass was calculated. Note that this average cost depends on the road density, the density of the storage network and proximity of end-processors. Specifically, when grass is collected in the vicinity of the end-processing facility, mobilisation costs drop below 40 €;
- Optimising the sourcing area helps to reduce mobilization costs, interplay between grass availability, transport costs and harvest cost brings forward the lowest cost sourcing area;
- The quality of the grass constraints the allowed end-processing type. The quality can be influenced by choice of road type (e.g. with minimal amount of litter), mowing type (e.g. flail vs. cut), harvest moment and manner of long-term storage.

Conclusion 1: The mobilisation cost is influenced by the quantity, quality and location of the available grass. On average a mobilisation cost of 55€ per tonne fresh grass seems realistic.

Conclusion 2: . The mobilisation mileage averages around 2-2,5 km/tonne fresh grass. If processing sites are strategically located, an increase in processing demand does not lead to an increase of mileage per tonne.

Conclusion 3: For the grass chain to be successful, coordination and cooperation in the grass chain is a prerequisite as well as correct price agreements between suppliers and processors.

3.1.2 *Data availability and accuracy*

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 on grassy roadsides is often not available. Such accuracy includes the road side's location, acreage, ownership, management type and harvestable yield.

The same is true for (potential) locations of short-term and long-term storage as well as processing sites 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 well 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 intensified and targeted data collection, processing and analyses.

Conclusion 4: Complete and reliable data is important to (scientifically) underpin policy making and strategic planning of a circular bioeconomy. Current data is often incomplete, inaccurate, fragmented… with a risk of data quality being insufficient to make adequate policy decisions and/or frame action plans.

Recommendation 4: Continue to strengthen a holistic and coordinated data centralization regarding a circular bioeconomy.

Conclusion 5: The mapped road side verges and related processing sites with differentiation to location, acreage, ownership, capacity, yield and requirements is the best available for Flanders.

Recommendation 5: The map could be further capitalised on i) by further completion (e.g. adding waterway verges, or other biomass(residual)streams

3.1.3 *Next steps*

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 renewed reality to assess the impact of such sites on the mobilisation strategy (and its KPIs) – including the effect on the sourcing areas.

Conclusion 6: Future scenarios show enough grass potential for the co-existence of established (compost, digesting, feed) and emerging commercial-scale end-processing sites (biomaterials).

Recommendation 6: The developed model can be used to assess the impact of alternative strategies or re-assess variations on current strategies – e.g. with further differentiation on source-separated quality grades.

This assessment is strategic in nature - scoping the larger areas as a whole. Divert to local study cases is possible but requires further finetuning to capture these local specifics (case-by-case assessments).

Note that most 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 inherently specific to the processing type.

The study results give a good reference of the optimised mobilisation cost for society as a whole, as well as indicate at the gate-prices to (future) end-processors. Scenarios show that stricter safety requirements, higher quality specifications or larger sourcing area lead to higher mobilisation costs. However, these higher costs could 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 7: Grass processing currently comes at a societal cost – management mainly occurs due to regulation/obligation or environmental development goals. With increased demand and/or feedstock differentiation (e.g. by origin) mobilisation costs tend to increase but can be compensated by higher value of better feedstock quality. The mobilisation cost increase sets the benchmark to be compensated by higher prices (or lower gate fees) for grass feedstock.

Recommendation 7: 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. In the calculated scenarios only transport (mileage) was used to express only part of the environmental impact to mobilise the grass feedstock. This could be further refined, incorporating additional environmental and circular parameters.

Mobilisation scenario TO BE 2 already indicates the relevance of multiple use of feedstock. If grass clippings 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 8: 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 8: 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 9: Trade-offs between mobilisation cost increase (as a result of increased local sourcing) and revenue increase (as a result of production of added-value products) could be defined.

Recommendation 9: This study developed the base-model to make such assessments. Further detailing of assumptions and constraints will benefit result accuracy.

3.2 Dissemination

Table 28: Overview of dissemination activities in relation to the MooV results of the Grassification project.

Date	*Title*	*Medium*	*Audience*
13/03/2019	Grassification – Value chain configuration	Workshop Grassification	Expert audience
08/2019	Preliminary results – verge grass availability in Flanders	LinkedIn – MooV page	General audience
11/2019	Save the date "Grassification workshop"	LinkedIn – MooV page	General audience
11/12/2020	Mobilisation strategies for road side grass cutting towards added-value products	Workshop IPO / Grassification	Expert audience
	Mobilize and optimize the grass-based value chain	Market research "Bermstroom"	Expert audience
In progress		Grassification deliverable	Political audience
In progress		Grassification newsletter	General audience
In progress		Journal paper	Scientific audience

ANNEX A – RESULTS OF THE MOOV SURVEY

This annex provides the questionnaire results and analysis. The answer to each question consists of multiple options. Preferences for the respective options could be reflected by dividing a 100%-score between the different options. The scoring expresses the likeliness of the option and allows to express a mixed preference between options. Additionally, a comment-box was foreseen for each question to motivate their scoring in writing.

E.g. For a question with 4 options a fictive division could be; Option A - 70%; Option B - 25%; Option - 5% and Option D- 0%. → Option A is the most likely and dominant one, however mixed with Option B. Option C is marginal, while Option D is expected to be non-existing.

The scoring-results hereunder reflect the average scoring of all respondents. The following partner representatives (10) participated in the questionnaire:

Name	Affiliation
Rahul Ravi	Ghent University
Willem Boeve	Inagro
Tom De Vrieze	Vanheede
Marcella Souza	Ghent University
Laury Chaerle	University College Ghent
Tom Anthonis	ProNatura
Dries Vansteenkiste	University College Ghent
Harm-Jan Thiewes	Millvision
Dieter Cuypers	VITO
Jappe De Best	Avans Hogeschool

A.1 Value Chain Configuration

Question

How will the Grassification value chain develop vis-à-vis the current value chain for road-side grass?

Answer options and average results

parallel with & plug-in with the current value chain	32%
replacing partly the current value chain	24%
parallel with & separated from the current value chain	19%
other…	15%
replacing completely the current value chain	11%

Discussion and comments

Respondents scored the development of the Grassification value chain *in parallel with and as plug-in with the current value chain* highest. Except for 3 out of 9 respondents this option received a score (not being 0). Most respondents thus believe the value chain is likely to be integrated with the current value chain and additionally it is given a high likelihood. Second and third are the answers which do not envisage the complete replacement of the existing value chain. The answer aiming for a more disruptive scenario vis-à-vis the current value chain received the least points.

Other answers refer to either

- a complete biorefinery approach with a multitude of input biomass feedstocks and output products;
- the partial replacement mainly due to the higher value of the novel end-product;
- existing value chains which can already be labelled as Grassification value chains.

In general comments point at using what already works, improving where possible, replacing where needed and parallel development where useful. These developments will depend upon the required specifications of the higher-value products aimed at, the facilities available and the roles of public and private stakeholders. All these arguments point towards a **likely integration with the current value chain**. At the same time timescale is also important when answering this question. The longer the term, the higher the likelihood of replacement of the current paradigm by another.

A.2 Quality and grades

Question

Will quality separation be relevant/important?

If yes, where in the value chain will this take place?

Answer options and average results

No Yes	0/10 10/10
Yes - in field/at field – mowing stage	36%
Yes - at the storage facility (or the processing facility if this serves as storage as well)	32%
Yes - after pressing (more focused on the separation of the solid fraction	29%
Yes - other…	4%

Comments

Based upon the respondent's answers the **quality separation is important but there is no clear majority of likeliness of where in the value chain this should happen**.

For those who scored separation in the field highest their argumentation was that separation should happen the sooner the better. For these respondents quality was mainly based upon the presence of contamination which could harm further processing. Those who prefer the separation further up the chain point towards either the need for a good assessment of the quality, payment for quality by the buyer or the maximal use of all components of the feedstock when separation is rather done upstream. It is clear that quality entails a multitude of parameters and the importance of these parameters are dependent upon each step in the value chain. Therefore, multiple quality checks are likely.

A.3 Transport mode

Question

Which transport modus is relevant in transporting the road side grass?

(If you choose +1 modus a transloading site is necessary.)

Divide your 100%

Answer options and average results

ROAD (truck)	57%
WATERWAY (boat)	30%
RAIL (train)	9%
OTHER…	3%

Comments

Respondents think it is **most likely that most road side grass is transported by road**, being the logical option given the fact that road side grass is harvested next to the road. However, this does not rule out other options, mainly **waterway once the need for transloading comes into the picture** for reasons of cost reduction and environmental reasons. Therefore, many respondents mention a multimodal development.

Can transloading be made more efficient? Could standardisation of container options between different transport modes be an option instead of transloading bulk?

'Other' refers to one respondent mentioning pipelines for grass slurry, scoring it as likely as the other options. These have high CAPEX but low OPEX.

A.4 Storage configuration

Question

How will the storage facility be organized?

Answer options and average results

DECENTRAL (several small storages – away from the processing facilities)	44%
DIRECT (storage at the processing facility)	28%
CENTRAL STORAGE (one big storage – away from the processing facilities)	18%
OTHER…	10%

Comments

There is a **clear preference for decentral storage** and, to a lower extent, **direct storage**. These options are somewhat opposed to each other, but both could be valid because the options are very much **dependent upon the product in mind** (raw, intermediate, end). Given answers are very much dependent upon the perspective taken as motivated in the comments, therefore the answers converge but not for similar reasons. The 'other' option's score is due to taking only anaerobic digestion at a landfill into account.

Main issues raised:

- Storage and quality assessment could go together;
- Separation and storage can be heavily linked for some products and for those products central storage allows for further transport and processing of the components in dedicated plants (proteins, polymers, building materials).
- The possibility of standardization/stabilization of certain products could improve storage opportunities at many sites
- Scale of processing facilities do heavily influence the options
- The portfolio of products very much influences the storage options

A.5 Storage type

Question

Which kind of storage do you envisage?

Answer options and average results

Clamp silage (concrete walls) or Cover bunker (plastic covered)	42%
Bale	33%
Other	16%
Bag silo	9%

Comments

Respondents **prefer both clamp silage (biogas related) and bales (fibre related)**. Clamp silage is rather preferred when biogas is the final product. Bales are preferred for applications where fibres are used.

Storage can be done either upstream or downstream depending upon the speed of processing. When fast processing of the raw feedstock is preferred, storage of the intermediate or end products becomes more relevant.

A.6 Pressing

Question

What kind of pressing is most likely?

Answer options and average results

Press at storage (or the processing facility if this serves as storage as well)	46%
Press in field (mobile) – solids to storage	23%
Press at transloading	21%
No press – fresh/wet to storage	11%

Comments

Pressing is preferred and ideally at the storage site. Although this is the preferred option respondents point to the opportunities a mobile press would have both for pressing in the field as for transloading sites. For anaerobic digestion pressing is only relevant for the digestate, not for the raw feedstock. Parts of the chain might benefit from pressing other parts not, quality separation might decide which part is. When the liquid fraction is important pressing should be done as soon as possible to conserve the target components.

A.7 Drying

Question

Is a dryer needed in the value chain?

If yes, which heat source will be used.

Answer options and average results

No	1/10
Yes	9/10
Yes – Waste/rest heat of local industry/…	47%
Yes – Waste/rest heat of local digester/CHP	44%
Yes - Other	9%
Yes - Dedicated (new) heating source	0%

Comments

The one respondent not needing any drying is logically for the landfill option. In case drying is needed **a waste/rest heat source (industry, digester, CHP) is the preferred** option to keep the carbon footprint of the process as low as possible. **The location of the processing installation will determine which source will be used**, therefore all rest heat sources are relevant when nearby.

A.8 Processing and end products

Question

Which mass (wet)/volume fraction (%) is/will be processed to the respective end-products (Now, in 10 years and in 20 years)?

Answer options and average results

	Now	*In 10 years*	*In 20 years*
Compost	79%	46%	34%
Digestate/biogas	11%	27%	21%
Fibres	0%	12%	18%
Protein feed (indirect)	0%	4%	13%
Soil conditioner/fertiliser	0%	9%	8%
Cattle feed (direct)	1%	1%	4%
Other	9%	0%	0%

Comments

In the above averages are 'quasi-averages' as some respondents did not divide the 100% correctly (small errors) or only indicated a likelihood for products instead of a percentage. Some respondents chose not to give any preference for current or in 20 years.

Respondents estimate **most of the current mass/volume of road side grass to be directed to compost**. Almost half of the respondents estimated it at 70%. A smaller amount is estimated to be used for anaerobic digestion and another portion could be regarded as not used (disappeared, left on the field, disposed of).

Respondents expect this situation to **change over the next 10-20 years shifting towards other uses, first towards anaerobic digestion** as a proven technology within a framework where sustainable energy is promoted **and later towards higher value products, like protein feed and fibres** for which economic viable value chains still need to be proven. However, by 2040 compost is expected still to be the dominant processed end-product from road side grass.

All products and by-products can be used in one way or another so quality and contamination of the feedstock, logistics, related costs and alternative feedstocks for the same products will be decisive.

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A.9 Processing and location

Question

Where are the processing units located vis-à-vis the current existing processing installations?

Answer options and average results

Neighbouring (but different operation/entity)	38%
Integrated in/plug in/part of the same operation/entity	31%
Other…	22%
Distant from competing installations	8%

Comments

According to most respondents the development of processing units will most likely happen **with links to the current processing installations, either by integration or neighbouring**. This question is heavily related upon the first question about the relations between the current and future value chains of road side grass. The comments provided by the respondents are, therefore, similar in nature. They refer to the opportunities for integration, using what works and building upon parts that are similar or even completely the same. Synergistic uses of both energy, by-products and installation units by both existing and new processing installations can have many benefits, especially at the dawn of new value chains with high CAPEX.

Some advocate for decentralized upstream processing or a drastic change in the processing paradigm.

A.10 Landscape grass vs. road side grass

Question

Will the value chain of these two types of grass feedstock configurations be different from one another?

Answer options and average results

Yes – but limited (especially related to grading)	64%
Yes – significantly	30%
No – (but…)	6%
Other	0%

Comments

Most respondents believe **the value chain configuration will differ for both types of grass feedstocks but to a limited extend**. Based upon the comments this is **mainly due to potential contamination** of road side grass (heavy metals, waste) which limits its potential applications. Once this is cleared both chains can be the same. For fibre applications it is also possible that for harvesting landscape grass other techniques are used than for road side grass, also influencing the quality of the fibres.

A.11 Overall comments on the questionnaire

Respondents could also give overall comments on the questionnaire given they were the first respondents to the survey.

Overall the questionnaire provoked many questions the respondents had not thought about before, forcing them to look at the bigger picture. It could be interesting to do the questionnaire again after some progress in the project or at the end as the project will generate new insights. Overall the questionnaire was welcome, and results awaited. The more stakeholders and experts filling it out, the more relevant its results become.

Question 8 seemed to be somehow difficult to answer, so in a later version this question should be recrafted a bit.

A.12 Conclusion

The results of this questionnaire provide some initial ideas on the configuration of a Grassification value chain. They will be used as first guiding principles in the *Design and development of the supply chain optimisation model*[56]. However, they can be subject to changes depending on new insight during the further course of the project.

According to respondents, the Grassification value chain -whatever it would look like and which by-products and end-products it will deliver in the end- will likely develop in parallel and/or as plug-in with the current value chain for roadside grass.

It is most likely that multiple quality checks will be necessary and this for different quality traits, probably upstream for contamination such as heavy metals and the presence of waste, and further downstream for quality traits which are rather related to the feedstock itself such as fibre length.

It is very likely that multimodal transport will be used with road transport being a condition for mobilizing the harvested grass at roadside, but where possible transloading will be used to reduce economic and environmental costs. Another option to be looked at could be the use of pipelines for grass slurry where relevant.

Both the storage configuration and storage types will be heavily dependent upon the main product choices made. Both direct storage at the processing facility and decentral storage are likely and both clamp silage and bales as storage types.

Pressing is preferred and ideally at the storage site. The idea of mobile pressing equipment enabling pressing at an early stage is widely supported. Pressing at an early stage would retain quality of certain product streams.

[56] Grassification-project (Deliverable D3.2.1).

When drying is concerned the value chain will have to count on waste heat either from processes within the value chain or elsewhere. No dedicated heat source is envisaged.

Respondents expect the current practice of composting road side grass, to shift partly in favour of other uses in the next 10-20 years; first towards anaerobic digestion as a proven technology within a framework where sustainable energy is promoted and later towards higher value products (proteins, fibre, …) for which economic viable value chains still need to be proven.

The development of processing units will most likely happen with links to the current processing installations, either by integration or neighbouring. There are opportunities for integration, using what works and building upon parts that are similar or even completely the same. Synergistic uses of both energy, by-products and installation units by both existing and new processing installations can have many benefits.

The configurations of the value chains will differ between road side and landscape grass, but to a limited extent. This is mainly due to potential contamination of road side grass (heavy metals, waste) and potential different harvesting techniques which limits its potential applications. Once this is cleared both chains can converge.

Apart from being informative for design and development of the MooV - supply chain optimisation model, the questionnaire proved to be effective in provoking stakeholders to reflect on the broader picture of the complete Grassification value chain.