Sustainable Gas Generation Potential in the Netherlands

Various waste streams from the Netherlands, EU and globally could potentially be treated to generate sustainable gas. This study focuses on identifying all available streams, both biogenic and non-biogenic. There is a theoretical potential in the EU to generate ~ 70-110 bn m^3 of sustainable gas with gasification technologies from the released organic waste (biogenic and non-biogenic) that is not recycled. Zooming in on the Netherlands, the theoretical sustainable gas potential from the released organic non-recycled waste is estimated to be between ~ 4-6 bn m^3:

- *up to 1.5 bn m^3 from biogenic waste streams (excluding streams like manure, food & agriculture waste which are typically recycled) and;*
- *up to 4.5 bn m^3 from non-biogenic streams (excluding unreleased streams like industrial sludges). 0.1 bn m^3 from non-recycled plastics, 4.4 bn m^3 from other non-biogenic streams.*

Recycled and unreleased streams are excluded from the potential feedstock for sustainable gas production. The efficiency of treatment technology, emission intensities and costs (both operational and capital expenditure) will determine the ability to capture these volumes. This study highlights the potential of sustainable gas generation in the Netherlands but does not assess the competitiveness of these technologies compared to other options.

Energy Transition and Challenges: The Role of Sustainable Gas

The energy sector is responsible for approximately 72% of global greenhouse gas emissions. This includes emissions from the combustion of fossil fuels such as coal, oil, and gas for electricity, transportation, industry, and buildings. In a bid to reduce the greenhouse gas emission and achieve a net zero economy by 2050, energy transition is required. Energy transition refers to the shift from fossil fuels to renewable energy sources, such as wind, solar, hydro, geothermal, and biomass.

As a result, transition to renewable energy sources has become a critical goal for many countries, especially for EU-countries and the Netherlands. Europe is heavily dependent on imported fossil fuels for its energy needs. For e.g., in 2021, the EU imported ~ 375 bn m^3 natural gas which is 90% of its total gas consumption. This dependency on external regions makes the EU vulnerable to supply disruptions and price fluctuations. The energy transition can help reduce this dependency and enhance energy security by increasing the use of domestic and renewable energy sources.

The Netherlands is aiming to reduce its reliance on fossil fuels in its energy mix and to meet its climate targets.

However, this transition presents significant challenges, including the intermittent nature of renewable energy sources, energy storage, transmission capacity and ensuring grid stability. Sustainable gas, produced from organic waste, is an additional source that can replace fossil natural gas, and it can contribute to addressing some of these challenges. **Sustainable gas can be produced from both biogenic as well as non-biogenic waste streams.**

In potential all organic waste streams can be used. However, focus should be on those streams where gasification would have a positive environmental and climate impact compared to the best alternative. Looking to the future sustainable energy mix, electricity can be sourced from wind and solar. Biogenic residual flows have high added value when upgraded to carbon molecules, like methane, which currently cannot be sourced from a sustainable source. These molecules will play an important role in decarbonizing industry feedstocks and high temperature processes. Sustainable gas produced from biogenic feedstock is termed as green gas/methane whereas gas produced from non-biogenic waste is referred to as circular gas/methane. This circular gas/methane produced from non-biogenic waste has a large processing CO_2 impact compared to the second-best alternative (currently mostly incineration) and in addition replaces fossil natural gas.

Different Technologies to produce Sustainable Gas

Anaerobic digestion (AD) and gasification are two key technologies capable of producing sustainable gas. Where AD can produce green gas, gasification can produce both green as well as circular gas. Anaerobic digestion is a process that decomposes biogenic organic matter in the absence of oxygen, resulting in biogas. This process allows a range of different biogenic feedstocks, e.g., sewage sludge or biowaste. Microorganisms digest these feedstocks with the absence of oxygen in a biogas plant, resulting in biogas. Different separation processes are available for the upgrading to achieve green gas/methane, for example water scrubbing or membrane separation. While initially biogas was primarily used for power and heat production directly at the biogas plant, an increasing number of installations now upgrade the biogas to green gas for further use. Looking to the future sustainable energy mix, electricity can be sourced from wind and solar.

In general, the residual flows have more added value when upgraded to carbon molecules, like methane, which currently cannot be sourced from a sustainable source. These molecules will play an important role in decarbonizing industry feedstocks and high temperature processes.

Gasification, e.g., **thermal gasification**, is a process where feedstock decomposes at high temperatures between 600-1200°C and, in the case of **supercritical water gasification**, at high pressure in a low-oxygen environment. This results in a mixture of gases like carbon monoxide and - dioxide, hydrogen, and methane, called production gas. In the gas treatment process, this production gas is cleaned and converted into pure sustainable gas converting CO_2 and H_2 in additional methane. By-products are water, which is treated and re-used, and solids, which are extracted from the process and discharged or re-used in case of valuable minerals. In comparison to digestion, with gasification not only biogenic feedstock such as manure or agriculture waste streams can be converted but also non biogenic feedstock such as plastic, waste oil, textile and other non-biogenic organic waste can be converted into methane. Compared to digestion, gasification technologies can unlock a larger number of problematic streams, which currently can not be recycled. The market for AD has been developed in the Netherlands for the last 20 years, with a close link to the big agrifood complex and the excess of manure which is used as a feedstock in the process. Gasification has a higher conversion ratio (up to 95%), producing more sustainable gas from the same feedstock and leaving no digestate. From a sustainability and financial perspective, gasification has a higher yield potential and brings more flexibility in feedstock. Due to the rapid conversion process compared to anaerobic digestion, gasification technologies allow for a rapid industrial scaling of sustainable methane production. The current study is focusing on potential feedstocks for sustainable gas production through gasification. The market for gasification projects still needs further development.

Feedstock availability

Feedstock is a critical element in scaling the production of sustainable gas. Feedstock here refers to waste that is released by households or through commercial activities such as industries or farming. Waste can be biogenic or non-biogenic in nature and both can have organic as well as inorganic contents (Slide 13). The organic component of biogenic and non-biogenic waste is converted into sustainable gas. Typically, there are two types of waste streams that are generated: released and unreleased. **Released waste streams** are streams that are available in the open market for treatment whereas **unreleased waste streams** are streams that are treated in-house (Slide 10).

Unreleased streams are used for e.g., steam and/or energy recovery via incineration. Although gasification of these streams could result in (significantly) higher energy efficiency and CO_2 footprint reduction, these streams are excluded from the theoretical waste stream volumes.

Currently, in the EU there is a theoretical potential to generate ~ 70-110 bn m^3 of sustainable gas from the released organic waste (biogenic and non-biogenic) that is not recycled (Slide 24). Waste management hierarchy gives preference to recycling over energy recovery and hence only the non recycled released waste is considered as potential feedstock. **Zooming in on the Netherlands, the theoretical sustainable gas potential from the released organic non recycled waste is estimated to be between ~ 4-6 bn m^3** (Slide 24). Even though the theoretical potential is high in NL, practical realization can be challenging mainly due to:

- **Availability**: The availability of feedstock as the waste management system is quite mature in Netherlands resulting in high demand of waste feedstock for various existing treatment methods and assets.
- **Accessibility**: Certain feedstocks can be difficult to access due to factors such as fragmented sources or immature supply chain.
- **Quality**: Feedstock with low calorific value or highly inhomogeneous contents are unattractive for conversion to sustainable gas.
- **Price**: High purchase price for waste feedstock can make the conversion process to sustainable gas economically unattractive.

Potential streams for gasification in NL

The aim of this study is to identify potentially attractive streams which can be unlocked for gasification in the Netherlands. For this purpose, more than 100 waste streams from released and unreleased streams have been analyzed (Slide 15). These streams are scored on availability and accessibility, and selected in such a way they cover a wide variety of characteristics to find potential streams for gasification. In this way the researched streams represent a wider variety of potential streams for gas production through gasification.

Released waste streams from biogenic sources assessed in this study are food waste generated at processing and households, agricultural waste, manure waste, household sludge and wood waste (Slide 17). **Within the Netherlands, the theoretical sustainable gas production from non-recycled released biogenic stream is estimated to be c. 1.5 bn m^3** (Slide 24). Within these streams, plant food processing waste has the highest volume (c. 8 mt) in NL but is indicated as almost fully recycled and therefore excluded from the 1.5 bn m^3 potential. Sustainable gas potential generation is highest for wood waste (c. 0.7 bn m^3) owing to higher non-recycled volume and higher calorific value of wood waste (Slide 19). **The c. 1.5 bn m^3 potential sustainable gas excludes biogenic streams indicated as recycled like manure, food and agriculture waste**.

Further, released waste streams from non-biogenic sources assessed are industrial waste (included solvents, used oils, chemical waste, industrial effluent sludge and waste treatment sludge), medical waste, household residual waste, industrial mixed waste, sorting residue, material specific waste such as from plastic, textile, rubber, and dredging spoils (Slide 17). **The theoretical sustainable gas production from non-recycled released non-biogenic stream in the Netherlands is estimated to be c. 4.5 bn m^3** (Slide 24). Among these streams household municipal waste has the highest volume in NL (c. 6.2 mt) with c. 0.9 bn m^3 potential of sustainable gas production (Slide 21).

Unreleased streams like industrial sludges are excluded from the potential 4.5 bn m3 sustainable gas production. New gasification technologies however could (significantly) improve the energy efficiency and CO_2 footprint impact compared to current on-site reuse of these streams.

In the unreleased waste stream category, the focus is on agricultural waste, food processing waste, manure waste and industrial waste. For agricultural and food processing waste, the total waste is estimated whereas for manure and industrial waste, unreleased waste is estimated. In the Netherlands c. 5 mt of agricultural waste and c. 2 mt of plant-based food processing waste is generated in the Netherlands within which potatoes, sugar beet and onions have the highest volume (Slide 29-31). In the animal-based food processing waste, c. 3 mt of waste is generated in which sheep has the highest volume followed by cattle (Slide 35). In manure, c. 75 mt of waste is generated annually in which c. 70% is unreleased (Slide 36). Finally in the industrial waste the focus is on refining and petrochemical (Slide 37), and it is estimated that c. 0.3 mt of waste is unreleased from this industry in the Netherlands (Slide 40).

Among the assessed waste streams, unreleased refining & petrochemical waste has been excluded from the shortlisting for potential streams for gasification due to limited potential driven by low volumes (Slide 43). Remaining streams are further assessed based on attractiveness and accessibility. In the released streams the attractiveness is determined by calorific value, environmental impact, and energy efficiency while accessibility is based on available volume in NL, BE and DE, ease of accessibility (degree of fragmentation of sources and maturity of international supply chain) and current treatment method. In the unreleased streams the attractiveness is determined by calorific value and environmental impact while accessibility is like released waste parameters. Based on analyzing more than 100 streams with these parameters, following streams from both released and unreleased streams are deemed to be potential for sustainable gas production (Slide 58):

- **Released streams**
  - Household municipal waste

    High accessibility due to large volume generated and not recycled. However lower calorific value leads to lower energy potential and inhomogeneous stream with more than 10 different types of wastes having different properties making it difficult to process.
  - Wood waste

    High attractiveness and accessibility as considerable volume is generated with almost 40-50% not recycled. An established supply chain exists, however current energy recovery methods for wood waste to heat and power have high energy efficiency in the range of 90%. However, conversion of these streams to carbon molecules, like methane will play an important role to decarbonize industry feedstocks and high temperature processes.
  - Plastic waste

    High attractiveness due to high calorific value and lower energy and environmental efficiency of the current energy recovery methods, however potential volume in NL is limited. Increased regulatory push for recycling will result in increased accessibility of plastic waste for chemical recycling and gasification..
  - Chemical waste

    High attractiveness due to high calorific value and lower energy and environmental efficiency of the current energy recovery methods. Limited volumes leading to lower accessibility. Additionally, consisting of multiple streams each having its own properties resulting in difficulty in processing.
  - Industrial effluent sludges

    Medium attractiveness and accessibility mainly due to moderate calorific value and limited volume. However, the majority are currently not recycled.
  - Waste treatment sludge

    Medium attractiveness and accessibility mainly due to moderate calorific value and limited volume. However, the majority are currently not recycled.
- **Unreleased streams**
  - Potatoes waste (Agricultural and food processing)

    High accessibility and moderate attractiveness as large volume generated in NL and has moderate calorific value, but majority is used for animal feed.
  - Sugar beet agricultural waste

    High accessibility and moderate attractiveness as large volume generated in NL and has moderate calorific value, but majority is used for animal feed.
  - Onion waste

    Moderate accessibility and attractiveness but the majority is used for biogas production which has relatively lower energy efficiency.
  - Unreleased manure waste

    High accessibility as large volumes are generated in NL but highly fragmented and majority is used as a fertilizer.
  - Sugarcane vinasse (international waste stream)

    High attractiveness and moderate accessibility as large volumes generated with moderate calorific value, high environmental impact, established supply chain but low non recycling uses.

Summary

Feedstock is a critical element in scaling the production of sustainable gas. Waste can be biogenic or non-biogenic in nature and both can have organic as well as inorganic contents. The organic component of biogenic and non-biogenic waste is converted into sustainable gas. Waste streams are categorized in released and unreleased streams. Released waste streams are available in the open market for treatment whereas unreleased waste streams are streams that are treated in-house. Unreleased streams are used for e.g., steam and/or energy recovery via incineration. Although gasification of these streams could result in (significantly) higher energy efficiency and CO_2 footprint reduction, these streams are excluded from the theoretical waste stream volumes.

Waste management hierarchy gives preference to recycling over energy recovery, therefor only the non-recycled released waste has been considered as potential feedstock for this study.

Based on these assumptions, there is a theoretical potential in the EU to generate ~ 70-110 bn m^3 of sustainable gas from the released organic waste (biogenic and non-biogenic) that is not recycled.

Zooming in on the Netherlands, the theoretical sustainable gas potential from the released organic non-recycled waste is estimated to be between ~ 4-6 bn m^3:

- **up to 1.5 bn m^3 from biogenic waste streams (excluding streams like manure, food & agriculture waste which are typically recycled) and;**
- **up to 4.5 bn m^3 from non-biogenic streams (excluding unreleased streams like industrial sludges)**

Market study on waste streams for sustainable gas

Key findings

Contents

Index of abbreviations

Abb.	Meaning
BE	Belgium
bn	Billion
CAGR	Compound annual growth rate
CBS	Centraal Bureau voor de Statistiek (NL)
DE	Germany
e.g.	Example
EU	European union
EUR	Euro
FAO	Food and agriculture organization
GDP	Gross domestic product
GFT	Groente fruit en tuinafval (NL)
HH	Household
kt	Kiloton
kg	Kilogram
MJ	Megajoule
mt	Million tons
n/a	Not available
NL	the Netherlands
PCB	Polychlorinated biphenyls
PJ	Petajoule
t	tons

A. Introduction and executive summary

Introduction

Background	• This publication presents the results of a study that was commissioned by SCW Systems, InvestNL and Gasunie. It shows the findings and content that was developed by Roland Berger • The main project work was over a period of six working weeks and took place between November 2022 and January 2023 • Analysis and results builds on secondary research and data retrieved from relevant national and international databases such as Eurostat, FAO, market reports, national databases, expert interviews and technical publications • Accordingly, all the raw data retrieved is based on official facts and figures. In certain instance, estimates, such as extrapolation/ interpolation, are made by Roland Berger
Goal of the study	• The Netherlands is making a transition to renewable energy and aiming to reduce the share of fossil fuels in its energy mix • Shares of solar PV and (onshore and offshore) wind power have increased in recent years, but additional renewable sources are still required to phase out fossil fuels • Sustainable gas[1)] is a potential additional source that can replace fossil fuel gas, and it can be produced from waste generated in the Netherlands • Accordingly, the goal of the study is to get an overview of volumes of waste streams which contain organic matter, both biogenic and non-biogenic and estimate the theoretical potential of sustainable gas generation
Segmentation of waste streams	• In this report all waste is mapped according to the following: – Released (waste that is outsourced for management by parties other than the emitter) or unreleased (waste that is treated on-site by the emitter) – Biogenic (waste originating from a natural source such as food or wood wastes) or non-biogenic (waste originating from fossil sources) – Organic (waste containing carbon-based compounds) or inorganic (waste that does not contain carbon-based compounds such as minerals, metals and salts)

1) Sustainable gas is an umbrella term for either a green gas or a circular gas where green gas is the gas that is generated from processing the biogenic waste streams and circular gas is the gas that is generated from processing the non-biogenic waste streams

Executive summary

Key findings

- Analysis included more than 3.5 bn tons of released and unreleased waste across more than 100 waste streams, originating from various sources and geographies
- Across the EU, there is a theoretical potential to generate 70-110 bn m^3 of sustainable gas from organic waste that is currently not recycle
- Zooming in on the Netherlands, the theoretical potential of sustainable gas generation is 4-6 bn m^3 considering organic waste generated but not recycled in the Netherlands:
    - up to 1.5 bn m^3 from biogenic waste streams (excluding streams like manure, food & agriculture waste which are typically recycled) and;
    - up to 4.5 bn m^3 from non-biogenic streams (excluding unreleased streams like industrial sludges)
- To determine potential interesting streams to gasify, waste streams that are generated from various sources and geographies are assessed according to multiple parameters, such as total volume, calorific value (i.e., energy content) and current treatment methodologies
    - Amongst released streams, household municipal waste, wood waste, chemical waste, plastic waste, waste treatment sludge and industrial effluent sludges can be considered potentially attractive for production of sustainable gas
    - Amongst unreleased streams, vinasse (by-product of sugar-cane based ethanol production), unreleased manure and waste from potatoes, sugar beet and onions can be considered attractive

B. Current status of waste streams

Within this chapter, categories of assessed waste streams, their definition and the assessments thereof are presented

Chapter content

Current status of waste streams

- In total, more than 3.5 bn tons of more than 100 waste streams across various geographies and sources have been analyzed
- In EU, wood & plant food processing waste have highest volume among released biogenic waste whereas plant-based food processing is the highest in NL
- In EU and NL, household municipal waste and sorting residue have the highest volume among released non-biogenic waste whereas
- It is estimated that 1.2 bn tons of global agricultural waste (harvest and post-harvest until distribution) is generated – NL volume is estimated to be 5 mt
- Waste from potato processing has the highest volume in NL with c. 0.8 mt followed by wastes from sugar beets and onions processing
- It is estimated that c. 200 mt of waste is generated globally from processing of animal products – NL volume is estimated to be at c. 3 mt

Chapter structure	Content
1 Waste streams categorization and definition	• Categorization of waste: Knock-out and final list • Difference between released and unreleased waste streams • Released feedstock definition
2 Released waste streams	• Overview on average calorific values, volumes, historical growth trend, expected future growth trend, current treatment methods and regulatory overview on recycling per stream in the EU and in the Netherlands
3 Unreleased waste streams	• Global cumulative production quantities of crops and types of waste generated across the food value chain • Calorific value, historical growth trend and estimated volumes of agricultural waste • Mapping of waste streams from plant-based food processing and estimation of the generated volumes • Mapping of waste streams from animal-based food processing and estimation of the generated volumes • Overview of the Dutch manure processing market • Scoping and estimation of generated waste volumes of refining and petrochemical plants

B.1 Waste streams categorization and definition

Various categories of waste streams are defined – As a first step, streams that lacked organic content were excluded from the analysis

Categorization of waste – First knock-out

Released waste stream
[Waste streams available in open market for treatment]

- **Biogenic**
  - **Organic**
    - Food waste ✓
    - Agricultural waste ✓
    - Manure waste ✓
    - Household sludge ✓
    - Wood waste ✓
- **Non-biogenic**
  - **Organic**
    - Industrial waste ✓
    - Medical waste ✓
    - Household residual waste ✓
    - Industrial mixed waste ✓
    - Sorting residue ✓
    - Material specific waste ✓
    - Dredging spoils ✓
  - **Inorganic**
    - Acids, alkaline and salts ✗
    - Mineral waste ✗
    - Equipment waste ✗
    - PCB waste ✗
    - Soil ✗
    - Material specific waste ✗

Unreleased waste stream
[Waste treated in-house]

- **Biogenic**
  - **Organic**
    - Food waste ✓
    - Agricultural waste ✓
    - Manure waste ✓
- **Non-biogenic**
  - **Organic**
    - Industrial waste ✓
  - **Inorganic** ✗

✓ Relevant ✗ Not relevant

Lack of organic content makes the stream irrelevant

Waste stream		Definition
Acids, alkaline and salts		Includes inorganic acids, like Hydrochloridic, sulphuric, phosphoric, nitric acids and inorganic salts
Mineral waste		Includes construction waste such as concrete, bricks and asbestos along with mineral waste from mining, quarrying, blasting materials & lining & refractory
Equipment waste		Includes discarded electrical and electronic equipment along with end-of-life batteries
PCB waste		Includes wastes containing Polychlorinated biphenyls (PCBs) such as capacitor and waste from transformer
Soils		Includes soil and stones incl. excavated soil from contaminated sites
Material specific waste	Paper	Includes used paper and cardboard waste
	Glass	Includes glass waste from packaging and production
	Metal	Includes ferrous and non-ferrous metal waste

Accordingly, the assessment is focused on multiple relevant organic, biogenic and non-biogenic, categories of waste streams from released and unreleased streams

Categorization of waste – Final assessment list

Released waste stream

[Waste streams available in open market for treatment]

Biogenic – Organic

- Food waste
  - Animal food processing waste
  - Plant food processing waste
  - Household waste (GFT)
- Agricultural waste
- Manure waste
- Household sludge
- Wood waste

Non-biogenic – Organic

- Industrial waste
  - Solvents
  - Used oils
  - Chemical waste
  - Industrial effluent sludge
  - Waste treatment sludge
- Medical waste
- Household residual waste
- Industrial mixed waste
- Sorting residue
- Material specific waste
  - Plastic
  - Textile
  - Rubber
- Dredging spoils

Unreleased waste stream

[Waste treated in-house]

Biogenic – Organic

- Food waste
  - Animal food processing waste
  - Plant food processing waste
- Agricultural waste
- Manure waste

Non-biogenic – Organic

- Industrial waste

Source: Eurostat, Secondary research

Common streams that are delineated in both released and unreleased waste differ in terms of what is outsourced and level of detail in terms of waste distribution

Difference between released and unreleased waste streams

	Waste stream	Released waste stream	Unreleased waste stream[1]
Biogenic waste	Animal food processing waste	Cumulative waste outsourced to other companies from all animal origin food processing industries (meat, fish, dairy, etc.) using national statistical databases	Total waste arising broken down by key industry (meat, fish, dairy, etc.) using bottom-up model which calculates waste arising at value chain step
Biogenic waste	Plant food processing waste	Cumulative waste outsourced to other companies from all plant food processing industries (cacao, sugar cane, etc.) using national statistical databases	Total waste arising broken down by end-products from the 11 most harvested crops (wheat, sugarcane, etc.) using bottom-up model which calculates waste arising at each value chain step
Biogenic waste	Agricultural waste	Cumulative waste outsourced to other companies from agriculture and forestry using national statistical databases	Total waste arising broken by 11 most harvested crops (wheat, sugarcane, etc.) using bottom-up model which calculates waste arising from post-harvest to distribution
Biogenic waste	Manure waste	Cumulative waste outsourced to other companies from manure using national statistical databases	Total waste arising from manure
Non-biogenic waste	Industrial waste	Cumulative waste outsourced to other companies from various industries (chemical, petrochemicals, etc.) using national statistical databases	Total waste arising broken down by key industry ((petro)chemical, utilities, etc.) using bottom-up model

1) To the extent possible, to be compared to released waste
Source: Interview with market participants, Secondary research

Each of the relevant streams consist of waste from different sources

Released feedstock definition

Category	Waste stream	Sub-stream	Definition
Biogenic	Wood waste		Includes wooden packaging and sawdust, shavings along with wood from production of pulp and paper construction and demolition of buildings and separately collected wood waste
Biogenic	Food waste	Animal food processing waste	Includes waste from preparation and processing of meat, fish and other foods of animal origin along with dairy product industry
Biogenic	Food waste	Household mixed food waste (GFT)	Includes biodegradable kitchen / canteen wastes, and edible oils and fats
Biogenic	Food waste	Plant food processing waste	Includes plant waste from food preparation and production in industry such as cocoa, coffee, molasses preparation, sugar, dairy products etc.
Biogenic	Household sludge		Includes sludge from wastewater treatment and food preparation and processing
Biogenic	Manure waste		Includes slurry and manure from agricultural activities
Biogenic	Agricultural waste		Includes green waste from agriculture and forestry
Non-biogenic	Household residual waste		Includes unsorted waste from household and commercial activities
Non-biogenic	Sorting residue		Includes sorting residues from mechanical sorting process for waste
Non-biogenic	Industrial mixed waste		Includes unsorted waste from mainly paper and pulp, construction and waste treatment industries
Non-biogenic	Industrial waste	Chemical wastes	Includes catalysts mainly used in chemical and petrol industry, off-specification wastes like agrochemicals, medicines, paint and chemical preparation waste like preservatives, brake and antifreeze fluids
Non-biogenic	Industrial waste	Industrial effluent sludges	Includes sludges and solid residues from industrial wastewater treatment, soil and groundwater remediation boiler cleansing and drilling mud
Non-biogenic	Industrial waste	Waste treatment sludges	Includes sludges from physio/chemical treatment and anaerobic treatment of organic waste
Non-biogenic	Industrial waste	Used oils	Includes mineral-based, biodegradable engine oils, gear, hydraulic and lubricating oils, oils for insulation and heat transmission, emulsions from metal surface shaping and residues from tank cleaning
Non-biogenic	Industrial waste	Spent solvents	Includes Hydrocarbons, fluor-carbons, organic halogenated & non-halogenated solvents, organic washing liquids, mother liquors, and fluorinated refrigerants
Non-biogenic	Plastic waste		Includes plastic waste from production process and source separated post consumer waste
Non-biogenic	Dredging spoils		Includes waste from construction and maintenance of water project, dredging and subsurface work
Non-biogenic	Rubber waste		Includes end-of-life tires
Non-biogenic	Textile waste		Includes textile and leather waste from packaging, fiber production and used clothes
Non-biogenic	Medical waste		Includes biological waste like body parts and organs and other waste such as plaster casts, clothing and diapers

Source: Eurostat, Interview with market participants, Secondary research

Study adopts the definition of the Waste Framework Directive for waste processing options

Waste processing options

Waste processing options	Description
Landfill	Method of waste disposal that involves deposit of waste into or onto land. It includes specially engineered landfill sites and temporary storage of over one year on permanent sites
Incineration	Method of waste disposal that involves the combustion of waste without energy recovery. It may refer to incineration on land or at sea. In this process the heat generated by combustion is dissipated in the environment.
Energy recovery	Method of waste disposal that involves organic fraction of waste being converted to some form of usable energy. Recovery may be achieved through the combustion of processed or raw waste to produce steam; through the pyrolysis of waste to produce oil or gas; and through the anaerobic digestion of organic wastes to produce methane gas
Recycling	Method of waste disposal that involves waste materials being reprocessed into products, materials or substances whether for the original or other purposes. It does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations
Others	Methods of disposal such as land treatment, backfilling, deep injection, impoundment of waste and the release of waste into water bodies
Export/leakage	Part of waste generated within EU is either leaked into the environment or exported to other countries for landfilling or recycling

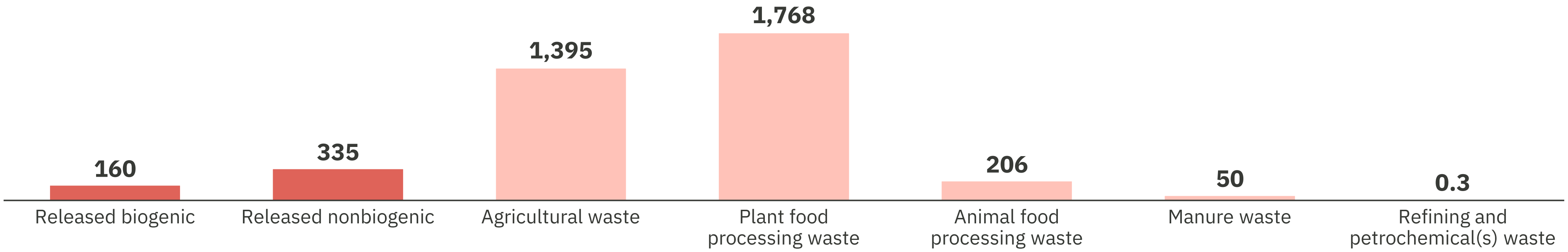
Source: Eurostat, Waste Framework Directive

More than 3.5 bn tons of released and unreleased waste across more than 100 waste streams were analyzed to identify interesting feedstock for sustainable gas

High-level overview of analyzed waste streams [2020]

Geography	EU	EU	Global	Global	Global	Netherlands	Netherlands
Rationale for geography	Traded at an EU scale	Traded at an EU scale	Traded at a global scale	Traded at a global scale	Traded at a global scale	Majorly catchment area driven	Catchment area driven
Number of streams	7	13	29	29	22	1	2

Waste volumes [mt]



Released[1] waste streams; Unreleased[2]/total waste streams

1) Waste streams available in open market for treatment; 2) Waste streams treated in-house

B.2 Released waste streams

Focus of this chapter is on released waste, both biogenic and non-biogenic

Categorization of waste streams – Final assessment list

Released waste stream

[Waste streams available in open market for treatment]

- **Biogenic**
  - **Organic**
    - Food waste
      - Animal food processing waste
      - Plant food processing waste
      - Household waste (GFT)
    - Agricultural waste
    - Manure waste
    - Household sludge
    - Wood waste
- **Non-biogenic**
  - **Organic**
    - Industrial waste
      - Solvents
      - Used oils
      - Chemical waste
      - Industrial effluent sludge
      - Waste treatment sludge
    - Medical waste
    - Household residual waste
    - Industrial mixed waste
    - Sorting residue
    - Material specific waste
      - Plastic
      - Textile
      - Rubber
    - Dredging spoils

Unreleased waste stream

[Waste treated in-house]

- **Biogenic**
  - **Organic**
    - Food waste
      - Animal food processing waste
      - Plant food processing waste
    - Agricultural waste
    - Manure waste
- **Non-biogenic**
  - **Organic**
    - Industrial waste

Source: Eurostat, Secondary research

In EU, wood & plant food processing waste have highest volume among released biogenic waste – HH sludge & wood waste have relatively lower recycling rate

Overview on released **biogenic feedstock** – EU[1)]

Waste stream		Calorific value [MJ/kg]	Volume EU[1)] [2020; mt]	CAGR [2016-2020; %]	Future trend	Waste treatment [2020; %]	Non-recycled volume [2020; mt]	Sustainable gas[2)] [2020; bn m³]	Regulatory overview on recycling
Wood waste		19-20	49.8	0.4%	→	100%	30.0	13.6	EU targets 30% of wood used in packaging to be recycled by 2030
Food waste	Plant food processing waste	14-23	49.6	2.6%	→	100%	8.8	4.0	No targets on recycling. Strict regulations on composition of product added back to the soil
	Household waste (GFT)	10-18	12.9	13.9%	↗	100%	4.5	1.5	Part of municipal waste where there is target of 65% of waste to be recycled by 2035
	Animal food processing waste	10-18	12.5	-3.0%	→	100%	4.3	1.4	No target on recycling
Household sludge		10-17	17.4	1.3%	→	100%	10.5	3.3	No targets on recycling. Strict regulations on composition of product added back to the soil
Manure waste		15-20	14.0	0.3%	→	100%	5.3	2.0	
Agricultural waste		14-23	4.2	0.8%	→	100%	0.7	0.3	

↗ Positive growth → Stable growth ↘ Negative growth

Landfill | Incineration | Energy recovery | Recycling | Other disposal method | Export/leakage

1) EU 27 countries; 2) Based on gasification efficiency of 80% and an energy content of 35.17 MJ/m³

Source: Eurostat, Secondary research

In NL, c.8 mt of plant food processing waste is generated which is the highest among the biogenic waste and it is almost completely recycled

Overview on released **biogenic feedstock** – The Netherlands

Waste stream		Volume generated NL [2020; mt]	CAGR [2016-2020; %]	Volume treated in NL [2020; mt]	Waste treatment [2020; %]	Waste source [2020; %]	Non-recycled volume [2020; mt]	Sustainable gas[3] [2020; bn m³]
Food waste	Plant food processing waste	8.1	1.0%	8.2[1]	100%	100%	0.1	0.1
	Household waste (GFT)	1.7	3.8%	1.6[2]	100%	100%	0.2	0.1
	Animal food processing waste	1.1	3.8%	1.1	100%	100%	0.1	0.0
Manure waste		3.5	-2.5%	3.8[1]	100%	100%	0.4	0.2
Wood waste		3.1	3.9%	2.3[2]	100%	100%	1.5	0.7
Agricultural waste		1.2	1.0%	1.2	100%	100%	0.0	0.0
Household sludge		0.6	-1.4%	0.6	100%	100%	0.4	0.1

Waste treatment: Landfill, Energy recovery, Other disposal method, Incineration, Recycling

Waste source: Agriculture & forestry, Utility, Manufacturing activities, Mining and quarrying, Construction, Households, Waste and water treatment, Services

1) Volume treated in NL is higher than volume generated as waste is imported in NL for treatment; 2) Volume treated in NL is lower than volume generated as part of waste is exported outside of NL for treatment; 3) Based on gasification efficiency of 80% and an energy content of 35.17 MJ/m³

Source: Eurostat, Secondary research

In EU, household municipal waste and sorting residue have the highest volume and the lowest recycling rate among released non-biogenic feedstock

Overview on released **non-biogenic feedstock** – EU[1)]

Waste stream		Calorific value [MJ/kg]	Volume EU[1)] [2020; mt]	CAGR [2016-2020; %]	Future trend	Waste treatment [2020; %]	Non-recycled volume [2020; mt]	Sustainable gas[2)] [2020; bn m³]	Regulatory overview on recycling
Household municipal waste		8-12	132.6	-1%	Negative growth	100%	118.2	26.9	Target of 65% recycling by 2035
Sorting residue		7-10	87.5	1%	Negative growth	100%	74.0	13.5	No targets on recycling but waste disposal is regulated and there is an ambition from EU to have the industry as circular as possible – There are strict regulation on proper treatment of hazardous wastes emitted from the industry
Industrial mixed waste		10-20	41.9	2%	Stable growth	100%	28.1	6.4	
Industrial waste	Chemical waste	20-30	16.8	2%	Negative growth	100%	13.4	7.6	
	Industrial effluent sludge	11-17	11.4	0%	Negative growth	100%	9.1	2.9	
	Waste treatment sludge	11-17	9.3	3%	Positive growth	100%	8.1	2.6	
	Used oil	25-35	4.0	1%	Negative growth	100%	2.2	1.2	
	Spent solvent	15-20	2.1	-1%	Negative growth	100%	1.4	0.7	
Plastic waste		20-30	19.3	6%	Stable growth	100%	11.2	6.6	Target of 55% recycling of plastics in packaging by 2030
Dredging spoil		11-17	3.1	-6%	Stable growth	100%	2.9	0.9	No target on recycling. Provision on hazardous waste management
Rubber waste		25-30	2.9	1%	Stable growth	100%	1.0	0.7	No target on recycling
Textile waste		15-20	2.0	1%	Stable growth	100%	1.1	0.4	EU ambition on making it more sustainable and circular
Medical waste		7-10	2.1	7%	Stable growth	100%	2.1	0.3	No target on recycling. Provision on hazardous waste management

Positive growth | Stable growth | Negative growth

Landfill | Incineration | Energy recovery | Recycling | Other disposal method | Export/leakage

1) EU 27 countries; 2) Based on gasification efficiency of 80% and an energy content of 35.17 MJ/m³

Source: Eurostat, Secondary research

In NL, household municipal waste is the highest within non-biogenic waste with a volume of c.6 mt and only c.3% of it is currently recycled

Overview on released **non-biogenic feedstock** – The Netherlands

Waste stream		Volume generated NL [2020; mt]	CAGR [2016-2020; %]	Volume treated in NL [2020; mt]	Waste treatment [2020; %]	Waste source [2020; %]	Non-recycled volume [2020; mt]	Sustainable gas[3] [2020; bn m^3]
Household municipal waste		6.2	-2%	4.0[2]	100%	100%	3.9	0.9
Sorting residue		3.0	17%	3.9[1]	100%	100%	3.0	0.5
Dredging spoil		2.5	-7%	2.5	100%	100%	2.5	0.8
Industrial mixed waste		1.6	7%	1.3[2]	100%	100%	0.4	0.1
Indust-rial waste	Chemical waste	1.1	0%	0.6[2]	100%	100%	0.4	0.3
	Industrial effluent sludge	0.3	-2%	0.3	100%	100%	0.2	0.1
	Waste treatment sludge	0.3	1%	0.2[2]	100%	100%	0.2	0.1
	Used oil	0.1	0%	0.1	100%	100%	0.1	0.0
	Spent solvent	0.1	-3%	0.1	100%	100%	0.0	0.0
Plastic waste		0.6	5%	0.6	100%	100%	0.1	0.1
Textile waste		0.1	8%	0.1	100%	100%	0.0	0.0
Rubber waste		0.1	2%	0.1	100%	100%	0.0	0.0
Medical waste		0.0	6%	0.0	100%	100%	0.0	0.0

Waste treatment: Landfill, Energy recovery, Other disposal method, Incineration, Recycling

Waste source: Agriculture & forestry, Utility, Manufacturing activities, Mining and quarrying, Construction, Households, Waste and water treatment, Services

1) Volume treated in NL is higher than volume generated as waste is imported in NL for treatment; 2) Volume treated in NL is lower than volume generated as part of waste is exported outside of NL for treatment;
3) Based on gasification efficiency of 80% and an energy content of 35.17 MJ/m^3

Source: Eurostat, Secondary research

Majority of the biogenic waste streams is expected to have stable volume going forward – Majority of the industrial waste is expected to decrease

Assessment of future trend

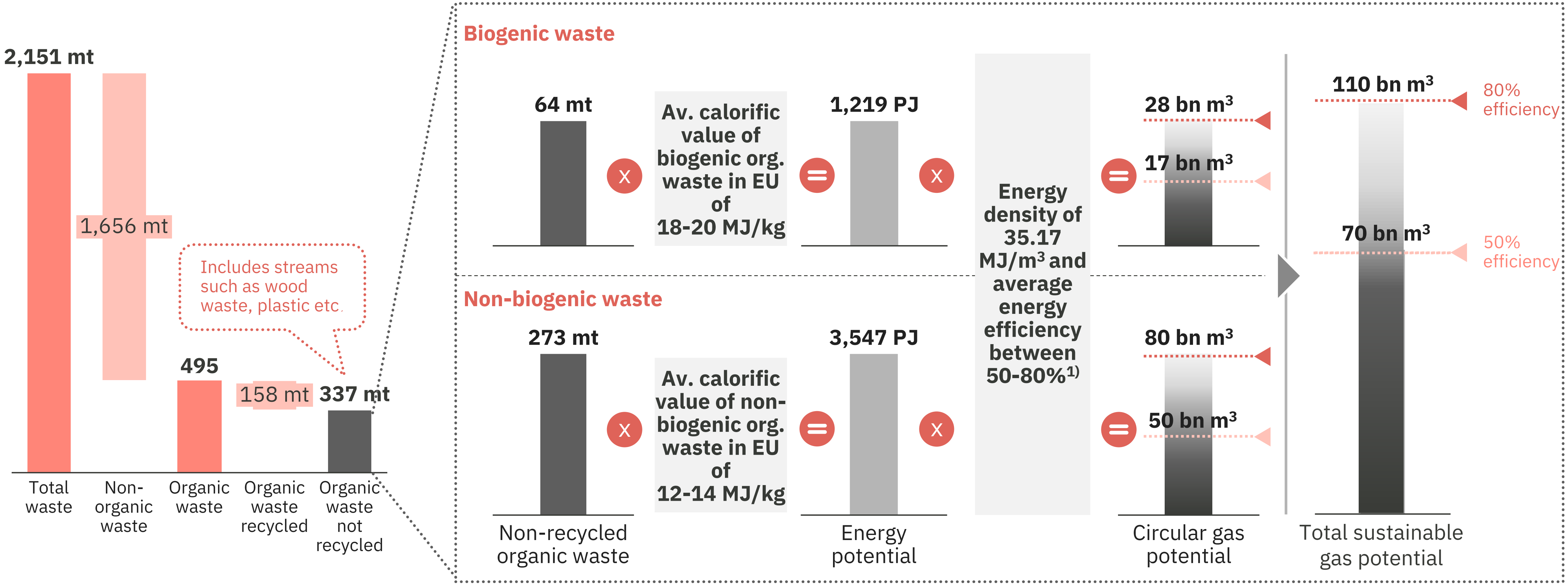
Category	Waste stream		Future trend	Substantiation
Biogenic	Wood waste		Stable growth	Is expected to grow with the GDP and population growth but reduction in paper and packaging consumption due to digitalization would slightly compensate for the growth
Biogenic	Food waste	Animal food processing waste	Stable growth	Is expected to grow with the population growth but increased focus on reducing food waste will offset it. Potentially a neg. growth if technology such as precision fermentation takes-off
Biogenic	Food waste	Household mixed food waste (GFT)	Positive growth	Increased focus on pre-sorting will lead to higher separately collected GFT waste
Biogenic	Food waste	Plant food processing waste	Stable growth	Is expected to grow with the GDP and population growth but enhancement in harvesting technology will slightly compensate for this growth
Biogenic	Household sludge		Stable growth	Is expected to grow with the GDP and population growth
Biogenic	Manure waste		Stable growth	Is expected to grow with the GDP and population growth but increased focus on emissions is expected to offset the growth
Biogenic	Agricultural waste		Stable growth	Is expected to grow with the GDP and population growth but increased focus on emissions and targets on reducing food waste is expected to offset the growth
Non-biogenic	Household residual waste		Negative growth	Increased focus on pre-sorting will lead to lower volume of mixed residual waste
Non-biogenic	Sorting residue		Negative growth	Sorting and recycling process is expected to become more efficient leading to reduction in residue waste
Non-biogenic	Industrial mixed waste		Stable growth	Is expected to grow with the GDP and population growth as the waste is mainly coming from paper, wastewater treatment and construction industry
Non-biogenic	Industrial waste	Chemical wastes	Negative growth	Increased efficiency of the plants will lead to reduction in waste volume. The focus towards decarbonization, could lead to chemical industry shifting to countries with abundant green energy
Non-biogenic	Industrial waste	Industrial effluent sludges	Negative growth	Will follow the trend of chemical industry
Non-biogenic	Industrial waste	Waste treatment sludges	Positive growth	Increased focus on treating wastes will lead to higher waste treatment sludge going forward
Non-biogenic	Industrial waste	Used oils	Negative growth	Petroleum industries is expected to decline in mid-term
Non-biogenic	Industrial waste	Spent solvents	Negative growth	Will follow the trend of chemical industry
Non-biogenic	Plastic waste		Stable growth	Plastic consumption is expected to remain flat in long term due to regulatory push, increased use of alternative material and efficient designs
Non-biogenic	Dredging spoils		Stable growth	Routine necessity in waterways
Non-biogenic	Rubber waste		Stable growth	Is expected to grow with the GDP and population growth
Non-biogenic	Textile waste		Stable growth	Is expected to grow with the GDP and population growth
Non-biogenic	Medical waste		Stable growth	Is expected to decline in short term towards Pre-COVID level and then grow with the GDP and population growth

Positive growth · Stable growth · Negative growth

Source: Secondary research

Currently in EU there is a theoretical potential to generate 70-110 bn m³ of sustainable gas from the organic waste that is not recycled

Sustainable gas potential EU from released waste streams (excl. recycled and non-released waste streams)

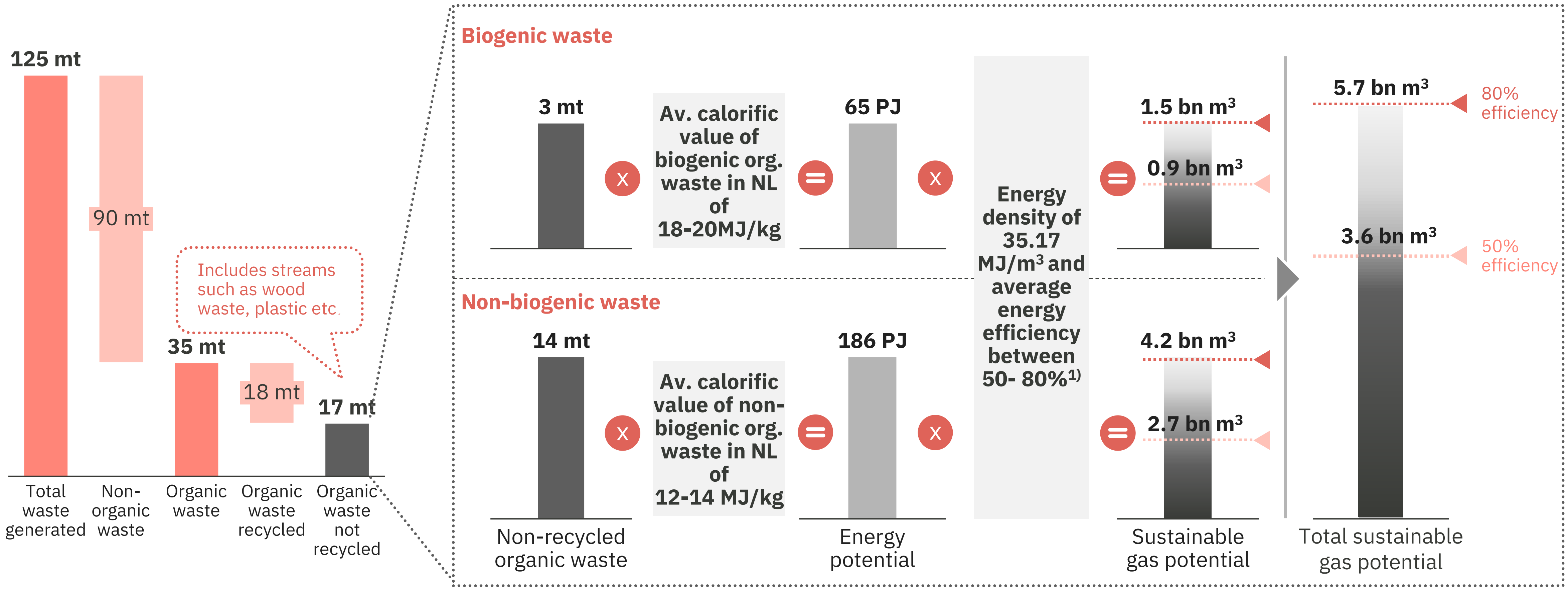


1) 50% energy efficiency typically corresponds to average energy efficiency of anaerobic digestion and 80% energy efficiency typically corresponds to average energy efficiency of gasification technology

Source: Eurostat

Within the Netherlands, the theoretical sustainable gas potential from organic non recycled waste is estimated to be between 4-6 bn m^3

Sustainable gas potential NL with released waste streams (excl. recycled and non-released waste streams)



1) 50% energy efficiency typically corresponds to average energy efficiency of anaerobic digestion and 80% energy efficiency typically corresponds to average energy efficiency of gasification technology
Note: Organic waste not recycled includes all waste generated in NL of which some is currently exported for treatment outside of NL, the potential calculation is based on all generated waste in NL

Source: Eurostat

B.3 Unreleased waste streams

Focus of this chapter is on unreleased waste, both biogenic and non-biogenic

Categorization of waste streams – Final assessment list

Released waste stream
[Waste streams available in open market for treatment]

- **Biogenic** – **Organic**
  - Food waste
    - Animal food processing waste
    - Plant food processing waste
    - Household waste (GFT)
  - Agricultural waste
  - Manure waste
  - Household sludge
  - Wood waste
- **Non-biogenic** – **Organic**
  - Industrial waste
    - Solvents
    - Used oils
    - Chemical waste
    - Industrial effluent sludge
    - Waste treatment sludge
  - Medical waste
  - Household residual waste
  - Industrial mixed waste
  - Sorting residue
  - Material specific waste
    - Plastic
    - Textile
    - Rubber
  - Dredging spoils

Unreleased waste stream
[Waste treated in-house]

- **Biogenic** – **Organic**
  - Food waste
    - Animal food processing waste
    - Plant food processing waste
  - Agricultural waste
  - Manure waste
- **Non-biogenic** – **Organic**
  - Industrial waste

Source: Eurostat, Secondary research

Food waste occurs across different stages of the food value chain and has varying causes depending on the stage of value chain

Type of waste generated along the value chain and causes of waste generation

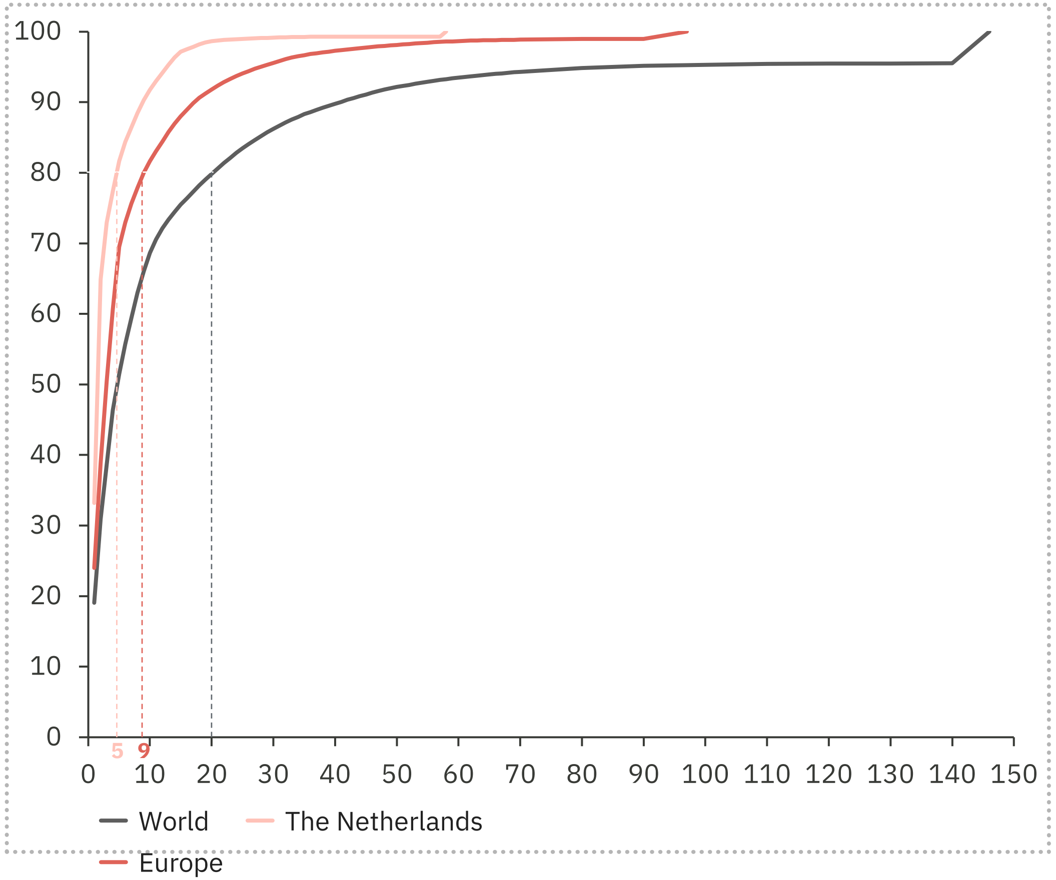
Unreleased waste intensity					
Type of waste	Agricultural waste		Food processing waste	specific/ municipal	Household food waste
Food value chain	Harvest	Post harvest (Primary processing, Storage, Transportation, Distribution)	Processing and packaging	Wholesale and retail	Household and food service
Causes of food loss	• Left in the field due to quality standards or sharp drop in prices • Production and agronomic practices and choices (e.g., choice of crop varieties) • Machine or laborer damage • Poor harvest scheduling	• Lack of proper storage or transportation facilities • Poor management of temperature and humidity • Prolonged storage (e.g., due to lack of transportation) • Logistical mismanagement (poor handling of delicate produce)	• Inadequate processing capacity for seasonal production excess • Technical malfunctions (wrong size or damaged packaging) • Lack of proper process management • Excessive trimming to attain a certain aesthetic	• Variability of demand for perishable products • Inappropriate product display and packaging • Removal of "imperfect" – looking foods • Overstocking	• Multitude of date labels • Confusion between expiration and preferred consumption date labels • Poor storage or stock management in the home • Oversized portions

Focus of unreleased waste streams

Source: FAOSTAT

20 crops constitute 80% of the global agricultural production – 11 crops were identified for further investigation

Cumulative production quantity of crops across different regions in [2020; %]



#	World	EU	NL
1	**Sugar cane**	**Wheat**	**Potatoes**
2	**Rice**[1]	**Sugar beet**	**Sugar beet**
3	**Maize**	**Maize**	**Onions**[2]
4	**Wheat**	**Potatoes**	**Wheat**
5	Oil palm fruit	**Barley**	**Tomatoes**
6	**Potatoes**	Sunflower seed	Carrots
7	Soya beans	Grapes	**Cucumber**[3]
8	Cassava	Colza seed	Chilies'[4]
9	**Sugar beet**	**Tomatoes**	Pears
10	**Tomatoes**	**Apples**	Lettuce
11	**Barley**	Oats	Mushrooms
12	Bananas	Triticale	Cabbages
13	**Onions**[2]	Olives	**Barley**
14	Watermelons	Rye	**Apples**
15	**Cucumber**[3]	Soya beans	**Maize**
16	Sweet potatoes	**Onions**[2]	Strawberries
17	**Apples**	Cabbages	Spinach
18	Seed cotton	Carrots	Cauliflowers
19	Grapes	Oranges	Eggplant
20	Oranges	**Cucumber**[3]	Pumpkin[5]

11 crops are further assessed:

- 9 crops (potatoes, sugar beat, wheat, maize, barley, onions, tomatoes, apples and cucumber) are the common crops that have higher production across world, EU and NL and could be potentially attractive streams to investigate their waste production
- 2 other crops (sugar cane and rice) have higher production globally but limited in EU and NL however could still be potentially attractive to investigate their waste production along with feasibility to transport to NL

1) Rice and paddy rice are combined; 2) Combined with shallots; 3) Combined with turnips; 4) Combined with pepper and capsicum; 5) Combined with squash and guards
Source: FAOSTAT

It is estimated that 1.2 bn tons of global agricultural waste (harvest and post-harvest until distribution) is generated – NL volume is estimated to be 5 mt

Global production of shortlisted crops and corresponding agricultural waste

Crops	Type of crop	Calorific value [MJ/kg]	Global production volume [2020; mt]	CAGR [2012-2020; %]	Global agricultural waste volume[1)] [2020; mt]	NL agricultural waste volume[1,2)] [2020; mt]	BE & DE agricultural waste volume[1,2)] [2020; mt]
Sugar cane	Sugars	17-19	1,870	0%	372	0.0	0.0
Rice	Cereals	16-24	1,261	0%	226	0.0	0.0
Maize	Cereals	17-24	1,162	4%	208	0.03	0.8
Wheat	Cereals	15-17	761	2%	136	0.2	4.3
Potatoes	Roots and tubers	15-17	359	0%	125	2.4	5.5
Sugar beet	Sugars	17-18	253	-1%	50	1.3	6.6
Tomatoes	Fruits	17-18	187	2%	60	0.3	0.1
Barley	Cereals	18-19	157	2%	28	0.04	2.0
Onions	Vegetables	10-15	105	3%	33	0.5	0.3
Cucumbers	Vegetables	10-15	91	3%	29	0.1	0.1
Apples	Fruits	17-19	86	1%	28	0.1	0.4

Harvest waste | Post harvest waste

1) Harvest waste is calculated based on an overall percentage for all crops (9%) and post-harvest waste include waste generated from post harvest to distribution which differs per crop; 2) Ratio of harvest and post harvest waste to the production is assumed to be similar to the global value

Source: FAOSTAT, WWF

Waste from potato processing has the highest volume in NL with c.0.8 mt followed by wastes from sugar beets and onions processing

Overview on plant-based food processing waste stream (1/2)

Crop	Potential feedstock	Calorific value [MJ/kg][1)]	Global waste volumes [mt]	NL waste volumes[2)] [mt]	BE and DE waste volumes[2)] [mt]
Sugar cane	Crude sugar filter cake	17	44	0	0
	Sugar cane bagasse	19	411	0	0
	Sugar cane molasse	15	42	0	0
	Sugar cane vinasse	10	386	0	0
	Sugar cane cellulose waste	10	43	0	0
Sugar beet	Sugar beet molasse	15	6	0.2	0.8
	Sugar beet vinasse	10	5	0.1	0.7
	Beet pulp	17	10	0.3	1.3
Maize	Distillers dried soluble grain (maize)	22	50	0.01	0.2
	Corn gluten feed	19	105	0.01	0.4
	Corn gluten meal	24	49	0.01	0.2
Wheat	Wheat bran	19	103	0.1	3.3
	Wheat shorts	19	21	0.02	0.7
	Distillers dried soluble grain (wheat)	20	3	0.0	0.1
Rice	Rice bran	17	28	0	0
	Rice husk	12	232	0	0
Barley	Barley bran	18	23	0.03	1.6
	Barley hulls	18	58	0.1	4.1
	Barley rootlets	18	1	0.0	0.1

Belgium Germany

1) Calorific values are specified on dry matter; 2) Ratio of waste generated is assumed to be similar to global values
Source: Secondary research

Waste from potato processing has the highest volume in NL with c.0.8 mt followed by wastes from sugar beets and onions processing

Overview on plant-based food processing waste stream (2/2)

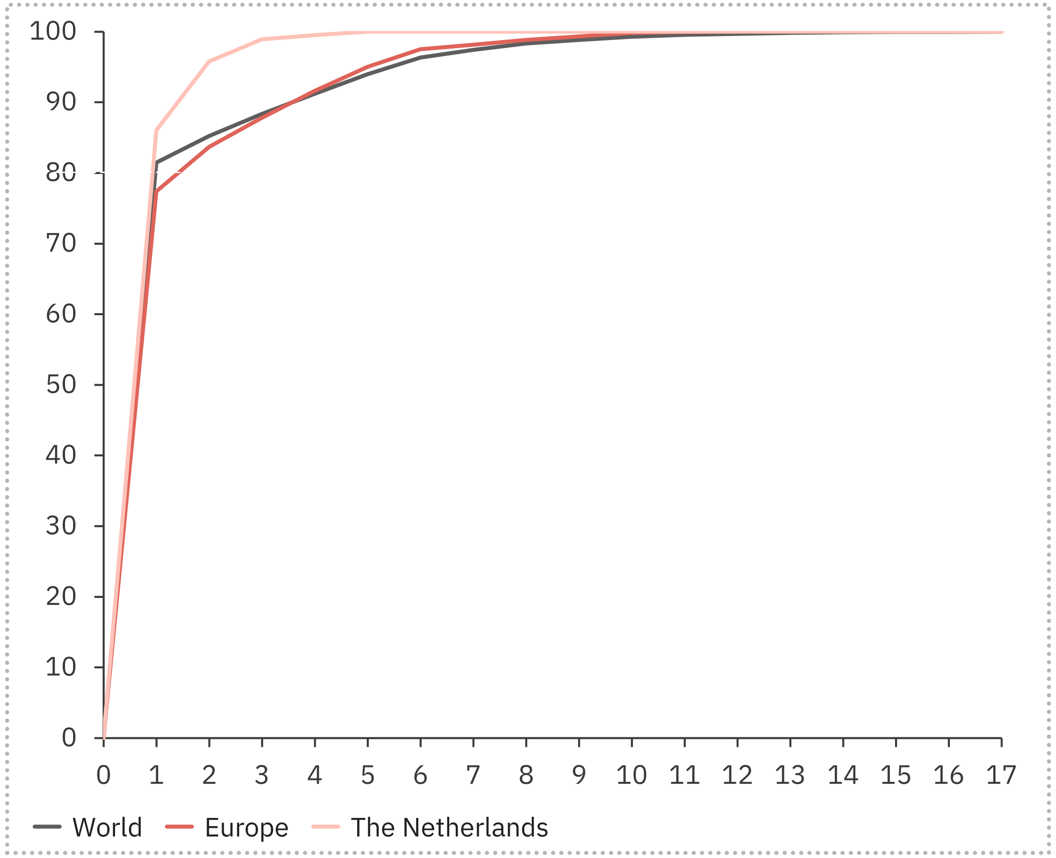
Crop	Potential feedstock	Calorific value [MJ/kg][1)]	Global waste volumes [mt]	NL waste volumes[2)] [mt]	BE and DE waste volumes[2)] [mt]
Potatoes	Spoiled potatoes	17	40	0.8	1.8
	Potato vinasse	10	35	0.0	1.5
	Potato protein residue	17	0	0.0	0.0
Tomatoes	Spoiled tomatoes	21	13	0.1	0.0
	Tomato peel/skin	21	2	0.01	0.0
	Tomato pomace	21	3	0.01	0.01
Onions	Spoiled onions	12[2)]	31	0.5	0.2
Cucumbers	Spoiled cucumbers	12	9	0.03	0.02
Apples	Spoiled apples	19	6	0.01	0.1
	Apple pomace	19	5	0.01	0.1

Belgium Germany

1) Calorific values are specified on dry matter; 2) With 9% moisture content; 3) Ratio of waste generated is assumed to be similar to global values
Source: Secondary research

Chickens and cattle are majorly the most cultivated live animals – Four live animals and corresponding food products were identified for further investigation

Cumulative number of live animals across different regions in [2020; %]



#	World	EU	NL
1	**Chickens**	**Chickens**	**Chickens**
2	**Cattle**	**Swine/pigs**	**Swine/pigs**
3	**Sheep**	**Sheep**	**Cattle**
4	Ducks	**Cattle**	**Sheep**
5	Goats	Turkeys	Goats
6	**Swine/pigs**	Ducks	Bees
7	Turkeys	Rabbits	Ducks
8	Geese	Bees	
9	Buffalo	Goats	
10	Rabbits	Geese	

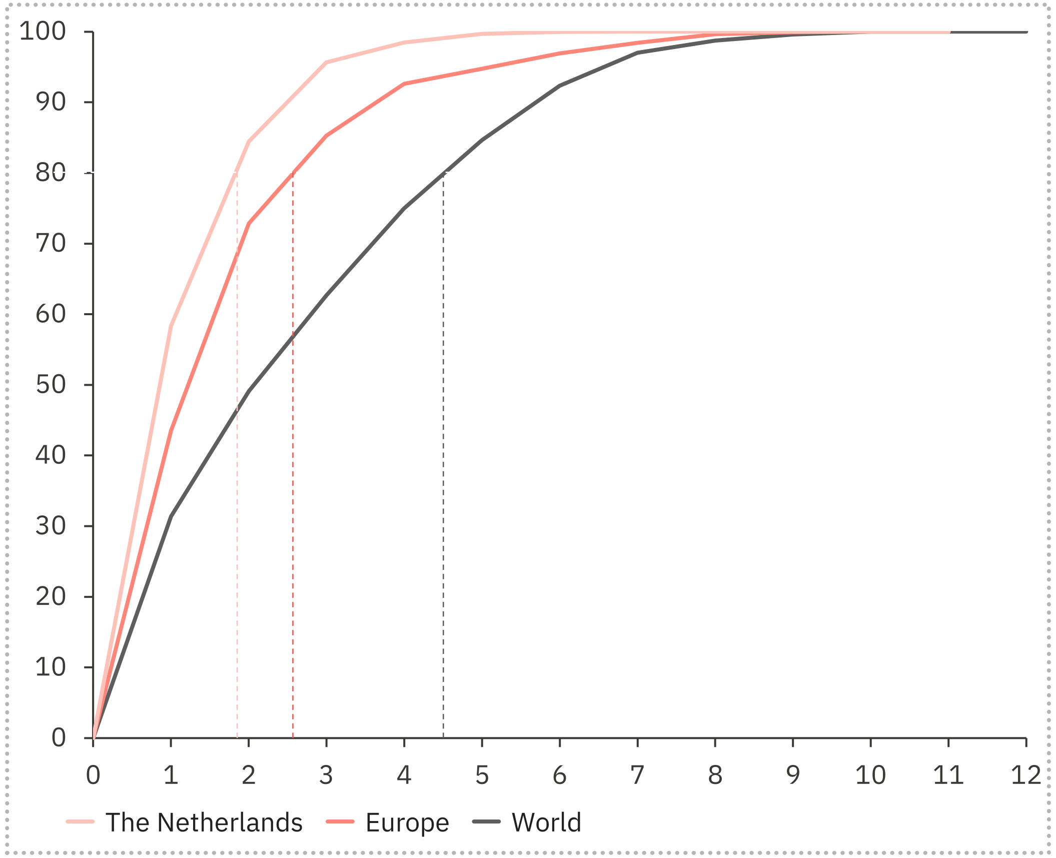
Four shortlisted categories are:

- Chickens, cattle, sheep and swine/pigs since their number is high in the Netherlands, Europe as well as in the world

Source: FAOSTAT

Five categories of fish cover most of cultivated fish, which were selected for further investigation

Cumulative production quantity of fishery across different regions in [2019; %]



#	World	EU	NL
1	**Freshwater Fish**	**Pelagic Fish**	**Pelagic Fish**
2	**Aquatic Plants**	**Demersal Fish**	**Demersal Fish**
3	**Pelagic Fish**	**Molluscs**	**Molluscs**
4	**Molluscs**	**Freshwater Fish**	Crustaceans
5	**Demersal Fish**	Crustaceans	**Freshwater Fish**
6	Crustaceans	Fish, Body Oil	Cephalopods
7	Marine Fish, Other	Cephalopods	Fish, Liver Oil
8	Cephalopods	**Aquatic Plants**	Aquatic Animals, Others
9	Aquatic Animals, Others	Marine Fish, Other	**Aquatic Plants**
10	Fish, Body Oil	Aquatic Animals, Others	Marine Fish, Other
11	Fish, Liver Oil	Fish, Liver Oil	Fish, Body Oil
12	Meat, Aquatic Mammals		

Five shortlisted categories are:

- Freshwater fish, aquatic plants, pelagic fish (ocean roaming salt water), molluscs (mussels), demersal (sweet and salt-water roaming fish)
- Freshwater fish and aquatic plants are worldwide the most the largest streams of fishery-related production
- In the Netherlands and EU these streams are less important, but the worldwide streams do cover the full top-3

Source: FAOSTAT

It is estimated that c. 100 mt of harvest and post harvest waste is generated globally from animals & fishery – NL volume estimated to be c. 1 mt

Global and NL production of animal products and corresponding agricultural waste

Animal agriculture product	Calorific value [MJ/kg]	Global production volume [2020; mt]	CAGR [2012-2020; %]	Global agricultural waste volume [2020; mt]	NL agricultural waste volume [2020; kt]
Egg shells waste	4-5	87	3%	11	83
Chicken offal	4-5	120	3%	12	103
Cattle milk spills	7-8	718	2%	31	623
Cattle offal[1)]	7-8	68	1%	4	20
Cattle spoiled meat	7-8	9	1%	0	0
Cattle spoiled fat	7-8	3	1%	0	0
Sheep milk spills	7-8	11	1%	0	0
Sheep offal[1)]	7-8	10	2%	0	1
Sheep spoiled meat	7-8	2	2%	0	0
Sheep spoiled fat	7-8	1	2%	0	0
Pig offal[1)]	7-8	110	0%	5	80
Pig spoiled fat	7-8	11	0%	0	0
Pig spoiled meat	7-8	7	0%	0	0
Freshwater fish waste	7-8	90	3%	13	1
Aquatic plants	7-8	51	3%	8	0
Pelagic fish waste	7-8	39	0%	5	36
Molluscs waste	7-8	35	2%	5	7
Demersal fish waste	7-8	28	1%	4	16

Harvest waste   Post harvest waste

1) For NL, offal waste also contains spoiled meat and spoiled fat
Source: FAOSTAT

It is estimated that c. 200 mt of waste is generated globally from processing of animal products – NL volume is estimated to be at c. 3 mt

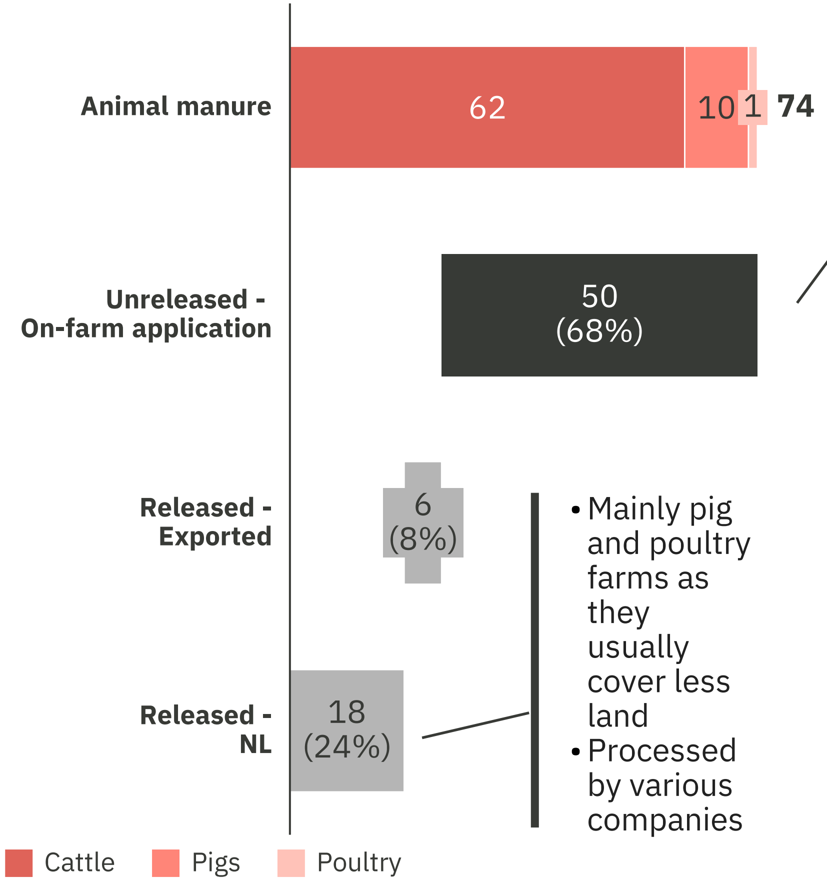
Global and NL production of animal-based food processing waste

Animal	Processing waste	Use of stream[1]	Calorific value [MJ/kg]	Global waste volumes [mt]	NL waste volumes [kt]
Chicken	Chicken inedible offal	Fertilizer, medicines, cosmetics	4-5	85	717
	Egg shell waste	Fertilizer, medicines, cosmetics	4-5	0	0
	Chicken offal	Animal feed, fertilizers	4-5	3	0
Cattle	Cattle inedible offal	Biofuel, solvents, animal feed	7-8	56	397
	Cattle milk spills	Irrigation sprays, animal feed	7-8	21	0
	Cattle offal	Biofuel, solvents, animal feed	7-8	2	0
	Cattle spoiled meat	Animal feed	7-8	0	0
	Cattle spoiled fat	Cosmetics, chemical	7-8	0	0
Sheep	Sheep inedible offal	Leather, medicines	7-8	2	1,713
	Sheep milk spills	Discarded into wastewater	7-8	0	0
	Sheep offal	Leather, medicines	7-8	1	0
	Sheep spoiled meat	Animal feed, fertilizer	7-8	0	0
	Sheep spoiled fat	Medicines	7-8	0	0
Pigs	Pig inedible offal	Animal feed	7-8	4	38
	Pig offal	Animal feed	7-8	11	0
	Pig spoiled fat	Landfill	7-8	0	0
	Pig spoiled meat	Landfill	7-8	0	0
Fish and aquatic plants	Freshwater fish waste	Oil, animal feed, fish food	n/a	8	0
	Aquatic plants	Waste-water treatment	n/a	4	0
	Pelagic fish waste	Oil, animal feed, fish food	n/a	3	0
	Molluscs waste	Oil, animal feed, fish food	n/a	2	0
	Demersal fish waste	Oil, animal feed, fish food	n/a	2	0

1) The specified use accounts for reusable part of the waste streams, the remaining part is either landfilled or incinerated
Source: FAOSTAT, Secondary research

Majority (c.70%) of Dutch manure is processed on-farm where it is used as fertilizer whereas the remaining quantities are outsourced for processing

High-level overview of the Dutch manure processing market [2018; mt]



- Mainly dairy farms and applied majorly as fertilizer for the ground
- Relevant players in on-site processing:
  - Producers of processing equipment, which can be a) sold or b) leased, and installed on-site
  - (Cooperatives) of farmers process manure on-site

- Mainly pig and poultry farms as they usually cover less land
- Processed by various companies

Comments

- Manure production and usage is regulated to prevent or limit nutrient dispersion in the environment – A part of the surplus of manure that cannot be used on the farmer's land must be processed
- Costs of manure disposal paid by livestock farmers ranges between EUR 5-25 per ton in NL
- As it is costly to dispose of and there is a potential to use on farm, various illegal practices/lawsuits are observed that relate to:
  - From farmers' side: (i) processing more or other manure than permitted, (ii) fraudulent reporting and (iii) using different processing methods than allowed
  - From treatment players: (i) illegal trading – especially in co-digestion where besides manure other waste streams are processed (ii) odor complaints (often related to exceeding the permitted capacity)
- Accordingly, there could be a potential to utilize manure and encourage more release of waste (which might aid to regulate nitrate levels in loess/sand) should there be an overall financial and ecological benefit (to be further assessed)

Source: Wageningen University & Research, CBS, Secondary research

Illustrative – High-level assessment

Within industrial sources of unreleased waste, refining and petrochemical sector is further assessed

Scoping of the unreleased non-biogenic industrial waste by source[1)]

Source	Description of waste	Estimated share of unreleased waste	Unreleased waste estimated energy content	Potential interest from industry to treat waste	Shortlisted?
Refining and petrochemical plants	• Chemical waste such as spent solvents and used oils and combustion waste such as waste from flue gas cleaning	◑	High	✓	✓
Utilities	• Combustion waste such as waste from flue gas cleaning and ashes and mixed mineral waste	◔	Low	✗	✗
Manufacturing plants	• Metal, mineral waste and certain material specific waste	◔	Low	✗	✗
Wastewater & waste management	• Sludges, sorting residues and mixed mineral waste	◔	Low/Medium	✓	✗

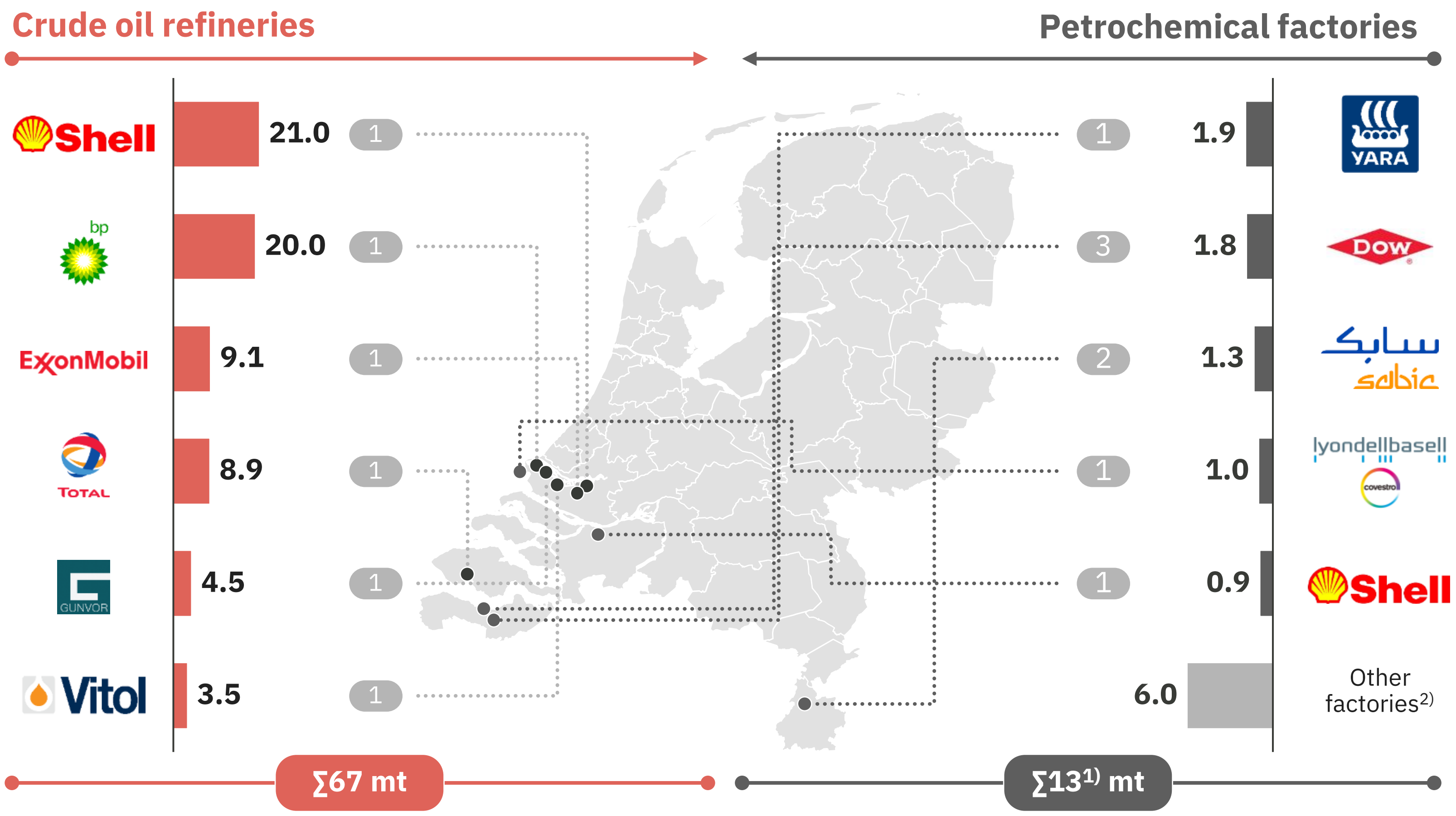
Shortlisted

1) Exclude non-biogenic inorganic sources such as construction and mining and quarrying
Source: Interviews with market participants

Non-exhaustive petrochemical facilities

Dutch refining and petrochemical industry processes a combined 80 mt of crude oil and derivatives, creating waste in the process

Nameplate capacity refining and petrochemical industry in the Netherlands [mt]



Comments

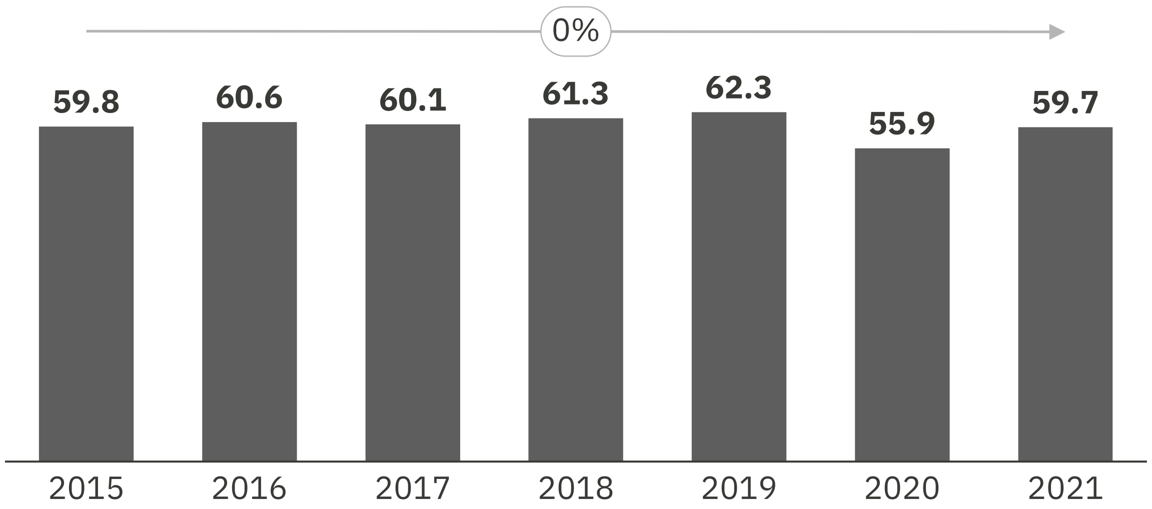
- The Netherlands has a large petrochemical and refining industry, the latter being largest in terms of absolute processing capacity
- Refining industry has a combined nameplate capacity of c. 67 mt of crude oil annually
  - Shell Pernis is the largest final refinery in Europe at 21 mt of crude oil, followed by BP Rotterdam with 20 mt
  - In 2021, c. 59.7 mt of crude oil was processed, implying a utilization rate of c. 90%
- Petrochemical industry has an estimated nameplate capacity of 13 mt, based on 95% utilization rate
  - Chemical factories in the Netherlands are clustered in five areas, namely Rotterdam-Moerdijk, Chemelot (Geleen), Amsterdam, Zeeland-West-Brabant and North of the Netherlands
  - In 2021, 12.3 mt of refined products was processed to produce petrochemical products
- Waste streams can be estimated assuming a percentage of processed products – Comparison with data on released waste streams provides an estimation on the unreleased waste streams

1) Based on assumed 95% utilization rate and average use refined fossil products of 12.3 mt in 2015-2021; 2) Remaining factories are collection of smaller factories located in the main five chemical clusters
Source: PBL, CBS, EU ETS, Secondary research

Production of refineries and petrochemical facilities has been constant over 2015-2021

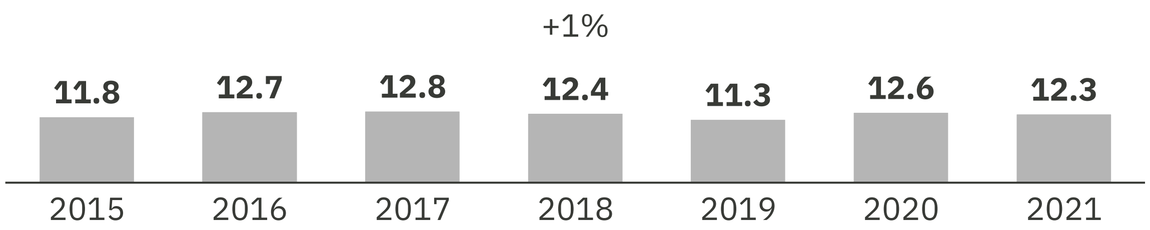
Production volume refining and petrochemical industry in the Netherlands [2015-2021; mt]

Refineries



- Oil refineries show a constant production level at c. 60 mt of processed crude oil, with the notable exception of 2020, caused by the COVID-19 pandemic

Petrochemical factories



- Petrochemical factories show a constant level as well over the years 2015-2021, however 2022 developments in the European energy market are not reflected in the data
  - Gas and electricity prices have sky-rocketed which are needed as fuel and feedstock, hurting competitiveness of the factories
  - E.g., fertilizer manufacturer Yara closed its Sluiskil factory (capacity 1.9 mt) in July 2022 due to high gas prices

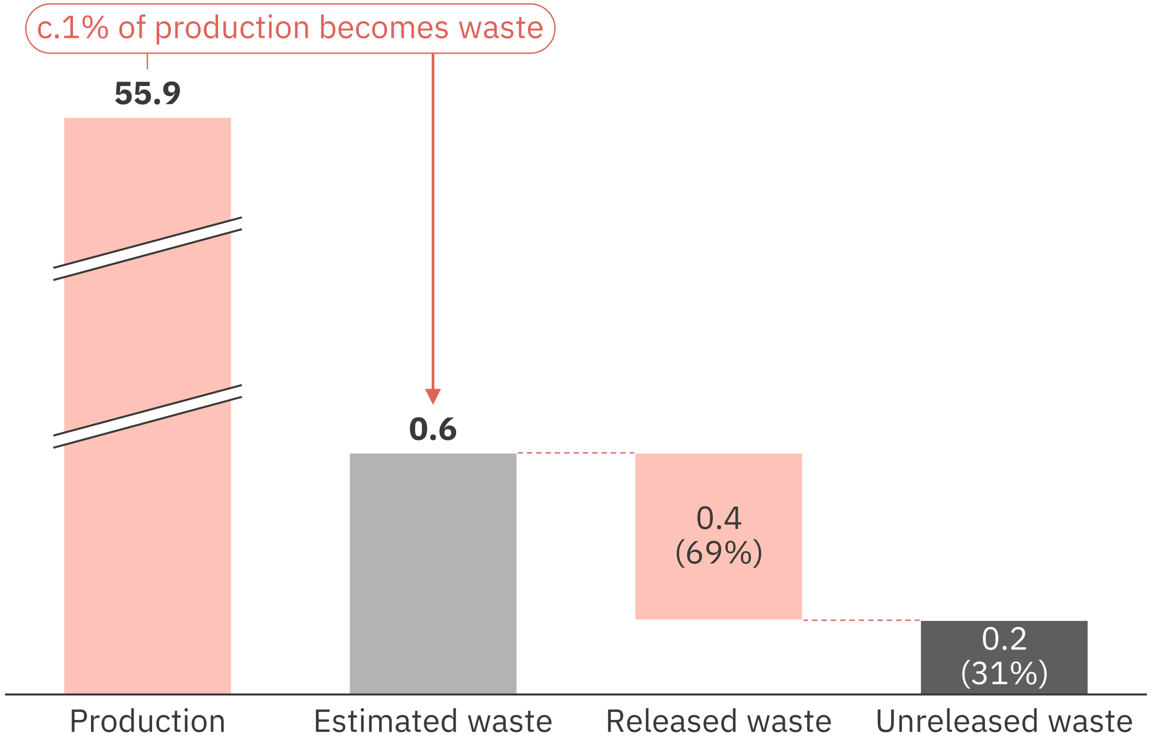
Source: CBS, Financieele Dagblad

High-level estimate

Based on high-level estimations, majority of waste streams are released to the market, both from refineries and petrochemical factories

Waste production refining and petrochemical industry in the Netherlands [2020; mt]

Refineries



Petrochemical factories

1) Eurostat provides data for aggregate category "chemical, pharmaceutical, rubber and plastic products" – CBS data is used to estimate 49% of this covers chemical sector

Source: Eurostat, CBS, Interviews with market participants

C. Deepdive on interesting streams for sustainable gas

Within this chapter, potentially attractive streams for sustainable gas generation were shortlisted

Chapter content

Current status of waste streams

- Among the assessed waste streams, unreleased refining & petrochemical waste has been excluded from the shortlisting due to limited potential driven by low volumes
- Potentially interesting type of feedstock for further assessment are:
- Released: household municipal waste, industrial sludges, chemical, plastic and wood waste
- Unreleased: Potatoes, sugar beet, sugarcane bagasse and vinasse, potato vinasse and spoiled potatoes and tomatoes

Chapter structure	Content
1 Released waste streams	• Knock-out filtration and shortlisting of released waste streams
2 Unreleased waste streams	• Knock-out filtration and shortlisting of unreleased agricultural waste from plants and animals • Knock-out filtration and shortlisting of animal and plant-based food processing waste streams

Illustrative

Among the assessed waste streams, unreleased refining & petrochemical waste has been excluded from the shortlisting due to limited potential driven by low volumes

Potential waste stream for shortlisting

Streams	Volumes [mt]	Geography	Calorific value [MJ/kg]	Energy potential [PJ]	Implied share[1]	Current treatment	Potential[2]
Released biogenic	160	EU	15-20	c. 3,000	1-5%	• Majority recycled	
Released nonbiogenic	335	EU	15-25	c. 5,000	1-3%	• Majority incinerated and/or landfilled	
Agricultural waste	1,395	Global	10-20	c. 25,000	0-1%	• Kept on farms and used as fertilizers/animal feed	
Plant based food processing	1,768	Global	15-20	c. 30,000	0-1%	• Part traded globally • Part used as animal feed/fertilizer	
Animal food processing waste	206	Global	5-15	c. 2,000	2-9%	• Reprocessed into animal feed, cosmetics, etc.	
Manure	50	Netherlands	15-20	c. 1,000	4-16%	• Kept on farms and used as fertilizers/animal feed	
Refining and petrochemicals	0.3	Netherlands	20-30	c. 10	400%+	• Reprocessed and/or used for energy generation	

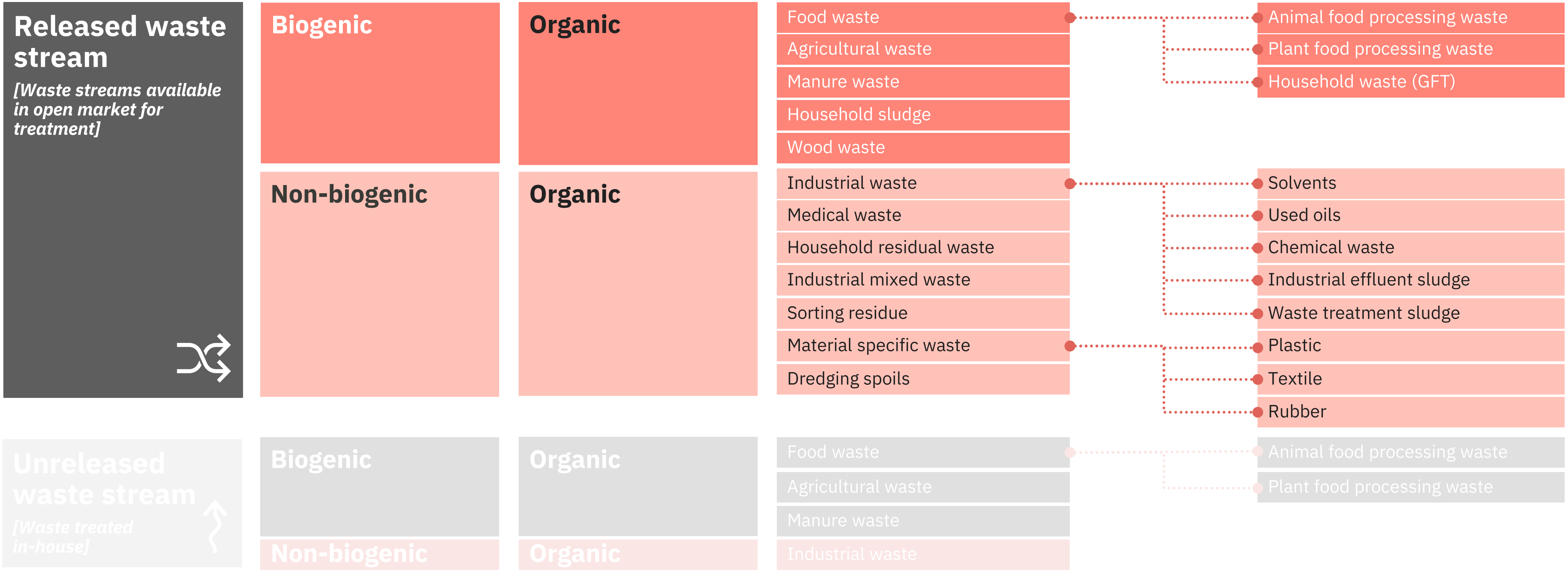
Released waste streams | Unreleased/total waste streams | Potentially attractive streams

1) Share to be acquired from total volumes to realize sustainable gas objective – 1 bn m³ sustainable gas as lower bound and 4 bn m³ as upper bound; 2) Potential is a high-level estimation based on combination of energy potential, implied share and current treatment

Source: Eurostat, FAOSTAT, World Wildlife Fund (WWF), Secondary research

C.1 Released waste streams

Focus of this chapter is on released waste, both biogenic and non-biogenic

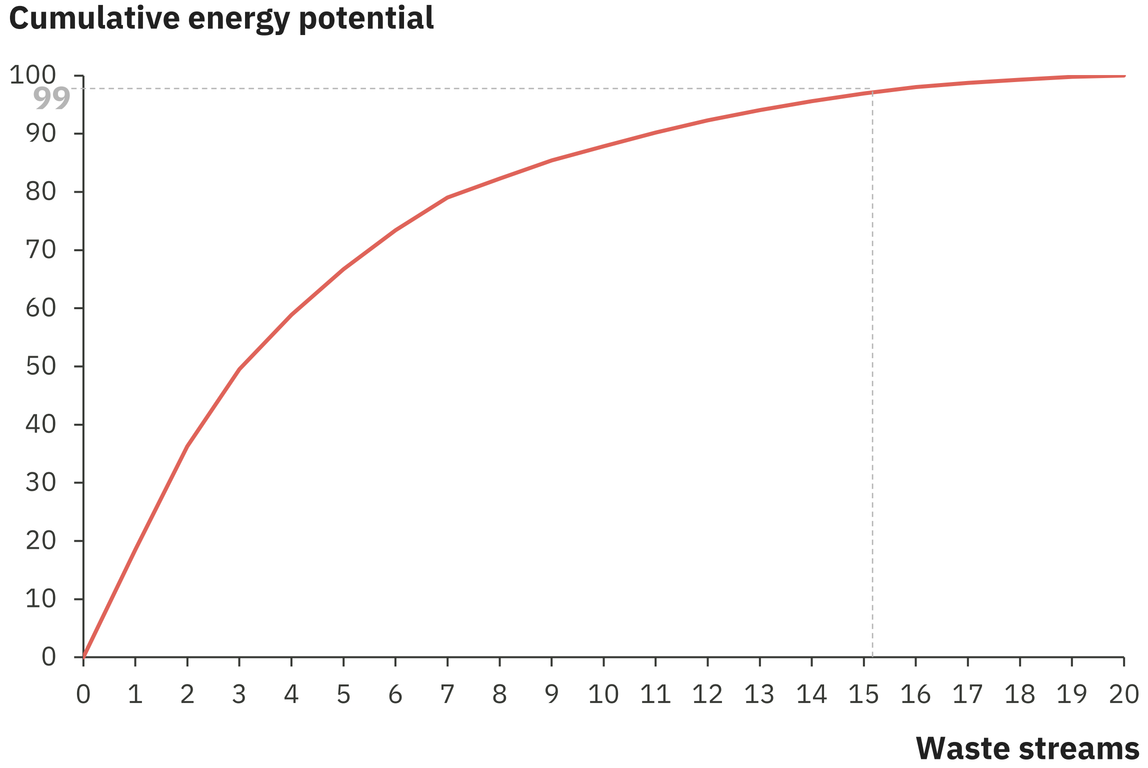


Source: Eurostat, Secondary research

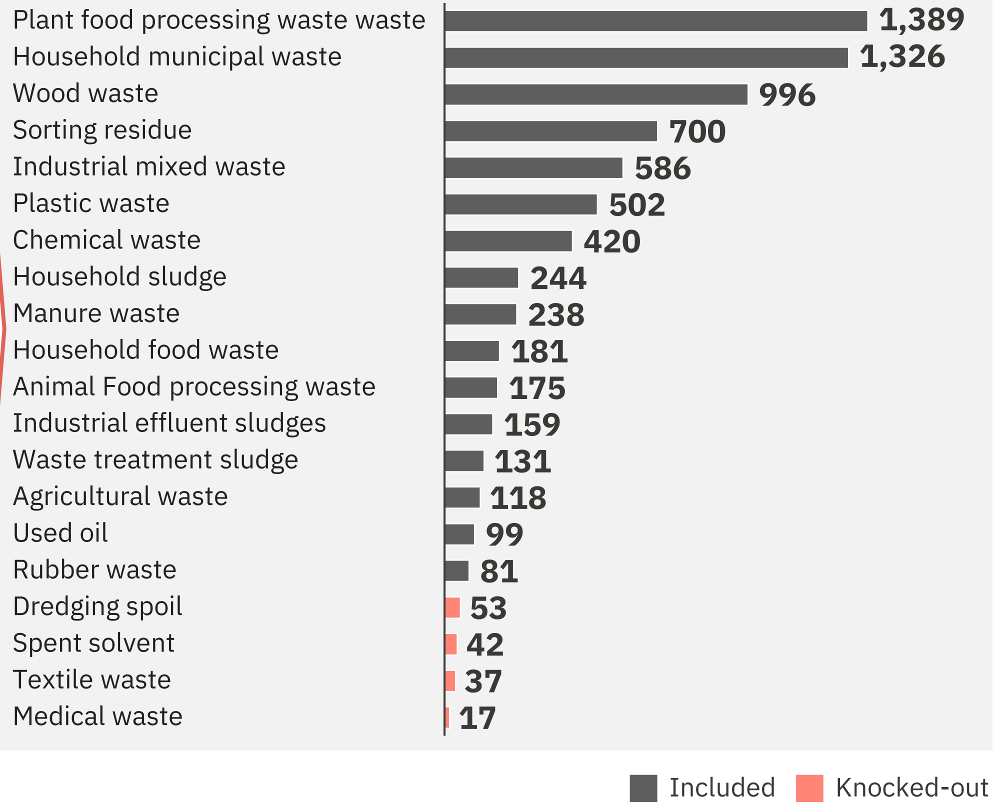
16 waste streams covering 99% of the total energy potential of the released waste streams were filtered for further assessment based on energy potential

Knockout filter for the released waste streams

Cumulative energy potential[1)] [%]



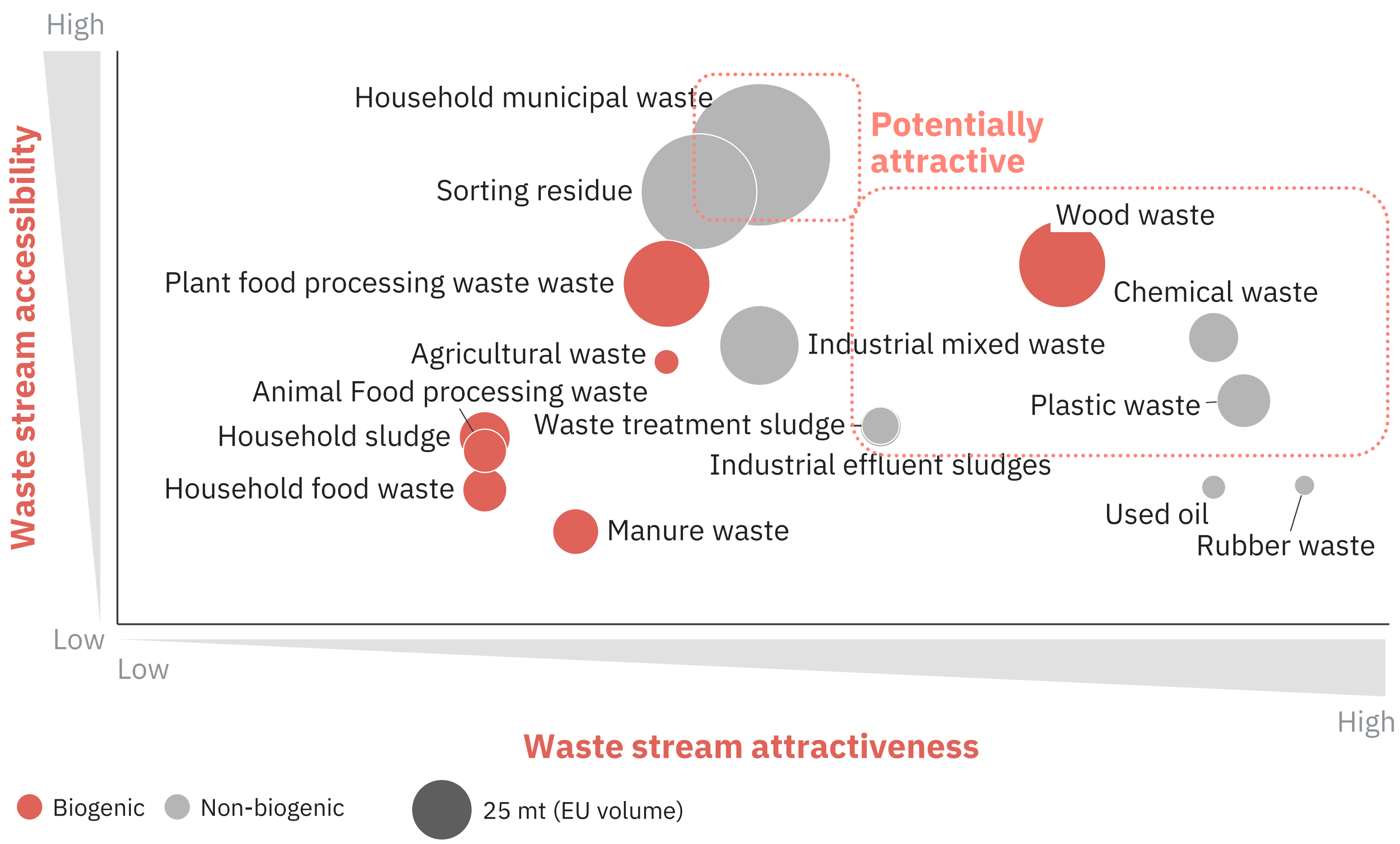
Released waste streams – Energy potential [PJ]



1) Energy potential is defined as product of volume at EU level and average calorific value
Source: Eurostat, Secondary research

Household municipal waste, industrial sludges, chemical, plastic and wood waste could be potentially attractive from the released streams

Shortlisting of released waste streams

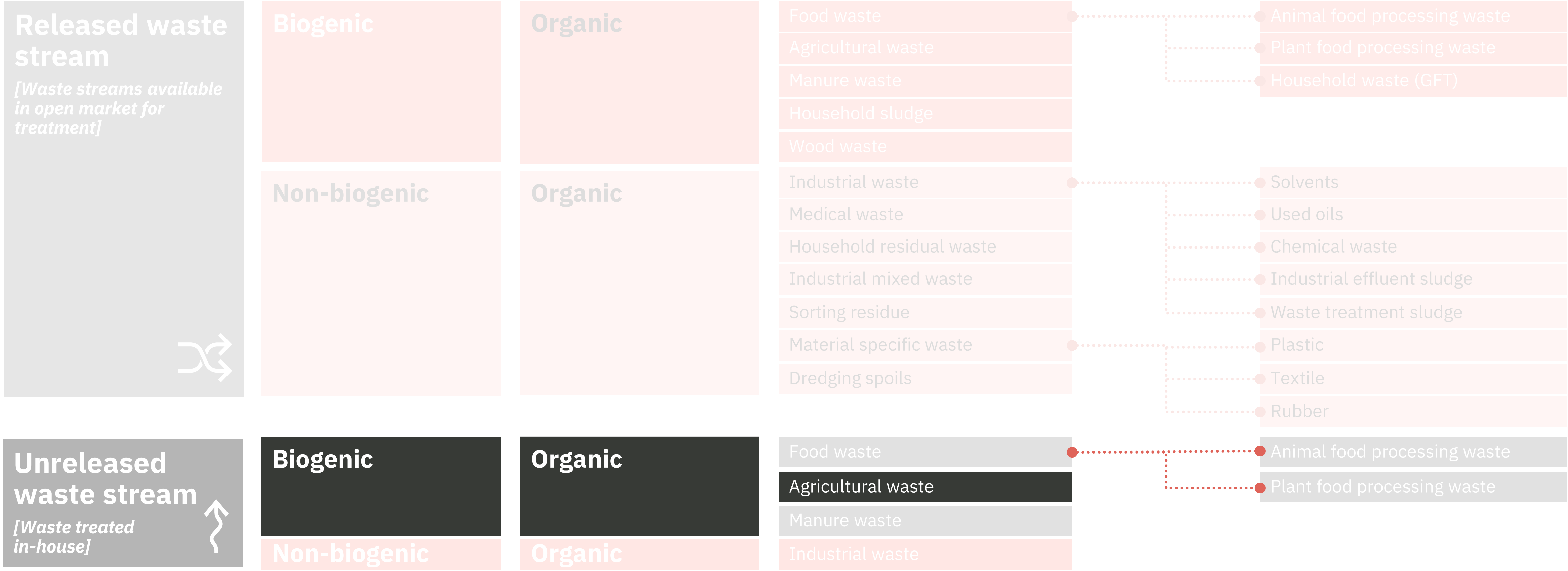


	Parameters	Rational	Weight
Attractiveness	Calorific value	High energy potential represents waste stream with either high volume or high calorific value or both	
	Environmental impact	High environmental emission of the current energy recovery method leads to better competitive advantage	
	Energy efficiency	Low energy efficiency of the current energy recovery method leads to better competitive advantage	
Accessibility	Available volume in NL, BE and DE	Higher volume of the waste in NL and surrounding regions represents higher potential to access it	
	Ease of accessibility	More fragmented the sources of the waste stream more difficult it is to access it and more mature is the import/export supply chain easier it is to access global volume	
	Current treatment method	High percentage of non-recycling treatment method represents high potential for feedstock to be treated with alternative methods	

Source: Eurostat, Secondary research

C.2 Unreleased waste streams

Focus of the following slides is on agricultural waste

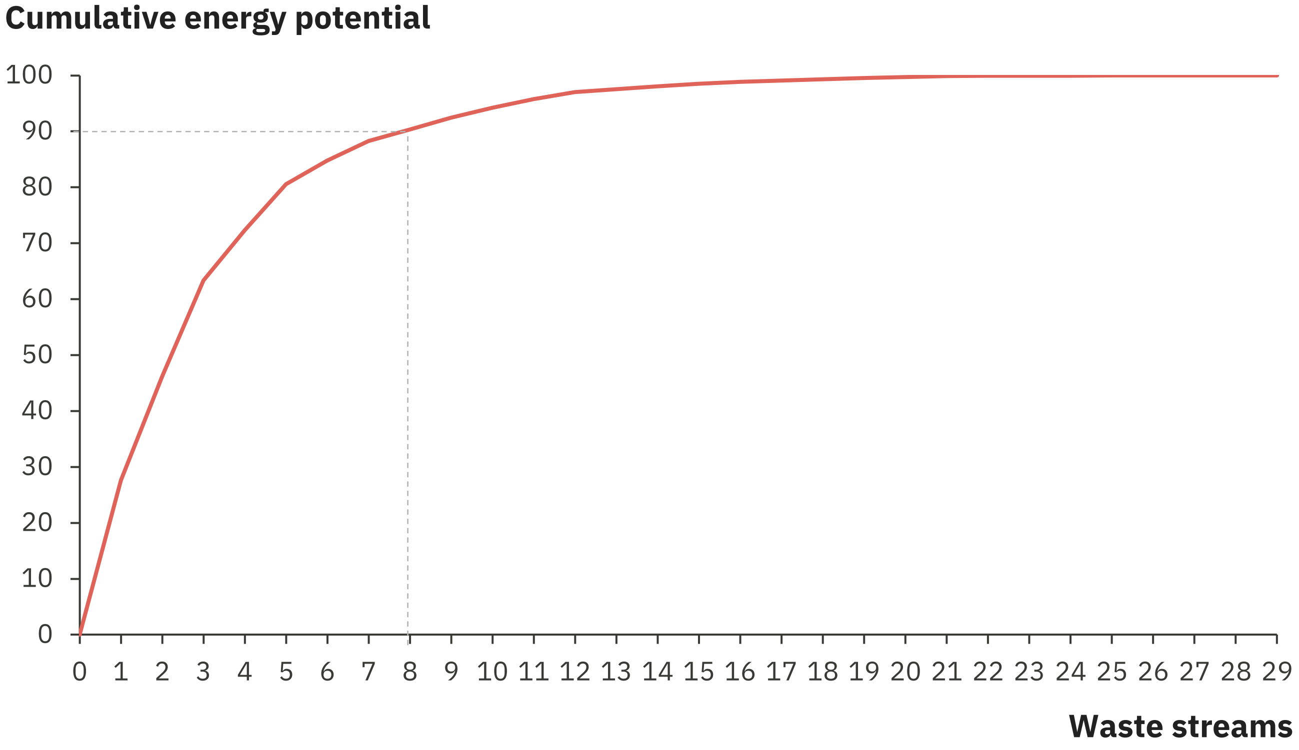


Source: Eurostat, Secondary research

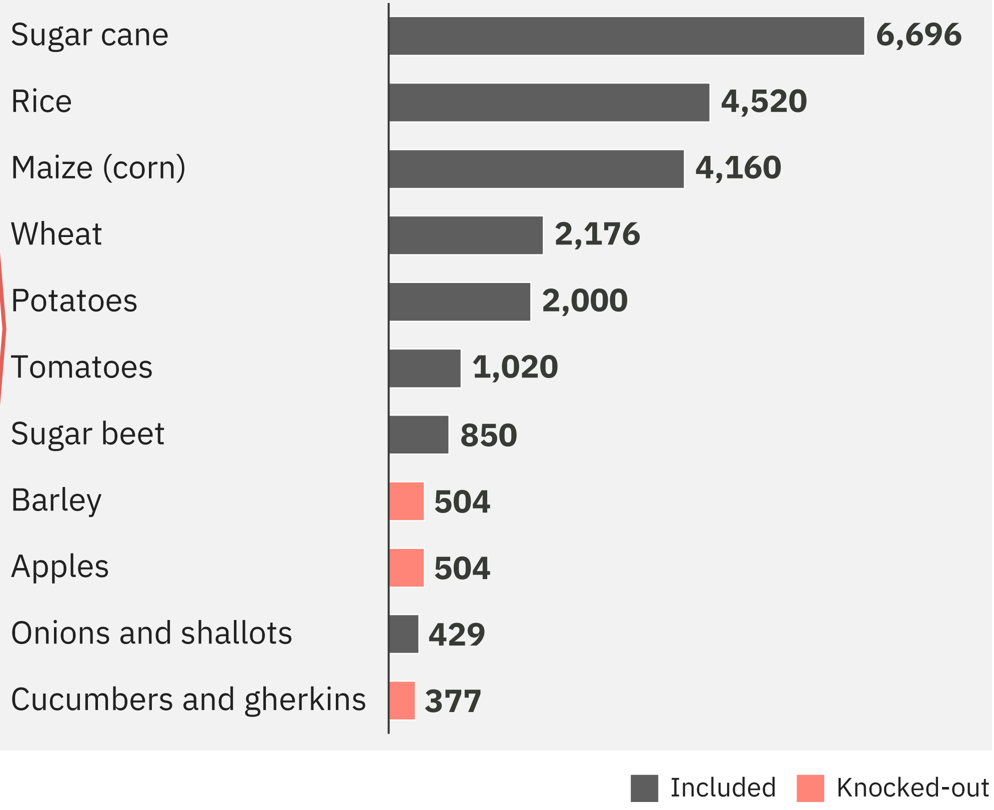
Eight waste streams from the unreleased agricultural waste were filtered for further assessment based on energy potential

Knockout filter for the agricultural waste streams from plants and animals (1/2)

Cumulative energy potential[1) [%]



Total agricultural waste streams – Energy potential [PJ]

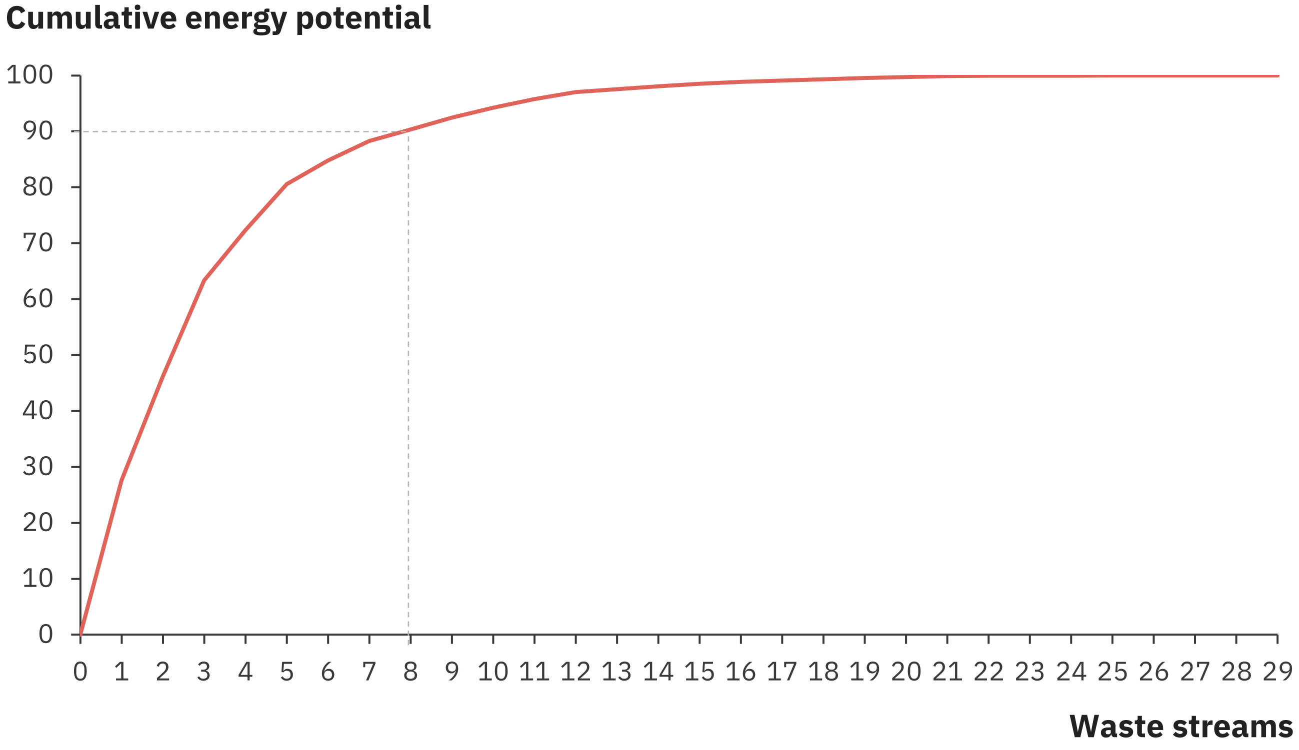


1) Energy potential is defined as product of volume at global level and average calorific value
Source: FAOSTAT, WWF, Secondary research

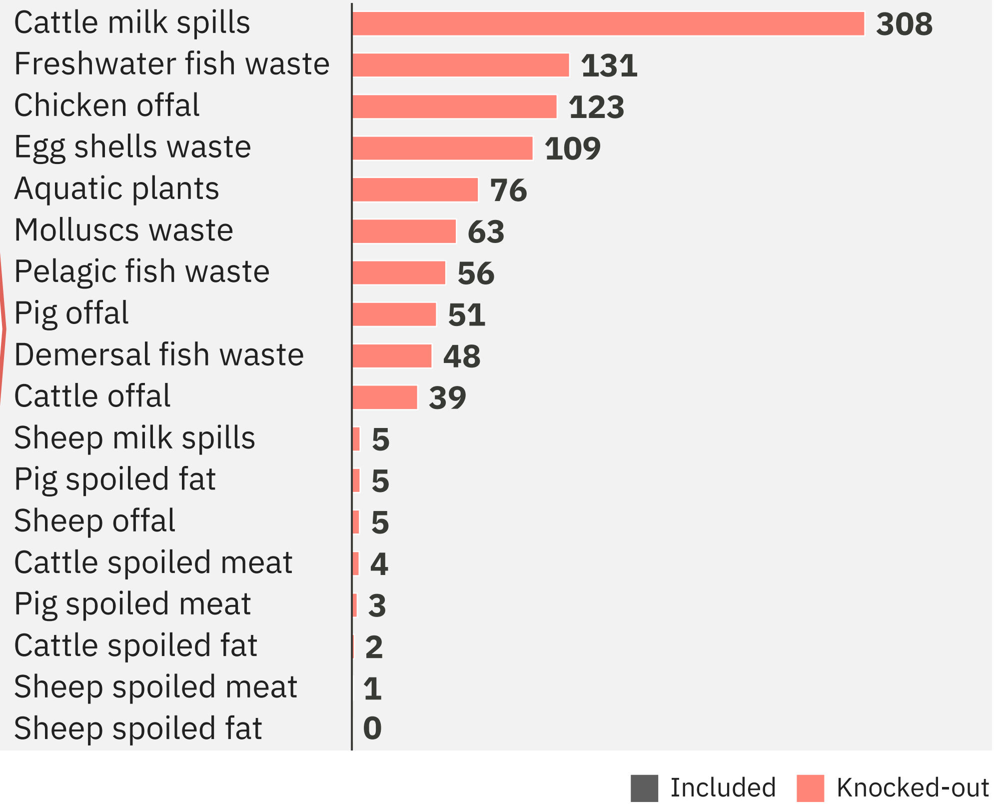
Eight waste streams from the unreleased agricultural waste were filtered for further assessment based on energy potential

Knockout filter for the agricultural waste streams from plants and animals (2/2)

Cumulative energy potential[1)] [%]



Total agricultural waste streams – Energy potential [PJ]

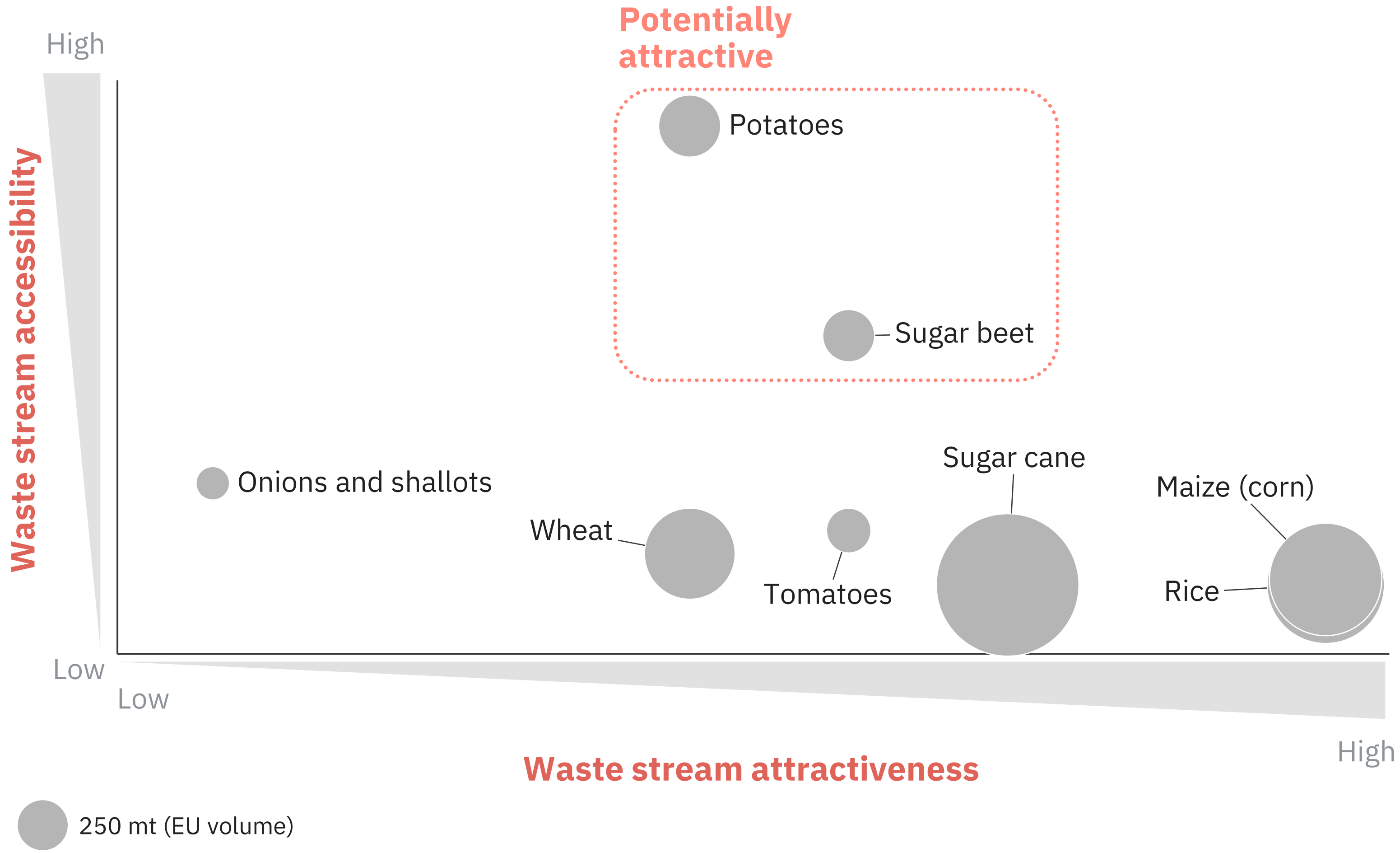


1) Energy potential is defined as product of volume at global level and average calorific value

Source: FAOSTAT, WWF, Secondary research

Unreleased agricultural waste from potatoes and sugar beet waste could be interesting type of feedstock

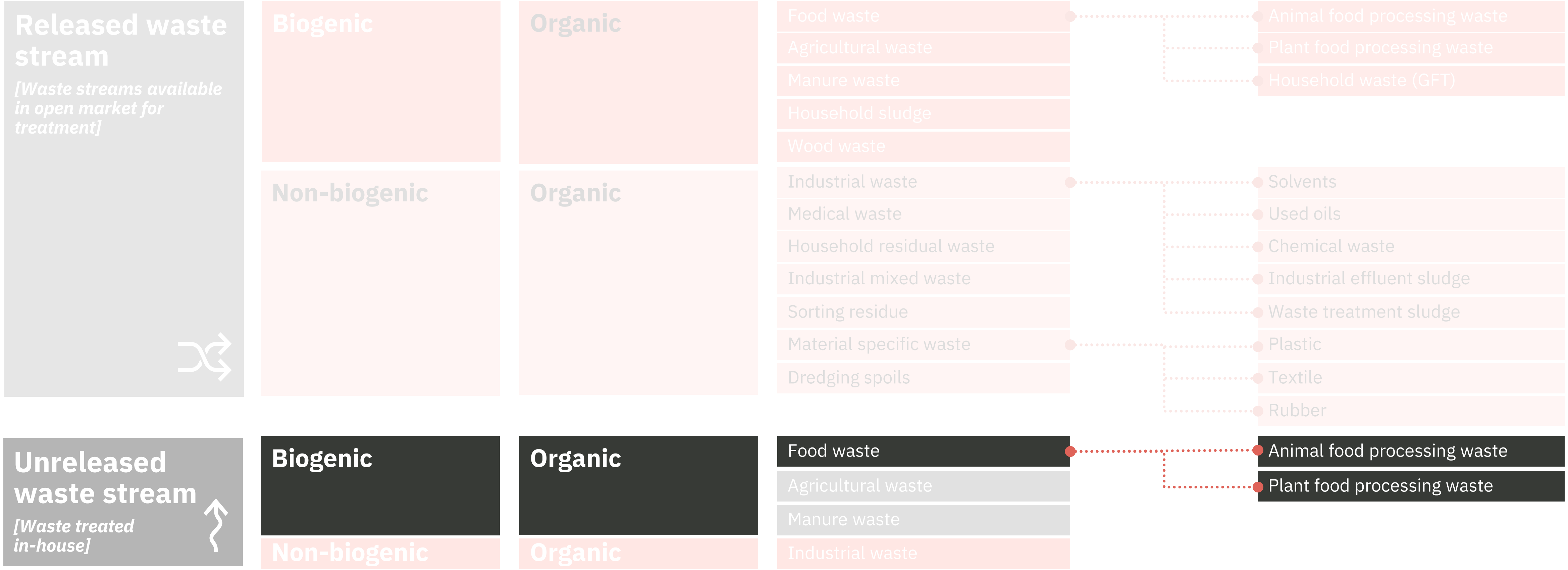
Shortlisting of agricultural waste streams



	Parameters	Rational	Weight
Attractiveness	Calorific value	High energy potential represents waste stream with either high volume or high calorific value or both	●
Accessibility	Available volume in NL	Higher volume of the waste in NL represents higher potential to access it	●
Accessibility	Ease of accessibility	Majority of the agricultural waste is repurposed locally and hence is hard to access	not considered
Accessibility	Current treatment method	Majority of agricultural waste is currently either sprayed on the soil or burned in the fields (mainly in developing countries)	not considered

Source: FAOSTAT, WWF, Secondary research

Focus of the following slides is on food waste, both animal and plant-based food processing

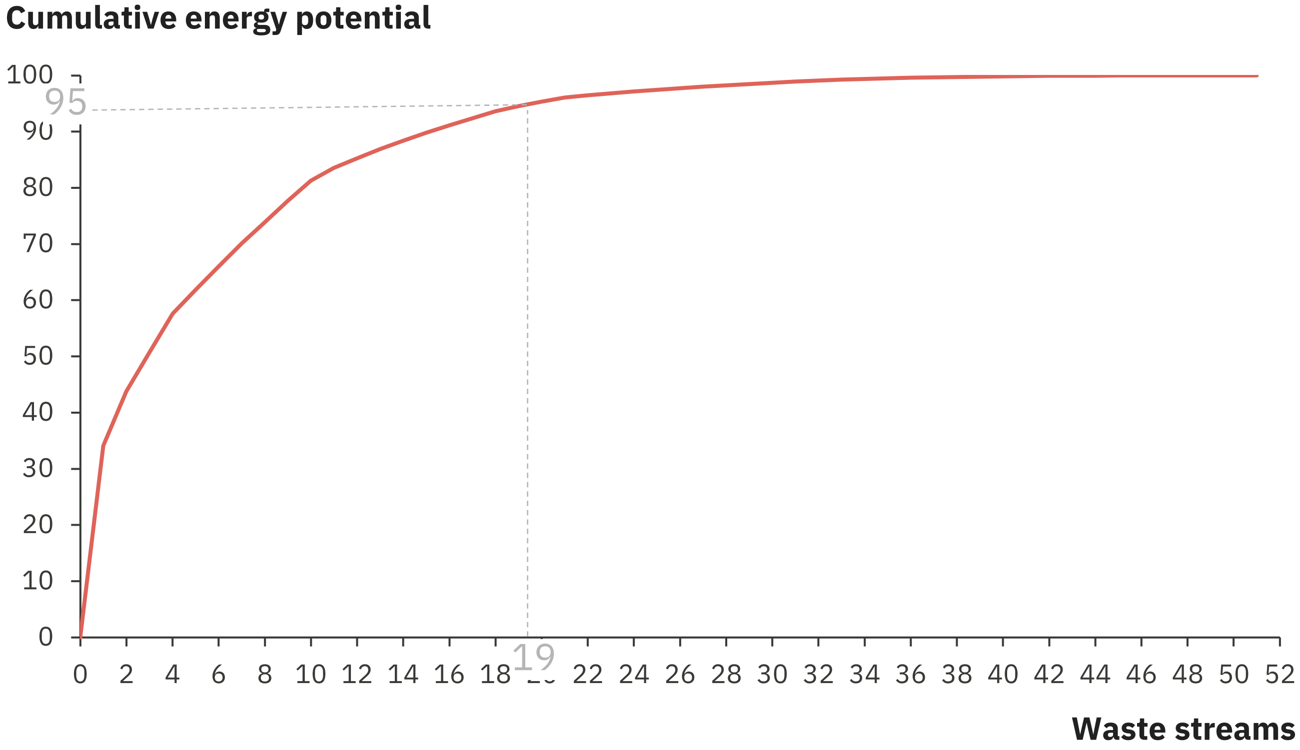


Source: Eurostat, Secondary research

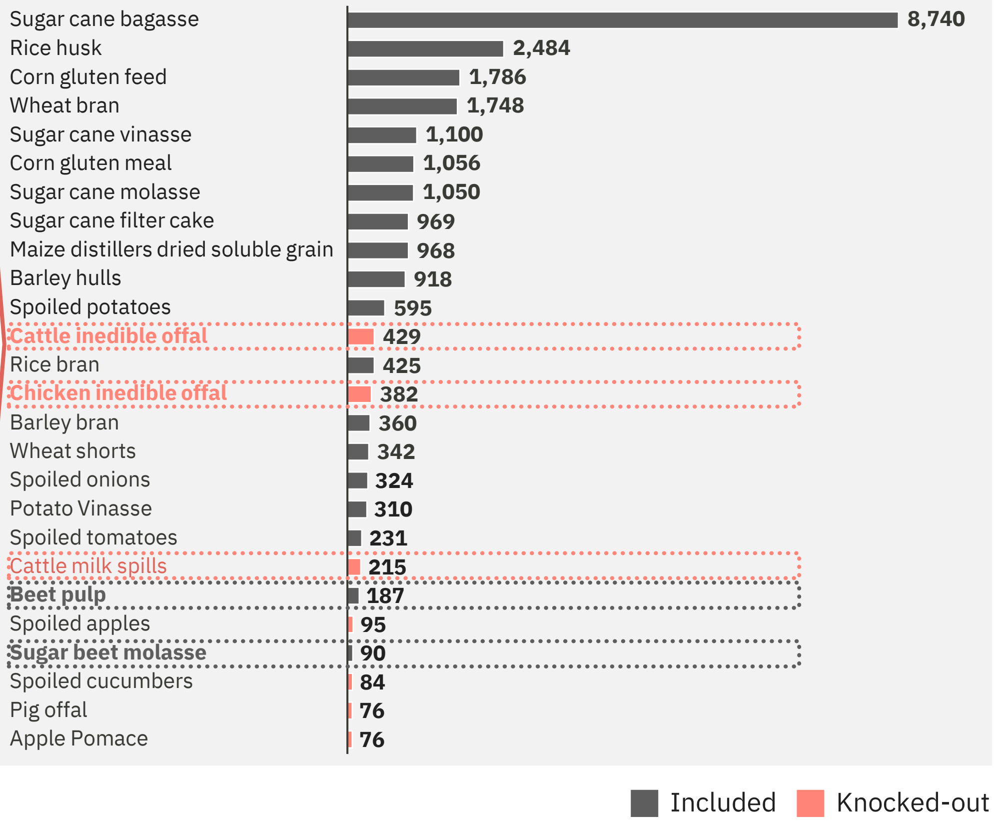
24 waste streams from the unreleased animal & plant-based food processing waste streams were filtered for further assessment based on energy potential

Knockout filter for the unreleased animal & plant-based food processing waste stream (1/2)

Cumulative energy potential[1) [%]



Total food processing waste streams – Energy potential [PJ]



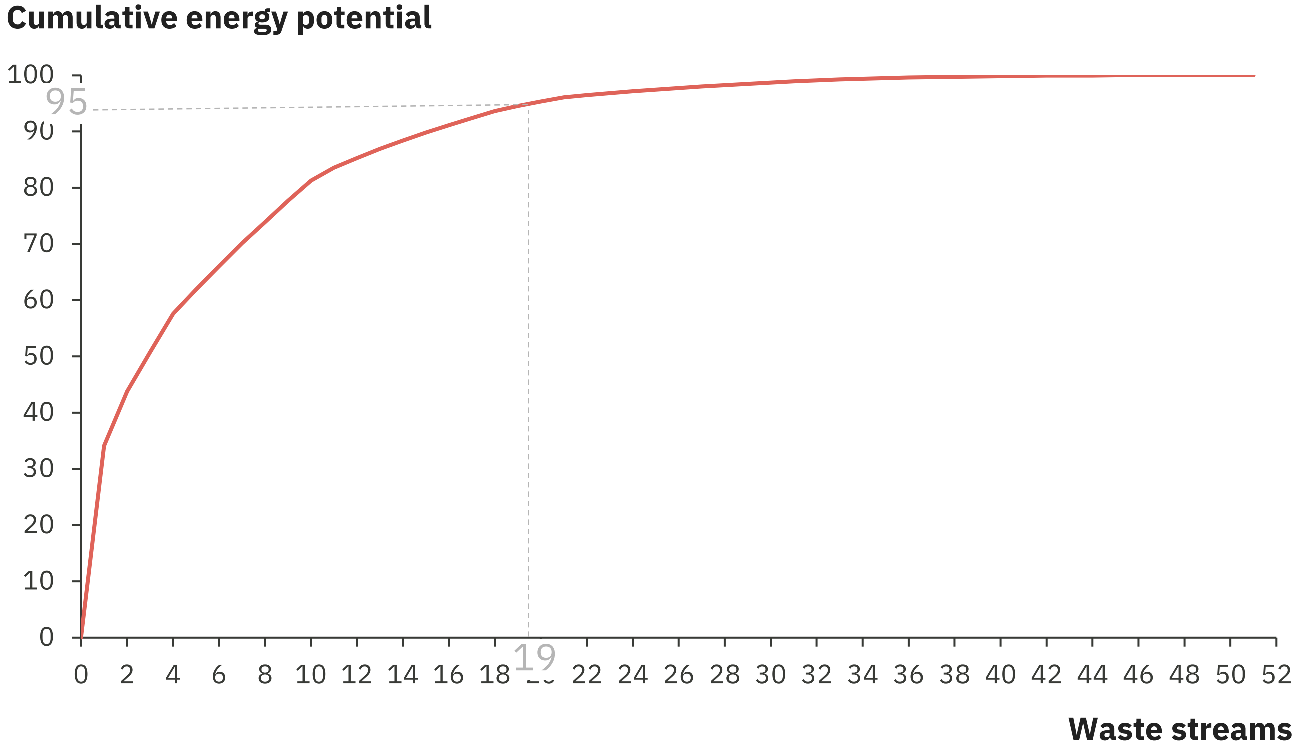
1) Energy potential is defined as product of volume at global level and average calorific value

Source: FAOSTAT, WWF, Secondary research

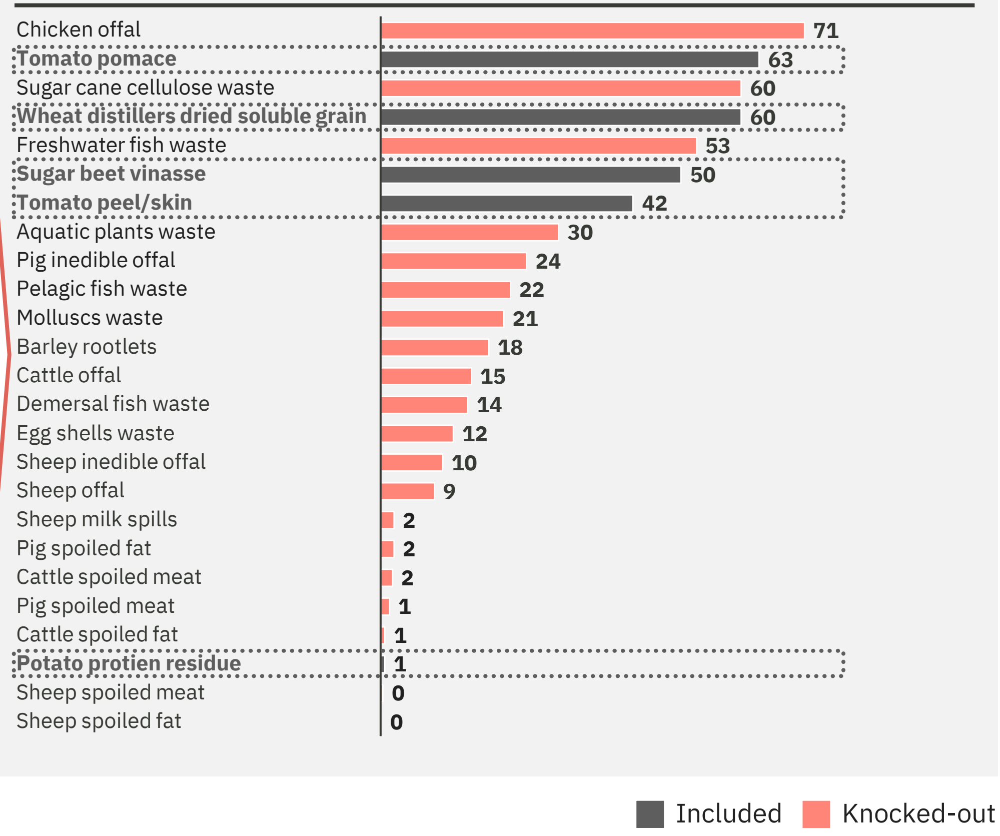
24 waste streams from the unreleased animal & plant-based food processing waste streams were filtered for further assessment based on energy potential

Knockout filter for the unreleased animal & plant-based food processing waste stream (2/2)

Cumulative energy potential[1)] [%]



Total food processing waste streams – Energy potential [PJ]

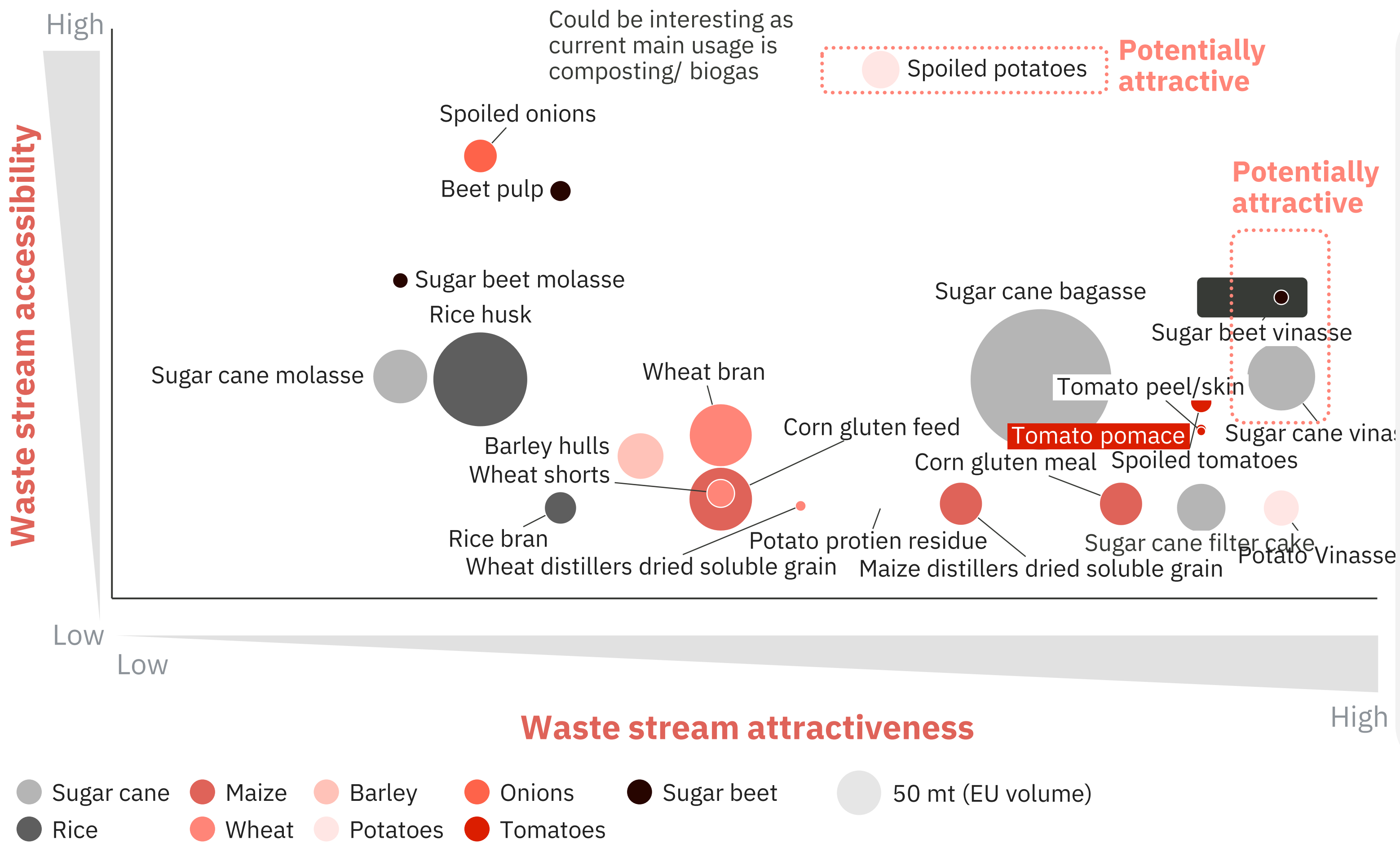


1) Energy potential is defined as product of volume at global level and average calorific value

Source: FAOSTAT, WWF, Secondary research

Sorts of bagasse, vinasse and waste from certain crops could be interesting type of feedstock from the animal & plant-based food processing waste streams

Shortlisting of unreleased animal & plant-based food processing waste stream



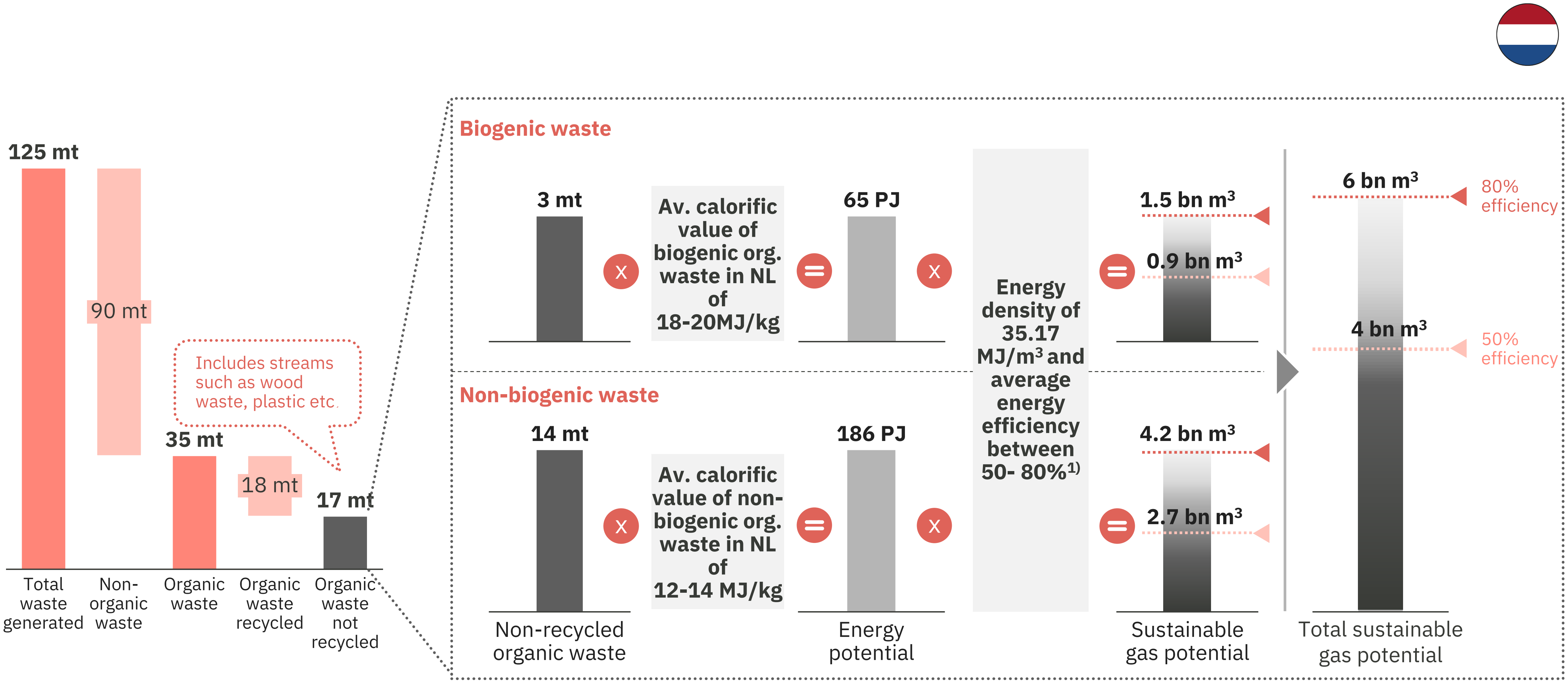
	Parameters	Rational	Weight
Attractiveness	**Calorific value**	High energy potential represents waste stream with either high volume or high calorific value or both	
	Environmental impact	High environmental impact leads to better competitive advantage – Environmental impact is high for waste that are currently having restriction on its use as fertilizer as it can potentially lead to soil pollution, medium for waste that are currently incinerated for energy production as it will have neutral carbon emission and low for waste that is currently mainly used as animal feed	
Accessibility	**Available volume in NL**	Higher volume of the waste in NL represents higher potential to access it	
	Ease of accessibility	More mature is the import/export supply chain easier it is to access global volume	
	Current treatment method	High percentage of non-recycling treatment method represents high potential for feedstock to be treated with alternative methods	

Source: FAOSTAT, WWF, Secondary research

D. Conclusions and suggested way forward

Within the Netherlands, the theoretical sustainable gas potential from organic non recycled waste is estimated to be between 4-6 bn m³

Sustainable gas potential NL with released waste streams (excl. recycled and non-released waste streams)



1) 50% energy efficiency typically corresponds to average energy efficiency of anaerobic digestion and 80% energy efficiency typically corresponds to average energy efficiency of gasification technology
Note: Organic waste not recycled includes all waste generated in NL of which some is currently exported for treatment outside of NL, the potential calculation is based on all generated waste in NL
Source: Eurostat

Conclusions and suggested way forward

- Various streams that are generated in the Netherlands, EU and globally are attractive to be treated to generate sustainable gas
- There is a theoretical potential in the EU to generate ~ 70-110 bn m^3 of sustainable gas from released organic waste (biogenic and non-biogenic) that is not recycled.
- In the Netherlands, the theoretical sustainable gas potential from the released organic non-recycled waste is estimated to be between ~ 4-6 bn m^3:
  - up to 1.5 bn m^3 from biogenic waste streams (excluding streams like manure, food & agriculture waste which are typically recycled) and;
  - up to 4.5 bn m^3 from non-biogenic stream
- Recycled and unreleased streams are excluded from the potential feedstock for sustainable gas production
- Ability to capture those volumes will depend on the efficiency of the treatment technology, emission intensities and costs (both operational and capital expenditure) in comparison with other technologies
- Accordingly, this study lays out the potential of sustainable gas generation but does not comment on the competitiveness of such technologies vs. others, which could be a follow-up study, using information found here as an input. A follow-up study could also focus on the developments of alternative treatment technologies and regulatory impact

scw systems

INVEST-NL

gasunie
crossing borders in energy

Roland Berger