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Contents

Abstract

The transition to a bioeconomy requires vast amounts of feedstock to serve a wide range of functionalities in a broad panel of applications in sectors as: construction, textile, paper, automotive, horticulture, and livestock farming. Herbaceous crops and residue streams like flax, hemp, miscanthus, cereal straw, reed and verge grass offer a wide range of characteristics which can serve multiple applications. This report analyses and explores the potential of production and valorisation of herbaceous feedstock in the Netherlands and eventually at regional level.

An analysis is made of current production and applications of herbaceous crops and residue streams. Present supply and demand were matched by an evaluation of imports and exports.
Circular economy policies, agendas and ambitions were reviewed for relevant topics: climate change, circular bioeconomy, regional development; and at 3 levels: EU, Netherlands and province of Gelderland. Also, important considerations regarding circularity and sustainability aspects of biobased value chains were discussed, with focus on construction and textiles sector.
Further, potential future use in products, indication of demanded product volumes for most promising applications, and production of herbaceous feedstock in the Netherlands in 2050 were studied. An exercise to match estimated demand and required production area was performed, taking into consideration typical scale of conversion technologies related to product demand.
Subsequently a SWOT analysis for use of each herbaceous feedstock for regional conversion into bio-based applications is carried out to identify the main points of attention and needs such as knowledge, infrastructure, collaborations, regulations and policies, technology for the valorisation of different feedstocks for different applications. Finally, recommendations are provided to next possible actions to materialise the transition to regional supply of herbaceous biomass for making bio-based products by local circular value chains.

Compared to conventional crops, flax, hemp and miscanthus are relatively small crops in production volumes. Each of them finds its way in a diverse range of applications as mentioned above. And despite the small volumes, flax and hemp feedstock and products are exported and imported for several reasons, circularity and regionality not being an aspect of decisive importance. Cereal straw as a side stream and verge grass and reed as residue streams are produced in much higher quantities, yet they are underutilised from a circular economy perspective and mainly ploughed under directly without prior other use. Using e.g. cereal straw as animal bedding first would retain the soil improving capacity while largely reducing the need to import straw.
Towards combatting climate change, establishing circular bioeconomy and developing regional value chains, policy frameworks are set at the 3 levels: EU, Netherlands and province of Gelderland. What is missing, however, is focus on value added specializations and innovations in circular economy. As a consequence strategies for the transition towards circular economy and agriculture concepts are not clear, implementation schemes are limited and long-term coordination and support is invisible. As it comes to practical rules of thumb for circularity and sustainability of biobased value chains, specific considerations are presented for construction and textiles sector.
Looking to the future (2050), herbaceous biomass will find increasing application in a wide range of sectors. For that, significant amounts of bio-feedstock will be required. The main reasons to expect that cultivation of herbaceous crops will increase substantially are: their potential to contribute to the circular economy and the use of biobased materials to replace fossil feedstock (circular economy policy goals), the storage of carbon (climate goals), and using less inputs like pesticides and fertilizer and less tillage compared to conventional crops (environmental goals).

To stimulate the transition to circular and regional value chains in the Netherlands and to avoid the ‘chicken-and-egg’ problem, it is essential to kick-start and provide long-term coordination of the triple requirement: accelerate increased cultivation of the feedstock, increase (collective) demand for circular and biobased products, and investments in production capacity. Regions and Provinces play an important role in this.

Also, regions and provinces need to review their strengths and opportunities and focus on specific value chains because the typical (economically feasible) conversion scales are relatively large and consequently a limited number of production facilities fit in the Netherlands.

1 Introduction

Human consumption of resources during past decades has been mostly in a non-circular (linear) way, leading to inefficient use of resources and their depletion. causing climate change and depletion of resources (the issues of finite fossil resources and the risk of climate change were raised in the 1970s already). The Paris Agreement (in 2015) has set a challenging goal to fight against climate change. In 2019 the European Commission adopted a comprehensive report on the implementation of the Circular Economy Action Plan.[1] The Dutch government launched a Government-wide programme "A Circular Economy in the Netherlands by 2050" which aims to reduce primary raw materials (minerals, fossil, metals) consumption by 50% in 2030 and realize a circular economy by 2050.[2] All these policy agendas put pressure on various sectors to achieve a transition towards a more sustainable and circular approach. Also at regional level, policies on sustainable production and consumption are established and circular concepts are being applied. Regional partner networks are searching for new opportunities for sustainable growth and innovation based on their regional characteristics.

Bio-based materials can be argued to be intrinsically circular as they are mostly made up of carbon which is recycled to the atmosphere at the end of life. Still, the production of bio-based materials requires labour, nutrients, water, energy and land. These are often scarce resources. Therefore, applying circular and cascading principles in the use of bio-based materials is important. Two types of cascading can be distinguished: parallel and sequential cascading. **Parallel cascading** means simultaneously utilising different fractions of the plant at different functionality levels (see Figure 1). For the example flax that could mean using the highest quality flax bast fibres for textiles, lower quality bast fibres in insulation material or composites, while shives are used for making particle boards and as animal bedding, and dust is used for heat production. On the other hand, **sequential cascading** means recycling a product at the end of its service life into material for making another product. This sequential cascading means that we should aim at making efficient use of the functionality of bio-based materials, conserve that functionality and maintain the material in the circle of (re)use for as long as possible before it is used for an application such as energy generation or soil amendment. Taking the example of flax bast fibres: long fibres may be first used in textiles (product level 4), in a second and third life the fibres could be used as insulation material (level 3) and composites (level 2), and finally the composite can be used for energy production (level 1). For lignocellulosic materials such as wood, flax and straw, extending the life of products means that carbon is stored temporarily when applied in durable products like building and construction. While new plants grow, CO_2 is taken up (extracted) from the atmosphere, thus achieving the opposite of CO_2 emissions (negative CO_2 emissions). Replacing fossil-based products will thereby mitigate climate change. Making better products such as based on specific biodegradable plastics may, under specific and strict conditions, further add to solving other issues such as counteracting plastic soup issues. Finally, at the end of the last life of the product, the scarce resources contained in bio-based materials (nutrients, especially P) should be efficiently and effectively recycled and brought back to the soil.

[1] European Commission, 2019. Report on the implementation of the Circular Economy Action Plan. COM/2019/190.
[2] Government of the Netherlands, 2016. A Circular Economy in the Netherlands by 2050.

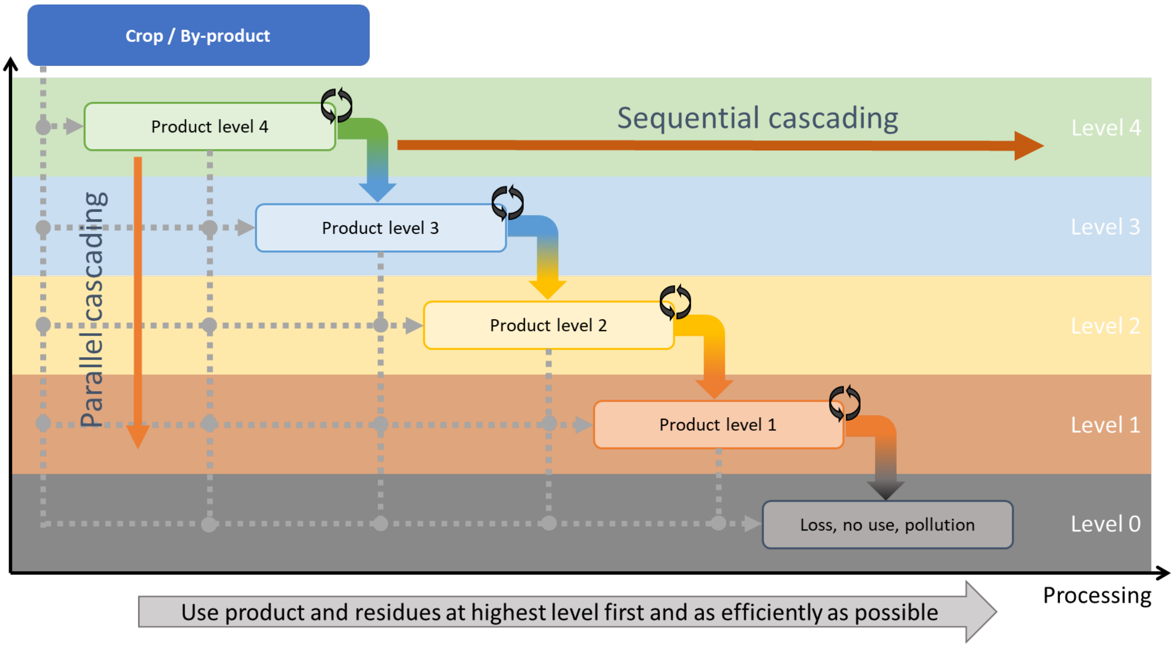

Figure 1 Illustrative scheme of parallel and sequential cascading use of bio-based feedstock (based on Höglmeier et al., 2015, Spijker et al., 2020 and Elbersen et al. 2022).

Whereas cascading use and local use serve the key goal of sustainability, maximum number of sequential cascading uses not automatically delivers optimum sustainability. Sustainability also relates to required recycling and subsequent conversion processing inputs (e.g. energy, chemicals) that require resources themselves. Next, the question is to which extent e.g. fibres from used textiles for the production of composites compare to specifically grown fresh biofeedstock. Moreover, the question is to which extent volumes of sequential cascading uses balance with demand volumes. The benefits of local conversion and use of biofeedstock relate to the sustainability efficiency of smaller scale conversion relative to centralised and specialised larger scale conversion. The question is what scale of conversion is optimal for which type of conversion processes and applications (materials, chemicals, fuels), and how small or large optimal cycles are. We aim to understand what the opportunities and challenges are to making best circular use of locally produced herbaceous crops and residues.

In this project we focused on the following herbaceous crops: flax, hemp, miscanthus, reed, straw, verge grass and common nettle. Jute may be abundantly available as a recycled feedstock, however, as its cultivation requires warm and humid climate, and typically is produced in Bangladesh and India,[3] it cannot be locally grown in the Netherlands. Tomato stems and bell pepper stalks were not considered herbaceous, and therefore not addressed. Cattail is addressed in the section on potential applications in 2050 as it is considered a potential crop to cultivate when peatlands would be made more wet.
For crops with a specific cultivation region, like flax and hemp, specific attention will be given to the relevant provinces. The Province of Gelderland acts as sounding board.

The goal of this study is to analyse and explore the potential of production and valorisation of herbaceous crops and herbaceous residues in the Netherlands and to provide answer to the questions:

- What is the current production and demand of herbaceous crops in the Netherlands and in specific regions? And to which extent are the value chains organised regionally and/or circular?
- What are relevant policy frameworks related to herbaceous crops and their products?
- What valorisation and application possibilities exist for the use of herbaceous crops?
- What is the potential (increase in) production related to potential demand of herbaceous crops in the Netherlands and in specific regions?
- To which extent and under which conditions can future primary production, processing and demand be matched regionally, and how can circularity be enhanced?

[3] http://www.worldjute.com/about_jute/abj_cultivation.html

- What are the drivers for production, supply and application and how can they be stimulated? And what are the hurdles faced and how can they be overcome?
- What are the requirements (knowledge, technology, infrastructure, capacities, financial means, legislations, collaborations, policy) to maximise circular use of locally produced herbaceous materials?

To gain insights to the answers for these research questions, different stakeholders along the value chain were mapped and series of interviews were conducted representing different actors in the chain. A SWOT analysis was then used to identify the main issues and needs (such as knowledge, infrastructure, chains, collaborations, policy, technology). Subsequently recommendations were provided for next possible actions and the role of the different actors in the chain to address these needs.

<u>Reading guide</u>

- Chapter 2: Current production, supply and applications of herbaceous feedstock in the Netherlands
- Chapter 3: Analysis of circular economy agendas and ambitions at EU, Dutch and Gelderland province level. As well as description of some technical circularity and sustainability aspects and strategies.
- Chapter 4: Potential applications, demand and production of herbaceous feedstock in Netherlands in 2050
- Chapter 5: SWOT analysis, definition of main points of attention and listing needs to accelerate use of herbaceous feedstocks.
- Chapter 6: Conclusions.

2 Current production, supply and applications of herbaceous feedstock in the Netherlands

The current production and applications of herbaceous crops are described in sections 2.1 and 2.2, respectively. The matching between supply and demand is discussed in section 2.3.

2.1 Production of herbaceous feedstock

In this paragraph we describe the current production of herbaceous biomass, with a focus on fibre-crops and residues such as flax, hemp, miscanthus, reed, straw, verge grass and common nettle. We describe the production in the Netherlands, and, as far as data are available, specifically per province. Data for several years have been presented, as far as available, in order to visualize variations over years, e.g. as an effect of dry growing seasons.

Herbaceous crops are part of so called 'trade crops', as opposed to food crops, because these crops are used as raw material for the industry.[4]

2.1.1 Fibre Flax (*Linum usitatissimum*)

Fibre flax is an arable crop that mainly grows on clay soils. It has been grown in the Netherlands for over millennia. Fibre flax is primarily cultivated for fibre applications such as linen textiles. However, the cultivation of this crop in the Netherlands nowadays is limited and tends to decrease due to increasing land prices. Simultaneously, the cultivation area of flax in Europe has nearly doubled during the last decade, particularly in France. Dutch flax processors cultivate flax in France as well.[5] In Table 1, data are given for the cultivation of fibre flax, both in area and weight. The weight is *as is*, comprising about 10 wt.% moisture content.

Table 1 ***Overview of production figures of fibre flax in the Netherlands (CBS data).***[6]

Fibre flax	Area under cultivation (ha)	Harvested area (ha)	Gross yield, per ha (ton *as is*)	Gross yield, total (ton *as is*)
2017	2,564	2,494	4.1	10,224
2018	2,232	2,218	4.0	8,783
2019	2,291	2,291	5.8	13,356
2020	2,378	1,925	3.8	7,353

The area used for the cultivation of fibre flax has fluctuated in recent years, but roughly amounts 2,200 – 2,500 ha per year.

[4] https://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2243
[5] Karel van Looij, personal communications.
[6] https://opendata.cbs.nl/#/CBS/nl/dataset/84296NED/table?dl=6E1BE

Figure 2 Flax straw in swads retting in the field.

In 2020, remarkably fewer hectares were harvested than cultivated in the Netherlands, namely 1,925 ha compared to 2,378 ha cultivated. 2020 was a very dry year and therefore part of the flax was not suitable for harvesting. Also in 2017 and 2018, less ha were harvested than cultivated, because these were also relatively dry years. Moreover, the yield per ha in 2017, 2018 and 2020 was significantly lower compared to 2019. In a 'normal' year, the yield should be 6 tons/ha[7], reaching 7 tons/ha.[5] in very good years.

After processing, flax fibres can be split to extract long fibres (1,200 – 1,500 kg/ha),[5] short fibres (approximately 900 kg/ha), and shives (more than 3,000 kg/ha).[8] Flax shives are the woody core pieces which are separated from the bast (linen) fibres during processing (section 2.2.1). Yield of linseeds is in the range of 600 – 900 kg/ha.[9]

Figures on regional cultivation of fibre flax per province are presented in Table 2. Cultivation is concentrated in the province Zeeland, followed by Noord-Brabant, Flevoland and Zuid- and Noord-Holland, while the other provinces virtually have no production.

Table 2 Regional production of fibre flax per province (2020, CBS data).[10]

Regions	Harvested area (ha)	Gross yield, total (ton *as is*)
Groningen	-	-
Fryslân	0	1
Drenthe	1	2
Overijssel	-	-
Flevoland	105	399
Gelderland	1	3
Utrecht	-	-
Noord-Holland	27	105
Zuid-Holland	39	149
Zeeland	1,630	6,225
Noord-Brabant	123	468
Limburg	-	-
The Netherlands	1,925	7,353

7 David Kasse, personal communications.
8 CLM, 2020, Bijdragen van vlas en hennep aan milieu- en klimaatdoelstellingen van het toekomstig EU-landbouwbeleid, p.21
9 https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7100oogs/table?fromstatweb
10 https://www.cbs.nl/en-gb/figures/detail/7100eng?q=flax#GrossYieldTotal_4

Competition with other crops

Fibre Flax is mainly grown in the south-west of the Netherlands. The profitability is similar to that of cereals and grass seed, crops that are grown quite a lot in this region. Therefore, it will compete especially with these crops concerning land use. Flax is grown as part of a rotation scheme and requires low nitrogen soils with a good soil structure. Flax can only be cultivated once in 7 years. Especially the cultivation of sugar beet (when harvested under wet conditions) in the rotation scheme can lead to lowering of the soil structure. Furthermore, legumes, such as kidney beans which are widely grown in the south-west, can increase soil nitrogen. In a typical rotation scheme, for example, consumer potato - summer cereal - sugar beet - winter grain (or possibly grass seed), flax fits best in the place of summer grain. In the end, a farmer considers the added value per hectare.

Oil flax is not cultivated in the Netherlands due to its low margin compared to other crops such as grains. Linseed was imported from Canada up to about 10 years ago when GMO contaminated seeds were found. Since then, linseed has been imported from former USSR republics. Including transportation costs (3,000 – 5,000 km distance by road), linseed has a market price of in The Netherlands 350 – 400 €/ton.[5]

Information on import and export of flax (and other crops addressed in following sections) is provided in section 2.3.

2.1.2 Fibre Hemp (*Cannabis sativa*)

Fibre hemp also has a long history in the Netherlands. It was used for rope production for sailing ships. Around 1910, the cultivation in the Netherlands nearly disappeared, apart from a few smaller cultures for local use. New applications of hemp fibre and the development of new machines for harvesting and processing led to the reintroduction of fibre hemp cultivation in Groningen in the 1990s.[8]

For the cultivation of hemp, legislation concerning cannabis as a drug is relevant. Tetrahydrocannabinol (THC) is the principal psychoactive constituent of cannabis. In the Netherlands, as in most European countries, the cultivation of fibre hemp has been legal since 1992. However, the THC content in the fibre hemp may not exceed 0.3%. The varieties that comply with this requirement are identified by the European Commission. No permit is required for the cultivation of these identified species. However, special certified seed must be used to grow fibre hemp.[8]

In Table 3 an overview of cultivation figures of fibre hemp in the Netherlands is presented. The area used for the cultivation of fibre hemp has somewhat fluctuated in recent years, but roughly amounts 2,000 ha per year. Considering the small differences between cultivated and harvested areas over the years, the difference of exactly 1,000 ha harvested less in 2017 seems remarkable, and it may not be ruled out that the 1,272 ha harvested contains a typo in the CBS data.

***Table 3 Overview of production figures of fibre hemp in the Netherlands (CBS data*).[11]**

Hemp	Area under cultivation (ha)	Harvested area (ha)	Gross yield per ha (ton *as is*)	Gross yield, total (ton *as is*)
2017	2,272	1,272	7.5	9,539
2018	2,122	1,990	7.7	15,323
2019	1,877	1,877	7.5	14,074
2020	1,827	1,827	7.0	12,786

Fibre hemp yields various products. The leaf and the flowers can be used for feed or nutritional supplements. Processing of fibre hemp straw yields ca. 25-27% hemp fibre, 55% shives and the remaining fraction is dust. The seeds are not ripened when the hemp is mown in August for fibre applications, as is mostly the case in the Netherlands.[12]

[11] https://opendata.cbs.nl/#/CBS/nl/dataset/84296NED/table?ts=1632998764089
[12] Albert Dun, personal communications.

In Table 4, figures on regional cultivation of fibre hemp per province are given. Cultivation is concentrated in the provinces Groningen and Drenthe, at a distance followed by Noord-Brabant, Zuid-Holland, Overijssel and Friesland, while the other provinces virtually have no production.

Table 4 ***Regional production of fibre hemp per province, 2020 (CBS data).***[13]

Regions	Harvested area (ha)	Gross yield, total (ton *as is*)
Groningen	1,267	8,871
Fryslân	14	97
Drenthe	305	2,136
Overijssel	50	349
Flevoland	1	7
Gelderland	32	225
Utrecht	1	8
Noord-Holland	-	-
Zuid-Holland	73	512
Zeeland	-	-
Noord-Brabant	83	581
Limburg	-	-
The Netherlands	1,827	12,786

Cultivated area for fibre hemp in the Netherlands is small compared to e.g. France, where about 18,000 ha are grown, versus nearly 50,000 in the EU.[8]

<u>Competition with other crops</u>
Fibre hemp is an annual crop which is grown as a rotation crop especially in the Veenkoloniën region of Groningen and Drenthe. Here starch potatoes are grown in a 1 to 2 rotation with fibre hemp and other crops. Fibre hemp may be cultivated, for example, to give plots with potato fatigue some additional rest. Due to its long roots, fibre hemp cultivation contributes to a good soil structure.[8] Concerning land use, fibre hemp competes with starch potato, sugar beet or cereals. Industrial hemp production in EU in 2018 was about 50,000 ha.[14]

2.1.3 Miscanthus (*Miscanthus gigantheus*)

In the Netherlands, estimates for the area cultivated with Miscanthus range from 250 – 1,800 ha.[15,16] *Miscanthus gigantheus* is a rapidly growing perennial C4 crop (10-20 years) native to East Asia, but it can also be grown in the Netherlands. *Miscanthus* produces a lot of plant mass both above and below the ground (i.e. the roots and rhizomes) and harvest can take place 2-3 years after planting the rhizomes. Harvesting the canes can be done once a year, typically in the period January – March, and using conventional farm machinery (e.g. self-propelled forage harvesters, etc.), producing either bales or chipped material. When it is fully established, it is some 3 to 4 m tall. The crop yield reaches up to 20 ton dry matter per hectare per annum when harvested in winter or early spring. We estimate average yield will be around 15 ton dry matter (DM) per year after a 4 year lag period when yield slowly increases from 0 to 15 tons per year.[17] *Miscanthus* is also often grown on less productive land, often leading to lower yields. Without using fertilizer, about 13.6 ton DM per year can be harvested.[15] Current *Miscanthus* production can thus be estimated at 250 – 1,800 ha x 12.5 ton DM = 3,125 – 22,500 ton DM/a. Several advantages are claimed for *Miscanthus*:[18]

- Miscanthus produces 2 – 4 times more biomass than forests in the Netherlands

[13] https://opendata.cbs.nl/#/CBS/en/dataset/7100eng/table?searchKeywords=hemp
[14] https://eiha.org/wp-content/uploads/2020/10/2018-Hemp-agri-report.pdf
[15] Jan-Govert van Gilst, personal communications.
[16] https://miscanthusgroep.nl/miscanthus/miscanthusgroep-haarlemmermeer/?et_fb=1&PageSpeed=off
[17] https://www.wur.nl/nl/Dossiers/dossier/Olifantsgras-Miscanthus.htm
[18] https://miscanthusgroep.nl/

- For the cultivation of *Miscanthus* no fertilizer or pesticides need to be used
- After planting, this perennial crop can be harvested for 15 to 25 years
- Applications for *Miscanthus* are expanding and being developed (see sections 2.2.3 and 4.1)

An example is the cultivation of *Miscanthus* near Schiphol Airport which has a specific objective: to reduce the number of geese. Geese are dangerous for air traffic because they can get caught up in the engines. Geese avoid *Miscanthus* because they avoid any thick tall vegetation where predators, such as foxes can ambush them. Near Schiphol the airport often pays farmers to uproot a rotation crop to avoid attracting geese especially around harvesting time. The damages incurred by farmers need to be compensated to farmers. Growing Miscanthus avoids these costs.

Competition with other crops
Miscanthus is a perennial crop, and therefore it does not compete with individual crops but with total rotation systems. *Miscanthus* is grown on agricultural land, but also on undeveloped land and on banks near rivers. So, it does not per-se compete with food production.

Miscanthus can be grown on almost all types of soil, as long as it is not flooded for extended periods, is not too dry (the roots grow 70 to 200 cm deep) and the is soil dry enough for machine operations at harvest time in March or April. You can also think of depleted soil or otherwise low quality soils, banks, groundwater protection areas, plots with agricultural nature management, or other places where a perennial reed-like crop is welcome.[19]

2.1.4 Reed (*Phragmites australis*)

The Netherlands is a country with a lot of water and therefore a lot of natural reed areas exist. This reed was traditionally used for several applications such as roofing. Reed is cultivated in the agricultural sector only to a limited extent, and foremost harvested in nature conservation areas.

"The Dutch reed area is still about 7,000 hectares of which about 4,500 hectares are mown; the Wieden and Weerribben areas together account for 2,500 hectares."[20] There are regional differences in quality. In the Netherlands the best quality within nature conservation areas of reed is harvested in the provinces Friesland, Noord-Holland and especially the Northern part of the province Overijssel (called the Weerribben, and the Wieden). Furthermore, reed grows and is harvested in the regions Stellendam, Nieuwkoopse plassen, and along the main rivers.[20]

The amount of reed that can annually be harvested from nature management areas per region is estimated by Natuurmonumenten as indicated in Table 5. Overall it is estimated that about 30,000 tons *air dried* of multi-annual reed – which is reed grown in multiple years – can be harvested each year in the Netherlands. Potentially there could be even more, depending on pricing levels.[21] Next to that, spread over the country about 70,000 ton/a *dry matter* of reed is mowed under management of Water boards and other land owners, not being nature management organizations,[22] and about 5,000 ton/a *dry matter* by the Dutch Department of Water Management (Rijkswaterstaat, RWS).[23] Not all reed can be harvested as 'pure' reed due to contamination with twigs, herbs, etc.

[19] https://www.louisbolk.nl/sites/default/files/publication/pdf/teelt-van-miscanthus-voor-strooisel.pdf
[20] https://www.riet.com/riet/natuurlijk_riet.html
[21] E. Keijsers et al., 2020, The development of reed composite fiber boards using partially bio-based, formaldehyde- and monomeric isocyanate-free resins, https://doi.org/10.1016/j.repl.2019.10.007
[22] https://www.stowa.nl/sites/default/files/assets/PUBLICATIES/Publicaties%202017/STOWA%202017-04.pdf
[23] Elbersen & Spijker, 2014, Biomassapotentie Rijkswaterstaat - Analyse van hoeveelheden en huidige toepassing, https://edepot.wur.nl/292594

Table 5 ***Regional production of reed that can be harvested from nature management areas and under management of Water boards and RWS in the Netherlands.*** [21,22,23].

Location	Regions	Harvested area (ha)	Gross yield, total (ton DM/a)
Wieden/Weerribben	Overijssel	2,500	6,000
Alde Faenen/Rottige Meenten	Fryslân	Not known	2,000
Randmeren	Flevoland, Gelderland, Utrecht, Overijssel	Not known	3,000
Vechtplassen/Nieuwkoop	Utrecht		2,000
Laag Holland	Noord Holland	Not known	5,000
Dutch Department of Water Management (RWS)		750	5,000
Water Boards		Not known	70,000
Total			94,000

Given the 2,500 hectares of reed in de Wieden/Weerribben, as mentioned above, and the 6,000 ton harvested per year, the yield of multi annual reed in this nature conservation area is assumed to be about 2.4 ton/ha. Annual production is about 6 ton/ha.[24] Elbersen & Spijker assume a yield of 6.6 ton/ha.a for reed growing at waterways like managed by RWS.[23]

Figure 3 ***Location of reed growing in nature conservation areas in the Netherlands (Keijsers et al., 2020).***[21]

Reed as an agricultural crop was introduced in the Agricultural Census in 2020, and there it is mentioned that 75 hectares of reed is harvested. However, only farmers are asked to complete the survey, nature conservation organizations are not supplying any data. Therefore, the 75 ha is the harvested area within the agricultural sector. Reed cultivation can be of interest for peatland areas if one wants to increase the groundwater level to reduce current CO_2 emissions. The peatland areas can then maintain their economic base in the agricultural sector, but must then switch from dairy farming to wet crop cultivation.[25]

The quality (e.g. length, strength, straightness) of reed grown in the agricultural sector and reed harvested from nature reserve areas may vary considerably. With reeds from nature reserve areas, the quality of the reed is not paramount, rather the quality of nature.

[24] Harald van den Akker, personal communications.
[25] https://edepot.wur.nl/13674

Competition with other crops

Reed in nature conservation areas does not compete with growing other agricultural crops. In the agricultural sector, reed is cultivated on a very small area so far. Peatland areas, covering some 300,000 ha in The Netherlands, are mainly used for grassland. Due to the low water table that is maintained to make agriculture possible, a significant amount of CO_2 is released from peatland each year. Due to GHG emissions connected to the low soil water level maintained in peat meadow areas, pressure increases to convert grasslands to wetlands. In such areas, reed (and other species such as cattail) may be cultivated.

2.1.5 Straw

Straw is a co-product of the cultivation of cereal crops such as wheat. Most straw is baled and sold as bedding in livestock farming and for the construction of tulip beds and other applications. Another part is chopped during harvest and worked into the soil to increase the organic matter content. Organic straw is in demand in organic mushroom cultivation.[26]

CBS does not provide specific figures on straw production, however, grain areas under cultivation and harvested are reported. The area of arable crops has been shrinking since 2000. After an increase in the area of wheat cultivation in 2019, the area decreased again in 2020 (Table 6).

The yield of wheat grains is about 9 ton/ha and the volume of wheat straw is about 5.7 ton DM/ha.[27] Over 50% of the farmers plough the straw under the soil to maintain the carbon content in the soil, adding up to a total of 370 – 410 kton/a over recent years. On average about 2.3 ton DM/ha is removed.[27] Drought, which is expected to occur more often due to climate change, decreases the yields and increases demand (because of decreased hay production more straw is used to feed young cattle), and therefore increases the price. In 2018, a year with severe drought, the prices increased to 60-65 euro per ton for barley straw and 120 euro per ton for wheat straw.[28] Also in 2020, straw production per ha was low due to drought, 3-3.5 ton/ha for wheat,[29] about 60% of the average of 5.7 ton DM/ha calculated by WR based on BIN and KWIN data.

Table 6 Cultivation of wheat and yield of straw in the Netherlands (CBS data).[30]

Wheat	Area under cultivation (ha)	Harvested area (ha)	Gross yield straw (ton DM/ha)	Gross yield straw, total (ton DM)	Straw, harvested (ton DM)
2000	136,686	136,072	5.7	775,610	312,966
2018	112,044	111,660	5.7	636,462	256,818
2019	121,064	120,546	5.7	687,112	277,256
2020	109,628	108,908	5.7	620,776	250,488

In 2020, 110,000 ha for wheat, 38,000 for barley and 4,500 for rye, oats and triticale all together were grown in The Netherlands.[31]

Competition with other crops

Straw is a byproduct of cereal production. Cereals are grown in rotation schemes with potatoes, sugar beet and sometimes vegetable crops.

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[26] https://www.agrifirm.nl/nieuws/stro-aanleveren
[27] WR calculation, based on CBS production data and data from BIN and KWIN.
[28] https://www.nieuweoogst.nl/nieuws/2018/07/28/schaarste-aan-stro-doet-prijzen-stijgen
[29] https://www.veeteeltvlees.nl/nieuws/economie/2020/stro-opbrengst-minder-maar-van-erg-goede-kwaliteit
[30] https://opendata.cbs.nl/#/CBS/en/dataset/7100eng/table?searchKeywords=wheat%20barley%20production
[31] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/7100oogs/table?fromstatweb

2.1.6 Verge grass

Road verges and river banks in the Netherlands are mainly managed by the Dutch Department of Water Management (Rijkswaterstaat, RWS) Water Boards (Waterschappen) and by provinces and municipalities. Additionally, State Forest Management (Staatsbosbeheer) manages nature areas from which nature grass is mowed after the bird breeding season, starting in July.[32] The Dutch Department of Water Management manages sites throughout the country, especially along roads and canals. On these sites the (harvestable) biomass production is estimated at 160,000 tonnes of dry matter per year, of which approximately 115,000 tonnes of dry matter of grass mixed with other herbaceous biomass and about 26,000 tonnes are woody biomass (Table 7).[23] In addition, about 70,000 tons of dry matter aquatic plants are produced on the (open) water. In addition to the area that the Department manages itself, it also has the (water security) responsibility over large area of mainly floodplains and water: 50,000 ha mainly producing grass, 18,750 ha water vegetation and 5,100 ha mainly producing woody biomass.[23] Data are summarized in Table 7. It may be noted that biomass collected from road sides, ditches and canal banks contains a significant share of sand; a study for Water Boards mentions a value of 14 weight%.[22]

Table 7 Production of verge biomass from sites Dutch Department of Water Management.[22,23]

	Herbaceous biomass (ton DM)	Woody biomass (ton DM)	Aquatic plants (ton DM)	Total (ton DM)
Sites managed by Department of Water Management (RWS)	115,000	26,000	1,750	142,750
Sites for which RWS has responsibility	300,000	23,000	75,000	398,000
Total	415,000	49,000	76,750	540,750

On average, the biomass production on Dutch road verges is 3-5 ton/ha of dry matter. For transportation purposes, that equates to 12-20 tons of fresh material.[33] Elbersen and Spijker (2014) assume higher values: 5.5-8.5 ton/ha of dry matter for road sides, about 6.5 ton/ha for ‘nature friendly banks’, 4-4.5 ton/ha for water vegetation.[23]

It may be noted that the estimated biomass production is a snapshot. In other words, it is the 'harvestable' biomass production in the current situation. However, if the biomass is harvested and disposed of more intensively than in the current situation, productivity will decrease due to nutrient removal (verges are not fertilized). Also, yields will depend on weather conditions (i.e. climate change). This is particularly true in the case of vegetation where the amount of nutrients present is limiting biomass production (e.g. grass vegetation on low quality soils).[23]

<u>Competition with other crops</u>

Verge grass is not grown as a crop, but is released as a kind of co-product of managing roads and waterways. In fact, most part of ‘verge grass growing areas’ cannot be used to grow any crop like e.g. *Miscanthus*.

2.1.7 Common Nettle (*Urtica dioica*)

Common nettle can be grown as a fibre crop in the Netherlands. It is now produced only on a small scale, for example on research farms.

Common nettle is a perennial plant which grows best on moist, slightly acidic and high nutrient soils. It can reach a height of up to 3 meters, with an average of 1.5 meter.[34,35] As no seeds are available so

[32] Wim Bies, personal communications.
[33] Zwart, K. and D. de Boer, 2015, Droge vergisting van berm- en natuurgras, Wageningen, juli 2015. https://edepot.wur.nl/350624
[34] Teelthandleiding Brandnetels, Christelijke Agrarische Hogeschool, Module PPR-3, 2008, https://edepot.wur.nl/134852
[35] https://www.biobasedgarden.nl/gewassenoverzicht/brandnetel/

far, rhizomes are used for propagation. The plants are toped (mowed) up to 3 times during the planting season to stimulate off-shooting of plants. During the next growing season (2nd year), harvesting can take place in July. The woody stems are dried on the land and pressed prior to further processing. To speed up the drying process, the plant can be pressed so the stems dry faster. When the crop has been taken off the land in September, the plants start sprouting for next year's harvest. An additional round of harrowing and hoeing is applied to optimize growing. This cycle can be repeated for about 6 years, until, the vitality of the plant drops, and so does the yield. The DM yield of fibre nettle increases over consecutive years. Reported yields vary between 5 and more than 15 tons DM per ha per year after te second year. The corresponding fibre yields vary between 600 and 1,700 kg per ha.[36,37,38] Some 6 years after establishment, when yield decreases, the crop is replanted.

Competition with other crops
Nettle fibre could be an alternative for flax or cotton fibre. Fibre yields are about 1,200 kg/h long flax fibres and 900 kg/ha short flax fibres (section 2.1.1) and 1,500 – 2,000 kg/ha for cotton, respectively.[39] Considering that development of Nettle as a fibre crop and breeding is not fully developed higher yields may be possible in the future. Nettle is a perennial crop and will therefore not fit in a rotation system. This can be a real disadvantage.

2.1.8 Conclusions

- Flax and hemp are relatively small crops, mainly grown in the provinces of Zeeland and Groningen, respectively.
- Nettle is not a commercial crop currently; it may be an alternative crop for flax fibre.
- Miscanthus is a small crop, grown at several locations in the Netherlands.
- Cereal straw and verge grass are produced in much higher quantities in agricultural regions and near infrastructure all over the country.
- Reed is produced at intermediate quantities in water rich regions in the Netherlands.

2.2 Current applications and volumes of herbaceous biomass in the Netherlands

2.2.1 Fibre Flax

Flax in North Western Europe (Province of Zeeland to Normandy) is primarily grown for its long bast fibre for linen manufacturing. Actually, bast fibre flax grown in this region is considered the highest quality flax fibre in the world.[40] The harvesting and processing of fibre flax is entirely focussed on extraction of the long bast fibre. First, the flax stems are pulled out of the soil (typically in the second week of July), in order to keep the fibres as long as possible. The stems are laid on the soil in swaths for dew retting, a microbial process which weakens the pectin bond between the bast fibres and the woody core of the plant. The swaths need to be turned regularly to allow smooth retting. During one of these turnings, the flax may be deseeded and collected at the same time. After retting, the flax stems (also called flax straw) are baled. If moisture content is low during the retting period, the dew retting process will be poor, and separation of bast fibre and woody core (called scutching) will be poor too. If moisture content is too high, the bast fibres will be affected too, leading to lower strength of the fibre. The bales are stored inside until scutching, a process to separate the bast fibres from the woody core (called shives). Part of the bast fibres are removed together with the shives, and separated later on to become short bast fibres. These short fibres are used for **high quality paper, composites** for formed

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[36] Teelthandleiding Brandnetels, Christelijke Agrarische Hogeschool, Module PPR-3, 2008, https://edepot.wur.nl/134852
[37] Bacci et al. 2009. Fiber yield and quality of fiber nettle (Urtica dioica L.) cultivated in Italy. industrial crops and products 2 9 (2009) 480–484.
[38] Anna Hartl and Christian R. Vogl. 2002. Dry matter and fiber yields, and the fiber characteristics of five nettle clones (Urtica dioica L.) organically grown in Austria for potential textile use. American Journal of Alternative Agriculture. Volume 17, Number 4, 2002
[39] https://www.indexmundi.com/agriculture/?commodity=cotton&graph=yield
[40] https://www.mugmagazine.com/focus-linen.html

products in e.g. the automotive sector or **insulation mats** for building and construction. The shives are used in **particle board** for furniture or building panels, and for **animal bedding**. The long fibres are combed (called hackling) to remove short fibres and impurities and shipped mainly to China (low wages) for further processing into very **thin yarns, fabrics and textile** products. During this hackling a further fraction of short fibres is removed, which is used for manufacturing **ropes, composites and insulation mats**. Composites are fibre reinforced polymers which are applied in e.g. the automotive sector, building and construction and in (chemical) processing industry. The seeds, finally, are used for **food and oil** applications such as **linoleum and paints**.
In the Netherlands, growing and processing (scutching and hackling) of fibre flax is concentrated in Dutch Flanders with 4 processors. Cultivation of oil flax, which has higher production of seeds and lower content and quality of bast fibres, has virtually disappeared from the Netherlands.[41]

Drivers, hurdles and competition
Long flax fibres (hackled fibres and hackling tow) are mainly exported to China for manufacturing into fine textile yarns and high quality linen fabrics for clothing.[7,8] Lower quality fibres (scutching tow) are used for upholstery, curtains, and ultimately carpet backing and ropes. China couples low wages and a long standing tradition regarding flax production and processing. At the same time, demand for flax fabrics and garments fluctuates with fashion 'cycles', and so does flax fibre price (Figure 4). These fluctuations in demand and price are tackled by storing flax in periods of low demand/price, and selling when demand/price goes up. If demand is strong, and prices tend to increase, high land prices in the Netherlands limit increase of production area; e.g. between 2015 and 2019, production area in Belgium has increased from 12,000 to 16,000 ha, and in France from 60,000 to 120,000 ha, whereas production area in the Netherlands stayed at around 2,000 ha per year.[42] This strong increase in cultivation area at a steady price level is a result of continued and increasing interest in ecological fibres and fabrics over the last decade. The demand for natural fibres like flax, especially in Asia, is growing because it is more sustainable than competing crops like for example cotton in terms of use of water and chemicals. Also, flax varieties grown are non-genetically modified (GMO), and flax provides a good soil structure for crops that are grown afterwards.[43] This has resulted in the (planned) establishment of four new spinning mills in Europe where flax fibres are processed into yarn for linen, with a production capacity of 2,600 tonnes of flax yarn in 2021.[43] Two of the small scale flax spinning mills are in France; one wet spinning mill for high quality yarns with a capacity of about 1,000 ton/a, and one dry spinning mill processing hackling tow. Drivers for the reshoring of spinning capacity include occasional problems regarding delivery from China and specific subsidy for 100% regional products in France, as well as specific EU subsidies for investment costs. In Portugal establishment of a new spinning mill is under consideration.[5] Large flax spinning mills in Europe have a capacity of typically 5,000 ton/a.[5] These mills are on top of existing five flax spinning mills in Europe with a combined production capacity of 10,800 tonnes of flax yarn per year.[42]

The flax weaving industry is larger than the spinning industry in Europe. This is due to relatively lower labour costs for weaving relative to the other feedstock costs: About 15% of fabric costs versus about 60% for yarn costs. Weaving is mostly located in Italy, Portugal, Spain, France, Switzerland and Austria.[5]
Linen textiles may be regarded as a niche market, yet it competes with cotton as the main vegetable fibre, and fossil based synthetic polyester (PET) as the main textile fibre. Compared to cotton, flax requires less fertilizer and crop protection agents.[44] As a reference, 2,200 ha of flax cultivated in the Netherlands produces about 4,500 ton/a of fibre, long and short, which is about 1.3% of the total volume of 343,000 ton of consumer clothing, working clothes and BBK (bath, bed and kitchen 'linen') which was sold on the Dutch market in 2018.[45]

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[41] Coninx et al., 2014. Met vlas naar een biobased economie: omgeving Enschede. https://edepot.wur.nl/327823
[42] https://www.nieuweoogst.nl/nieuws/2019/09/13/vlas-laat-dit-jaar-mooie-opbrengstcijfers-zien
[43] https://www.foodagribusiness.nl/krimp-europees-vlasareaal-ondanks-groeiende-afzet/
[44] https://linenshed.uk/blogs/news/environmental-impact-flax-vs-cotton
[45] https://www.rijksoverheid.nl/binaries/rijksoverheid/documenten/rapporten/2021/05/20/bijlage-4-monitoring-circulair-textiel-infographic/bijlage-4-monitoring-circulair-textiel-infographic.pdf

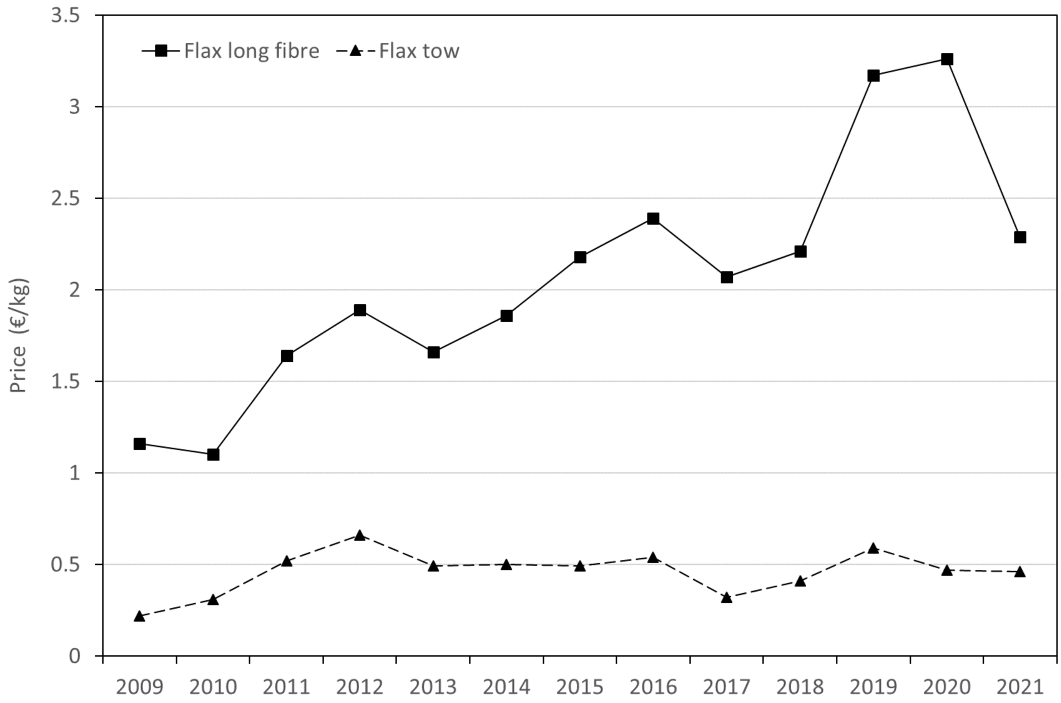

Figure 4 ***Fluctuation of long flax fibre and flax tow (short fibre, containing up to 50% shives) prices in the Netherlands over the past 10 years: Cumulative prices per June over past 12 months (Vlas en Hennep.nl).***

Insulation mats based on short flax fibres (scutching tow) are manufactured in the Netherlands.[46] Compared with mineral glass wool and rockwool based insulation mats, the insulation performance of flax mats is comparable, and indoor temperatures during summer are claimed to remain even lower due to the higher heat capacity of bio-based fibres. In this application, flax is competing with other bast fibres like jute and hemp, as well as with polymer foams like fossil based polystyrene (PS), (partly bio-based) polyurethane (PUR) and bio-based polylactic acid (PLA).
The total market for insulation materials in the Netherlands is about 23 million m^2 of mineral (and to some extent organic) wool per annum, and 28 million m^2 of polymer foam.[47] Assuming an average insulation layer thickness of 8 cm this would mean a volume of 4.1 million m^3. At an estimated density of 40 kg/m^3, this would translate into 163 kton/a, about a 60-fold of the annual flax fibre production in the Netherlands.

Prior to production into **composites**, bio-based fibres like short flax fibres (scutching tow) are often converted into non-wovens first. As large part of such composites are used by automotive industry,[48] non-woven industry as well as composite industry is mainly located 'near' automotive production in e.g. France and Germany. In these composite applications, flax competes to several other vegetable fibres like hemp, jute, sisal and wood. Nova institute reports about 15.2 kton/a of flax fibre based composites were produced in Europe in 2012;[48] at 50% fibre content this would equal 7.6 kton/a of flax. As a reference, the about 2,300 ha of flax cultivated in the Netherlands (Table 1) yield about 2.1 kton/a of short flax fibre, 30% of current European demand. In the Netherlands flax fibre based composite intermediates are converted into products at relatively small scale by e.g. NPSP; these composites are based on non-wovens, but also based on so called unidirectionally (UD) oriented flax fabrics which are imported from Belgium and France Pilot applications of flax based composites include building facades.[49] Flax based composites compete with glass fibre composites, as well as with composites based on other biofibres like hemp, jute, cotton, sisal.
Total EU market for composites (glass, carbon, organic) in 2012 was about 2,400 kton/a, of which about 260 kton/a of wood polymer composites (WPC) and about 92 kton/a of plant fibre based like cotton,

[46] https://www.isovlas.nl/
[47] https://www.rvo.nl/sites/default/files/2021/02/marktinformatie-isolatiematerialen-isolatiegas-en-hr-ketels-2010-2019.pdf
[48] https://compositesuk.co.uk/system/files/documents/WPC-NFC-Market-Study-Short-Verson%202015.pdf
[49] https://www.npsp.nl/project/biocomposiet-gevel-voor-gasontvangststation

flax, kenaf, hemp.[48] Translation to the Netherlands based on its 6% share in EU GDP in 2020,[50] volumes would be 144, 15.6 and 5.5 kton/a of total composites, WPC and plant fibre based composites, respectively, about half of which comprises the fibres, the other half comprising the polymer matrix.

Based on flax shives, **flax particle boards** ('vlasspaanplaat') have been produced since over 60 years in the Netherlands.[51] Due to their low density, 320 – 540 vs. 650 – 800 kg/m^3 for regular particle board,[52,53] these boards are claimed to have better sound and heat insulation properties than wood based particle boards,[54] and they are in particularly interesting as a core/filler material in furniture, doors, inner (separation) walls, and even heels of shoes. Also, the flax particle board have improved fire resistance compared to wood, hemp or miscanthus based boards.[55] The low density of the shives is a disadvantage for transportation; nevertheless about 70% of required shives are imported from Belgium and France. The lightweight flax board comprises insulation and rigidity characteristics in between fibre based insulation mats and 'standard' wood based particle boards.[56]
The plant in Koewacht produces about 25,000 ton/a of flax particle boards. The boards are sold in many countries, including US and Scandinavia; while only about 5% of volume is sold in the Netherlands.[55]
As a reference, about 160,000 m^3/a of board materials are produced based on Dutch round wood,[57] assuming a RWE (round wood efficiency) factor of 1.4.[58] Total consumption of board materials in the Netherlands in 2010 was 1,320,000 m^3,[59] equal to about 924,000 ton/a at an estimated density of 700 kg/m^3.

Also for **animal bedding**, significant amounts of flax shives are imported, estimated at 15-25 kton/a. Market volumes for wood shavings and dust, and cereal straw based animal bedding in the Netherlands are estimated at 200 and 350 kton/a, respectively.[60,61]

Very short flax bast fibres and flax fibres having defects, e.g. as a result of poor retting, are used for production of **'value paper'** because of its high strength and its limited sensitivity to multiple deformation:[5,62] bible paper, bank notes, passports, contracts, diploma's, and cigarette paper. In these applications, flax competes with hemp and cotton; cotton linters are fibres too short for yarn and textile production and cotton linter pulp costs up to about 2 €/kg.[62]

2.2.2 Fibre Hemp

Fibre hemp has very low THC content, the compound known for its psychoactive effect. Whereas the valorisation of fibre flax is focussing on the most valuable long bast fibre, valorisation of different components of the hemp plant is more equally distributed:
Bast fibres are used in **composites** for formed products in e.g. the automotive sector, furniture[63] and in injection moulding compounds; for **insulation mats** for building and construction; in **substrate mats** for short rotation crops in horticulture **and geotextiles** as slope protection. Nova institute reports about 4 kton/a of hemp fibre based composites were produced in Europe in 2012;[48] at 50% fibre content this would equal 2 kton/a of hemp fibre. As a reference, the about 2,000 ha of hemp cultivated in the Netherlands (Table 3) yield about 3.75 kton/a of hemp fibre. Eventually, very fine hemp fibre could be used in **textiles**; such as curtains; IKEA e.g. is using hemp in a fabric (kitchen) container.[64] The shives

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50 https://www.cbs.nl/nl-nl/nieuws/2021/28/bbp-per-inwoner-in-nederland-nog-altijd-relatief-hoog-binnen-de-eu
51 https://www.linex.nl
52 https://www.eco-logisch.nl/kennisbank-Vezelplaten-291
53 https://www.woodproducts.fi/content/particle-board
54 https://www.linex.nl/producten/vlasspaanplaat/
55 Vincent van Noten, personal communications
56 https://adoc.pub/hernieuwbare-grondstoffen-als-bouwmateriaal.html
57 Probos Bosberichten 2020 #5 and 2021 #3, https://www.probos.nl/bosberichten
58 http://www.globaltimber.org.uk/rwevolume.htm
59 Probos Bosberichten 2016 #3, https://www.probos.nl/bosberichten
60 https://platformduurzamebiobrandstoffen.nl/wp-content/uploads/2020/01/2017_DNV_GL_Rapport_Biomassabeschikbaarheid-in-Nederland_DEF.pdf
61 Estimation based on data provided by Hisfa.
62 Edwin Keijsers, personal communications.
63 https://superegoworld.com/blogs/the-world/hemp-made-furniture-from-ikea-in-the-netherlands-is-the-future
64 https://www.ikea.com/nl/en/p/nereby-container-natural-90429097/

are used as **animal bedding** for horses and small animals, and in lime bonded hemp **building panels** (Hempcrete) for lightweight non-load bearing insulating walls. DunAgro is manufacturing lime hemp panels including a construction frame.[65] Also lime hemp **building blocks or mortar** are offered.[66] An issue is the relatively slow curing of the lime binder which affects production rate.
The leaves and flower tops contain cannabinoids and terpenes, from which cannabidiol (**CBD**) can be extracted; CBD is associated with health claims[67], however it is not allowed to collect hemp flowers and leaves for this purpose in the Netherlands, whereas it is in Germany. The leaves also contain up to 18% of protein, which makes it suitable for ruminant feed. So far hemp leaves are not on the list of allowed feed constituents due to (basically not officially tested) fear of undesired effects of THC on cattle. Seeds, which may be collected when harvesting in October, are used in **food and for nutraceuticals**. However, harvesting in October would not allow retting and drying on the field in the Dutch climate.

Dedicated hemp harvesting machines allow separation of seeds, flowers & leaves, and stems. The pioneers in hemp growing and processing have developed their own equipment.[68,69] For handling purposes, the hemp stem is cut into pieces of about 60 cm length. Mowing takes place around midst of August, and after field retting the stems are collected in September, the exact moments depending on weather. The flowers and leaves are directly collected, the stems are laid on the soil in swaths (though stems are not laid in parallel like for flax) for dew retting. Dew retting is a microbial process which weakens the pectin bond between the bast fibres and the woody core of the plant. Weakening the bond facilitates separation of the bast fibres and the woody core later on. The swaths need to be turned regularly to allow smooth retting. After retting, the stems (also called straw) are collected. Like for flax, the moisture content during the retting period affects the separation process and fibre quality: low moisture content results in poor retting and poor separation of bast fibre and woody core; high moisture content will lead to lower fibre strength. The hemp straw is stored inside until further processing to separate the bast fibres from the woody core (called shives). A cheaper method is storing as dry silage.[12]
Currently, there are 2 hemp fibre processors in Groningen.

For long textile fibre, hemp stem is cut to 120 cm length, and stems are kept parallel for further conversion using flax processing lines. This method is being developed in Belgium.

Drivers, hurdles and competition
Hemp bast fibre is manufactured into **insulation mats** at a facility in (Northern) Germany.[70] Hemp is competing with other bast fibres like flax and jute, as well as with polymer foams like fossil based PS, (partly bio-based) PUR and bio-based PLA. To improve insulation performance of hemp, it may be blended with finer fibres like jute[71] or flax.
For market volumes of insulation materials, see section 2.2.1.

Hemp bast fibre based **non-wovens**/felts are produced in Groningen. These non-wovens can be used in a wide range of applications: **composites**, substrate for short rotation crops in horticulture, **geotextiles**, floor underlay and in chairs and sofas.[72] In these applications, performance is related to fibre rigidity and hemp fibre is competing with other annual fibres like the finer flax and jute, and the coarser sisal and coir. Regarding composites, hemp has a higher strength than many annual fibres, and has similar strength as flax fibre. F.i. BioPanel is using hemp reinforced PLA to make road signs.[73]
For market volumes of composites, see section 2.2.1.

[65] https://dunagrohempgroup.com/construction-projects/
[66] https://www.hempflax.com/en/applications/construction/
[67] https://www.hempflax.com/toepassingen/
[68] https://www.hempflax.com/wp-content/uploads/Hemp-Harvesting-Solutions-2020B.pdf
[69] https://dunagrohempgroup.com/agriculture/
[70] https://www.hempflax.com/en/applications/construction/hemp-insulation/
[71] https://www.thermo-hanf.de/wp-content/uploads/2021/04/210401_TDB_THERMO_HANF_COMBI_JUTE.pdf
[72] https://www.hempflax.com/en/applications/construction/felt/
[73] https://bio-panel.nl/

Total EU market for geotextiles, mainly polypropylene (PP) and polyethylene teraphthalate (PET) in 2019 was about 210 kton.[74] Assuming that geotextile consumption is proportional to GDP, while the Dutch share in EU GDP is 6% in 2020,[50] geotextile volume in the Netherlands would be 12.6 kton/a.

Hemp bast fibres are coarser than flax fibres, thus yielding coarser yarns and less flexible fabrics. As a consequence, hemp based clothes are very limited.

Hemp shives are made virtually dust-free and with claims of natural antibacterial properties, and they are much demanded for **animal (horse) bedding**.[75] Competitors are flax shives, cereal straw and saw dust.
For market volume of animal bedding, see section 2.2.1.

Lime bonded hemp shive materials, also called Hempcrete, are offered as a **lightweight non-load bearing breathable building material** with excellent (thermal) insulating properties.[76] Lime hemp can replace the insulated wall cavity and due to its breathability and relatively high heat-storing capacity, the need for heating or air conditioning systems becomes smaller. This product is commercially offered and first pilot buildings have been established.[77]

Hurds can also be used to produce low density particle board. Hemp shives based particle boards are commercially produced in the US and Canada; in Europe no examples have been encountered so far; the economic value of hemp shives for animal bedding and hempcrete is significantly higher than for particle board.

2.2.3 Miscanthus

Applications for Miscanthus are being developed and several **pilot trials** have resulted in a couple of products: **animal bedding**,[78,79] **paper**,[15,78,80,81] **filler in plastics**[82] and **concrete**[83,84,85]. The relatively low mineral content also makes Miscanthus a suitable feedstock for both **energy**[78,82,86] (heat, electricity and bioethanol).

<u>Drivers, hurdles and competition</u>
Miscanthus can reach productivity of up to about 13.6 ton/ha.a harvestable dry matter, without the use of fertiliser. This is in the same range as crops like potatoes, wheat and sugar beet. Additionally, Miscanthus also fixates about half its aboveground dry matter production in its roots,[87,88] thus contributing to soil quality. As a reference, wheat root biomass weight is about 25% or less of above ground dry matter production, 130-150 g carbon per m^2,[89] which, at a carbon:total root fraction of 0.5, translates into 2,600-3,000 kg/ha of root biomass.

Chemical pulping of Miscanthus yields the plant cell fibres of about 1 mm length, similar to hardwood fibres and shorter than softwood fibres, which can be used for **paper** production. The cell wall of

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[74] https://www.centexbel.be/sites/default/files/node/publication/eindrapportbevorderen-gebruik-kunststofrecyclaten-bouwtoepassingen.pdf
[75] https://www.hempflax.com/en/applications/animalcare/
[76] https://www.hempflax.com/en/applications/construction/hb/
https://www.hempflax.com/en/applications/construction/iso-hemp-blocks/
[77] https://dunagrohempgroup.com/hempcrete-building/
[78] https://cradlecrops.nl/olifantengras-toepassingen/
[79] https://miscanthusgroep.nl/stalstrooisel/
[80] https://www.wepa.eu/fileadmin/downloads/csr/MVO-data_NL.pdf
[81] https://bio4life.nl/vibers/
[82] https://www.vibersinside.com/index.php/grondstof-materialen/vibers-in-bioplastic
[83] http://www.struktonprefabbeton.nl/producten/green-silence-wall/
[84] https://www.acroniq.nl/
[85] https://biobound.nl/
[86] https://www.miscanthus.nl/houtpellets-energie-berekening.html
[87] https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1044768.pdf
[88] https://www.infona.pl/resource/bwmeta1.element.elsevier-dbe6fe77-6da8-36f2-8da1-4ca58da22697
[89] https://www-sciencedirect-com.ezproxy.library.wur.nl/science/article/pii/S0167880918302871

Miscanthus is thicker than of wood, which adds to paper stiffness, however, strength and flexibility are less. Miscanthus currently used in paper is not necessarily pulped; adding as small fibres to 'standard' paper pulp results in a paper sheet exhibiting a specific look while retaining printability.
Paper production and consumption in the Netherlands is about 2,500 kton/a of cellulosic fibres, excluding ca 10% of fillers.[90,91] This is about 100-fold of current Miscanthus production. It may be noted that the Netherlands has significant paper production, however, no production of pulp; paper pulp is imported from Scandinavia and Austria.

After milling, Miscanthus can be incorporated as a **filler in concrete**, and during the past years several pilot products have been delivered: concrete pavers, sound barrier walls along roads and rail tracks, and in street furniture. But also sound insulation boards like wood wool cement boards can be developed. Features claimed include sound dampening and lightweight. When mixed correctly in a concrete mixture, compression strength values of 35 MPa at a density of 1,900 kg/m3 can be obtained.[15]

Miscanthus is claimed to have significantly higher absorbing capacity compared to cereal straw and sawdust, which makes it very attractive as **animal bedding**.[78,79]
For market volume of animal bedding, see section 2.2.1.

After milling and screening of Miscanthus, very short fibres or rather particles are obtained. When using these particles in polymers they act as a filler: it makes the material more stiff, however, strength and in particular impact strength is reduced. Miscanthus **as a filler in polymers** would compete with other lignocellulosic feedstock like e.g. milled prunings or verge grass; and with mineral fillers. Value of fillers is (typically far) below 100 €/ton.

Miscanthus can be stored well in covered storage. Chips have the drawback of low bulk density (150 kg/m^3), low fuel mass in combustion chambers, and potential bridging and clogging in automated feed systems. To overcome this disadvantage, Miscanthus can be pelletized to a bulk density of about 800 kg/m^3. Energy costs of large-scale pellet production are reported to vary in the range 40 – 80 €/ton pelleted biomass at a capacity of approximately 3 t/h.[92] For **energy** purposes, Miscanthus pellets compete with wood pellets, based on e.g. prunings from regional origin, or imported from overseas.

On the other hand, pelletization decreases suitability of Miscanthus in applications like paper, animal bedding and plastics, because in these applications loose or even refined fires are required. So these applications would require low density storage and transportation of Miscanthus.

Drivers for growing Miscanthus may also be other than utilising it as a material source. E.g. at Schiphol trials have been performed to grow Miscanthus in order to reduce the number of geese around the airstrips in order to reduce incidents with geese entering jet motors causing significant damage. Also, Miscanthus can be cultivated next to bicycle lanes or railroads, etc. to sweeten the view. Eventually, the Miscanthus can be applied locally as well, e.g. in one of the applications mentioned above.

2.2.4 Reed (*Phragmites australis*)

Common reed (Phragmites australis (Cav.) Trin. ex Steud.) is growing in several regions of the Netherlands, mostly in nature conservation areas. Main organisations managing reed include Natuurmonumenten, Water management boards and other owners, not being nature management organizations. Currently the demand for reed in the Netherlands is small. For **thatching**, one year old reed is harvested in January-April,[93] however the market share is declining, due to inadequate quality. In order to increase biodiversity, nature management organisations cut the reed once in about 2-3 years (multi-annual reed) in the period December up to 15th of March,[94] a.o. to prevent willow and alder to

[90] https://www.bosenhoutcijfers.nl/de-houtmarkt/houtproducten/papier/
[91] https://www.gelderland.nl/bestanden/Documenten/Gelderland/06Werk-en-ondernemen/191125_Circulaire_Atlas_Gelderland.pdf
[92] https://www.app.panacea-h2020.eu/crop/15
[93] https://www.riet.com/
[94] https://www.natuurmonumenten.nl/natuurgebieden/de-wieden/nieuws/overjarig-riet-van-grote-waarde

grow. Harvesting of multi-annual reed, however, affects reed quality. After the growing season, the reed dies, and during subsequent year(s) the reed deteriorates as a result of the weather and is not suitable anymore for thatching. Also, other plants can be present in between the reed. Currently, the multi-annual reed is mainly ploughed under the soil (**soil fertilizer**) and to some extent (about 5%) used for **animal bedding** by biological farmers. In some areas, the reed is disposed through **compost**ing, which involves a cost for the nature manager.[24]

Drivers, hurdles and competition

Large part of the reed growing areas in the Netherlands is managed to support bird life (breeding) in particular and biodiversity in general. This reed is harvested every 2-3 years. Driving force to utilise the multi-annual reed is to reduce costs for disposing off the material while increasing circularity. Disposal for composting costs about 30-40 €/ton, while bringing to a farmer only costs a few €/ton.[24]

Due to the low level of fertilizers in nature conservation areas, rivers and canals, the reed is more brittle and bent than required for thatching.[24] As a consequence, a large part of the high quality reed required for **thatching** in the Netherlands is imported, about 80%, mainly from China. Even at the relatively high transportation costs in 2021. About 20% of thatching reed is still grown in the Netherlands, equal to about 800,000 bushels or 2.4 kton of reed.[95] Annually, about 3,000 building and farm houses are thatched with a total of 12,000 ton reed.[96] Thus, about 4.0 ton of reed is used for thatching one building. For comparison, in 2019 the amount of houses in the Netherlands amounted 7.8 million,[97] with 150 thousand houses having a thatched roof.[96]

2.2.5 Straw

Straw is a residual stream from cereal cultivation. However, it is a residual stream which is used for a long time now. Straw is used as **animal bedding** in livestock farming, for **protecting tulip bulbs** against frost and **protecting strawberries** (what's in a name) from deterioration when touching the soil. Organic straw is in demand in organic **mushroom cultivation**. When (organic) straw is used in (organic) mushroom cultivation, this produces spent mushroom substrate called **champost**, an A-fertilizer with which the organic grower can increase the organic matter content in the soil. Another part of the straw is chopped during harvest and **worked into the soil to increase the organic matter content**. Furthermore, straw is utilised as an **insulation material** in the construction sector. To date about 150 houses in the Netherlands comprise straw panels or bales for insulation purposes.[98] To reduce transportation and storage costs, straw is often baled to increase bulk density.

Drivers, hurdles and competition

Price fluctuations for cereal straw may be as high as a factor of 2 within one year.[99] This may be related to the seasonal availability of straw, the wide range of applications, and the limited transportation range of the relatively low density material. Nevertheless, straw is imported from France and eastern Germany.

For **animal bedding**, straw competes with sawdust (side product of wood processing industry), with Miscanthus (a dedicated crop) and hemp shives. Due to its waxy surface, cereal straw has lower absorbing capacity compared to its competitors. At the same time, straw retains its structure which is an advantage in certain livestock farming systems.

Market volume for cereal straw based animal bedding in the Netherlands is about 350 kton/a DM.[61] Large part is used for horse bedding: 450,000 horses,[100] at 1.5 kg/horse.day.[101]

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95 Corné and Kees Daemen, personal communications.

96 NOS, Rietdekkers schrikken van prijsexplosie, 24 august 2021, https://nos.nl/artikel/2394922-rietdekkers-schrikken-van-prijsexplosie-het-vervoer-is-onbetaalbaar-geworden

97 https://www.clo.nl/indicatoren/nl2166-woningvoorraad-naar-bouwjaar-en-woningtype

98 https://strobouw.nl/

99 https://www.nieuweoogst.nl/nieuws/2018/07/28/schaarste-aan-stro-doet-prijzen-stijgen

100 https://www.knhs.nl/media/11389/nederland-paardenland_web-v2.pdf

101 https://doi.org/10.1016/j.wasman.2010.04.016. Next reference refers to 10 kg/day: https://www.hertenhof.nl/tarieven/

Cereal straw may also be used as **feed** for ruminants. Market volumes for (cereal) straw based feed in the Netherlands is estimated at 130 kton/a DM.[102]

The **insulation** performance of straw is lower compared to other lignocellulosic materials like flax, hemp and wood fibres.[103] However, it is also cheaper and the lower moisture absorption capacity of straw may give an advantage when moist conditions in a building may pose an issue. If building space is large enough to allow e.g. 50 cm thick facade walls, straw may be a very suitable insulation material.
For market volumes of insulation materials, see section 2.2.1.

Protecting strawberries from wet soil is also based on the low moisture content of straw, in particular at the outer surface as a result of the waxy layer. For **tulip bulb cultivation**, protection is required throughout the entire winter season, and the lower moisture absorbing capacity of straw gives an advantage over other lignocellulosic materials which are more hygroscopic and therefore more prone to degradation and losing their protective capacity against frost.
In the Netherlands about 27,000 ha of flower bulbs are cultivated annually.[104] Considering that about 4–14 ton/ha of straw is applied for different type of flowers,[105,106] total straw consumption by the Dutch bulb sector is estimated at 137 kton/a DM. Hisfa (Dutch Association of Traders in Straw, Forages and Related Products) estimates that a volume of about 100 kton/a DM of straw is applied in bulb sector. At the end of winter, about 85% of the straw brought onto the bulb bed is removed again.[107]
For protecting strawberries, Hisfa estimates that about 67 kton/a DM is used. Considering that about 10 ton/ha is used for 1000 ha open field cultivation and 5 ton/ha for 500 ha strawberries in greenhouses, about 11.25 kton/a DM would be used.[108,109] The large difference is difficult to explain.

Straw has been used as a **substrate for mushroom** production for a long time. Different calculations and consultation with the sector have resulted in an estimated use of 217 kton/a DM straw for mushroom production.[110] Main The bulk of the straw used for mushroom production has been used for (horse) animal bedding first, which means that the straw has been used twice before it can be used as fertilizer and soil improver. About 50% of horse manure-straw for mushroom production is imported.[110] Main competitor for straw in substrate is hardwood sawdust, but also other materials are used, in particular in the home growing sector: grain or seed hulls, coffee grounds, composted manure, etc.[111]

2.2.6 Verge grass

Nature and verge grass becomes available mainly as a result of management of nature management areas, floodplains, verges, banks, etc. Nature reserve areas are mowed after the breeding season, in August/September. When mowed, nature grass is mainly brought to farmers to plough it under as **soil improver**.[32] Floodplains are also **grazed** by livestock during spring and summer seasons. Clippings from ditches and banks managed by Water Boards are mainly left on the ground, about 25-50% is disposed via **compost**ing or ploughed under the soil by farmers.[22] When it is clean, nature grass may also be utilised as animal feed and as co-feedstock for biogas production.[60] The vast majority of verge grass is composted; a small amount is used for pilot trials to develop potentially new outlets such as paper and board, insulation material and composites, and eventually feed for ruminants.[112] Regulations, defining verge grass as waste, so far block material use of verge grass biofeedstock.[113] In the

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[102] Estimation based on data provided by Hisfa and SecureFeed.
[103] https://www.mdpi.com/2075-5309/7/1/11
[104] https://longreads.cbs.nl/nederland-in-cijfers-2020/welke-bloembollen-telen-we-het-meest/#:~:text=Het%20bloembollenareaal%20groeide%20van%2022,keer%20zoveel%20als%20in%202000.
[105] https://library.wur.nl/WebQuery/groenekennis/1795524
[106] https://www.akkerwijzer.nl/artikel/127788-fotoreportage-bloembollen-tegen-vorst-beschermen-met-strodeken/#:~:text=De%20tulpen%20en%20narcissen%20groeien,zand%20van%20de%20bollenvelden%20wegstuift.
[107] https://edepot.wur.nl/294191
[108] https://www.nieuweoogst.nl/nieuws/2021/06/15/nederlanders-eten-steeds-meer-aardbeien
[109] https://edepot.wur.nl/170085
[110] Pieter Vervoort, personal communications.
[111] https://learn.freshcap.com/growing/understanding-mushrooms-substrates/
[112] Jan IJzerman, personal communications.
[113] Yuri Wolf, personal communications.

Netherlands, approximately 480 kton/a of 'wet' roadside grass at an estimated dry matter content of 25% was composted in 2013.[114]

Drivers, hurdles and competition

Till recently, verge grass was considered waste. Volume was minimised by e.g. mowing management. Because verge grass is currently legally considered waste, it may not be utilised in products, with the exception of some pilot trials. A technical challenge is to collect grass without adhering sand, which is harmful to especially mechanical processing equipment.

2.2.7 Common Nettle (*Urtica dioica*)

In the Netherlands, the company Brennels worked on developing nettle fibres as an alternative for cotton in the 2000s, but in the end failed.[115] In particular, low conversion yields were mentioned to be an issue. Also abroad some initiatives on nettle based fashion have been developed.[116] Other brands abroad are still working with nettle.[117]

2.2.8 Conclusions

Each of the herbaceous feedstocks find their way in several and a diverse range of applications. Cereal straw, reed and verge grass are underutilised from a circular economy perspective. Over 50% of straw is left on the field and ploughed under, whereas it could have been used for animal bedding or flower bulb and strawberry protection first, and or which a similar amount of straw is imported. Verge grass is considered waste as a result of regulations which limit applications. Reed and verge grass are mainly ploughed under or composted.

2.3 Matching current supply and demand

Production and application of herbaceous crops and residues in the Netherland was addressed in sections 2.1 and 2.2. However, not all herbaceous crops and residues that are converted into (half) products in the Netherlands are also harvested domestically. By the same token, not all products that contain herbaceous materials are produced in the Netherlands. Consequently, the current domestic supply and demand is matched by import.

The question is now whether there are opportunities to produce some of the additionally needed herbaceous feedstock nationally or regionally instead of importing it. Also, what options are available for local processing of crops that are exported? Therefore, this paragraph focuses on import and export in order to get insights in domestic production compared to domestic demand.

Flax

Import and export volumes and values of retted flax straw and scutched flax fibres are presented in Table 8. It is important to distinguish the crop (flax straw) and its components: the flax (bast) fibres and the shives (core fibres). Retted flax straw is mainly imported, whereas hacking tow is mainly exported, and scutched flax is both imported and exported. Both production, import and export exhibit large variations during the course of three consecutive years. **Import of flax straw** is the result of a combination of two factors: 1) Importing flax straw from France can compete with local production in the Netherlands,[5] where flax production faces fierce competition from other, more profitable crops (also taking into account high land use prices in the Netherlands); 2) Scutching the straw into fibres and shives is still economically interesting. Import numbers, however, vary by a factor 3 over three years:

[114] https://www.rvo.nl/subsidies-regelingen/projecten/winning-van-hoogwaardige-vezels-uit-bermgras-voor-productie-van-biocomposieten

[115] https://decorrespondent.nl/9053/deze-multimiljonair-wilde-met-brandnetels-de-wereld-verbeteren-maar-legde-het-af-tegen-katoen/3647161451054-b697d54d

[116] https://fashionunited.nl/nieuws/mode/duurzame-textiel-innovaties-brandnetelvezels/2017090429480

[117] SwicoFil, a Swiss supplier of nettle fibers and yarns, https://www.swicofil.com/commerce/products/nettle/271/introduction

30 kton in 2018, 21 kton in 2019, and 67 kton in 2020. And in absolute values, import numbers are much higher than national production: ca. 21-67 kton/a vs. 7-13 kton/a (Table 1). The table and CBS data are not complete, however. Next to scutched fibre, scutching yields scutching tow; and next to hackling tow, hackling yields hackled fibre. And considering that flax straw yields about 30% of long and short fibre in total (section 2.2.1), the export of hackled fibre and scutching tow must be high (Table 9). It may be reasonably assumed that stock is not increasing that much for three consecutive years.

Since the Netherlands do not have a (flax) spinning industry, partially due to high labour costs, basically all (long, scutched) **flax fibres are exported**: "80% of sales of long flax fibre are to countries outside the EU, with China as its main destination. In addition, India emerges as a new market." [7,8] The remaining 20% is exported to European countries like Poland, Lithuania, France and Italy. The short flax fibres remain in Europe and find outlet in technical applications like insulation mats and composites for automotive industry. The shives find regional use in animal bedding and flax particle boards.[5,7] On top of that, the scutched fibre is also imported at high volumes.

The CBS price data for scutched flax seem rather puzzling and hard to explain: export value in €/ton in 2020 was much lower than import value; and the values in 2019 are significantly lower than data presented by Vlas en Hennep.nl (Figure 4).

As mentioned in section 2.2.1, in France a flax spinning mill with a capacity of about 1,000 ton/a is being established (with governmental support);[5] the fact that this is about half the volume of long flax fibres produced in the Netherlands, raises the question whether a flax spinning mill in the Netherlands could be feasible.

Hemp

Import and export volumes and values of retted hemp straw and processed (scutched) hemp fibres are presented in Table 10. It is important to distinguish the crop (hemp straw) and its constituents: the hemp (bast) fibres and the shives (core fibres). Hemp is mainly exported, both as hemp straw as well as processed hemp (fibre).

Miscanthus

Miscanthus is relatively new as a production crop. Applications are being developed and in the pilot or niche phase. Consequently production volumes are still small, and matching supply and demand focusses on anticipating future opportunities.

Reed

Whereas reed production in the Netherlands is a multiple of reed used for thatching, nearly 100 kton/a (section 2.1.4) vs. 22 kton/a (section 2.2.4), 80% of thatching reed is imported due to quality differences (imported reed has a superior quality) (section 2.2.4). In the Netherlands, reed mainly grows in nature reserve areas and along waterways, where preferred environmental conditions do not match with conditions to obtain strong and straight reed strands. The lower quality (multi annual) reed produced in the Netherlands has been disposed via composting or burning for a long period of time. In order to reduce composting costs and to avoid unwanted burning, reed has recently found outlets such as ploughing under as soil improver or as animal bedding to a small extent. Sections 4.1.3, 4.1.4 and 4.1.8 will address further options for reed based bio-based materials.

Table 8 Flax import and export figures for the Netherlands (2018-2020, CBS data),[118] calculated value of traded products, and production data for the Netherlands (CBS).[6]

	Year	EU and non-EU	Import value (1,000 €)	Import quantity (ton *as is*)	Import value per quantity (€/ton *as is*)	Export value (1,000 €)	Export quantity (ton *as is*)	Export value per quantity (€/ton *as is*)	Production in NL (ton *as is*)
Retted flax straw	2018	EU	2,222	30,129	74	0	0.3		8,783
Retted flax straw	2018	Non-EU	12	46	261	-	-		
Retted flax straw	2019	EU	998	20,900	48	270	3,751	72	13,356
Retted flax straw	2019	Non-EU	10	32	313	0	0.3		
Retted flax straw	2020	EU	4,272	67,007	64	245	3,798	65	7,353
Retted flax straw	2020	Non-EU	10	39	256	-	-		
Scutched flax	2018	EU	2,682	3,073	873	5,794	4,540	1,276	
Scutched flax	2018	Non-EU	-	-	-	70	22	3,182	
Scutched flax	2019	EU	3,171	2,355	1,346	6,392	3,982	1,605	
Scutched flax	2019	Non-EU	0	0	-	941	261	3,605	
Scutched flax	2020	EU	3,414	1,030	3,315	4,887	3,549	1,377	
Scutched flax	2020	Non-EU	7	0.3	-	795	272	2,923	
Hackling tow	2018	EU	586	1,777	330	516	3,016	171	
Hackling tow	2018	Non-EU	-	-	-	0	2		
Hackling tow	2019	EU	334	952	351	377	3,658	103	
Hackling tow	2019	Non-EU	-	-	-	3	14	214	
Hackling tow	2020	EU	526	2,682	196	353	3,829	92	
Hackling tow	2020	Non-EU	1	8	-	3	3		

Table 9 Balance for flax production, fibre production, fibre export and stock; based on Table 8.

Year	Net flax straw import & production (ton *as is*; table 8)	Potential fibre production * (ton *as is*)	Net export of scutched fibre & hackling tow (ton *as is*; table 8)	Balance (export of hackled fibre & scutching tow + increased stock) (ton *as is*)
2018	38,958	11,687	2,730	8,957
2019	30,537	9,161	4,608	4,553
2020	70,601	21,180	3,933	17,248

* At 30 wt.% fibre in straw.

[118] https://opendata.cbs.nl/#/CBS/nl/dataset/81262ned/table?dl=5F2B4

Table 10 ***Hemp import and export figures for the Netherlands (2018-2020, CBS data),[119] calculated value of traded products, and production data for the Netherlands (CBS).[11]***

	Year	EU and non-EU	Import value (1,000 €)	Import quantity (ton *as is*)	Import value per quantity (€/ton *as is*)	Export value (1,000 €)	Export quantity (ton *as is*)	Export value per quantity (€/ton *as is*)	Production in NL (ton *as is*)
Retted hemp straw	2018	EU	35	58	603	2,769	4,706	588	15,323
Retted hemp straw	2018	Non-EU	5	15	333	213	362	588	
Retted hemp straw	2019	EU	-	-		3,992	6,628	602	14,074
Retted hemp straw	2019	Non-EU	-	-		264	595	444	
Retted hemp straw	2020	EU	1,219	1,263	965	10,765	9,429	1142	12,786
Retted hemp straw	2020	Non-EU	12	13	923	2,483	1,394	1781	
Processed hemp	2018	EU	8	6	1333	2,700	3,579	754	
Processed hemp	2018	Non-EU	3	0.7	4286	299	168	1780	
Processed hemp	2019	EU	1,277	885	1443	1,500	3,413	439	
Processed hemp	2019	Non-EU	14	3.8	3684	313	280	1118	
Processed hemp	2020	EU	13	2.9	4483	9	3.5	2571	
Processed hemp	2020	Non-EU	26	3.5	7429	586	954	614	

119 https://opendata.cbs.nl/#/CBS/nl/dataset/81262ned/table?dl=5F394

Straw

Import and export volumes and values of straw for the Netherlands are presented in Table 11. The Netherlands is a net importer of cereal straw, mainly due to the intensive agricultural and horticultural systems and the horse sector. In 2020, France exported cereal straw & husk to the Netherlands for a total value of 8.75 Mio US$;[120] at a price of 100 US$/ton, this would mean 87.5 kton imports from France alone. Both the import and export of straw currently have a high value, 130 – 167 €/ton (import value) versus 247 – 293 €/ton (export value).

Table 11 ***Cereal straw import and export figures for the Netherlands, including chaff (2017-2020, CBS data)[121] and calculated value of traded products.***

	Import value (1,000 €)	Import quantity (ton *as is*)	Calculated value import (€/ton *as is*)	Export value (1,000 €)	Export quantity (ton *as is*)	Calculated value export (€/ton *as is*)
2017	31,997	246,096	130	12,701	43,398	293
2018	44,784	273,660	164	17,071	63,385	269
2019	55,253	339,668	163	17,665	71,448	247
2020	77,945	466,045	167	13,948	49,585	281

Verge grass

Even though nature grass and verge grass are currently used as soil improver or even as feed, grass is mainly regarded as an unwanted product which amount is preferably minimised by e.g. mowing as little as possible, and to leave the clippings on the ground. The little demanded feedstocks of nature grass, verge grass and reed offer an underutilised potential, which may provide opportunities for regional conversion into material and products prior to returning to the soil (See sections 4.1.2, 4.1.3 and 4.1.8). If indeed verge grass changes from a waste to a valuable raw material, the view on mowing versus harvesting may also change.

2.3.1 Conclusions

Import and export of herbaceous crops stems from efforts to minimize production costs, historical investment decisions, intensive local agricultural practices and horticultural systems, and increasing efforts in the Netherlands to protect nature at the expense of crop yields. Dutch farmers plough under cereal straw at large scale, while the demand for various applications is large. In total, the amounts ploughed under and imported are of the same order of magnitude. Cultivation of flax is cheaper in France than in the Netherlands. Moreover, due to the increasing demand for linen, importing flax straw from areas relatively far away is still profitable for flax processors in the Netherlands. Reed is mainly grown in the nature, where the focus is on protecting and improving biodiversity and not on harvesting quality and yield. As a result, the quality of this reed is generally insufficient for thatching. Therefore, only a small part of the demand for high quality reed is covered by domestically produced reed, the remainder is matched by imports.

Simultaneously, a substantial share of the Dutch herbaceous crops and products is exported. The Netherlands is a net exporter of flax hacking tow, retted hemp straw, and processed hemp. Scutched flax is both imported and exported, but there is a net export, as flax fibres are processed into yarns abroad, mainly in Asia. Another reason to export is the requirement of some lean manufacturing industries like the automotive sector to have their direct suppliers of half products to be near their OEM factories (e.g. hemp fibre); and the fact that highest quality crops can be grown domestically, while further processing is performed abroad due to lower wages (e.g. flax). Alternatively, the fact that the number of processing facilities for some crops is limited in the Netherlands may push the primary production of these crops more towards countries with more processing facilities.

[120] https://trendeconomy.com/data/h2/France/1213
[121] https://opendata.cbs.nl/statline/#/CBS/nl/dataset/81260ned/table?dl=5E53F

3 Circularity

3.1 Circular economy agendas and ambitions

The description of the policies at European, National and provincial level may lead to the conclusion that the strategic frameworks are becoming more favourable for the use and valorization of bio-resources, especially as the circular economy is becoming the leading direction and concept for Europe, the National government in the Netherlands and for the Dutch provinces, among them the province of Gelderland. In this sense there is direction and alignment at the strategic level. The challenge now is to bring the missions into practice, to realize the **circular bio-economy**, and to create and implement new perspectives for regional economies in balance with the planetary boundaries. Europe has been leading in developing ambitious strategies and programs on bio-economy. Europe has developed large knowledge and innovation programs to invest in expert knowledge on technologies on the potential of various forms of biomass and the valorisation in different kind of production lines. The Bio-economy Stakeholder Panel, consisting of stakeholders from universities, industries, civil society and regions, have concluded that more attention should be given at "*putting the expertise in practice, bringing the ideas and pilots further into full scale investments* and to *reach out for the civil society"* (Bioeconomy Stakeholder Panel, 2017)[122]. Regional partners are being challenged to develop innovative solutions for implementation at the regional level and to discover their specializations and opportunities based on bio-resources, in contributing to developing a circular bio-economy.

3.1.1 EU level

Green deal – EU Growth Strategy

The **Green Deal** (2019)[123] is an integral part of this Commission's strategy to implement the United Nation's 2030 Agenda and the sustainable development goals (climate, biodiversity loss). The European Green Deal is a response to climate and environmental-related challenges. It is a new **growth strategy** that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. The regional level is important for Europe, as regions will be able to bring together optimally the resources for Mission driven innovations. It will be important to empower local and regional authorities and to provide them with direct funds to deliver the priority investments citizens need. The EU Green Deal is an important Frameworks for regional development. The Committee of the Regions has developed an initiative in which the Green Deal is being elaborated at the local level[124] The European Green Deal is a driver of new economic opportunities. Many European firms are motivated and supported to cut their carbon footprint, for example by discovering cleaner technologies to be applied by European firms. They understand that there are planetary boundaries. They also know that if they discover the sustainable solutions of tomorrow, this will give them first mover advantage.

Regional Policies and strategies

Regions are challenged to discover their potential to contribute to EU missions, by focusing and optimizing their assets and resources. From regional policies and funds (EFRO), EU regions are requested to make strategic choices to invest in specific sectors or challenges, which fit to the characteristics and qualities of their economies and environment, and which give the regions comparative advantages to other regions (Regional Innovation Strategy Smart Specialization, RIS3).

<u>*Response by regions*</u>

Many regions have mentioned the bio-economy as one of the main drivers for regional innovation and growth. Within the bio-economy many routes are possible, depending on the combination of availability

[122] Bioeconomy Stakeholder Panel, 2017; Manifesto. Brussel
[123] Europese Commissie 2019. Mededeling. Brussel
[124] https://cor.europa.eu/en/engage/Pages/green-deal.aspx

and components of the regional biomass and the existing industries for valorisation. But regions also suffer with uncertainties. Many regions are not fully aware of their potentials and it seems to be difficult to connect the value chain partners. Furthermore, collaboration within quadruple helix partner networks in setting strategic choices and the priorities for the allocation of the capacities, knowledge and the financial means to implement the strategy, is difficult. Support, for example from intermediate organizations as clusters or development agencies, is often needed.

EU Bio-economy

The 2018 update of the **Bioeconomy Strategy**[125] aims to accelerate the deployment of a sustainable European bioeconomy with 14 concrete measures (see annex A) based on three key priorities:

1. Strengthen and scale up the bio-based sectors, unlock investments and markets
2. Deploy local bioeconomies rapidly across the whole of Europe
3. Understand the ecological boundaries of the bioeconomy

The transition towards a circular bio-economy will also take place at regional level. Transitions demand for a systemic approach, which will address Bio-based innovations including in farming, **to produce bio-resources and building blocks** with involvement and **increased benefits for primary producers**. And, new opportunities arising for the forestry sector in view of replacing non-sustainable raw materials in construction, packaging with bio-based materials and for providing more sustainable innovations in sectors such as forestry-based textiles, furniture and chemicals. A systemic approach is conditional for a successful uptake, but it is also difficult to set all required conditions. Some regions perform better than others. The EU gives directions towards the developments and support, based on insights gained from Research programs and projects, good practices, advises from experts and specialists, and from exchange on various panels and conferences. The EC aligns the different strategies and regulations among the DG's. The EU asks members states to align also their strategies and policies. The EU is actively searching for drivers for implementation of the bioeconomy. Insight is that just technology developments are insufficient. Also environment, economy and society are relevant. For the EU, the regional policy is focussing on developing place-based innovation strategies for growth and wellbeing, due to landscape characteristics and social-cultural identities. The region is a suitable scale for applying an integrated approach of socio-economic, environmental and technological innovations, as well as the suitable level for mobilising different relevant quadruple helix partners. The EU offers programs, guidelines, strategies, networks and funding for regions to implement their strategies. Understanding the underling concepts and the ability to translate these to the specific regional context as well physical as organizational, but also cultural, is key factor for successful bioeconomy uptake. It starts with the directions and (smart) specializations, and the collaborative approaches, which is supported by guidelines of Joint Research Centers (JRC) or other service providers. When the directions are clear and common, there are several opportunities for attracting funding and investments, for research and innovations and for supporting new biobased value chain and new business development, and investments in supporting infrastructures and facilities. Then the EU frameworks can become very concrete. But regions themselves should create the conditions.

EU Circular Economy

The European Commission has adopted a **Circular Economy Action Plan** (CEAP, 2018)[126] - one of the main blocks of the European Green Deal (see paragraph above). This Plan announces initiatives along the entire life cycle of products, targeting for example their design, promoting circular economy processes, fostering sustainable consumption, and aiming to ensure that the resources used are kept in the EU economy for as long as possible.

Achieving a climate neutral and circular economy requires the full mobilization of industry. **It takes 25 years** – a generation **– to transform an industrial sector and all the value chains**. The CEAP has a focus in particular on resource-intensive sectors such as textiles, construction, electronics and plastics. Promoting new forms of **collaboration with industry** and **investments in strategic value chains** are essential. The CEAP will include a 'sustainable products' policy to support the circular design of all

[125] European Commission (2018). A new bioeconomy strategy for a sustainable Europe. Brussel.
[126] European Commission (2020) New Circular Action Plan, factsheet (March 2020). ISBN 978-92-76-17035-8 doi:10.2775/855540 NA-03-20-127-EN-C.

products based on a common methodology and principles. It will prioritise reducing and reusing materials before recycling them. It will foster new business models and set minimum requirements to prevent environmentally harmful products from being placed on the EU market. This will be supported by the EPR, the Extended Producer Responsibility Directive, a policy tool that extends the producer's financial and/or operational responsibility for a product to include the management of the post-consumer stage, in order to help meet national or EU recycling and recovery targets. The EPR will be implemented in 2023.

The **circular economy concept** is becoming a central component in local and regional economies, which have a suitable scale for closing resources loops, creating sustainable circular ecosystems and designing community-based participatory schemes. An increasing number of cities, regions, industries and businesses are engaged in testing and improving circularity in their territories, supported by EU Horizon Europe Framework.

The CEAP is being elaborated in different ways, for example by the formulation of a EU Textile Strategy [127](2022), relevant for Dutch initiatives on circular economy solutions for the textile sector, collection and re-use of waste and the growth of bio-resources.

3.1.2 Dutch policies

The main National Frameworks for the Biobased and the Circular Economy are **National Climate Agreement** and the **Circular Economy Framework 2050**.

The last decade there still was demand for using biomass as a renewable energy source as a transition fuel. Currently[128] it is decided to "*reduce this practice as quickly as possible"* and to optimize the use of biomass for higher applications of valorization. From 2030 it is important to use biomass primarily for high-value applications such as: feedstocks for **biochemicals and biomaterials,** in order to move away from the dependency of fossil resources, and to develop alternative renewable resources.

The aim is to **increase the supply of sustainable biomass** as much as possible. The Dutch government is aiming at doubling national production.[129] An adequate food supply and preservation of soil fertility and quality of soil, water and air are important preconditions for the development of the biobased economy. In addition to increasing the sustainable supply of biomass, major challenges are the improvement of conversion techniques and market change to give biobased raw materials and energy preference over 'fossil' applications.[130] Growing biomass for non-food applications is difficult in the Netherlands, as food production is main priority. Focus is on using the agricultural residues, and other organic waste and rest materials, to stimulate growing biomass at waste land or land where food production is not possible. Furthermore to improve the collection of (also non bio-based like textiles and plastics) residue streams towards new commodities and to optimize the utilization of biomass and components. To discover new applications of biomass in a broad pallet of biochemicals and biomaterials, investments should take place in new production capacity, in research and development and in new technologies: first of a kind fabrics, bio-refineries, alternative protein production.[131] Also stimulated is the increase of bio-resources, as the volume of forests, which is stated in the new **Bossenstrategie** (2020)[132], as part of the National Climate Agreement. The objective is to focus on planting 37,000 ha with forest in order to increase the capture of CO_2, in combination with biodiversity objectives and raising production of renewable resources for high value biobased products, for example for use of wood in

[127] https://environment.ec.europa.eu/strategy/textiles-strategy_en
[128] Coalition Agreement Dutch Government; 15122021
[129] Ministerie van Economische Zaken en Klimaat (2015). Biomassa 2030. Strategische visie voor de inzet van biomassa op weg naar 2030
[130] Beschikbaarheid en toepassingsmogelijkheden van duurzame biomassa. Verslag van een zoektocht naar gedeelde feiten en opvattingen. PBL, 2020.
[131] Ministerie van Economische Zaken en Klimaat (2015). Biomassa 2030. Strategische visie voor de inzet van biomassa op weg naar 2030.
[132] Ministerie van LNV (2020). Nieuwe Bossenstrategie en beleidsagenda 2030.

construction sector. Growth of herbaceous crops may be interesting when stimulating agro-forestry. There are regional variations in opportunities for growing more biomass and herbaceous.

The Biomass policy plan is actually leading to a strategy to enhance the use of **bio-resources** instead of fossil resources, important for as well the climate agreement as well for the implementation of the circular economy.[133] The SER came to the conclusion that within Europe sufficient bio resources are available until 2030 to fulfill the need in the Netherlands. Towards 2050 the demand will increase. Much demand relies on the production of sugar beets, green protein and fibers production. In order to arrive to sustainable bio-resources production and to safeguard the volumes needed for the transition, the government has stated that increase of bio-resources at national level is needed. In the Route map for bio-resources there is attention for increasing growth of herbaceous, replacing grass land or other crops, depending on the demand from the different sectors.[134]

Agriculture

The Dutch Minister of Agriculture, Nature and Food is exploring the concept or **Circular Farming** (2018).[135] This is taking place at demonstration farms expressing the different agricultural systems in the different production regions, within research and innovation programs and by bringing together all kinds of experts at conferences, to elaborate the concepts of circular farming. Relevant for the increase of biobased production is the initiative of the Ministry of Agriculture, nature and Food Quality (LNV) to assess possibilities to increase the biomass production in the Netherlands, based on potential of different landscape and soil characteristics. Focus on arable farming (sugar beets), 2nd generation biomass (Miscanthus, other grasses), and wood. Is also relevant for the province of Gelderland: investigate how to increase the 2nd generation of biomass and the wood production in Gelderland, where, what role is foreseen for agricultural sector, and how to grow resources for applications in construction industry.

Circular Economy

The **Circular Economy Plan by 2050** (2016)[136] has a focus on reducing primary raw material use, reduce imports, replace fossil source with renewable sources), Construction is one of the main sectors (2018).[137] Relevant actions are:

- All public procurement based on circular economy
- Reduction of CO_2 emissions in construction
- Decision about Materials passport for buildings
- Subsidy for development of circular business models
- Monitoring and measurement of circularity
- Circular building will be integrated in Educational programs
- Knowledge institute for circular building awareness raising

Regional development

Broad economic prosperity and well-being (Brede Welvaart) is an upcoming frame for economic development in Dutch regions. This concept entails as well the economic, ecologic as the social aspects of welfare. It deals about the well-being of people and entails all what people find important and valuable for living a good life. As people live their lives mainly in regional daily systems, the regional conditions are relevant for the inhabitants. The Dutch Parliament is willing to integrate this concept in new regional policies: The power of the region ("de kracht van de regio"),[138] and with signing contracts with several Dutch regions: "**Region deals**", regional programs and large budgets on prosperity and well-being, with a focus to invest commonly in regional implementation agenda's, as well economic (regional growth potential), social as well as ecological (physical living environment) and with the transition to sustainable and circular societies. Within these Region Deals governments, private sector, knowledge institutes and civil society collaborate on regional problems, well-being, smart specializations and mission driven innovations.

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[133] Kamerbrief over duurzaamheidskader biogrondstoffen, 16 oktober 2020.
[134] https://www.klimaatakkoord.nl/documenten/publicaties/2020/06/29/routekaart-nationalebiogrondstoffen
[135] Ministerie van Landbouw, Natuur en Voedselkwaliteit (2018); Visie Landbouw, Natuur en Voedsel: Waardevol en Verbonden.
[136] Government of the Netherlands (2016). A Circular Economy in the Netherlands by 2050.
[137] Transitieagenda Circulaire Bouweconomie, (2018-2023).
[138] https://www.krachtvanderegio.nl/

In Gelderland, two Region Deals between National government and the region have been concluded. The Achterhoek is aiming to become the frontrunner in circular farming; agriculture is working nature-inclusive, climate neutral and with new business models. Herbaceous crops and residues could be part of this new concept, which will grow efficiently on rest streams from livestock and dairy farming, and will lead to valuable fibers for local valorization in small industries and crafts The region of Food Valley is working on circular economy and protein transition. It is the question if growing herbaceous might be part of this transition.

In 2020 the SER has formulated an ambition for the National Government, among others to three sustainability objectives and objectives regarding the concept of broad well-being (brede welvaart):

- replace use of fossil fuels by renewable bio-based resources which will lead to decrease of CO_2 emissions (climate transition);
- the development of a circular economy, when carbon is being stored in materials and products for a long period (transition to circular economy);
- the development of a circular agriculture, when bio resources are being used for soil improvement (agricultural transition).

These three transitions are relevant for future perspectives for Dutch economies. Important is to valorize to high added value, which means focus on multiple use of the different components of the bio-resources first, prior to using for energy. We are currently in the bridging period between fossil based and circular biobased economy. The SER is concluding that the public sector should make strategic choices for the allocation of bio-resources, to be supported by policies and business models. Also attention should be paid to the negative aspects, people who are losing their shares and jobs, with decreasing incomes. The SER has proposed a framework for sustainability (value chain, economy, social and ecological aspects) and a framework with cascading principles.

3.1.3 Province of Gelderland

In the former RIS3 (2014-2020)[139] the strengths of East Netherlands are described as following: *originate from the knowledge areas such as microbiology, sustainable and green chemistry, life cycle analysis, ecology, biobased materials & products and more specifically from research into pyrolysis and biomass, leading to new chains and techniques for a more sustainable economy (circular economy)*. The province of Gelderland clearly focuses on three bioeconomy routes as drivers for regional innovation and growth: *valorisation of manure, vegetable proteins and lignocellulose*. Being the countries most wooded province and hosting a significant paper mill industry, innovations in fibre applications of wood and fibre-rich crops and residues are a logical and very promising choice. Elements for implementation are: growing natural fibres (wood, hemp, miscanthus), pilot industrial site, biorefineries, waste collection, cluster approach.

In the new **RIS 2021-2027** (2020),[140] there is no focus anymore at Biobased Economy or Circular Economy. It is a frame that supports Eastern Netherland companies in food(tech), materials(tech) and health (medtech) to innovate and grow. The priorities have been connected to the three existing clusters in this part of the country, and not to the Challenges or Missions society is facing. Connection with the regional physical characteristics and regional bio-resources are missing In the new RIS document there are no directions towards innovation sustainable smart specialization, greening the economy and towards the circular bio-economy. So this framework does not offer direct and focused support to the development of a circular bio-economy. This means that EU funding, via the European regional development funds (ERDF), will not be available for supporting the transition to bio-economy. This means also that the investments from the former period will not be continued, so initiatives will hamper to reach the next step of their developments, higher TRL's and up-scaling.

Although it is not anymore the priority for regional development strategies in Eastern Netherlands, it is still at the policy agenda. Gelderland started with the Circular Economy objectives (**Circular Action**

[139] OP Oost (2013). Operationeel Programma EFRO 2014 – 2020 Oost-Nederland.
[140] Op Oost (2020). Slimme specialisatiestrategie (RIS3) Oost-Nederland 2021-2027.

Agenda 2016-2020), [141] with opportunities for high value applications of bio resources such as proteins, manure and natural fibres (as agricultural side streams, hemp, grasses and wood). The Plan is aiming at supporting circular initiatives, pilots and awareness raising with the following tracks:

1. Province as launching customer: circular buying strategy
2. Smart industries: awareness raising, reduction and recycling of waste
3. New biobased resources: natural fibres (hemp and grasses), extraction of nutrients from manure and transition towards green proteins.

At the innovation track for natural fibres different new regional value chains between crops and industries have been explored, with much focus at the sustainable application in paper and textile industry.

In 2019, the political agreement Gelderland '**Together for Gelderland**' still focusses on the Circular Economy Implementation Agenda (2020 - 2024).[142] The provincial coalition will further invest in the circular economy, as part of the food and energy transition, with a focus on using waste as resources, limit imports of resources (by 50%) and use the current resources in the province as optimal as possible. This should lead to decrease of CO_2 emissions.

From 2019 to 2020, the province has supported many new initiatives and pilot projects. In the next phase of development, Gelderland wants to support initiatives which have the objective to scale-up. Based on the **Circular Atlas** (2019),[143] the province of Gelderland considers three options:

- Decrease of use of primary or virgin resources and materials
- Re-use of resources and materials in closed circles
- Replace primary and finite resources by biomass and biobased resources

Compared to the former framework on circular economy, Gelderland has decided in the 2nd phase of their policy regarding circular economy to focus more on value chains instead of individual business cases; every initiative should have two or more partners working together in the value chain. Effort must increasingly shift to the actual reduction of raw materials consumption, stimulating market demand, application and realization. The province wants to achieve this by stimulating the multiple valorization of biomass (using all the fractions of biomass, sales in various sectors) and to support the formulation of a solid business case.[141] Policy objective regarding biomass availability and application in Gelderland:

- research how, where in Gelderland, what types, in which quantities and for which applications, extra biomass can be made available as raw material for new protein-rich food, regionally grown animal feed, construction material and the (paper, textile, …) industry.
- Draw up an implementation-focused, action plan together with (potential) producers of biomass, processors and market parties.
- Investigate whether a (provincial) incentive instrument can be created to open the market for specific biomass applications to replace finite, fossil raw materials.

The province is searching for value chain projects in four categories: agrofood, construction, consumer waste and manufacturing industry. These sectors process the largest volumes of resources, and they are challenged to come with project proposals, in order to realize a decrease of 50% CO_2 in primary resource use.

Construction

The objectives in the coalition agreement/Circular Economy Implementation Agenda regarding the category building and construction, are focused on recycling of buildings and construction materials, and on the use of biobased materials for construction, for example based on wood, flax and miscanthus. The other sub goals are flexible building formulas and new functions for existing buildings, mainly for housing. The Circular Economy policy focuses at the production or collection of resources, the processing

[141] Provincie Gelderland (2016). Uitvoeringsagenda Circulaire Economie.
[142] Provincie Gelderland (2019). Van ketens naar kringlopen Uitvoeringsprogramma Circulaire Economie 2021 – 2023.
[143] Provincie Gelderland, Royal Haskoning DHV (2019). Circulaire Atlas Gelderland.

of building materials and the construction sector. The province is looking for projects and initiatives underneath the different policies. The province's contribution is the following: as a buyer of circular products and with their provincial environmental services organizations ("Omgevingsdiensten"), as a policy maker, as a supporter with their innovation ecosystem partners (Oost NL, KIEMt cluster, Circles program), and offering the financial means and incentives for innovation (EFRO). The Province is working at a regulation for material use in new housing programs.

Bio-based resources play an important role in the transition towards a CO_2 emission neutral and circular economy. Bio resources are mentioned in Gelderland framework documents. By the valorization of bio-based resources towards new and high applications, the province will focus on reduction of fossil CO_2 emissions (Gelderland Climate Plan 20021-2030) by using biomass and will focus on replacing the use of fossils by using waste (implementation program Circular Economy 2021-2030).

Fiber rich bio-based resources are relevant for the following sectors:

- Construction: new construction materials
- Mobility and infra: lignin in asphalt
- Agriculture and forestry: supply of fiber rich biomass, side streams, new crops production

Biobased products will contribute to climate mitigation by storing CO_2. Focus is also on connecting the value chain between biobased and waste supply and valorization within various (small) industries in Gelderland.

The insight has grown that fibers are an important biomass for Gelderland, as Gelderland is the province with relatively most lignocellulosic biomass in the Netherlands, and as in the past fiber-based industries have performed well in Gelderland / Eastern Netherlands, as the paper industry and textiles. Next step is to elaborate a vision on bio-based resources in Gelderland (in preparation). The main goals will be:

I. Stimulating biobased applications in construction and infra.
II. Public buy in: application of biobased resources in public works, infra.
III. Stimulating innovation value chains in bio chemicals, focus on biobased coatings, biobased fibres in construction and packaging, to be used and applied by Gelderland private sector.
IV. Lobby towards National and Eu government for level playing field.
V. Impact monitoring and as steering instrument.

Agrofood policies

In the policy framework "Toekomst voor de Gelderse boer (2020)"[144] the vision on the future of agriculture in the province of Gelderland is described. Agriculture is focusing on food production in a sustainable way, but more functions are relevant, such as quality of life on the country-side, biodiversity, soil improvement, climate adaptation. There is slightly more attention for valorization of waste from agriculture and for growing new crops, rich of proteins, but also rich of fibers. Also the exploration of new agroforestry systems are part of the agro vision of the province. Systems in which lignocellulosic crops are being combined with arable farming and livestock. New instruments are being developed to support this development and to work on attractive business models for producers.

Next to this, the province is working on a vision on forestry (*Bosvisie)*, together with the nature management organizations. The province should contribute to the implementation of the National Bossenstrategie, to increase the amount of forest with 10%. Wood captures CO_2 and the high-end use of wood for furniture or for building houses will contribute to a more sustainable and circular society. It is not clear what the production locations will be.

3.1.4 Conclusions: Reflection on policies and strategic choices

Accordingly, we conclude that the relevant policy frames are available at all levels: climate, circular bio-economy and regional growth strategies, but may not be perfectly in line with each other at the regional

[144] Provincie of Gelderland (december 2020). Toekomst voor de Gelderse boer; Programma Agrifood 2021-2030.

level. There is a shift from biobased economy towards circular bio-economy, a shift which is being made also in Gelderland.

As the European Green Deal is seen as a Growth Strategy, and as the concept of RIS3 (regional innovation strategy of smart specialization) is moving towards RIS4 (regional innovation strategy of sustainable smart specialization) with strong focus on certain specializations, sectors or transitional pathways, this is not followed by Gelderland. It seems that Eastern Netherlands (Gelderland and Overijssel) is choosing for the pragmatic way and does not explicitly choose to continue a strong focus on a circular economy like within the framework of RIS3. In the RIS strategy of Eastern Netherlands, biobased valorisation seems to have less attention than some years ago. This is not supportive for biobased innovations and specializations. The transition towards a circular (bio-) economy takes time and needs long term support and strategic decision making.

In the Circular Economy Action Agenda (2016) and the Circular Implementation program (2020) of Gelderland, there is foremost attention to the volume of resources used by different sectors and industries. The objective is to decrease the use of resources (imports) and to optimally reuse waste. The attention for the production of biomass, relevant for the development of sustainable products in regional value chains based on renewable resources such as herbaceous or other fibre-rich bio-based resources, is growing. But focused policies have been missing until recently. In 2022 the province of Gelderland published their Agenda on bio-resources.[145] There has been limited attention for the role of agriculture in producing herbaceous biomass, as part of concepts from sustainable, circular farming. And the increase of the amount of forest by 10% has not started yet, forest which may take place on agricultural land, where also food, feed and herbaceous crops likely will be produced.

Sustainable circular farming requires involvement of the whole value chain and development of supply and demand relationship, on volumes, qualities and on the sustainable production conditions and effects on CO_2 emissions. For the development of the market of specialized bio-resources and applications, it will be important to discover the optimal scale for collecting and processing the bio-resources. In order to become a frontrunner on the smart specialization niche, it will be important to create an innovation ecosystem of quadruple helix partners and the intermediate organizations, and to commonly develop support services to enhance capacities and capabilities within a region to strengthen the profile of their specialization and to deploy the transition.

So, there are existing policies which are not well aligned to coherent frameworks. Within the Netherlands and within the province of Gelderland, there are different initiatives and pilots, but a regional bio-economy with strong focus and specializations is not taking place. Due to the limited space available for producing herbaceous, the strong position of Dutch agriculture and the neo-liberal way of policy making, the development is depending on the willingness of the market. But, on the other hand, the policies and approaches are pragmatically going in the direction of circularity, in which public sector is applying circularity in their own investments and focusing on stimulating the circular bio-economy by incentives for pilots. This, to discover the conditions for the transition, to learn from collaborative approaches and about the drivers and hurdles, which should lead to more clear directions and investments, and to the development of supportive instruments and business models need to be developed in order to scale-up the pilots.

So, in summary, what is available and missing for the regional herbaceous valorization:

- At all levels frameworks are set for combatting climate change, decrease of CO_2 emissions, and for circular-economy development.
- There is growing attention for stimulating the use of Bio-resources from perspectives of contributions towards Climate policy and Circular Economies; important is the added value from concept of wellbeing (brede welvaart) and optimal balancing between ecological, social and economic perspective.
- A growth and development strategy at National and regional level, with focus on specific value-added specializations and innovations in circular economy is missing.

[145] https://gelderland.stateninformatie.nl/document/11326755/1/Bijlage_Strategische_Agenda_Vezel-biogrondstoffen_%28PS2022-195%29

- Actually there is no clear strategic decision to enhance the production of bio-resources availability for the transition towards circular economy and to develop new agriculture concepts; but bio-resources are gaining attention.
- Provinces are developing the Circular Economies with funding opportunities for piloting and testing project initiatives, to explore and enhance circularity, for example in the construction sector and other industries. The government aims at private sector initiatives, which remain small and fragmented.
- There is attention for value chain approach, but implementation schemes and specific support for connecting the VC partners are limited.
- For the transition towards a circular (bio-)economy, long term coordination and support is needed, on innovation, governance and on financing.

3.2 Circularity and sustainability aspects of potential applications

In order to continue feeding humanity, provide it with the necessary goods and to guarantee social wellbeing in the view of planetary boundaries, a fundamental change in how we use resources is necessary. This calls for transforming our current "take – make – waste" industrial model. The urgency of taking measures to decouple economic growth from resource use, increase resource use efficiency and stimulate a more sustainable production and consumption system all come together in the concept of circularity. The essence of a circular economy is that the value of products, materials and resources is maintained in the economy for as long as possible, and the generation of waste minimized, while ensuring sustained quality of the means of production: soil, rivers, seas, oceans. To support this transition, strategies and targets have been set by governments (regional, national, EU) to encourage the implementation of circular economy principles. Supporting the European Commission's Circular Economy Action Plan, the Dutch government's programme *A Circular Economy in the Netherlands by 2050* states the ambitions and actions to achieve the goal of 50% reduction in the use of primary raw materials.[146] These ambitions are also taken up in the provincial level. The Province of Gelderland in its Circular Atlas Gelderland identified possible circular options.[147]

Three strategic objectives have been defined by the Dutch Government that aim to accelerate the transition to the circular economy[146]:

1. Make better use of natural resources in existing product chains by using and reusing products and product parts and recycling of materials as efficiently as possible. This should reduce resource demand in existing product chains.
2. If new natural resources are needed to produce new materials, substitute abiotic resources with renewable, widely available natural resources. This should conserve natural capital.
3. Develop new production methods and product designs, encourage new ways of consuming and implement new forms of spatial planning. This should result in new product chains that make it even easier to achieve the required reduction (first strategic objective) and substitution (second strategic objective).

PBL published a circularity strategy ladder (9R) in 2016 that aims for efficient use of resources in product chains (*first and third strategic objective*).[148] As a rule of thumb, fewer primary materials are used as we move from lower level (high R) to higher level (low R) circularity strategies. Less primary material use also means less resource extraction for, and less production of, primary materials. Avoided resource extraction and primary material production also prevent any related pressure on the environment. The circularity ladder is divided into three main categories: 'smarter product use and manufacture' (R0 – R2), 'extend the lifespan of the product and its parts' (R3 – R7) and 'useful application of materials' (R8 – R9). Furthermore, if new resources are needed to produce new products, the use of renewable natural

[146] IenM and EZ (2016). Nederland circulair in 2050. Rijksbreed programma Circulaire Economie ['A circular economy in the Netherlands by 2050'. Government-wide programme for a Circular Economy]. The Hague.
[147] Provincie Gelderland (2019). Circulaire Atlas Gelderland
[148] Potting J, Hekkert M, Worrell E, Hanemaaijer A. (2017) Circular economy: Measuring innovation in the product chain. The Hague: PBL Netherlands Environmental Assessment Agency. Report No.: 2544.

resources is considered. This is regarding the *second strategic objective* and not represented in the R ladder.

Construction sector

European Commission's Circular Economy Action Plan states that, in the EU, the construction sector is responsible for 50% of primary raw materials use and over a third of total waste generation.[149] This highlights the importance of transition to a circular economy. The Dutch Circular Economy programme is focused on five priorities that are important for the Dutch economy of which one is the Construction sector. 'De Bouwagenda', presented to the government by chairman Bernard Wientjes on 28 March 2017, also has circularity as a prominent theme.[150] The objectives for the Dutch construction sector are set out in the Transition Agenda for the Circular Construction Economy and the associated Implementation Programme.[151] Also in the Circular Atlas Gelderland Construction sector is a focus point. An overview of the potential circularity strategies pointed out by governments (regional, national, EU) for the construction sector is provided in Table 12 including linkages to the 3 strategic objectives of the Dutch Government and the circularity strategy ladder of PBL.[152]

Table 12 Circularity strategies in the construction sector.[153]

Circularity strategies	Examples
first and third strategic objective	
R0 Refuse	Tiny house
R1 Rethink	Shared use of buildings
R2 Reduce	Decrease amount of waste produced during production of building materials Reduce energy requirement of buildings through improved insulation or solar panels
R3 Reuse	Buy old house rather than new build
R4 Repair/R5 Refurbish	Use durable materials, extend lifetime of existing infrastructure and materials (allows keeping the product in use for longer, preserving its value in its original function)
R6 Remanufacture	Use elements of old buildings in new buildings (through designing for reuse, smart demolition and disassembly)
R7 Repurpose	Old construction materials (floors, doors) used to make furniture Cascading use of biobased building materials
R8 Recycle	Recycling building/demolition waste Secondary resource use in new buildings in high quality applications as possible
R9 Recover	Incinerate demolition waste with energy recovery
second strategic objective	
Substitute	For virgin input renewable sources are used - Bio-based building materials

149 European Commission (2015) Communication from the Commission. Closing the loop – An EU action plan for the Circular Economy (COM(2015)614 final). Brussels.
150 Taskforce Bouwagenda (2017). De bouw agenda. Delft. https://debouwagenda.h5mag.com/de_bouwagenda/eindpagina
151 Circular Construction Economy Transition Agency (2018). Transition Agenda for the Circular Construction Economy. Building on the circular economy for the Netherlands in 2050 together. Delft
152 PBL (2018) Circular economy: what we want to know and can measure. The Hague: PBL Netherlands Environmental Assessment Agency. Report No.: 3217.
153 Adapted from the PBL 2018 Circular economy report, Appendix 2

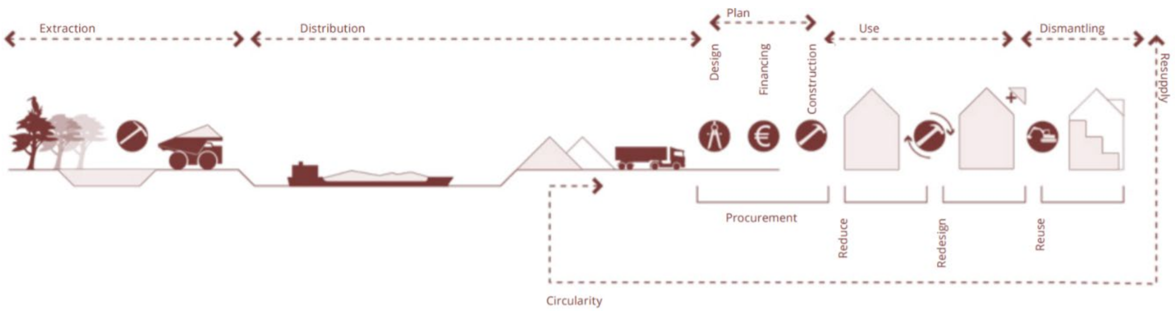

Figure 5 ***Stages of a construction project.***[151]

Secondary resource use is a current practice in the construction sector (see Figure 5), however only 3% of the resources return to its original use, the rest is recycled in low-grade form and used for example as foundation material for roads.[151] High-grade application of recycled materials in existing product chains is needed. Gaining insight into the materials and resources used in buildings and other works at building and work level is an essential step along this route. This can be realised for example by means of a materials passport. Platform CB'23 (Circular Construction 2023) is working on principles and guidelines for the preparation and/or use of passports for the construction sector.[154] They are also working on methods for measuring circularity in the construction sector.[155]

The change must happen starting from the design stage to consider use of all materials that will be suitable for high-quality reuse. Design for disassembly so that construction products are easy to separate into components that can be reused, reassembled and recycled. Smart demolition so that separation takes place at the source into high-grade material fractions suitable to return to its original use. Hazardous waste or materials that interfere with recycling are separated. The implementation of these practices for improved waste source separation, tracking, quality management and recycling processes call for cooperation between various stakeholders (architects, contractor, demolition work and waste management, ..) along the value chain to ensure high grade recycling of materials.

Dutch 'Circular Economy in the Netherlands in 2050' programme[146] calculates that the construction industry in the Netherlands is responsible for an estimated 50% of the resource consumption, 40% of the total energy consumption and 30% of the total water consumption. It is estimated that the industry is responsible for about 35% of the CO_2 emission.

In accordance with the second strategic objective, more use will be made of biomass as a renewable source for the construction sector and this is expected to contribute to the reduction of the environmental impact of the construction industry. It is important to ensure the sustainability of the biobased building materials considering the range of environmental impacts. This is also highlighted in 2018 EU Bioeconomy Strategy which states that "to be successful, the European bioeconomy needs to have sustainability and circularity at its heart." Accordingly, it is important to provide supply of biomass to the construction industry sustainably and manage trade-offs: As increased demand for biomass will have consequences for agricultural and forestry activities and associated impacts such as land use, biodiversity, soil quality and eutrophication (due to fertilizer applications).

A method for calculating environmental pressure has been developed for the construction sector: the environmental performance of buildings and civil engineering works (Milieuprestatie gebouwen en GWW-werken), making use of the national environmental database (NMD).[156,157] This method includes calculation rules and validation guidelines for calculating the environmental performance of a whole project based on the performance of the products and elements used. It is based on European standard NEN-EN 15804 Sustainability of construction works - Environmental product declarations.[158]

[154] Platform CB'23 (2020). Guider to Passports for the Construction Sector version 2.0. Delft: Platform CB'23
[155] Platform CB'23 (2020). Guide to Measuring circularity version 2.0. Delft: Platform CB'23
[156] Stichting bouwkwaliteit (2019), Bepalingsmethode milieuprestatie gebouwen en gww-werken.
[157] Stichting Bouwkwaliteit. Nationale milieudatabase. https://www.milieudatabase.nl/
[158] NEN-EN 15804 (2019) Sustainability of construction works - Environmental product declarations - Core rules for the product category of construction products.

Textile sector

European Commission's Circular Economy Action Plan identified textiles as a priority sector. In EU textiles are the fourth highest-pressure category for the use of primary raw materials and water, after food, housing and transport.[149] The textiles system operates in an almost completely linear way: large amounts of resources are extracted to produce clothes that are often used for only a short time, after which the materials are mostly sent to landfill or incinerated.[159] The EC will publish an EU strategy for sustainable textiles to develop a transition pathway for the textiles sector applying circular economy principles.[160] In the Dutch Circular Economy programme, textiles is covered within the priority area of consumer goods. At the provincial level, Circular Atlas Gelderland includes a strategy for textiles which concerns improved separate collection of used textiles from consumers and recycling. An overview of the potential circularity strategies for the textiles sector is provided in Table 13.

Table 13 Circularity strategies in the textiles sector.

Circularity strategies	Examples
first and third strategic objective	
R0 Refuse	Minimise buying of brand new clothes Reject fast fashion, short lived products
R1 Rethink	Design products for better, high-quality recyclability
R2 Reduce	Reduce resource consumption / waste produced in production of textiles Reduce clothing going to landfill
R3 Reuse	Donation to charity Buy from second hand shops Swap, borrow, lend clothing
R4 Repair/R5 Refurbish	Produce durable, high-quality textile products (allows keeping the product in use for longer, preserving its value in its original function) Mending clothing that have holes, stains, tears
R6 Remanufacture	Use parts of old clothing in making new textiles (blanket, pillow case, bag)
R7 Repurpose	Old clothing used to make furniture stuffing or insulation material Recycled denim used for making paper Cascading use of textiles (apparel, furniture or toy stuffing, insulation for housing or automobiles)[161]
R8 Recycle	Separate collection of clothing waste Fibre recycling Secondary resource use in new textiles in high quality applications as possible
R9 Recover	Incinerate textile waste with energy recovery
second strategic objective	
Substitute	Use renewable resources when virgin input is needed

3.2.1 Conclusions

In term of use of herbaceous biomass and circular economy, the following are important considerations:

1. Use biomass efficiently and in high-quality application
2. Extend the lifetime of use in original application (maintenance, repair)
3. Keep the biomass in economy through reuse, repurpose and recycling
4. Substitute traditional materials with bio-based alternatives

[159] Ellen McArthur Foundation (2017), A new Textiles Economy
[160] https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12822-EU-strategy-for-sustainable-textiles_en
[161] Ellen McArthur Foundation (2013), Towards the Circular Economy

4 Potential applications, demand and production of herbaceous feedstock in Netherlands in 2050

4.1 Possibilities for new applications (value chains) and estimated feedstock demand

In section 2.2 a wide range of current applications of herbaceous feedstock is addressed already. Possibilities for new applications and value chains depend on the chemical composition and physical structure (morphology) and properties (e.g. strength) of the feedstock, as well as on the extent to which high value added products exist already, and on the extent to which bio-based materials can replace fossil based materials and products. E.g., high value added products based on flax are in the marketplace already, and a new regional value chain may be established by reshoring textile manufacturing. Or further high end applications may be developed to increase bio-based application volumes in the market. At the other end, verge grass is virtually not utilised at all and roadside managers may wish to have 'ever green non-growing grass'. And even if mowing regimes are adapted to minimise labour for roadside maintenance and disposal costs of verge grass (composting), suitable applications for this relatively large volume of biofeedstock would be of interest. In between, hemp, miscanthus, straw and reed from nature management areas are used in one or more applications, however, options to shift to new and higher added value applications are being searched for. In the sections below, possibilities for new applications are discussed.

4.1.1 Textiles

Textile industry faces challenges like polluting production, poor labour conditions, short life of fashion, poor recyclability, etc. Solutions may be found in, a.o., reshoring, design for recycling, replacing much used fossil based fibres by bio-based fibres, and last but not least consumer behaviour. More details about circularity and recycling in relation to textile fibre materials can be found in 2 recent publications by Harmsen et al.[162,163]

Hemp as alternative to flax

Flax has a long standing tradition as fine and strong fibre for high quality linen. Compared to flax fibres, hemp single fibres are relatively coarse, 15-25 versus 11-42 micron in diameter,[164,165] while fashion prefers the fine fibre. Aiming to obtain finer hemp fibres, so called 'baby hemp' has been developed: hemp is sown at high seed density and harvested at an early stage of maturation when the bast fibres are not yet fully developed and when the share of very short secondary fibres is still small. The 'baby hemp' delivers fibres which resemble flax fibres more than the fully grown hemp fibres, however, yield also moves towards the (lower) flax yields. Hemp straw yields of about 5.5 ton/ha DM are reported at stem length of about 140 cm,[166] while yield of flax straw is in the range 4 – 7 ton/ha (section 2.1.1) and hemp straw yield in the Netherlands is in the range 7.0 - 7.7 ton/ha (section 2.1.2). So far, the value chain for 'baby hemp' based textiles in Europe has not been established due to regulated harvesting of hemp in the period of 30 days before and after flowering, while for baby hemp earlier harvesting would be required.[167] Coarser fabrics may be suitable for f.i. upholstery, curtains, etc.

[162] https://edepot.wur.nl/517183
[163] https://edepot.wur.nl/568425
[164] https://doi.org/10.1016/j.indcrop.2005.08.003
[165] https://doi.org/10.1016/j.jcomc.2020.100010
[166] W. Westerhuis, Hemp for textiles: plant size matters (PhD thesis), p.93/93. https://edepot.wur.nl/378698
[167] R. Sauveur, personal communications.

Nettle as alternative to flax

Nettle single fibre has a fineness comparable to hemp, 15-40 micron diameter,[168] and has been used in the past for clothing, however, its use decreased when cotton was introduced for its easier harvesting and spinning.[169] In the first decade of the millennium, Brennels started nettle production to develop fashion textiles. The initiative was not commercially successful, which may be due the relatively high price of the nettle fibre, about 25 €/kg versus typically 2 – 3 €/kg for cotton and flax.[170] Other initiatives in Europe suggest to still offer nettle based textiles (e.g. Maeko,[171] Camira,[172] Havetex[173]), whereas other have stopped doing so (e.g. NFA Naturfaser).[174] The small scale of production, related lack of standardisation, as well as lack of alignment between nettle production, processing into fibre and application into textiles cause high transaction costs, irregular quality, high losses in processing.[175] Considering the significant fibre yield per ha (section 2.1.7), a significantly lower cost for nettle fibre may be expected when a full scale production value chain is established.

Flax and hemp as alternative to wool, viscose and polyamide

Flax and hemp fibres are relatively long fibres, which may potentially compete with wool, viscose and polyamide. Further beneficial properties can be high strength, recyclability, textile luster, and 'feel'. This would require development.

'Cottonised' flax and hemp as alternative to cotton

When the upon repeated recycling originally long fibres become too short for long fibre spinning, steam explosion technology allows the isolation of e.g. flax and hemp single plant cell fibres, which resemble cotton regarding fibre length and diameter.[176] This fibre can be used in the high productivity rotor spinning process, like used for cotton. Attempts to commercialise this technique for flax started in the 1990s,[176] and recently example calculations for hemp also showed potential profitability.[177] Others, at present, question the cost competitiveness of 'cottonised' flax or hemp versus cotton.[175] Bottleneck for establishment of such a value chain is that the investor for a steam explosion plant would like to have a guaranteed demand and that the spinner would like to test processing of the fibres at large scale prior to signing a long term purchase contract.

Textile product demand, Scale of conversion technology & Feedstock demand

If 25% of the 343,000 ton of textiles brought to the Dutch market, so including fossil based polyester, (see section 2.2.1) could be replaced by flax, hemp or nettle, and considering a fibre yield of 2 ton/ha (sections 2.2.1, 2.2.2, 2.1.7), the required cultivation area would be estimated at 42,875 ha, about 11 times the total present cultivation area of flax and hemp.

Considering that a state of the art cotton spinning mill processes about 25 ton/day,[178] thus about 6,250 ton/a, which is about 7% of 85,750 ton fibre yield for 42,875 ha of fibre crop.
A flax wet spinning mill as recently established in France would require 1,000 ton/a (section 2.2.1).

The characteristics of flax and hemp fibres are very different from fossil based fibres in textiles like polyester, which is a thermoplastic, both technically and regarding processing. Bio-based thermoplastics may present an alternative to polyester in applications where the typical characteristics of thermoplastics play a role. Flax and hemp fibre may replace fossil based fibres in textiles to some extent. Replacement of fossil polyester by both bio-based plastics as well as flax and hemp comes with technical and technological challenges which would need to be addressed.

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[168] https://www.tandfonline.com/doi/abs/10.1533/joti.2004.0023
[169] https://www.swicofil.com/commerce/products/nettle/271/introduction
[170] https://decorrespondent.nl/9053/deze-multimiljonair-wilde-met-brandnetels-de-wereld-verbeteren-maar-legde-het-af-tegen-katoen/3647161451054-b697d54d
[171] https://www.maekotessuti.com/eng/nettle/
[172] https://www.camirafabrics.com/en/fabrics/contract/nettle-aztec
[173] https://havetex.de/lang1/
[174] https://www.nfa-naturfaser.de/NFA-Naturfaser.html
[175] Michiel Scheffer, personal communications.
[176] https://doi.org/10.1016/S0961-9534(97)10040-X
[177] https://www.ihog.nl/wp-content/uploads/2019/10/Bachelor_IP_Dirk_van_de_Riet_Final.pdf
[178] http://bannarimills.com/?page_id=774

4.1.2 Insulation

Verge grass and cattail as alternative to flax and cellulose
The principle of insulation materials is basically based on stagnant air contained in a fibrous or foam based structure. Verge grass and cattail could be potential sources for such fibre based insulation materials, and form an alternative for mineral wool, polymer foam, or even flax and hemp fibre insulation. Technical challenges relate to coarser fibre structure, which translates into thicker insulation product required to deliver the same insulation performance. Also, protein content should be as low as possible as this may attract vermin.

Insulation material demand, Scale of conversion technology & Feedstock demand
At present about 23 Mio m^2 of mineral wool and 28 Mio m^2 of polymer foam insulation are applied per annum.[47] At a thickness of 8 cm, a density of 40 kg/m^3,[179] and a 50% replacement share by flax and hemp fibre insulation at equal product density, an amount of (23+28) * 1,000,000 * 0.08 * 40 / 1000 = 81,600 ton/a of fibre would be required. At a fibre yield of 2 ton/ha, the required cultivation area for fibre crops would be estimated at 40,800 ha/a, about 10 times the total present cultivation area of flax and hemp. When using verge grass at a fibre extraction yield of 50%, 81,600 ton/a of refined grass fibre would equal 163,200 ton of verge grass, about 40% of annual production.

In Germany and Belgium, commercial grass based insulation material plants are established, having output rates in the range 1,400 – 4,000 ton/a.[180,181] The German plant is based on meadow grass, the Belgium plant on nature grass. Several such production units could be established in the Netherlands considering insulation material demand (about 80,000 ton/a) and fibre feedstock available (415,000 ton/a; see Table 7). NewFoss announced the construction of a 11,000 ton/a plant, in Amsterdam.[182]

4.1.3 Composites

Stronger flax and hemp based composites
In principle any lignocellulosic material like herbaceous crops can be applied in composites, either as reinforcing fibre or as a filler. Strong fibres like flax and hemp have reinforcing properties when their so called aspect ratio, the length over the diameter, is long enough to transfer load from the polymer matrix to the fibres. In non-woven based composites the aspect ratio in general is long enough to obtain full reinforcing potential. In extrusion compounds for injection moulding applications, however, the aspect ratio often is so short that the strength of these fibres is sub-optimally utilised only. If fibre length in such extrusion compounds could be retained twice as long, a 30% composite strength increase is expected based on mechanical stress modelling. Such improvement of composite strength would make flax and hemp thermoplastic composites more competitive with glass fibre reinforced composites.

Miscanthus, cereal straw, reed and grass fibre as alternative to flax and hemp fibre
When blending Miscanthus, cereal straw, reed and grass in polymer matrices, they will act as a filler: the particles increase stiffness, however, usually strength and certainly impact performance decreases. As a filler, these materials compete with any lignocellulosic feedstock or chalk or talk. In principle these herbaceous feedstocks can be pulped and refined to fibres with a larger aspect ratio than particles, as has been demonstrated for miscanthus and verge grass during pilot trials to make paper. If such fibres could be made in dry form, incorporation in polymers would deliver improved strength properties compared to particles, though the strength level of strong bast fibres like flax and hemp is not expected.

Security of supply
Non-woven based composites are applied as door panels, dashboards, trunk liners in the automotive industry since over 2 decades. One of the key requirements for automotive industry is security of supply, which is met by traditional fibres like flax, jute, sisal and cotton, and in the meantime also for hemp. Actually, security of supply is key for any large industry. Outlet of composites based on new

[179] https://www.biobasedbouwen.nl/producten/isolina-vlasisolatie/
[180] https://gramitherm.ch/?lang=en
[181] https://www.ieabioenergy.com/wp-content/uploads/2019/07/IEA_grass-refinery_end.pdf
[182] https://newfoss.com/

types of fibre will require the same security of supply. For sectors like automotive industry this often also requires the presence of several (potential) suppliers.

Miscanthus, cereal straw, reed and grass fibre as alternative to wood fibre

Composites used in the building and construction sector are mostly wood fibre/particle based thermoplastics (also called wood polymer composites, WPCs), and applied as siding, decking and fencing. Wheat straw, miscanthus and reed could provide an alternative to these WPCs. Key aspect is that durability guarantee requires long term testing. NPSP has developed flax based formed products such as a facade element to cover e.g. a heat pump.

Composite material demand, Scale of conversion technology & Feedstock demand

If during the next 10 years 100,000 houses per annum would be built, and 50% of them being covered with composite façade of 5 mm thickness, 1200 kg/m^3 density and 50 wt.% flax/hemp fibre at an average façade area of 50 m^2/house,[183] an amount of 100,000 * 0.5 * 0.005 * 1.2 * 0.5 = 7,500 ton/a of fibre would be required. At a fibre yield of 2 ton/ha, the required additional cultivation area for fibre crops would be estimated at 3,750 ha/a, similar to the total present cultivation area of flax and hemp.

European market for glass fibre mat (GMT) and long fibre injection moulding compounds (LFT) in 2019 was about 40,000 and 115,000 ton, respectively.[184] The Dutch share for glass fibre composites overall was 4.0%, translating into 1,600 and 4,600 ton/a for GMT and LFT, respectively. If 25% of composites could be replaced by flax or hemp fibre based composites, composite production/demand in the Netherlands would be 400 and 1,150 ton/a for fibre mat and mouldable composites, respectively. Assuming a fibre content in the composite of 50 wt.%, total fibre demand would be 200 + 575 = 775 ton/a. At a fibre yield of 2 ton/ha (sections 2.2.1, 2.2.2, 2.1.7), the required cultivation area for fibre crops would be estimated at 388 ha, which is about 10% of the total present cultivation area of flax and hemp.

The wood polymer composite (WPC) market volume in Europe in 2020 was 455,000 ton.[185] Assuming a same share for the Netherlands as for GMT and LFT, this would translate into 18,200 ton/a. Considering that largest part of the WPC is applied as decking, siding and fencing (Figure 6), having moderate strength performance requirements, it is expected that technically speaking cereal straw, miscanthus and reed could replace the wood fibre/particles, eventually after upgrading the feedstock into fibres. Assuming that 50% of composites would be based on cereal straw, miscanthus or reed, composite production for Dutch market would be 9,100 ton/a. Assuming a fibre content of 60 wt.%, total fibre demand would be 5,460 ton/a, which is small compared to available feedstock.

Typical scale of compounding is in the range of 2,500 – 8,000 ton/a.[186] This is the same order of magnitude as the estimated WPC demand in the Netherlands. This production scale is a factor of 2 – 5 larger than the estimated substitution volume of LFT, however, also other types of composites could be produced using the same equipment. Also, not included in these estimates is potential growing markets in building and construction sector (e.g. furniture, siding) and 3D printing.

[183] Assuming on average a block of 4 houses: Side walls: 2 times 8*5+10 (for 4 houses) = 25 m^2 per house; Front side: 15 m^2 per house; Back side: 10 m^2 per house. Total: 25+15+10 = 50 m^2.

[184] https://www.avk-tv.de/files/20201111_avk_market_report_2020.pdf

[185] https://www.mordorintelligence.com/industry-reports/europe-wood-plastic-composite-market

[186] http://www.compoundingworld.com/cop_zsk

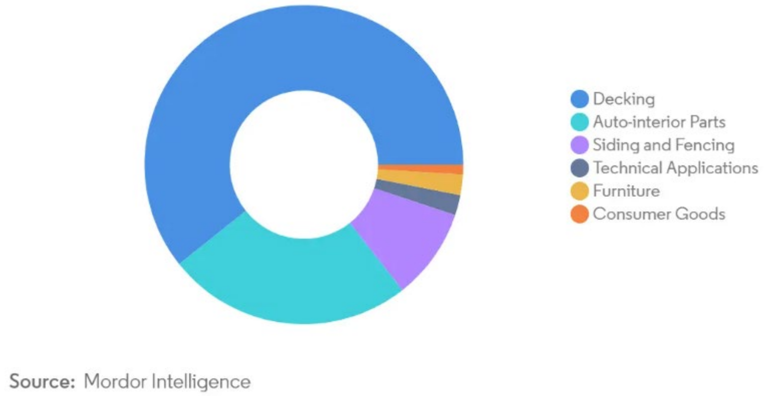

Figure 6. WPC volume distribution per type of application in Europe (Mondor Intelligence).[185]

4.1.4 Panels & Boards

Cereal straw as alternative to wood based particle boards

Cereal straw can be very well used in particle board. The waxy layer on straw surface makes particle boards more resistant to water than traditional wood based particle boards, which makes them suitable for damp rooms like bathrooms. The mechanical performance of straw based particle boards is comparable to wood based particle board.[187] Worldwide, about 20 production lines to manufacture particle boards based on a range of biofeedstock are installed: wheat straw, rice straw, sugar cane bagasse, blue grass.[188] The nominal output of the equipment is 14,000 – 56,000 m^3/a. This is a factor of 10 lower compared to standard wood based particle board plants.[189]

Economic disadvantages compared to wood based particle boards are the lower bulk density of straw feedstock which may increase transportation costs and the smaller production scale of straw based boards so far. Further disadvantage of straw based boards is that so far it requires toxic pMDI to firmly bond the lignocellulose through a waxy layer on the surface of straw. Even when the pMDI is usually fully reacting to non-toxic polymer, in principle the use of this binder resin poses a risk.

Reed or Miscanthus as alternative to wood based particle boards

The technology used for making cereal straw based particle boards is claimed, and may be reasonably expected, to be suitable to make reed or Miscanthus based particle boards as well. Reed based particle boards are expected to have a moisture resistance in between cereal straw and wood based boards. A development project by DSM, Natuurmonumenten and WFBR showed that the mechanical performance of pMDI bonded multi annual reed are comparable to straw based boards, and that potentially partly bio-based and less hazardous binders than pMDI can be used.[190]

Panel & Board demand, Scale of conversion technology & Feedstock demand

Consumption of particle board and fibre board in the Netherlands in 2020 was about 1,000,000 m^3.[191]
At an estimated density of 750 kg/m^3, this is 750,000 ton/a.

Whereas cereal straw is widely used and even imported, reed is hardly utilised so far. The annual production of about 94,000 ton of reed would be sufficient to feed a 50,000 m^3/a particle board plant. Actually, such a plant would be expected to allow processing of other feedstock into boards as well, such as e.g. miscanthus or bell pepper stalks.

4.1.5 Paper and cardboard

Ingredient for paper is mainly cellulose. Apart from specialty paper, the traditional source for cellulose is wood. Pilot trials have shown that also Miscanthus and verge grass can be utilised in paper. In these

187 https://chesapeakeplywood.com/straw-board-wheatboard/
188 http://www.csprocessengineering.com/
189 https://www.hdforest.com/news/lithuanian-particle-board-manufacturing-capacity-is-expanding
190 https://doi.org/10.1016/j.repl.2019.10.007
191 https://www.bosenhoutcijfers.nl/de-houtmarkt/houtproducten/platen/

pilots, part of the cellulose pulp was successfully replaced by the alternatives. Fully Miscanthus or verge grass based paper would require pulping. Conventional (wood) pulping is done at huge scale in wood rich regions like Scandinavia, Austria, etc. at 400,000 – 2,000,000 ton/a of pulp.[192] Paper mills are a factor smaller, 40,000 – 100,000 ton/a.[193] Total paper production in the Netherlands is estimated at 2,869,000 ton/a, which would require the full production of a large wood pulp mill or a few smaller mills. Virgin pulp required for this, the rest is covered with 'old paper', is about 480,000 ton/a.[194] Production of 400,000 ton/a of pulp would require roughly double the amount of feedstock, 800,000 ton/a. For reference: Miscanthus production is estimated at 3,125 – 22,500 ton/a (section 2.1.3), and verge grass at 415,000 ton/a (section 2.1.6). This means that a small scale conventional pulp mill requires about double the total amount of Miscanthus and verge grass presently harvested in the Netherlands. In a biorefinery concept, however, smaller scales are considered to be feasible. E.g. Fibers365 (Germany) has established six 5 – 30 kton/a plants based on wheat straw so far, a.o. delivering cellulose fibre for paper packaging and pulp moulding.[195]

4.1.6 'Concrete' products

Hemp shives can be mixed with lime to form a relatively low density mortar, 300 – 600 kg/m^3,[196] called 'hempcrete' with claims for humidity tempering, combined thermal insulation and thermal mass, and sound insulation. This makes the material very suitable for (non-load bearing) building materials. The production involves a long drying time, thus prefab system is beneficial. First buildings have been established.[197] After end of life, the hempcrete can be potentially recycled, or used as fertilizer; lime is often applied to increase the pH of the agricultural soil.

In a similar way, Miscanthus-concrete panels, blocks and mortar can be prepared. Even if some pilot products have been delivered (sound barrier walls along roads and rail tracks, and in street furniture), limited data about the materials' technical and environmental performance are public.

<u>Building product demand, Scale of conversion technology & Feedstock demand</u>
If during the next 10 years one million houses would be built, and 50% of them being built with 40 cm of hempcrete material at an average of 50 m^2/house,[183] an amount of 1,000,000 * 0.5 * 50 * 0.4 = 10 million m^3 of hempcrete. At a bulk density of the hemp shives in the hempcrete of 100 kg/m3, this corresponds to 1,000,000 ton of hemp shives, or 100,000 ton/a. Considering that current hemp shive production in the Netherlands of about 6,500 ton/a (50% of 13,000 ton/a hemp straw, see section 2.1.2) is probably fully utilised for other outlets, and that hemp yields about 3.7 ton/ha of shives (50% of 7.4 ton/ha of straw), the area of hemp cultivation would need to be expanded by 27,000 ha. Considering that the techniques used to produce hempcrete are easily scalable, production volume of hempcrete can keep pace with demand.

4.1.7 Roofing

Roofing requires the quality of annually harvested reed. Nowadays, this is only done for some privately owned fields and small areas of nature management. Most reed areas which were formerly harvested for roofing are nowadays managed for their qualities for nature like providing shelter for birds, and the related multi annual mowing scheme does not deliver quality required for roofing. Thatching sector has still interest in sourcing from Dutch reed fields. At current demand, imports of about 9.6 kton/a could be replaced by home grown reed (see section 2.2.4). This would require dedicated reed production, including fertilization and annual harvesting.

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192 https://www.euwid-paper.com/news/singlenews/Artikel/arauco-to-complete-mapa-pulp-mill-expansion-in-october-2021.html
193 https://www.gld.nl/nieuws/18228/Gelderland-nog-steeds-papierprovincie
194 https://www.ivvd.nl/wp-content/uploads/2019/10/191029_CirculaireAtlasGelderland.pdf
195 https://fibers365.com/news
196 https://www.hanfstein.eu/home-english/hempcrete/
197 https://www.ecodorpboekel.nl/mijlpaal-kalkhennepmuren-worden-geplaatst/

4.1.8 Animal bedding

Most herbaceous crops addressed in this report are used as animal bedding: flax and hemp shives, as well as cereal straw have been used for a long period already. Miscanthus is used as animal bedding since its introduction in the Netherlands, however, producers of this dedicated crop aim for higher added value products such as in composites, paper and concrete.
Multi annual reed is mainly directly ploughed under the soil, however, when using it as animal bedding first, it still could go to soil fertiliser, thus providing an additional service, and potentially saving other feedstock like cereal straw which is currently imported for animal bedding purposes.
Dried verge grass potentially could be used as well for animal bedding as a replacement of cereal straw, or as a replacement of sawdust when milled.
Market volume of sawdust and cereal straw used for animal bedding is estimated to be 200 and 350 kton/a, respectively (section 2.2.1), while net import of cereal straw is 200 – 400 kton/a (section 2.3). When utilising reed and verge grass for this application, part of straw imports may be avoided, or straw may be utilised for other applications such as panels & boards.

4.1.9 Conclusion and summary of current and potential applications

Herbaceous biomass comprises a diverse range of feedstock, which may find application in a wide range of sectors. The barrier between potential and actual applications sometimes relates to cheaper fossil alternatives, while in other cases technical development is required. In Table 14 an overview of current and potential applications is presented.

Table 14 Current applications of herbaceous feedstock in the Netherlands. Niche applications or potentially future applications have been inserted in italic.

Feedstock	Application	Sector
Flax bast fibre	Linen fabric	Fashion
	Insulation mat	Building & construction
	Fibre reinforced composites	Automotive, Building & construction
	High quality paper	Value paper
Flax hurds	Particle boards	Furniture, Building & construction
	Animal bedding	Animal farming
Hemp bast fibre	Composites	Automotive, Furniture
	Insulation mat	Building & construction
	Substrate mat	Horticulture
	Geotextile	Slope protection
	Textiles	Fashion
Hemp Hurds	Animal bedding	Horses
	Lime hemp (Hempcrete)	*Building & construction*
Hemp flowers & leaves	*CBD oil*	*Nutraceutical*
Nettle	*Textiles*	*Fashion*
Miscanthus	*Animal bedding*	*Animal farming*
	Paper	*Paper and packaging*
	Filler in plastics	*Diverse*
	Concrete based products	*Public space*
Reed (1 year old)	Thatching	Roofing
Reed (multi annual)	*Animal bedding*	*Biological farming*
	Soil fertiliser	Agriculture
	Particle boards	*Building & construction*
Straw	Animal bedding	Animal farming
	Soil improver	Agriculture
	Protection of flower bulbs	Horticulture
	Protection of strawberries	Horticulture
	Mushroom cultivation	Food sector
	Insulation material	*Building & construction*

Table 14 ***(Continued) Current applications of herbaceous feedstock in the Netherlands. Niche applications or potentially future applications have been inserted in italic.***

Feedstock	Particle boards	Building & construction
Straw	Feed	Animal farming
Verge grass	*Insulation mat*	*Building & construction*
	Paper and cardboard	*Packaging*
	Composites (limited performance)	*Diverse*
	Soil improver	Agriculture
	Animal bedding	*Animal farming*
	Feed	*Animal farming*

4.2 Potential primary production in 2050

The Netherlands faces several major challenges in the physical environment, like conserving biodiversity and mitigating climate change. Future agricultural and land use developments and climate and environmental policies and targets are key in dealing with these challenges. The question is how land use and agriculture will change over time. How much land will be used for agriculture in the future, what will be the size of the livestock, and what is the environmental and climate impact of the sector in the future? And especially regarding this study: what opportunities and threats are there for herbaceous crops in the future, taking into account these developments?

To get a better grip on what the future might hold, often hypothetical scenarios are used. In this study, we take as a starting point the four different hypothetical scenarios that were developed for agriculture and land use by 2050 by Lesschen et al. (2020).[198] In their report, the developments under potential future climate and environmental targets were taken into account and it was assumed that all farmers in the Netherlands will follow the chosen development direction and apply all associated measures. A distinction is made between the development direction of agriculture, either productivity driven or nature-inclusive business operations, and environmental limits defining the operation space via envisaged and stricter environmental policy objectives:

- Productivity-driven management, with intended policy goals and basic measures (*Productivity intended*)
- Productivity-driven management, with stricter policy goals and “pull out all the stops” measures (*Productivity stricter*)
- Nature inclusive management, with intended policy goals and extensive package of measures (*Nature inclusive intended*)
- Nature inclusive management, with stricter policy goals and extensive package of measures (*Nature inclusive stricter*)

At the national level, these limits determine the emission space for greenhouse gases, ammonia and nitrogen and phosphorus loads to surface water for the agricultural sector by 2050. For each scenario, a package of measures has been defined, appropriate to achieve the relevant development direction of agriculture and the environmental activities. If these measures are insufficient to achieve the environmental targets, land use change and reducing livestock numbers have been included as options for achieving the environmental targets.

The results of the four scenarios have been compared to a reference scenario, which is based on existing policy without additional measures, but includes autonomous developments in agricultural area,

[198] Lesschen, J. P., Reijs, J., Vellinga, T., Verhagen, J., Kros, H., de Vries, M., Jongeneel, R., Slier, T., Gonzalez Martinez, A., Vermeij, I., & Daatselaar, C. (2020). Scenariostudie perspectief voor ontwikkelrichtingen Nederlandse landbouw in 2050. (Rapport / Wageningen Environmental Research; No. 2984). Wageningen Environmental Research. https://doi.org/10.18174/512111

livestock and crop productivity and food consumption, among other things. By 2050, the total agricultural area will have decreased by about 200,000 hectare in all scenarios, roughly from 1,75 million hectare in 2017 to 1,55 million hectare in 2050. This results from the autonomous trend that yearly about 0,3% or 6,000 hectare of agricultural land is converted to other forms of land use, like building and construction.

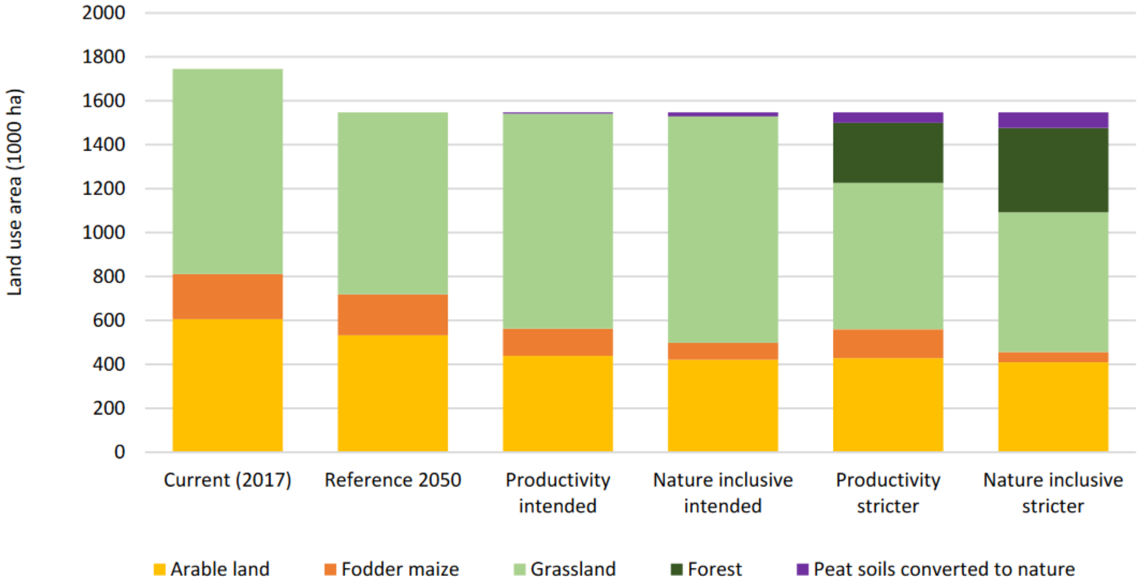

Figure 7 ***Areas of land use (in 1000 ha) for the current situation (2017) and 2050 scenarios (source: Lesschen et al. 2020).***[198]

In all scenarios, the area of arable land decreases as well compared to the current situation. This relates both to foreseen more extensive dairy farming which needs more land per cow and to a necessary increase of forest area in the scenarios with stricter policy objectives, in order to compensate for carbon emissions. Without a decrease in arable land, it is assumed to be not possible to meet the climate target of net-zero emissions. If measures in livestock farming prove to be less effective, the necessary reduction in livestock numbers will need to be higher and more land will go to arable farming (Lesschen et al., 2020).

As far as the arable area is concerned, in the extensive package (either *Nature inclusive intended* or *Nature inclusive stricter*), the area of open field horticulture and arable vegetables (including onions) will increase by 25% compared to now, and the area of tree cultivation (fruit and tree nursery) remains the same as currently. However, flower bulbs will no longer be part of the cultivation plan. For the remaining area, a shift from potatoes and sugar beet to cereals and possibly herbaceous crops like fibre hemp and miscanthus is foreseen, as an implementation of a more extensive arable farming plan. In addition, with good management, the use of artificial fertiliser can be reduced and less tillage is required.

The extensive package of mitigation measures is based on the principles of nature-inclusive management. This goes hand in hand with a very limited increase in productivity, a reduction in the use of external inputs and more space for grazing and free-range farming. Further emission reductions will have to follow from the reduction in production volume (less livestock or a larger area of nature).

In this sense, nature-inclusive agriculture certainly has common ground with circular agriculture, although there are also differences. Solar panels and reuse of residual heat, for example, fit perfectly into circular agriculture, but they have little to do with nature-inclusive agriculture. On the other hand, management for meadow birds contributes to nature inclusiveness, but not to circular agriculture.[199] Nevertheless, the nature-inclusive scenarios used in Lesschen et al. (2020) will give an indication of the direction of circular scenarios. Crops like flax, hemp, miscanthus, reed and cereals (straw) can contribute to both circular agriculture and/or biodiversity.

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[199] https://edepot.wur.nl/521302

What do we take from this? Although the study by Lesschen et al. (2020) is not spatially explicit, it suggests that the area of arable land will decrease over time. At the same time, in the extensive scenarios (either *Nature inclusive intended* or *Nature inclusive stricter*), there is room to implement a more extensive farming plan, without flower bulbs and with a larger area of cereals and herbaceous crops instead of potatoes and sugar beets. Ultimately, how many herbaceous crops will be grown in the Netherlands will depend for a large part on demand (both within the Netherlands and abroad), and thus on what price farmers will get for their produce.

Reasons to expect a substantial increase of cultivation of herbaceous crops are:

- Contribution to the bioeconomy, and therefore contribution to policy goals (see 3.1).
- Storage of carbon (climate goals) and linked to that the carbon market on which farmers may obtain an extra income. When the price of carbon rises, it becomes more interesting to cultivate these crops for e.g. building products.
- Less inputs like pesticides and fertilizer and less tillage are required for (some of) these crops (contribution to a solution of the nitrogen crisis, and a more nature-inclusive agriculture).

Reasons to <u>not</u> expect a substantial increase of cultivation are:

- There are not many facilities (yet) to manufacture bio-based products in the Netherlands. So, there is not much internal demand for feedstock.
- The current relatively low value of the crops (i.e. euros earned per ha), compared to livestock, flowers, and horticulture.
- There are many other claims for the limited amount of land in the Netherlands, both from within and outside the agricultural sector. Examples from within the agricultural sector are: extensification of the sector, and the discussion about protein transition, which is the replacement of proteins from livestock by vegetable proteins, and thus a smaller stock of cattle. At the one hand, less cattle could imply that there is less land needed for the production of feed, like grain corn and cereal. At the other hand, extensification of dairy farming means that more grassland is needed per cow for grazing. Thus a smaller livestock does not automatically imply that there will be more land available for other crops like herbaceous. On top of that, there are also claims from outside the agricultural sector, such as housing, nature, and the energy transition, e.g. more solar panels and wind turbines.

Sometimes different policy goals may not be attainable at the same time. This is called trade-offs. Some trade-offs concerning policy goals towards a bio-based economy and other, conflicting policy goals, are:

- There may be a trade-off between policy goals towards biodiversity conservation and bio-based economy. For example, Miscanthus (positive for soil; negative regarding multi-annual land use) is an exotic plant and does not support much biodiversity. Another example is either mowing verge grass regularly for harvesting biomass or skip mowing turns because of insects.
- There might be a trade-off between bio-based residuals like straw used for soil improvement versus use for bio-based products. However, this trade-off does not have to exist. For example, straw can be used for animal bedding and subsequently mushroom cultivation, and after the cultivation, so-called mushroom compost remains, which is a high-quality compost for the soil. To use a resource in a consecutive manner and therefore make use of its value as long as possible is called cascading, and cascading is an important aspect of circular economy. Nevertheless, not all straw is needed for mushroom cultivation and many bio-based products based on straw are no longer suitable for soil improvement, e.g. construction materials.
- Bio-based resources for energy (in order to fulfill international agreements on sustainable energy) instead of bio-based products. Here also cascading is an issue. It is better to use biomass first for bio-based products and finally use it for energy.

4.2.1 Conclusions

We conclude from the above that the main reason to expect that the cultivation of herbaceous crops will increase substantially, lies in its potential to contribute to the circular economy and the use of biobased materials to replace fossil feedstock (circular economy policy goals), the storage of carbon (climate goals), and using less inputs like pesticides and fertilizer and less tillage (environmental goals).

However, there are not yet many facilities to manufacture bio-based products in the Netherlands, the internal demand is low, and the value of herbaceous crops is relatively low compared to livestock, flowers, and horticulture. Moreover, there are many other claims for the limited amount of land in the Netherlands, both from within and outside the agricultural sector. To stimulate a transition towards producing more herbaceous crops in the Netherlands, the government should come up with financial incentives and regulations in order to streamline and kick-start the triple requirement to establish such new value chains: increased cultivation of the feedstock, increased demand for circular and biobased products, and building conversion facilities.

4.3 Matching supply and demand in 2050

This section reviews how the estimated future feedstock demand for a range of applications (section 4.1) potentially can be matched with local primary feedstock production, considering regional or national scales, and the land area required for that.[200]

Table 15 shows an estimated potential demand for herbaceous feedstock in different applications. Starting with underutilised feedstock (verge grass, reed, etc), it can be concluded that for replacing 50% of insulation by verge grass based materials, about 40% of national production could be used for this application. In addition, if 25% of domestic virgin pulp consumption could be supplied by verge grass, the other 60% of national production could be used. However, the typical conversion scale for pulping fibres is larger than demand by Dutch paper industry.

Currently used wood feedstock for manufacturing panels and boards could be partly replaced by cereal straw and reed. The current reed production of 94,000 ton could cover about 25% of the demand, assuming a potential 50% replacement of wood based feedstock. The remaining 281,000 ton could be based on cereal straw. This is the same order of magnitude as the amount of straw incorporated into the soil directly (section 2.1.5), and which could eventually be used if soil carbon content could be maintained in another way. If hemp would be part of the crop rotation, the extensive and deep rooting of hemp may allow higher removal shares for cereal straw.

About 43.000ha of hemp/flax would need to be cultivated to match the demand for replacing 25% of current textiles consumption. When we include 50% of 100,000 buildings per annum with biocomposite facades, an additional 1,875 ha of flax/hemp would be required.

If verge grass and cereal straw could not be utilised for insulation, paper pulp and particle boards, additional area would be required to cultivate the replacing feedstock. E.g. additional 41,000 ha of flax/hemp would be required to replace 50% of current insulation materials. And covering 25% of virgin paper pulp consumption in the Netherlands by Miscanthus would require about 24,000 ha. When cereal straw would be unavailable for use in panel and boards production, and if reed would be used, additional 3 times the present reed production from large areas in the Netherlands would be required, adding up to about 56,000 ha of reed additionally.

The required volumes and areas relate to partial replacement only. If 100% replacement would be the goal, the following areas would be required additional to the above figures: 130,000 ha of flax/hemp for textiles and composite facades; 75,000 ha of reed for panels & boards; 72,000 ha of Miscanthus for paper pulp.

An indication of typical scales of conversion technologies is given in Table 15 to put in perspective the feasibility of establishing dedicated facilities in the Netherlands. For textiles, insulation materials, animal bedding and even for panels & boards, the volumes are similar or larger than typical sizes of production facilities. So the size of these facilities for the Dutch market is not a limitation.

[200] It may be noted that all these data are estimates. The assumptions have been indicated, so that everyone can easily make their own indicative demand and potential production volumes by changing assumptions to their own insights.

To illustrate the current increase in demand for herbaceous feedstocks, several examples may be mentioned. The relatively high prices for flax and hemp feedstock over the last few years (2020 – 2022) indicate a steadily increasing demand. Vibers b.v. sees an increasing demand for Miscanthus in packaging.

From the above it becomes clear that tens of thousands of ha are required to produce hundreds of thousands of tons of feedstock to only partially replace current demand in several applications. As far as verge grass and reed can be used as feedstock, this would not require increased land use or conversion of land use. However, even if verge grass, reed and cereal straw which is currently ploughed under the soil can be used for insulation, paper pulp and particle boards, about 50,000 ha of flax/hemp would be required to replace 25% of currently used feedstock for textiles. If verge grass would remain a waste and could not be used in industrial applications, e.g. additional 65,000 ha would be required for growing flax/hemp for 50% replacement of insulation and Miscanthus for paper pulp for 25% replacement of paper pulp.
At the same time it should be noted that the above data refer to 25 – 50% replacement of fossil and imported biobased feedstock demand only. Full 100% replacement would require additional 277,000 ha.

This production will compete with other land uses. Yet, such crops have a positive effect on biodiversity compared to traditional crops (potatoes, sugar beets, cereals, corn, meadow grass).[201] Reed could be cultivated on grassland area which would be taken out of production in a 'strict nature inclusive' scenario (about 450,000 ha, Figure 7) and if groundwater level will be increased. Hemp and Miscanthus could be an alternative in regions where there is a need to reduce nitrogen emissions.

4.3.1 Conclusions

In order to cultivate or harvest biofeedstock in the Netherlands to replace 25 to 50% of the fossil feedstock used for textiles, insulation, facades, panels & boards and paper pulp, about 50,000 ha of land would be needed, next to full use of current verge grass and reed production as well as use of the large amount of cereal straw which is currently directly ploughed under the soil. At higher replacement shares, up to 327,000 ha would be required. At the same time flax, hemp, Miscanthus, and reed should have a positive effect on biodiversity over traditional crops, thus contributing to nature values.

[201] https://www.rvo.nl/sites/default/files/2018/03/Tabel-1-Stikstofgebruiksnormen-2018.pdf

Table 15 ***Estimated potential demand for herbaceous feedstock in different applications at given replacement shares. Also, the typical conversion scale relative to material/product demand is indicated.***

Application	**Current consumption (ton/a)**	**Anticipated Replacement share**	**Feedstock required for replacement (ton/a)**	**Feedstock productivity (ton/ha)**	**Required cultivation area (ha/a)**	**Current feedstock production (ton/a)**	**Current feedstock production (ha/a)**	**Required volume relative to current production (-)**	**Typical scale of conversion (ton/a)**	**Typical conversion scale relative to demand (-)**
Textiles	343,000	25% of total textiles by flax and hemp	85,750	2	42,875		4,000	11x	1,000 – 6,250	5 – 30%
Insulation	163,200 (23 Mio m^2 mineral wool + 28 Mio m^2 polymer insulation; 8 cm thick, 40 kg/m^3)	50% by flax and hemp	81,600	2	40,800		4,000	10x	1,000 – 11,000	1 – 13%
		50% by verge grass	163,200 (at 50% biorefinery yield)			415,000		40%		
Composites for Facades	15,000* (100,000 houses/a, 50 m^2/house, 5 mm thick, 1200 kg/m^3, 50 wt.% fibre)	50% by flax and hemp	3,750	2	1,875		4,000	47%	2,000 – 4,000	50 – 100%
Other Composites	6,200 (GFT+LFT at 50% fibre)	25% by flax and hemp	775	2	388		4,000	10%	2,000 – 4,000	2 – 5x
	18,200 (WPC at 60% fibre)	50% by straw	5,460	4	1,365		150,000	1%	8,000	1.5x
		50% by reed	5,460			100,000		5%		
		50% by miscanthus	5,460	10	546		1,025	53%		

* Volume required at given assumptions.

Table 15 ***(Continued)Estimated potential demand for herbaceous feedstock in different applications at given replacement shares. Also, the typical conversion scale relative to material/product demand is indicated.***

Application	Current consumption (ton/a)	Anticipated Replacement share	Feedstock required for replacement (ton/a)	Feedstock productivity (ton/ha)	Required cultivation area (ha/a)	Current feedstock production (ton/a)	Current feedstock production (ha/a)	Required volume relative to current production (-)	Typical scale of conversion (ton/a)	Typical conversion scale relative to demand (-)
Panels & boards	750,000	50% by straw	375,000	4	93,750		150,000	63%	30,000 – 450,000	10 – 100%
		50% by reed	375,000	5		94,000		4x		
Paper pulp	480,000								400,000 – 2,000,000	1 – 4x
Paper	2,900,000 (480,000 virgin pulp)	25% by verge grass	240,000 (at 50% biorefinery yield)			415,000		58%	40,000 – 100,000	17 – 42%
		25% by miscanthus	240,000 (at 50% biorefinery yield)	10	24,000		1,025	23x		
Animal bedding	550,000 (200 kton saw dust and 350 kton straw)	50% by verge grass	275,000			400,000		69%	2,000 – 23,000	1 – 10%
		50% by reed	275,000			94,000		2.9x		

5 Activities needed to accelerate circular use of herbaceous feedstock

5.1 SWOT Analysis

This SWOT focusses on the use of herbaceous feedstock for regional conversion into bio-based applications, considering quality, volumes, drivers. For each feedstock, a separate SWOT has been prepared.

5.1.1 General

Strengths

- Several herbaceous crops contribute to increase of carbon content in soil via roots. Depending on the actual soil composition, increased carbon content may improve soil quality. Perennial crops like Miscanthus store a significant amount of carbon in the soil. Biomass like straw, reed and verge grass may be ploughed under the soil, preferably after utilising in another application like e.g. animal bedding.
- Herbaceous crops contain characteristics and components which are proven to be considerable alternatives for fossil based resources.
- The Netherlands landscape, soils and climate is very suitable for growing herbaceous crops.
- Herbaceous crops partly grow outside cultivated agricultural land, for example in nature areas, in wet conditions and on non-fertile soils.

Weaknesses

- Small scaled production; small volumes.
- Biomass collected from nature management areas often consists of a variety of components (reed contains twigs; verge grass contains all kinds of herbs), while industrial conversion into products prefers to start from uniform feedstock for reason of process stability and product quality.
- No large demands, fragmentation in applications; niche markets.
- Facilities for processing are often missing.
- High agricultural land prices in the Netherlands add to costs of biofeedstock production, thus reducing competitiveness with foreign countries.
    - E.g. one (of 3) flax processors in the Netherlands cultivates 75% of its flax in France for cost reasons.[5]
- Regional value chains may typically involve smaller processing volumes compared to global value chains, which generally implies higher costs per volume of products (due to economies of scale) and more challenges to establish a competitive level of knowledge.
- Many policy agendas and strategies provide a direction only, whereas widespread establishment of bioeconomy (and required innovation and development) requires clear specializations, targets, support schemes and investments.

Opportunities

- In the growth season, herbaceous crops capture CO_2 from the atmosphere. When utilising the herbaceous feedstock in a product for a long period (e.g. in buildings), the CO_2 is stored, which may be regarded as a negative CO_2 emission or a sink.
- Diversification of crops may contribute to increase of biodiversity.
- Herbaceous biomass as new/renewed feedstock may contribute to a circular economy and circular farming.
- There is a growing interest on the demand side; public sector (policy frameworks as Green deal), companies and society are searching for alternatives for fossil-based resources and products.

- Climate change and climate adaptation measures will lead to increasing opportunities for growing herbaceous crops. Some herbaceous crops grow very well in wet circumstances, some do well in dry circumstances. Some herbaceous may be better suited to climate change than current crops.
- Less livestock as a result of nitrogen crisis will lead to more space available for growing herbaceous crops.
- Human capacities are scarce in the Netherlands. Some herbaceous grow very extensively and do not require much labour.

Threats

- Competition with food.
- Competition with nature.
- Consumers lack confidence in innovative new materials with limited (known) track record, especially for building and construction purposes.
- Simultaneous development of new products, production of required feedstock and market demand requires huge investment and long-term approach.
    - This is even more challenging for multi annual crops like Miscanthus than for annual crops like flax and hemp.

5.1.2 Flax

Strengths

- The climate (and soil) in the Netherlands is very well suited for growing high quality fibre flax.
- The Dutch climate conditions are generally well suited for dew retting on field.
- Fibre flax is a well-established crop in (southwest of) the Netherlands with a long standing tradition.
- Fibre flax delivers several products, like long fibres, short fibres, shives and linseed. Consequently, flax sector operates on different markets with different market prices. As a result, the sector is not dependent on just one market (price) and in principle more resilient.

Weaknesses

- Fibre flax markets are affected by fashion trends, especially with respect to clothing, causing strong price fluctuations.
- Fibre flax is relatively expensive to produce.
- As a consequence, fibre flax products are more expensive than e.g. products with cotton or fossil based textile fibres, making it a premium product, for a niche market.
- The profitability of flax is similar to that of cereals and grass seed, crops that are grown quite a lot in this region. Therefore, it will compete especially with these crops for land use.
- The Netherlands has a relatively low fibre flax production in terms of hectares compared to Belgium and France.
- The fibre flax processing industry in the Netherlands is small compared to Belgium and especially France. In the Netherlands only 3 – 4 processors are still in business.
- Long fibre flax is exported, mainly to China, for processing into yarns and fabrics. This strong interdependency could be a weakness, for example in times of crises.
- Producing oil flax is unattractive due to low margins and fierce competition from Canada, Russia and other countries.
- Processing of flax into high quality yarns (and fabrics) has moved to Asia because of low wages. Result is that knowledge about textile production has decreased in the Netherlands.
- Automotive industry, key user of composites based on biofibres like flax (and hemp), is located in France and Germany and wishes suppliers to be located next door. Even if Dutch flax (and hemp) fibres are applied in these composites, such lean manufacturing principles pose a barrier for regional value chains.
- Related to the previous 2 topics: Innovative materials like so called unidirectional (UD) flax fibre fabric for high performance composites were developed in France and Belgium, and not in the Netherlands.

Opportunities

- Fibre flax is biobased and has a smaller environmental footprint than other resources, like cotton (lower use of fertilizer and crop protection agents) and synthetic fibres (lower GHG emissions).
- Fibre flax is produced mostly in the EU, but spinning and weaving is often done outside of Europe. If spinning and weaving would be established locally, this would be in line with the preference for locally produced feedstock.
- There are opportunities for reshoring to Western Europe, since there is still knowledge on small-scale processing (spinning mills) in France.
- In the light of the (current) nitrogen crisis, it would be beneficial to put flax (and hemp) production in a rotation instead of for example cereals, since flax (and hemp) requires low nitrogen soils; and at a lower nitrogen dose to the soil, emissions to the air will be lower as well.
- Flax fibre based mats are applied in small quantities as insulation material for buildings. As building with natural materials becomes more customary, the share of flax fibre based insulation may increase significantly.
- Fibre reinforced composites are applied because of their high strength and stiffness. Composites based on natural fibre based like flax (and hemp) offer high stiffness relative to a low density, when compared to much used glass fibres. This is an advantage in e.g. transportation sector. The strength of these natural fibres, however, is still lower compared to glass fibres due to unfavourable structure. The structure of flax (and hemp) fibres may be improved by developing technology which allows production of fibres with a structure more similar to fibre glass.

Threats

- Crises like Covid-19 and the Ukrainian conflict have shown vulnerability for interdependencies, like the global value chains (exporting fibres to China, and importing back yarn and fabrics).
- Textile is fashion, which faces cycles of demand and resulting fluctuations in prices for feedstock.
- If feedstock prices tend to go up, recent history shows that cultivation area in NL does not increase, whereas it does in France (and to a lesser extent in Belgium). This relates to high land prices in the Netherlands.

5.1.3 Hemp

Strengths

- Hemp is a high yielding, low maintenance fibre crop.
- Hemp improves soil structure by its roots. At the same time it improves soil quality as roots bring carbon to the soil.
- The climate in the Netherlands is very well suited for growing high quality fibre hemp.
- The Dutch climate conditions are basically suited for dew retting on field.
- Fibre hemp is a well-established crop in (northeast of) the Netherlands since a couple of decades.
- Fibre hemp delivers several products, like long fibres and shives. Consequently, the sector operates on different markets with different market prices. As a result, the sector is not dependent on just one market (price) and in principle more resilient.

Weaknesses

- The THC-content of fibre hemp needs to be below 0,3% according to EU regulations. This limits the number of varieties which may be cultivated, and as a result decreases multi-use options for hemp.
- Hemp in North-Western Europe is fully mature, including the seeds, only in October. This is too late in the season to allow proper drying of the stems after retting. Therefore, hemp in the Netherlands is usually mown in August and harvested in September.
- Hemp fibre is more coarse than flax fibre, which makes it less favourable for use in clothing.
- Low density of hemp stems limits transportation distance to conversion facilities. Scale of cultivation and scale of processing need to match.
- Fibre hemp competes especially with cereals, sugar beets and starch potatoes in the farmer's cultivation plan.

- The Netherlands has a relatively low fibre hemp production in terms of hectares compared to e.g. France.
- The fibre hemp processing industry in the Netherlands is relatively small, with only 2 processors in business.
- Automotive industry, key user of composites based on biofibres like flax and hemp, is located in France and Germany and wishes suppliers to be located next door. Even if Dutch hemp and flax fibres are applied in these composites, such lean manufacturing principles pose a barrier for regional value chains.

Opportunities

- Alignment of Dutch regulation with EU regulation would allow to valorise flowers and leaves for CBD, thus increasing total crop use and profitability.
- If higher THC-contents were to be allowed (EU regulation), more fibre hemp varieties would be allowed to be cultivated, thus increasing valorisation options, like higher CBD content.
- To improve retting control, green decortication in combination with degumming at industrial scale could be developed.
- Another route could be so called stem retting. Upright stems will dry more easy compared to laying on the ground, thus potentially allowing harvesting and retting later in the season. To such extent that seeds can be harvested, next to high amount of relatively coarse hemp fibre and shives.
- ‘Cottonisation’ of hemp fibre using (bio)chemical extraction techniques could be developed in order to (partially) replace cotton. Cottonisation is the process to convert bast fibres like flax and hemp into their plant cell fibres which resemble cotton regarding length and diameter.
- Hemp fibre based mats are applied in small quantities as insulation material for buildings. As building with natural materials becomes more customary, the share of hemp fibre based insulation may increase significantly.
- Fibre hemp has a reported smaller environmental footprint than most other fibre resources, like cotton and synthetic fibres.
- Light weight non-load bearing breathable insulation materials based on lime-bonded hemp shives production can be increased. A limiting factor is the relatively low curing rate.
- In the light of the (current) nitrogen crisis, it would be beneficial to put fibre hemp production in a rotation instead of for example cereals. Fibre hemp can take up nutrients from deeper soil layers through its deep rooting and thus requires lower nitrogen dose, with less emissions to the air and neighbouring nature areas.
- Fibre reinforced composites are applied because of their high strength and stiffness. Composites based on natural fibre based like hemp (and flax) offer high stiffness relative to a low density, when compared to much used glass fibres. This is an advantage in e.g. transportation sector. The strength of these natural fibres, however, is still lower compared to glass fibres due to unfavourable structure. The structure of hemp fibres may be improved by developing technology which allows production of fibres with a structure more similar to fibre glass.
- In general, there is a growing demand and expectations of hemp.

Threats

- When rules and restrictions around fibre hemp will not be adapted, all things hemp will stay the way it is.

5.1.4 Miscanthus

Strengths

- Growths on unfertile soils, may be grown on land that is not in use for arable farming.
- Requires limited to no inputs (manure (N) or water).
- Minimal labour needed for production and harvesting.
- Fast growing, highly productive, lignocellulose crop.
- While growing fast, captures much CO_2 from the air.
- Contributes to (temporary) CO_2 sequestration in soil, as a result of extensive root system which is not degrading as long as the plant is growing. CO_2 storage deep in soil will last long.

- Soil improvement for next crops; however then CO_2 stored in the roots starts to emit to the atmosphere again.
- Many potential applications: paper, construction materials (panels).
- Relation with biodiversity: Non-native but provides shelter for many species especially during winter and summer.

Weakness
- Production area is limited currently.
- Difficult to scale up to large scale production, due to other land claims, high land prices and competition with food.
- Takes about 3 years before the crop can be harvested.
- Crop may be polluted when growing on industrial sites.
- Large scale pulp and paper producers will only use miscanthus if there is lot of supply and demand and, more importantly, a competitive price.
- As long as the crop is 'small', this requires small and flexible production lines. These are not available in mainstream industries.
- Permanent crop, does not fit in the traditional rotation.

Opportunities
- Growing awareness of Miscanthus characteristics, in the Netherlands, but also globally
- Main demand coming from construction sector and packaging, which are searching for sustainable and CO_2 neutral alternatives.
- Much knowledge on miscanthus and valorization options available.
- Existence of some Miscanthus start-up companies and processing facilities in the Netherlands.
- May fit a low N input future agriculture. Compensation for more intensive production activities.
- Low input crop can be a solution for farmers who are stopping their business. Growing miscanthus can also be combined with another job.

Threats
- Growing pressure on space for different functions; limiting available land for Miscanthus production.
- Biomass has a relatively low value. The quality characteristics are limited for high value.
- Climate change, heavy rainfall and flooding. Wet circumstances are not in favour of growing Miscanthus

5.1.5 Reed

Strengths
- Reed (1 year old, often privately managed) grown in the Netherlands is suitable and used for thatching.
- Reed production in nature conservation areas does not need addition of nutrients.
    - Though not suitable for thatching.
- Dutch nature organisations and the private reed growing and utilisation (thatching) sector have a good knowledge base on reed.
- Reed production, in particular in nature management areas, contributes to nature conservation and biodiversity.

Weaknesses
- Nature conservation conditions do not match with the utilization of one year reed required for thatching applications.
- 80% of the reed used for thatching in the Netherlands is imported from abroad, mainly China, only 20% comes from local production. This relates to required quality.
- Multi-annual reed from nature management areas consists of 1 – 3 year old reed stems, and consequently shows relatively large variation in quality.
- Multi-annual reed is not a mono stream, but contaminated with twigs, herbs, etc.

Opportunities

- Only a small fraction of reed grown in the Netherlands is used for thatching. Technologies to upgrade local reed may be developed.
- A large fraction of multi-annual reed is composted, directly ploughed under the soil by farmers or even incinerated. First using it in other applications like animal bedding would optimise feedstock use and increase circularity, and reduce imports of e.g. cereal straw used as animal bedding. Alternatively, the straw may be used for building and construction.
- Multi-annual reed could be a suitable feedstock for basic quality particle board production. The annually harvestable amount of multi annual reed is in the same order as required for a small scale particle board plant (30 kton/a).
- Increasing the water level in peatland in order to avoid further CO_2 emissions will lead to more wetlands, and consequently more space for e.g. reed production.

Threats

- Residues from nature management cannot be used automatically for other applications, due to waste regulations.
- Crises like Covid-19 have shown vulnerability for interdependencies, like importing reed from China.
- Whereas (multi-annual) reed is harvested seasonally in the period February-March, utilisation in e.g. particle boards requires establishing a logistical chain: collection from swamp areas, drying in cold period of the year, storage. Comparing to a more or less similar type of feedstock like cereal straw, mowing is done simultaneously with cereal harvesting, collection on land allows using heavy machines, residual drying generally does not pose a problem in full summer.

5.1.6 Straw

Strengths

- Straw is widely available as a co-product of cereal production for food and feed.
- Straw is useful feedstock for wide range of applications: feed, animal bedding, protecting tulip bulbs and strawberries, mushroom production, soil fertilizer. Further it is demonstrated as an insulating wall for housing.
- When using straw for subsequently horse bedding, mushroom production and finally soil fertilizer, it is a nice example of sequential cascading use.

Weaknesses

- In the Netherlands, more than half of harvestable straw is left on the field and ploughed under to maintain organic material content in the soil, while it is not exactly clear how much organic matter is required in the soil.

Opportunities

- If all harvestable straw could be used in current applications, (large) imports could be reduced by about 80%.
- Cereal straw has relatively hydrophobic characteristics compared to other lignocellulosic feedstock, which makes it suitable for production of panels and boards for use in the construction sector, e.g. in so called wet environment in buildings like bathrooms.
- With increased interest to use other herbaceous biomass for animal bedding, like reed from nature management areas, increasing volumes of cereal straw may become available for other applications.
- Miscanthus production does not need addition of manure, thus offering an opportunity for a low nitrogen agricultural system.

Threats

- Drought decreases straw yield and increases demand due to decreased hay production.
- When removing more biomass residues from the field as biofeedstock for bioeconomy applications, required carbon content in the soil may decrease below critical level.
    - What is this critical level? How much biomass in ton/ha.a needs to be left in the field or brought back to the field to maintain the required soil carbon content?

- Cereals cultivated in the Netherlands are basically used for feed, however, forced by the so called nitrogen crisis, the amount of livestock is under pressure.

5.1.7 Verge grass

Strengths:

- Verge grass is the result of nature management of nature areas, verges, banks and the like, so there are no additional costs involved to obtain the biomass feedstock, that is other costs than the nature management costs.
- Verge grass is not grown as a crop, but it is somewhat a co-product of managing roads and waterways. Therefore, it does not have to compete with (other) crops or other types of land use.
- Floodplains can be grazed by livestock during spring and summer.

Weaknesses:

- The volume and quality of the harvest is very variable, depending on for example the weather conditions and availability of nutrients (it is not managed like an agricultural crop).
- The biomass collected often contains a significant share of sand.
- A small scale conventional pulp mill requires about double the total amount of Miscanthus and verge grass presently harvested in the Netherlands.

Opportunities:

- A significant amount of nature grass and verge grass is underutilized.
- Mowed grass is currently discharged at compost sites at a gatefee, which is a cost to the mowers and in the end road owners who would like to get rid of that cost and turn it into a neutral or positive value.
- New outlets such as paper and board, insulation material and composites, and feed for ruminants are developed in pilot trials.
- The protein transition may lead to new opportunities for verge grass. Early mowed, clean nature (and verge) grass contains proteins, a valuable component in animal feed.
- Small scale mobile processing equipment for separating protein and fibre from grass have been developed, but not yet implemented on commercial scale.
- Utilisation of nature and verge grass is on the agenda of public sector, waterboards etc.

Threats:

- Potential biofeedstock like verge grass is legally considered waste, which currently hampers utilisation in products like e.g. paper.

5.2 Main points of attention

In order to derive the main points of attention from the SWOT (step 1), the resulting elements from the SWOT inventory are analysed by relating the internal factors (strengths and weaknesses) and external factors (opportunities and threats) to each other into a so called a confrontation matrix (Step 2).[202] The SWOT elements may be 'prioritized' in order to provide focus to the exercise of relating internal and external factors. This confrontation results in main points of attention.

Depending on the combinations of the internal and external factors, the direction of a strategy to address the points of attention may be found from the following different strategies: 'attack', 'defend', 'maintain' and 'back-off' (Figure 8). Next, possible options to address each main point of attention from different approaches and viewpoints will be generated (step 3). Finally, the most appropriate options to address the main points of attention form the basis for the concrete action plan (step 4). The last 2 steps will be addressed in section 5.3.

[202] Santema et al., 1997. Succesvolle marketingplannen. Denken, kiezen, doen. F & G Publishing, Utrecht. 169 p.

	Opportunities O1 O2 O3	Threats T1 T2 T3
Strengths S1 S2 S3	'Attack'	'Defend'
Weaknesses W1 W2 W3	'Maintain'	'Back-off'

Figure 8 Type of strategies to address points of attention for specific relations between internal and external SWOT factors in the confrontation matrix (source: Santema et al. 1997).[202]

Main points of attention (MPA) and possible actions per type of herbaceous feedstock are presented below.

5.2.1 General

- MPA: How can the increase of carbon capturing and sequestration by growing herbaceous crops be stimulated, in order to contribute to meeting the climate mitigation objectives? How can this be aligned with meeting biodiversity objectives and production for food and (building) materials, while taking into account land use practices, land prices and public and private values?
    - Need: Knowledge-based and policy-supporting research towards the optimal configuration of land use and the production of public and private values needs to be carried out.
- MPA: How can the valorization of herbaceous crops into new products be optimized, in a way that it will be an alternative for fossil-based products, and how can the optimal conditions for their production be created (facilities, policies, supportive services, skills, scale)?
    - Need: Explore and demonstrate opportunities for valorization of herbaceous crops, from the perspective of specific biomass/crop and from the demand side (sector, for example construction). For this, partners from public sector, private sector, and knowledge institutes, need to collaborate. In addition a regional perspective may be explored.

5.2.2 Flax

- MPA: How can the low environmental impact of high quality flax fibre production in the Netherlands compared to cotton and fossil-based polyester fibres be used to stimulate demand for fibre flax and to serve generally increasing demand for sustainable fashion by establishing regional linen production?
    - Need: Stimulate and respond to the global trend of reshoring of spinning and textile processing industries, in order to be more resilient and reduce risks regarding lock downs, global transportation issues, and also avoid high transportation costs.
- MPA: How can the cultivation of fibre flax in the Netherlands with its relatively low demand for fertilizers (manure) compared to traditional crops (potatoes, cereals, corn, sugar beets) benefit from stricter policies on animal husbandry (reduced number of animals)?
    - Need: Quantify the sustainability benefits of fibre flax cultivation in areas where reduced 'nitrogen' emissions need to be realised. Communicate and stimulate the option of cultivating and processing fibre flax in promising regions.

5.2.3 Hemp

- MPA: How can more knowledge about effects of higher THC-contents in fibre hemp support the process of adaptation of EU regulations to increase multi-use options for fibre hemp?
  - Need: Investigate consequences of increasing maximum allowed THC-content in fibre hemp.
  - Need: If higher THC-content does not come with higher human health risks for workers in the fibre hemp sector, EU regulation may be adapted.
- MPA: How can positive aspects of hemp (improving soil quality, multi-purpose crop) help to establish more processing facilities and primary production volume (limited transportation distance) to help meet sustainable building product demand (many houses need to be built)?
  - Need: Stimulate establishment of one or more regional production chains.

5.2.4 Miscanthus

- MPA: How can Miscanthus become an attractive crop to grow in the Netherlands, producing large volumes of biomass, nearly without any additional fertilizers (low N, P and K), while supporting the 'nitrogen' emission challenge?
  - Need: Assess what role miscanthus can play in future low nitrogen agricultural setting at farm level or at regional level, in combination with livestock and other crops. How to interest farmers, and how to support farmers in changing agricultural practice. Explore potential valorization routes and upscaling activities. Direction of search: biobased building (construction and insulation) materials, paper industry.

5.2.5 Reed

- MPA: How can multi annual reed be utilized as animal bedding and subsequently as soil fertilizer, while substituting cereal straw, thus allowing to minimize cereal straw imports and increasing straw removed from the land?
  - Need: Investigate the suitability of reed as animal bedding considering different aspects: Different stable systems; animal welfare; do animals 'like' the reed bed; combination with cereal straw and/or wood shavings; soil fertilizer qualities after use.
- MPA: How can the following aspects be combined: Increasing water level on peat lands (related to climate change/climate mitigation and adaptation); cultivation of crops like reed as a bio-based feedstock for construction materials (particle boards and thatching); and increased biodiversity (increased variety of cropping systems)?
  - Need: Explore possibilities, potential, benefits and risks of cultivation of crops like reed (or e.g. cattail) on peatlands at different conditions: higher water level; after excavating soil; using fertilizers.

5.2.6 Straw

- MPA: How can (expected increased) demand for widely applicable cereal straw for bio-based applications be (partly) regionally matched by increased collection of harvestable straw?
  - Need: Investigate how recycling loops may be established and how much and what quality of organic matter needs to be brought to the soil in order to maintain soil health on the long run.
- MPA: How can competition from other (herbaceous) feedstock for animal bedding market result in cereal straw to be utilised for bio-based building products?
  - Need: Support utilisation of sustainable bio-based building products by e.g. true pricing and support the development of technologies for high-rate production of straw-based building products.

5.2.7 Verge grass

- MPA: Considering that verge grass does not compete with agricultural crops e.g. for food production, and can be made available nearly for free, but is currently considered waste: How

can the potential of verge grass be fully utilised for feed and (much demanded) bio-based (building) applications?
    - Need: Modify the waste regulation on verge grass in such a way that safe utilisation of the herbaceous biomass can be realised in applications such as feed, paper & board and insulation materials, which have been proven on pilot scale.
- MPA: How can the relatively low quality of verge grass (variation in composition, sand), which is available in high quantities spread over the country, be tackled to make it suitable feedstock for growingly demanded building materials?
    - Need: Develop new mowing techniques and a grading system for variation in composition, which allow trading of verge grass batches suitable for efficient industrial conversion into different products.

5.3 Logical steps: Action plan

In this report herbaceous crops have been reviewed for their current production and use, and for their potential in the future. Current production and use are small, potential is high, especially in the light of the societal switch to move towards a more sustainable agriculture as well as a more sustainable society in general (textiles, building materials, etc.).

Dutch agriculture will have to change over the next period, in order to become more sustainable:

- reduction of N emissions (low N crops); herbaceous crops like flax and hemp require less fertilizer, and consequently emit less nitrogen compared to traditional crops like corn and cereals.
- climate change mitigation (a.o. fossil free); herbaceous crops like flax and hemp are a low carbon emissions alternative to synthetic fibres.
- circular use of biomass will be necessary to have sufficient amount of renewable feedstock to replace fossil-based feedstock (also links to climate change); biomass is a renewable feedstock. Nutrients need to go back to the soil to retain production capacity, and materials are preferably utilised several times before being disposed of.

These aspects are also relevant for the construction and textiles sectors.

Herbaceous crops can contribute to address these issues. Based on the SWOT and the main points of attention (MPAs) derived from that, logical steps forward for a number of value chains based on the described herbaceous crops will be described in sections below. Also, actions to organise the transition are proposed.

5.3.1 Flax and hemp: Crops for textile and construction sector

Flax and hemp (and possibly nettle) may contribute to sustainable textiles (bast fibres) and building products (bast fibres and shives). Establishing a 'local' production chain in the Netherlands for e.g. 25% substitution of currently consumed fabrics would require upscaling of feedstock production by a factor of 10 and establishing spinning and weaving industry. The bast fibres can also be applied in strong and stiff composite facade elements, which can be combined with timber frame construction. The shives can be used for low density flax particle board with good flame retarding properties (production facility in the Netherlands existing for decades) or for hemp-lime non-constructive insulating walls (demonstrated in several houses).

Advantages:

- Flax and hemp cultivation requires less fertilizer compared to traditional crops, thus contributing to reduced nitrogen emissions. Hemp does not require pesticides, while cotton cultivation at the other hand uses a vast amount of pesticides.
- Flax and hemp require far less water during cultivation than cotton, and also less fertilizer and crop protection agents.
- Linen clothing is experienced as cool during hot summer periods.
- Flax and hemp fibres do not contribute to micro-plastics like plastic fibres in textile do.
- The estimated fibre volume demand matches well with the typical scale of spinning industry.

Requirements:

- Arable land is needed for cultivation. A trade-off decision needs to be made while improving biodiversity: cultivation of flax and hemp for the circular economy with less inputs and improved biodiversity compared to traditional agriculture; transforming agricultural land into nature; other land uses like construction of houses.
- Low quality, high impact, cheap textiles would need to be replaced by lower impact, high quality textiles. Regional production of flax and hemp could be a proper alternative. In the light of public awareness and corporate governance, the fashion industry could help promoting textile made from flax and hemp.
- Substitution of cotton and especially fossil based polyester and polyamide fibres by sustainable flax and hemp requires a key role for designers to translate options for these fibres into durable and suitable clothing and other textile products.
- Environmental impact of textiles would need to be made visible, like is done for construction of buildings through the so called 'environmental impact of buildings' ('Milieuprestatie gebouwen' in Dutch, MPG).
- Crop cultivation, establishing processing industry, and developing markets for high quality bast fibres for textiles on one hand, and lower quality fibres and the shives for insulation and composites for building and construction on the other hand would need to be organised in parallel. This will require coordination.

Further:

- Historically, flax ripens too late in the north of the Netherlands to allow proper field retting. However, proceeding climate change may improve conditions for favourable field retting of flax in the north.
- Hemp shive lime panels and walls offer thermal insulation, breathability and indoor moisture regulation at the same time. A faster curing process would need to be developed to increase production rate to a level which allows (modular) mass production.
- Used textiles may be used for insulation mats for buildings, and in another life the flax and hemp fibres may serve as a reinforcing fibre in composites. This would mean at least 3 lives. What would need to be developed is: 1) protection aids for insulation which would not negatively affect composite production, or rather contribute to composite performance, e.g. by using a flame retardant which performs well in insulation material as well as in composites for e.g. cladding; 2) or alternatively a procedure to efficiently and effectively remove and recycle protection aids from the insulation material prior to application in composites.
- The leaves contain up to 18% of protein, which makes it suitable for ruminant feed. However, hemp leaves are not on the list of allowed feed constituents. Independent investigation of the effects of (low) THC content in leaves of fibre hemp on cattle health and productivity will clarify potential benefits (or adverse effects) of using hemp leaves for feed.
- The perennial 'crop' nettle may come with interesting features like less tillage and therefore expected improved soil health and carbon storage. Nettle based textiles have been developed, however, would need substantial further development. Topics include improving cultivation and conversion yields.

5.3.2 Cereal straw and reed: Side and residue streams for construction sector

Cereal straw and reed can be used for making particle board and fibre board to replace imported wood-based boards, thus contributing to a more regional value chain.

Advantages:

- 1 Year old reed is very suitable for making particle boards, but also multi annual reed from nature management areas would offer feedstock for lower qualities particle board, thus contributing to both nature values as well as biofeedstock production for the circular economy, without using arable land.
- Instead of disposing off multi annual reed as a waste at certain cost, it can be a feedstock.
- Applying biobased feedstock for a long time in a building means storing CO_2 extracted from the atmosphere, which can be regarded as a temporarily negative CO_2 emission which means buying time to find solutions for climate change.
- Rising ground water levels in peatland areas to reduce e.g. CO_2 emissions and to stop subsidence may be used to increase reed cultivation. Or to grow cattail for e.g. insulation panels.

Requirements:

- Lab scale development has shown the technical potential of reed-based panel boards. Both increased reed production in peatland areas with raised ground water level, as well as increasing TRL level of reed-based particle boards would require simultaneous development. This will require coordination.
- Also cereal straw offers an excellent feedstock for making particle board with higher water resistance than conventional wood-based particle board, whereas nowadays a large fraction of the straw is ploughed under for soil quality considerations. What would need to be developed is a method to keep soil quality intact (and a clear 'definition' of what a healthy soil is) while utilising the straw, e.g. through converting the panels at end-of-life into biochar which can be added to agricultural soil.
- Binder systems in traditional wood-based boards are toxic or even suspected carcinogenic. More sustainable binder systems are being developed; however, they need further development to increase curing rate and strength performance closer to current industrial practice.

Further:

- Alternatively, (multi annual) reed for application as animal bedding may be developed further, thus creating space to use more cereal straw for boards.

5.3.3 Miscanthus: Crop for paper and construction sector

Miscanthus is a crop which can be used for paper pulp production to replace imported pulp, thus contributing to a more regional value chain. Miscanthus may also be used in basic composites for e.g. cladding for timber frame construction.

Advantages:

- Miscanthus is a multi-annual high yield crop which requires less tillage than annual crops (so far), while delivering much higher feedstock yields per ha per year than forest. At the same time it requires low amount of fertilizer, thus contributing to reduced nitrogen emissions.
- Miscanthus develops an extensive root system, thus contributing to carbon storage in the soil.

Requirements:

- For use in e.g. composites for facades, relatively small area is needed to produce required Miscanthus volume. For paper production, crop cultivation and establishing a state-of-the-art (large scale) pulping plant would need to be organised in parallel. This will require coordination.

5.3.4 Verge grass: Residue stream for paper and construction sector

Verge grass can be used for production of insulation material and for paper pulp production.

Advantages:

- It can be regarded as a side stream of roads and waterway management, thus providing biofeedstock for the circular economy, without using arable land.

Requirements:

- Verge grass comes with variation in composition (=quality) and adhering sand. Optimal use of verge grass requires development of mowing techniques which focus on collection of low inorganic content feedstock (e.g. kind of double mowing system) and development of grading system for variation in composition to facilitate 'trading' for conversion into further products.
- Verge grass is legally considered waste. It would need to be investigated to which extent verge grass poses hazardous effects when used in particular applications. Waste regulation would need to be modified such that safe utilisation can be guaranteed.

5.3.5 Actions organizationally

Transformation from a fossil-based economy and society requires an interplay between public sector, private sector, knowledge and society to set the right conditions for stimulating the uptake of using herbaceous instead of fossil-based resources for applications in different sectors and products. We have concluded that directions are set in the different policy frameworks, but the strategic choices of specializations, the collaborations between domains and the support of initiatives at the local (regional) level are missing. It is important to have dedicated support services for the specific transition towards a circular bio-economy. At the regional level transition support is needed for agricultural sector to grow

herbaceous, to invest in processing facilities and to support processing companies to valorize the crop components for new applications. At the same time, product demand needs to be bundled to give clear signals towards crop and residue producers and processing industry which levels of investments pay back. Also support services are needed to connect the different domains (public, private, knowledge and civil society) and to strengthen engagement and commitment. Further support of the innovation process is relevant, to bring new ideas and initiatives to grow and valorize herbaceous further towards exploration, and towards demonstration (scaling up). For a transition utilization of all available means is needed, but also to attract means from outside the region are important: a service organization which is able to mobilize and collect capacities, capabilities, knowledge and financials to support this innovation process. These are often intermediate organizations such as clusters or platforms, which needs to be suited to support the interplay and to find the synergies.
The action which should take place, based on the analysis and observations, is that for the different herbaceous crops and for the different Dutch potential production areas, strategic decision should be made to stimulate the production and valorization. Some decisions need to be made at National level, for example the decision to reward agriculture for capturing and sequestration of carbon, and to contribute to climate adaptation and or to the increase of biodiversity. Also to stimulate the use of biobased feedstock (circularity) above the use of fossil-based resources by producers of consumer goods by the implementation and operationalization of the Extended Producer Responsibility. These are important new frames for the uptake for a circular biobased economy and will lead to an equal level playing field for biobased, as externalities are nowadays to be seen as societal costs. Also at regional level, strategic decisions should be made about the smart specializations, based on the landscape characterizations, to grow specific herbaceous, as well to optimally use the economic structure, for processing and/or use of the biobased resources to process, apply or use these resources, in order to create added value, as well public as private, and in order to strengthen the regional profiles.

6 Conclusions

This report presents information on bio-based fibre feedstock availability and estimates for potential feedstock demand for realising circular applications in relation to typical relevant processing scales. Realising the transition to regional value chains requires making choices at regional level regarding where to focus on, and the required matching between feedstock availability related to product demand, and typical (economically feasible) conversion scales.

In order to cultivate or harvest biofeedstock in the Netherlands to replace 25 to 50% of the fossil feedstock and imported wood based feedstock used for textiles, insulation, facades, panels & boards and paper pulp, about 50,000 ha of land would be needed. This is in addition to full use of current verge grass and reed production as well as use of the large amount of cereal straw which is currently directly ploughed under the soil. At higher replacement shares, up to 327,000 ha of land would be required. At the same time flax, hemp, Miscanthus, and reed are expected to have a positive effect on biodiversity over traditional crops, thus contributing to nature values.

Typical conversion processing scales for textiles, insulation materials and particle boards are in the same order of magnitude or smaller than product volumes required at partial (25-50%) replacement of traditional (fossil based) products. This means that for these applications a facility in the Netherlands may cover estimated demand, eventually for textiles and insulation materials a few regional facilities may be considered.

Due to the relatively large (economically feasible) conversion scales and consequently limited number of production facilities in the Netherlands, regions and provinces need to review their strengths and opportunities and focus on specific value chains.

This report shows that demand for biobased feedstock is huge, and also that each biofeedstock has its own range of applications. The transition to a (regional) supply of herbaceous biomass for local circular bio-based industries is complex and involves many aspects: primary production, collection of side streams (like reed and verge grass), investment in (upscaling of) conversion technologies from pilots to regional demonstrators to industrial scale implementations, technological developments, matching volumes and scales, cost prices for biomass and biobased products, as well for delivering public values, consumer behaviour, and eventually regulations. This requires coordination in order to avoid the 'chicken-and-egg' problem: Farmers want guaranteed sales of crop products, whether annual or perennial crops; manufacturers require guaranteed supply of feedstock and long-term demand for their products; consumers want products with proven quality and service guaranteed for a minimum period of time. More specifically this requires collaboration, collective initiatives, bringing together means of production (knowledge, investments, aspirations and capacities) for a longer period of time, extending the networks and creating the conditions for upscaling, by finding alignment with public policies and regulations, market developments and innovations and societal needs.
In other words: while the topic of bioeconomy gets considerable attention nowadays, people may tend to think that the topic will develop itself and focus their attention on other topics, while the transition towards bioeconomy still needs full and coordinated attention to become mature.

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Abbreviations

CBD	Cannabidiol
CBS	Centraal Bureau voor de statistiek (Statistics Netherlands)
CEAP	Circular Economy Action Plan
C4	Specific photosynthetic processes of carbon fixation in plants
CO_2	Carbon dioxide
DG	Directorate General
DM	Dry matter
EC	European Commission
EFRO	Europees Fonds voor Regionale Ontwikkeling (European Fund for Regional Development)
EPR	Extended producer responsibility
ERDF	European regional development funds
GDP	Gross domestic product
GHG	Greenhouse gasses
GMO	Genetically modified organism
GMT	Glass fibre Mat Thermoplastic
ha	Hectare
JRC	Joint Research Centre
K	Potassium
kton	Kiloton
LFT	Long Fibre Thermoplastic
m	Meter
Mio	Million
N	Nitrogen
NMD	Nationale MilieudataBase (Dutch National Environmental Database)
OEM	Original equipment manufacturer
P	Phosphorous
PBL	Planbureau voor de Leefomgeving (Netherlands Environmental Assessment Agency)
PET	Polyethylene terephthalate
PLA	Polylactic acid
pMDI	Polymeric methylene diphenyl diisocyanate
PS	Polystyrene
PUR	Polyurethane
RIS	Regional Innovation Strategy
RWS	Rijkswaterstaat (Dutch Department of Water Management)
SER	Sociaal economische raad (The Social and Economic Council of the Netherlands)
THC	TetraHydroCannabinol
ton/a	Ton per annum
TRL	Technology Readiness Level
UD	Unidirectional
WPC	Wood Polymer Composite

Annex A. Concrete measures in EU Bioeconomy strategy

Delivering a sustainable circular bioeconomy requires a concerted effort by public authorities and industry. To drive this collective effort, and based on three key objectives, the Commission will launch 14 concrete measures in 2019, including:

Strengthen and scale up the biobased sectors, unlock investments and markets

- mobilise stakeholders in developing and deploying sustainable biobased solutions
- launch a €100 million circular bioeconomy thematic investment platform
- analyse enablers and bottlenecks for the deployment of biobased innovations
- promote and develop standards
- facilitate the deployment of new sustainable biorefineries
- develop substitutes to fossil-based materials that are biobased, recyclable and marine biodegradable

Deploy local bioeconomies rapidly across the whole of Europe

- launch a strategic deployment agenda for sustainable food and farming systems, forestry and biobased products
- launch pilot actions for the deployment of bioeconomies in rural, coastal and urban areas
- support regions and EU countries to develop bioeconomy strategies
- promote education, training and skills across the bioeconomy

Understand the ecological boundaries of the bioeconomy

- enhance knowledge on biodiversity and ecosystems
- monitor progress towards a sustainable bioeconomy
- promote good practices to operate the bioeconomy within safe ecological limits
- enhance the benefits of biodiversity in primary production

To explore the potential of nature to improve the quality of life

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The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR’s Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.