The growing competition between the bioenergy industry and the feed industry

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Date: 29 June 2022 | Wageningen University & Research

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Date: 29 June 2022 | Wageningen University & Research

Environmental project studies ETE25812_2021_5

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Commissioned by:

European Federation of Manufacturers of Compound Feed & Premixes (FEFAC) &

European Former Foodstuff Processors Association (EFFPA)

I. Disclaimer

This report is the final result of a study carried out by 2nd years' students of Environmental Sciences at Wageningen University. It was conducted in the framework of the subject Environmental Project Studies.

The aim of this report is to have students gain experience with problem-oriented environmental research. The real-life problems elaborated during the subject stem from suggestions by research institutions, consultancy firms, governmental bodies, environmental advocacy groups, etc.

These institutions will receive the final report of the studies proposed in reward for their help. In this subject the students work in groups and pass through various stages in which they train themselves in analyzing the societal context of environmental problems, formulating a definition of the research problem and related research questions, in executing literature research and data collection, drawing conclusions, writing a final report, and giving an oral presentation of the study. The students are supervised by staff of Wageningen University interested in the problem at hand. The total time spent on the research work proper is about 120 hours per student. Given the limited duration and nature of the study publication and wider dissemination of results may only occur after consultation with the responsible supervisor. It is not allowed to copy or publish in any way the results from this report without permission of the Sub-department of Environmental Technology of Wageningen University, P.O. Box 17, 6700 AA -Wageningen Tel.: 0317-483339.

II. Preface, list of abbreviations

AB = Advanced Biofuels

ACLA = Attributional Life Cycle Assessment

Bmc = Billion metric cubes

CLCA = Consequential Life Cycle Assessment

CO_2 = Carbon Dioxide

DDGS = Dried Distiller Grains with Solubles

E.B.A = European Biogas Association

Etc = Et cetera

EEA= European Economic Area

EJ = Exajoule[1]

EU = European Union

eWFD = Revised Waste Framework Directive

FiP = Feed in Premium

FiT = Feed in Tariff

GDP = Gross domestic product

GHG = Greenhouse gas

GWP = Global Warming Potential

i.e. = Id est (that is)

LCOE = Levelized cost of electricity

LU = Land use

NoS = No bioenergy support

PLN = Polish złoty (Currency)

PoE = Palm oil elimination

REDII = Revised Renewable Energy Directive

RVO = Rijksdienst voor Ondernemend Nederland (in English: Netherlands Enterprise Agency)

SDE++ = Stimulering Duurzame Energieproductie en Klimaattransitie (in English: Stimulating Sustainable Energy Production and Climate Transition)

[1] 1 EJ = 10^{18} J

III. Summary

In recent years the European Union has been implementing new directives and policy initiatives to promote and encourage the development of energy from renewable sources. The Green Deal (2019) provides incentives to cut greenhouse gas emissions associated with the livestock sector (Farm to Fork strategy). Additionally, the Circular Economy action plan promotes the valorization of waste and co-products in the food, feed and bioenergy sectors. The Revised Waste Directive of 2022 introduces the concept of the 'Food Waste Hierarchy' to support the management of food co-products and waste.

The European Biogas Association has set a goal to increase the biogas industry tenfold by 2030 and then multiply it again by three times by 2050, reaching 95 billion metric cubes per year in Europe. Currently, the biogas plants in Europe use a mix of feedstock, consisting mainly of energy crops, agricultural residues, and manure. The higher methane yield and convenience of co-products could incentivize some biogas plants to choose to source feedstock that could be used by the feed industry. This could be an increasing problem if the biogas industry continues to receive financial support and nations do not implement legislation to ensure that feedstock available for feed does not get diverted to the biogas industry. Furthermore, due to the limited availability of raw materials, many countries in Europe are suffering from an increase in the prices of feed materials.

Italy has been significantly affected by this phenomenon which adds pressure to local farmers, who receive very little financial support to sustain their production systems. One of the latest national laws, passed in 2022, promotes the use of co-products for the production of biogas, to reduce the energy crisis. The increasing pressure from the EU to invest in renewable energy has pushed France to reduce the amount of energy produced with nuclear power and increase investment in other sources of energy such as biogas. This, combined with France's limit to using no more than 15% of energy crops for the production of biogas, led to unfair competition for the sourcing of co-products. The Netherlands has implemented the SDE++, which provides incentives to biogas-producing plants. In the past decade, The Netherlands witnessed a progressive shift from co-fermentation to mono-manure fermentation, which lowers the pressure on the feed industry for sourcing co-products. In Poland, the situation is different compared to the Western European countries as there is no apparent competition for the sourcing of (co-)products between the feed sector and the biogas sector, which is still not very developed.

For the scope of the research, a comparison between different scenario analyses was carried out with the aim of predicting possible scenarios for the development of the two sectors. The scenario analysis of the developments of the biofuel industry under the Renewable Energy Directive objectives shows that there will likely not be sufficient biomass available to support the growth of the biofuel industry. Another scenario analysis shows the possible market fluctuations and impacts of different policy regulations on the bioindustry sector. Next, the potential of circular agricultural production and the cascading use of co-products is investigated as a possible future scenario. These results are then applied to the biogas sector for sourcing co-products in competition with the animal feed industry, based on the assumption that the bioenergy industry and biogas industry will follow similar trends. The results show that directing co-products to the biogas sector will shift competition from the bioenergy and feed sectors to the feed and food sectors. Therefore, there are tradeoffs and potentials for either scenario. Competition and tradeoffs can be minimized and controlled, providing that there is sufficient regulation and governance.

To investigate the environmental impacts of using food co-products from either the animal feed or biogas sector, multiple studies were researched. In these studies, either an Attributional Life Cycle Assessment or a Consequential Life Cycle Assessment was used. The first study is about the use of supermarket food products in Sweden for multiple waste management options, such as anaerobic digestion and animal feed production. The second study is about the co-existence of the usage of food co-product for both sectors. The third study concerns a new feed diet mix, the NOSHAN mix. Fourthly, about implementing beet tails in the diet of dairy cattle feed instead of using the beet tails for anaerobic digestion. And lastly, about the impact of different usage of sources for on-farm anaerobic digestion. Some studies concluded that using food co-products has a lower impact on the environment when used for anaerobic digestion instead of for the animal feed sector.

Points of discussion were the legal requirements that create difficulties and extra costs for animal feed sectors to use co-products, so that manufacturers might favour selling their co-products to the bioenergy sector. It was also evaluated that assumptions had to be made to predict the future scenario for the biogas and animal feed sector, and that the researched example scenarios analyses covered theoretical and simplified outcomes. Also, the complexity of researching the environmental impact of both sector was addressed. Indirect environmental impacts by other sectors caused by improving sustainability in one sector was one of the main identified points of discussion.

Mentioned limitations were the recognized uncertainties in the EU directives concerning the classification of co-products. Also unforeseen impacts on development trends such as the war in Ukraine were seen as a limitation, since it showed that variables can cause a unrepresentative view of how development trends will evolve, and made it more difficult to come to a clear conclusion. On top of that, the identified limitations of using interviews as a research instrument were: no response from some stakeholders, the possible bias and subjective view of interviewees, and conflicting statements made by interviewees.

The conclusion of the research was that future competition can be expected between the sectors. Research showed that the use of biogas instead of fossil fuels could significantly lower GHG emissions and reduce the global warming potential, but that other implications are created if the biogas sector were favoured by EU policies. An example of these implications are that animal feed sectors will compete with the food sector for agricultural land and will have to rely on more import from other countries. Aditionally, a lot of factors influence sustainability of the two sectors, making it too complex to give one clear solution. It was recognized that giving simple solutions would likely not address the problem as a whole, but effective governance and policy regulations inline with the food waste hierarchy are recommended to manage the competition between the biogas and animal feed sector. Finally, it was acknowledged that this research investigated and clarified the stated problems and formed a basis for constructing potential solutions and conducting further research into this topic.

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1. Introduction

1.1. Background and problem statement

The animal feed industry has long been one of the major ways food losses have been avoided. One of the main ways this is done is by using food co-products to produce animal feed. Food co-products are secondary products derived from a production process which is recognized for their value as a nutrient resource (FEFAC, 2020). By incorporating food co-products into animal feed, food losses are recovered, nutrients are kept within the food chain, and the environmental impact of animal products is reduced (FEFAC, 2019). However, these same co-products can also be used to produce bioenergy. A rapidly growing industry in Europe is largely powered by the European Commission's renewable energy targets. Thus, competition between the two sectors may arise in sourcing the same feedstock for the production of either feed or bioenergy.

Two of the major stakeholders involved in this possible competition are the European Feed Manufacturers' Federation (FEFAC) and the European Former Foodstuff Processor Association (EFFPA). FEFAC is a federation representing the European compound feed and premix industry. It ensures that the European Directives, concerning feed production and safety are applied in every Member States of the European Union (FEFAC, 2020.). EFFPA is a non-profit European Union (EU) trade association, representing former foodstuff processors producing feed for farm animals (*Home | EFFPA*, 2022). Former foodstuffs are a type of co-products that consist of foodstuffs no longer intended for human consumption but still hold a nutritional value for animal feeding (EFFPA, 2022). FEFAC and EFFPA's main concern is that an increasing share of the co-products formerly used to produce animal feed is now being diverted to the anaerobic digestion industry to produce biogas, hence causing concerns regarding the future of the feed industry.

Some stakeholders within the animal feed industry believe that due to the Green Deal and its policy initiatives that financially support bioenergy, the biogas industry is able to outbid the feed sector for feedstock. Therefore, this report investigated the European directives and the national legislations in four European countries: The Netherlands, Italy, France and Poland. These countries were chosen due to their different geographical areas within Europe and different situations between their biogas and animal feed industries.

To understand why incentives are given primarily to the bioenergy sector, FEFAC also wants to know whether the use of co-products for anaerobic digestion is more sustainable than their use for feed production. The environmental assessment of the two sectors, using the same co-products, could be eventually used to create guidelines for future regulations regarding the governmental financings of the two sectors.

The redirection of co-products to the biogas industry is socially relevant, as a shift of food co-products away from the feed sector could lead to a rise in feed prices; putting farms into difficulty as they might not be able to afford their feed products, and eventually need to raise feed prices. Additionally, many companies producing feed with co-products might decide to revert to producing feed with conventional products. More information on food co-products used in animal feed can be found in *Appendix 10.1*

The hypothesis when starting this research is that the bioenergy sector will not outcompete the compound feed sector. However, increased competition between the compound feed and bioenergy sector is expected in the future. This is because it is preferable to have feed produced sustainably and the EU will therefore promote this sector to have co-products available while simultaneously supporting the bioenergy sector to grow. To verify this theory, stakeholders from the two sectors will be interviewed and the information gained will be compared and combined with the existing one from literature. Additionally, a clearer overview of European directives and on the policies adopted by the countries is also needed to gain a better understanding of the competition between the two sectors at the national level, and recognize what policy instruments are promoting such competition so that in the future the competition can be better regulated.

1.2. Bioenergy and biogas

Europe is currently the content that produces the most biogas (Jaganmohan, 2022). In 2020, bioenergy provided 58% of the renewable energy consumption in the EU and 11% of the total EU energy mix (Bioenergy Europe, 2021). Bioenergy is seen as one of the key methods of achieving renewable energy goals as well as energy independence within the EU. Europe is slowly shifting away from first-generation bioenergy (produced from crops) to second-generation bioenergy (produced from non-edible plant residues).

This study focuses on second-generation bioenergy, specifically biogas produced through anaerobic digestion. As biofuel (biodiesel and bioethanol) production competes less with the animal feed industry due to the co-products produced during the production that can be used by the feed industry. And biogas produced through the gasification of wood uses different feedstock than the feed industry and thus does not compete with the feed industry either. An overview of the first, second and third generations of biomass used for bioenergy is given in *Figure 1*.

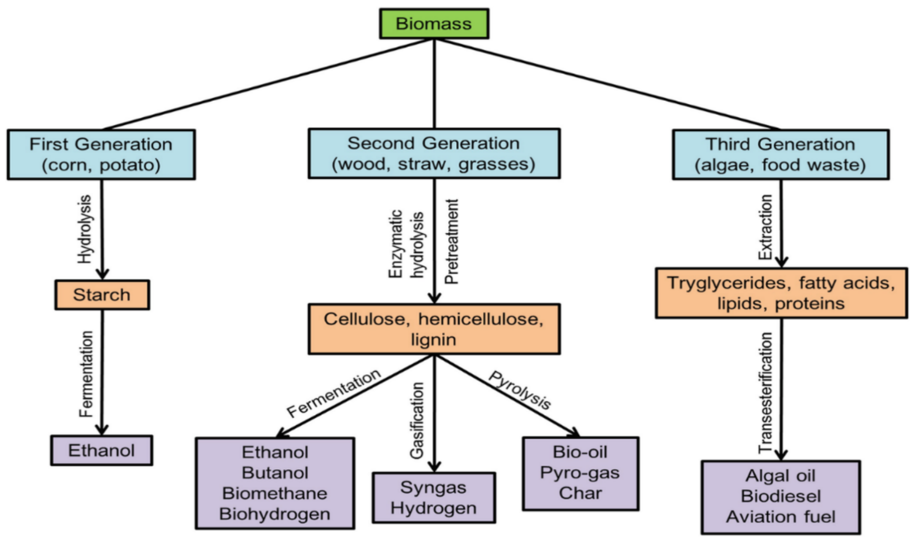

Figure 1: First-, Second-, and Third-Generation Biofuels (Sarangi et al., 2018)

Biogas is a mixture of methane, CO_2 and small quantities of other gases produced by anaerobic digestion of organic matter (biomass). Biogas can be transformed into biomethane by "upgrading" biogas (a process that removes any CO2 and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation. Biogas production is a way to recover methane, a potent greenhouse gas, and an alternative for the treatment of organic waste such as livestock manure, crop residues, household waste, et cetera (IEA, 2022). Currently within the EU, biogas is used primarily for electricity and heat production, while biomethane can be used for the same end consumer applications as natural gas (European Biogas Association, 2020). The various production and consumption pathways for biogas and biomethane are shown in Figure 2.

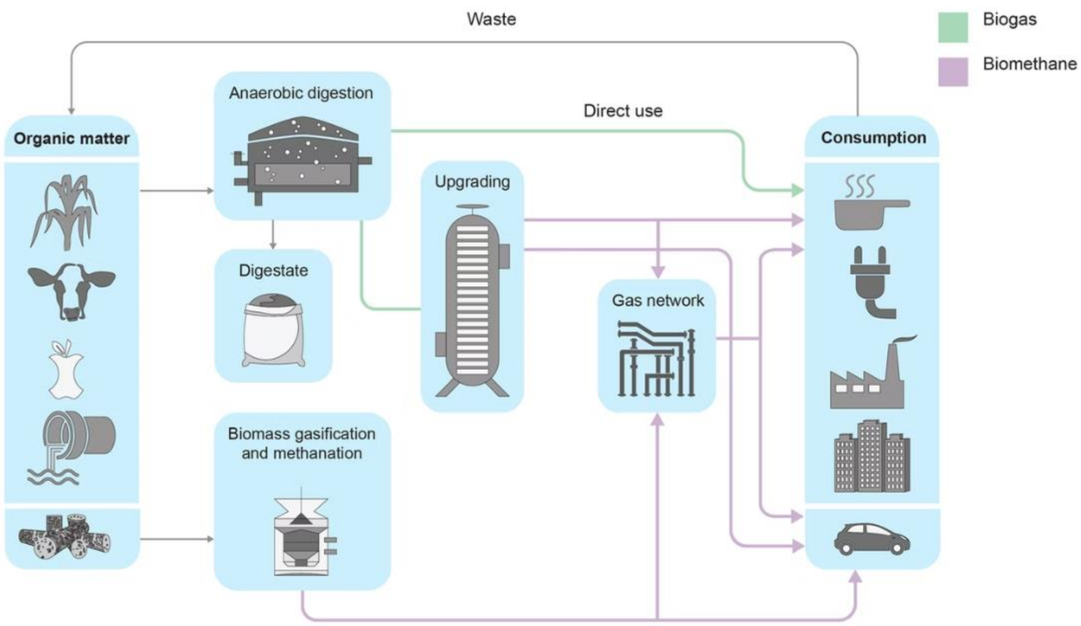

Figure 2: The various production pathways for biogas and biomethane (IEA, 2022).

1.3. Research objective

The main objective of this research is to investigate the impact of the bioenergy sector's development on the feed industry. In specific, the sourcing of co-products for the production of biogas will be researched, and to what extent the two sectors will compete for the sourcing of the same co-products. To reach this objective, this study seeks to gain knowledge about the existing EU Directives and their impact on the development of both sectors. On top of that, the objective is to identify current and future development trends in biogas and animal feed sectorsectors. This will help to predict possible scenarios for the developments. However, the scenario analysis of future development and possible outcomes will be a simplified analysis. And the impacts of irregular events, such as the ongoing war in Ukraine, will not be researched. The secondary aim is to investigate to what extent competition for co-products between the two sectors can be managed, by evaluating the scenario analyses and current regulations.

The research initially focuses on Europe and its policy instruments that regulate the bioenergy industry and animal feed industry, for the sourcing of agricultural and food co-products. Gaining knowledge about these EU policies will give an overview and background information which will thereafter allow the research to zoom in on how the different Member States bring these policies into practice. In particular, the focus will be on the development and degree of competition between the biogas and animal feed sector in four European countries, i.e. The Netherlands, Italy, France and Poland. By investigating the situation of four specific countries, the research will provide a more detailed picture of the problem. Researching the current developments in these countries will also allow the research to predict a more accurate potential future outcome of the developments, since the factors that can influence developments are identified this way.

Another aspect that was originally planned to be a part of the research project was a sustainability assessment of the use of co-products to produce bioenergy versus animal feed. However, sustainability is a broad concept and estimating it for the two sectors can be quite challenging and the outcome will likely be unreliable. Therefore, due to the limited time and resources available, it will not be possible to conduct a sustainability assessment of the use of co-products within the two sectors. Instead, the few existing studies will be reviewed to compare co-products used by the two sectors and summarize and highlight their most important findings.

1.4. Research questions

1.4.1. General research question

How does the current and anticipated development of the anaerobic digestion sector impact the feed industry's capacity to competitively source co-products and former foodstuffs in the feed and food chain?

1.4.2. Specific research questions

The sub-research questions that will be researched to answer the main research question and to achieve the research objective are the following:

1. What are the effects of the present European (and national) policy instruments that regulate the bioenergy and feed sector over the competition for sourcing the same food and agricultural co-products?

2. What feedstock is currently being sourced by the biogas industry and which factors influence this decision?

3. How would the feed industry be affected in the case that food co-products would be directed primarily to the bioenergy sector? And how would it be affected if only prohibited and non-nutritional food waste was transformed into bioenergy?

4. What does current literature state about the environmental impact of using these co-products to produce animal feed or bioenergy?

2. Methodology

2.1. Research instruments

This research was designed as a case study, which researched the phenomenon of the bioenergy sector increasingly competing with the animal feed sector for agricultural and food co-products to use as feedstock to produce energy. This was studied in the context of the EU's recent Green Deal, and the renewable energy directives.

A descriptive, prospective, theory-building single case study design was used, which was chosen because the research started with a great amount of uncertainty. Five main aspects were identified within the case:

1. The growing anaerobic digestion sector;
2. The increasing interest of the animal feed sector in sourcing food co-products for feed;
3. Incentives, if present, for the anaerobic digestion sector to source co-products;
4. Possible coexistence of both sectors with limited competition;
5. The sustainability of co-products used for bioenergy versus animal feed.

These cases highlight the most important aspects of the overall phenomenon of the research. These cases each play a key role in the research questions mentioned in *Section 1.4.2.*

In order to answer the research questions, data from past and current trends in both industries were used to conduct scenario analysis for the possible developments of the bioenergy and animal feed sector under the EU Renewable Energy Directive. For the scenario analysis, the first example scenario analyses about developments in the bioenergy and agricultural sector and their competition for resources have been researched. Second, the results from these scenarios are applied to predict the potential future developments of the biogas sector and animal feed sector. Despite the use of past trends, this can be considered a prospective study since the research aim was to set up a scenario analysis that could give a clearer picture of how the future might develop, investigating different potential future outcomes. The investigation of these cases provided a clearer picture of the stated problem and corresponding phenomena at play.

The research instruments used are as follows:

- **Literature review**
  Literature review was chosen as one of the main research instruments since this type of research is appropriate for the time and recourses available. Sources provided by EFFPA and FEFAC were used and experts from both industries were contacted to gather sources. The principle of triangulation was used, by collecting information from a variety of sources.
- **Interviews**
  We interviewed experts from both the biogas and feed industries. We found a lot of the contact info on FEFAC and EFFPA's websites. It was expected that these industry experts could share valuable insights about their experiences with the researched developments and implications in the field. Conducting interviews gave insight into different points of view in the sectors and provided information about the research in parts where literature research falls short.

- **Triangulation of methods and research**
  The principle of triangulation of methods and researchers was applied since two measurement instruments were used throughout the research project. The principles of triangulation will be applied for a six-week period within which it will be assumed that the phenomenon has not significantly changed.

2.2. Analysis and evaluation methods

During and after the interviews it was important to keep in mind that some of the information received might be biased, as the stakeholders interviewed are involved directly in the feed or biogas industry. For this reason, the information gained was critically evaluated and used as a starting point for further research. The data and knowledge gathered from the literature review and interviews were primarily used to understand the relationship between the development of the two sectors, and how one sector influences the other, as both sectors are using the same feedstock. Understanding their correlation allowed for better projections of these correlations in the future.

The commissioner was also interested in assessing the sustainability of the two sectors when utilizing co-products. Through literature review, data and information was collected to allow a comparison between the two sectors. It is expected to reach a conclusion from this comparison and an evaluation of which sector can be deemed more ‘sustainable’ has been put into perspective.

3. European and national policy instruments

In this section, political and financial incentives granted to the bioenergy sector will be analysed from an EU perspective and subsequentially on a national level. An estimation of the costs of a biogas plant will be provided and put in comparison with other sources of renewable energy; policies regarding biomasses and co-products will be briefly described thereafter. Finally, regulations about the feed industry will be given so that a thorough overview of the current situation in Europe is provided and the competition can be better understood between the two sectors for the sourcing of co-products.

3.1. Europe

3.1.1. Bioenergy sector

In the past decade, the EU has strongly supported the development of renewable energy. In 2019 it published the Green Deal, a set of policy initiatives aimed at increasing the share of renewable energy within the EU. One of the most popular types of renewable energy is bioenergy, because of its low entry barrier, and its ability to be used in many different sectors and increase energy independence. Biogas and biomethane are the fastest-growing types of bioenergy. The Bioenergy sector in Europe is mainly regulated at the national level. Although each Member State of the EU has to comply with European Directives, concerning the transition from fossil to clean energy.

The most relevant governmental bodies administrating biogas production are the following:

- Environment and Climate
- Energy
- Agriculture
- Forestry and Regional Development
- Economy and Finance
- Infrastructure and Transport

Strategies and goals for bioenergy production are not regulated by a contract between the Government and the biogas companies, which allows them to be altered or replaced on short notice. (Gustafsson & Anderberg, 2022)

According to the European Commission, state aid regulations and subsidies for the production of renewable energy cannot be higher than the cost discrepancy compared to the fossil alternative (EC, 2003). Hence, when biogas plants use substrates that are more expensive to collect and treat, they receive higher financial support from the national governments. Biomethane from bio-waste, such as manure (and sometimes agricultural co-products) qualifies as advanced biofuel, which is prioritized in the European goals, as it avoids competition with other sectors for agricultural land.

Local and regional policies are framed by national legislation. However, local conditions, as well as regional plans and investments, have frequently resulted in significant differences between regions. It is no surprise that Member States have different interests and requirements for the development of the sector, which often leads to differences in how bioenergy is regulated and supported. The main economic instruments applied by Member States are a mix of Feed-in Tariffs (FiT), Feed-in Premiums

(FiP), tax exemptions and project financings (from both public and private organizations). Specifically, FiT have been the main type of incentive in many European countries between 2008 and 2014, and they were usually fixed for new biogas producers for a time of 20 years (Gustafsson & Anderberg, 2022). This system allowed producers to receive payment (according to a fixed FiT) for delivering (bio)gas to electricity networks or industry. Although the FiT enabled a rapid increase in the number of biogas plants, the national governments soon realized that such financial support was inefficient as an excessive amount of money was being spent. In Germany, Italy, the Czech Republic and Denmark, the support system has been revised to make the budgetary expenses more foreseeable (Gustafsson & Anderberg, 2022). However, the plants which already had an agreement with the government were allowed to continue benefitting from these tariffs for the remaining period of about 20 years.

In May 2022, the European Commission published the REPowerEU. This is a set of recommendations and plans for the development of the energy sector in the EU to become self-dependent and no longer rely on Russian fossil fuels. In this plan, the new biomethane target of 35 billion metric cubes (bcm) is set (EC, 2022). REPowerEU encourages the Member States to '*avoid the use of food and feed feedstocks that would lead to land-use change problems*' (EC, 2022). It also states that by 2024 organic waste must be collected separately to be used in anaerobic digestion. Incentives are granted for the development of biomethane plants and their sustainable integration into the grid. Lastly, cooperation across countries is encouraged and funding for new transnational plans is granted.

Biomass and co-products

In December 2005, the European Commission drew up the Biomass Action Plan (COM 2005/628). Aimed at encouraging the use of agricultural and forestry biomass to produce liquid fuels from wood and residues (EC, 2005). The main objectives of this plan are the following:

1. Reduction of greenhouse gas emissions through the use of bioenergy;
2. Protection of employment in rural areas;
3. Limitation of Europe's dependence on energy imports;

The Action Plan promoted information campaigns for agricultural and forestry entrepreneurs in the interest of investing in new biogas power plants. Additionally, each Member State was asked to create guidelines on the management of biomasses and subsequent energy production.

In the Renewable Energy Directive (REDII), the European Commission has issued a non-binding recommendation plan on biomass sustainability standards that apply to biogas plants of at least 1 MW (EC, 2018). The plan forbids the use of first-generation biomass retrieved from forests (and other high carbon stock areas) as well as highly biodiverse areas. It also promotes a cut of 35% of the greenhouse gas (GHG) emissions associated with biofuels production over its entire lifecycle (thus including cultivation, processing and transport) (EC, 2018). For new installations, the cut in emissions rose to 50% in 2017 and 60% in 2018 (Groenestege, 2020). Finally, the plan encourages the monitoring of the origin of all biomasses consumed in the EU to ensure their sustainability and it favours highly efficient installations by providing national biofuel support schemes.

The European Parliament and the European Council also decided that the share of energy from the first-generation biofuels (produced from energy crops) must be reduced due to the competition for land with the food sector and the possible increase in food prices (EC, 2012). The EU is therefore encouraging advanced bioenergy and the production of biogas from waste materials.

Animal by-products have been divided by the European Union under three categories (1069/2009). The first category of by-products, such as carcasses, is not allowed to be used for feed production. Category 2[2] and 3, such as manure and specific animal body parts (e.g. placenta and fish carcasses), need to go through sterilization[3] or hygienisation[4] before they can be used by the feed industry due to the potential risk of contamination from pathogenic bacteria which can be highly dangerous for humans and animals[5] (EC, 2009). However, most unprocessed agricultural organic co-products can be used for anaerobic digestion without further treatment (except for wood waste).

Profits and Costs

Biogas plants usually do not require a long time to be constructed and start being operational. This low entry barrier increases the appeal of biogas production and allows more biogas plants to be built within a shorter timeframe. It takes from 8 months to 2 years to build a medium to large-scale biogas plant and 1 to 2 months for a smaller plant (10 m^3 or less) (Electrigaz, 2017). In comparison, it takes 4 to 7 years to build an operating hydroelectric power station (AQPER, n.d.), 2 months to 2 years for a wind farm (Renewable Firsts, n.d.), 7 and a half years for a nuclear power station and 4 years to have an operational coal power plant. (AQPER, n.d.; Mearns, 2016) The initial investment for building a bioenergy plant is lower than those producing energy from other renewable sources or fossil fuels. It is estimated to cost around 6 million euros for a biogas plant with an average capacity of 1.6 MW (Electrigaz, 2017). Although the initial investment costs are generally low, the operating costs are quite high (EC, 2014). The current LCOE[6] of biomethane in the EU is around 90 €/MWh but it is expected to decrease in the coming years (below 70€/MWh by 2050) (ENGIE, 2021).

3.1.2. Animal feed sector

Food losses represent a great economic loss, as well as a waste of resources such as land, water, fertilizers and, energy, which can be recovered by other industries while promoting circularity. When foodstuffs become unsuitable for human consumption, they can become suitable for animal feed use. The Guidelines for the feed use of food no longer intended for human consumption (2018/133/EC), provide a framework for ensuring compliance of co-products for feed use. The European Commission recognizes the nutritional and economical values of a wide list of co-products of the food chain (including former foodstuffs) by excluding them from the scope of the Waste Framework Directive (2008/98/EC). According to this past regulation, food processors occasionally found their operations of recovery of food co-products interrupted by the control authorities who incorrectly interpreted food co-products as waste. In May 2018 the European Commission mandated the revised Waste

[2] Category 2 can be used only to feed specific animals and cannot be used for farmed animals
[3] 133°C, 20 min, 3 bars
[4] Under around 70°C for 1 hour
[5] The risk of spreading any serious transmissible disease for category 2 and category 3 by products must be judged by the competent authorities.
[6] Price at which the generated electricity should be sold for the system to break even at the end of its lifetime (Papapetrou & Kosmadakis, 2022).

Framework Directive (eWFD) to reduce food waste and food losses at each stage of the food supply chain (i.e. production, processing and manufacturing, retail, and distribution). The eWFD provides a legal framework for incentivizing the application of the Food Waste Hierarchy, as is shown in *Figure 3*, across the Member States. The hierarchy provides guidance for using various management options to reduce food waste and lock resources at a higher level of the hierarchy.

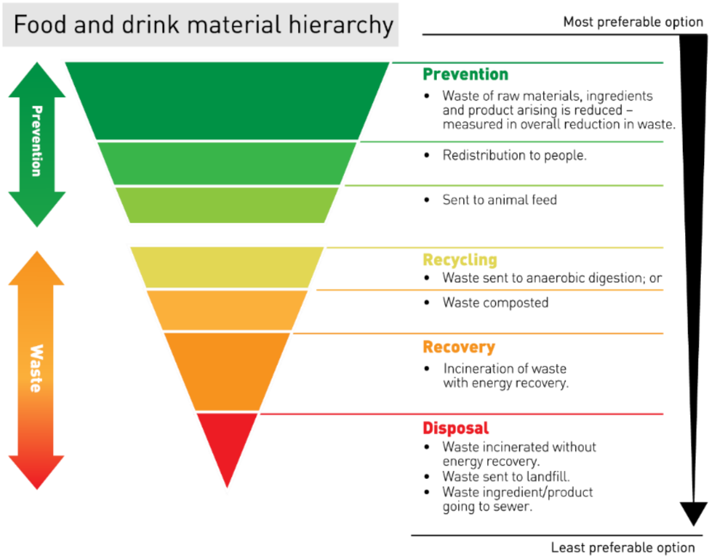

Figure 3: Food Waste Hierarchy (EC, 2008)

The Regulation (EC) No 183/2005, outlines the hygiene requirements for feed and feed additives that co-products producing companies have to comply with in order to be able to sell their products as feed. Additionally, the regulation obligates all feed and food businesses that handle feed and feed ingredients to register as Feed Business Operators. The requirements the Feed Business Operator must follow are very strict. Especially for avoiding cross-contamination with animal products (which are strictly banned from feed material), the labelling, separated storage, and transportation of the feed ingredients must be rigorously monitored.

3.2. Italy

3.2.1. Animal feed sector

In Italy, co-products from agriculture and food processing are highly valued as feed ingredients. Every year the feed sector uses around 4.7 million tonnes of co-products from the seed oil extraction industry (i.e. oilseed flours), 3.1 million tonnes of bran residual from the processing of wheat, and 1.3 million tonnes of co-products from the processing of sugar, dairy products (e.g. whey and milk powder), beer and former foodstuffs (Assalzoo, 2021b).

Despite the almost 14 million tonnes of feed produced annually, Italy imports around 50% of the total raw materials used for feed production, for a total of 7 million euros spent annually (Assalzoo, 2021b). Italy is dependent on the import of feed ingredients (especially maize and wheat) from other countries, mainly Hungary and Ukraine. The reduced market availabilities, as well as the increase in production costs, caused an increase by +1.8% in maize price and by +0.7% in wheat price (Assalzoo, 2021a). The steep increase in prices has dramatically affected farmers and feed producers. One of the leading feed producers in Italy, Veronesi Group, declares to be using food co-products (around 20% of the total feed material) as the costs for the feed production would have been unsustainable if they were using only. This, in addition to lowering the costs of the feed formula, also contributes to making the animal and feed sector more circular and sustainable. (Veronesi Group, n.d.)

In March 2022, *Decreto-Legge Tagliaprezzi*[7] (in G.U. 21/03/2022 n.21) was introduced to limit the destructive effects of the Ukraine-Russia war on the Italian economy. The Decree delivers urgent measures to support the energy sector, by providing extraordinary financial support to energy and gas-producing companies. Specifically, the Decree stimulates the production of biogas through anaerobic digestion of co-products such as beet pulp, molasses, and former foodstuffs. These same co-products are currently used for feed production, due to their optimal nutritional values. Hence, the promotion of using co-products for biogas production creates 'unfair and unnatural competition' between the feed and bioenergy sectors (Assalzoo, 2022). This would eventually affect both the food and the feed sector, as the competition would cause an additional increase in prices of raw materials, for which there is a high demand, but also higher pressure on the final consumer since the increase in prices of raw materials would ultimately effect the prices of the final products available to the end-user (Assalzoo, 2022).

3.2.2. Bioenergy sector

Italy is the second-largest producer of biogas in Europe after Germany (AZZERO CO2 SRL/2018). In 2008 a support system consisting mainly of FiT was introduced in Italy leading to the quick development of the sector. The system was changed in 2013, resulting in less favourable conditions for new biogas plant investments: FiTs were lowered and stricter criteria for the eligibility for the incentives were enforced (M. Gustafsson & S. Anderberg, 2022). After the occurrence of COVID-19, the NextGenerationEU 2019 introduced recovery instruments for coping with the economic and social impact of the pandemic. Following that, the Italian Government endorsed the *Piano Nazionale di Ripresa e Resilienza* (PNRR)[8], which was officially approved by the European Commission on the 30th April 2021. According to the PNRR, 1.9 billion euros were given to the bioenergy sector for the production of biomethane, and the modernization of digestate storage and distribution systems in existing plants (the money must be used by 2026) (Ministero delle Finanze, 2021).

In 2016 the Minister of Economic Development dictated a Decree, promoting the development of renewable energy in Italy. In the Decree, incentives were granted to the bioenergy sector for the construction of biogas and biomethane plants based on the type of biomass used and on the energy produced by the plant (Ministero dello Sviluppo Italiano, 2016). This is shown in *Appendix Table 1*. The Decree also provides a list of co-products that can be used for bioenergy production, and it is stated that co-products which could be utilised by other sectors are not allowed for bioenergy production. However, in March 2022 with the introduction of the *Decreto-Legge TagliaPrezzi*, some points of the previous Decree were modified. The article states that any kind of co-products (also those previously meant exclusively for the feed industry) are now allowed to be used by the bioenergy sector:

[7] Decree-Law Prices Cut
[8] National Recovery and Resilience Plan

'In order to simplify the production process in biogas and biomethane plants, by-products (a) originating from agriculture, livestock farming, landscape management and forestry activities (b) from food and agro-industrial may be admitted to biogas and biomethane production plants and are understood to be included in the definition of "residues deriving from agro-food activity' (Decreto-Legge Taglia Prezzi, 2022).

3.3. The Netherlands

3.3.1. Animal feed sector

In The Netherlands, almost 9.5 million tonnes of co-products from the food, beverage and bioethanol industry are being used annually to produce feed. The total amount of feed raw materials in 2018 accounted for around 16.7 million tonnes. Around 51.9% of these feed materials consist of raw materials, whereas 42.7% consist of co-products of the food industry (Nevedi, 2019a). The main types of co-products used in The Netherlands for feed are beet pulp and potato co-products, rapeseed meal and palm kernel meal which are imported respectively from other European countries and Asia. Only 12% of the feed materials used in feed come from The Netherlands, and the share is gradually decreasing (Nevedi, 2019a). The rest is being imported from other countries: around 55.6% of co-products are imported from the rest of Europe, 20.5 % from South America, 7.6% from North America and finally 4.4% from Asia (Nevedi, 2019a). Food businesses and industries that want to place food co-products on the market as material for feed need to register with the *Nederlandse Voedsel-en Warenautoriteit* (NVWA)[9] as a Feed Business Operator. NVWA is the Dutch inspection body for food safety and ensures the compliance of the co-products with the hygiene requirements (HACCP) and avoidance of cross-contamination with animal products on the basis of the *Kaderwet Diervoeder*[10].

The representative of the Dutch animal feed industry, the *Nederlandse Vereniging Diervoederindustrie* (Nevedi)[11], in November 2019 provided an outline of the future trends and developments of the Dutch animal sector in 2020-2025 (Nevedi, 2019b). According to Nevedi, in the following years, the share of co-products in animal feed is expected to increase. This will increase the circularity of the animal and food chain, as the Dutch government aims at achieving leadership in circularity by 2030 in Europe.

3.3.2. Bioenergy sector

In 2019, the National Climate Agreement was mandated to reduce GHG emissions in The Netherlands by 49% in 2030 compared to 1990s levels. The Dutch Government aims to have 27% of their total energy produced come from renewable sources by 2030 and to achieve carbon neutrality by 2050. Specifically for biogas production, the Climate Agreement introduced the Renewable Gas Roadmap, which outlines the potential for biogas production from anaerobic digestion of agricultural and/or industrial residual flows. The Roadmap proposes the target of producing 70 PJ (2 bcm) of biomethane in The Netherlands by 2030 (RVO, 2017). The objectives of the Climate Agreement are supported by

[9] Dutch Food Safety Authority
[10] Animal Feed Framework Act
[11] Dutch Animal Feed Industry Association

the *Stimulering Duurzame Energieproductie en Klimaattransitie* (SDE++)[12] scheme, which provides subsidies (over a period of 12 or 15 years) to energy-producing companies that produce energy from renewable sources and use CO_2-reducing techniques (RVO, 2021). To be eligible for the subsidies, the energy companies must ensure that the biomass used for generating energy complies with certain sustainability requirements set in the European Directive (EC) 2018/2001 (RVO, 2021). Better Biomass is the certification scheme that demonstrates compliance with the aforementioned international sustainability criteria (found in NTA 8080) of biomass used for energy applications (Better Biomass, n.d.). The *Rijksdienst Voor Ondernemend Nederland* (RVO)[13] gives out the subsidies on behalf of the Ministry of Economic Affairs and Climate, and Vertogas provides data to RVO for the provision of these subsidies, as well as issuing the Better Biomass certificate.

For the production of biogas, a distinction is made between co-fermentation and mono- fermentation. In co-fermentation, at least 50% manure is used with other organic biomasses (such as crop residues and/or food co-products); whilst mono-fermentation refers to the fermentation of a single product (e.g. animal manure and sludge) (RVO, 2021). In the past decade, The Netherlands witnessed a gradual shift from co-fermentation to mono-fermentation of manure (Winquist et al., 2021). This is probably explained by the fact that mono-digesters that work based on mono-fermentation contribute to reducing the manure surplus, which is a big issue in The Netherlands. According to the Fertilizer Act, the digestate resulting from mono-fermentation can be directly used as fertilizer and applied on the agricultural lands in the vicinity of the bio-plants. On the other hand, depending on the input mixture used, the digestate of co-digesters may need further processing, which makes it more problem, rather than a valuable resource for substituting artificial fertilizers. (Rijkswaterstaat, n.d.) Moreover, the co-fermentation sector is in competition with other sources of renewable energies for obtaining subsidies. In fact, co-fermentation has high costs for the sourcing of the co-products, but low revenues for the electricity produced (Winquist et al., 2021). In 2019, biogas from co-digesters accounted for 2.8% of total final renewable energy consumption in the Netherlands. In comparison, wind and solar energy recorded a market share of 21% and 11% respectively (Brummelaar, 2021).

With the intention of promoting mono-fermentation, in 2019 the Dutch dairy cooperative FrieslandCampina launched the so-called Jumpstart program. (Winquist et al., 2021). According to FrieslandCampina (2019), mono-manure fermentation has the potential of producing more than 1 bcm of green gas. Additionally, mono-manure fermentation contributes to lowering methane emissions associated with manure management by up to 80%, as well as limiting nitrogen emissions. (FrieslandCampina, 2019) Thus, the shift from co-fermentation to mono-manure fermentation contributes to reducing the manure surplus of the Dutch animal sector; it lowers the emissions associated with the use of artificial fertilizers; and finally, it reduces the competition for the sourcing of food co-products for biogas production.

3.4. France

France is the third-largest producer of compound feed in Europe (Rabobank, 2017). In 2018, 201 companies and 314 factories produced approximately 20.8 million tonnes of compound feed for

[12] Stimulating Sustainable Energy Production and Climate Transition
[13] Netherlands Enterprise Agency

livestock (Mon Cultivar Élevage, 2019). In recent years, the number of companies has been relatively stable, but the number of factories has increased slightly.

After the last review of the national energy policy (dictated by the International Energy Agency (IEA) in 2015), the government has taken important steps to lower emissions associated with energy production. The Energy and Climate Act of 2019 mandates carbon neutrality by 2050 and a stricter strategy for reducing fossil fuels to 60% of 2012 levels by 2030. This resulted in a significant expansion of the production of renewable energy in France, particularly bioenergy (IEA, 2021).

France is the country with the largest biomass potential in the EU due to the great distribution of cereals production and the decrease in livestock farming (despite France still being the third-largest producer of meat in Europe) (Gradziuk et al., 2020). Thanks to the generation of nuclear energy, which constitutes almost 70% of the total energy produced, France is also one of the least GHG emitting countries in Europe (Eden, 2018). For this reason, in France using biomethane as a source of energy is not considered the most effective decarbonization strategy. In fact, bioenergy production has been pursued mainly as a waste management and agricultural development strategy (Eden, 2018).

In 2015, the French Government has established the *Programmation Pluriannuelle de l'Energie*[14] (PPE) which sets the goals for the development of the French renewable energy sector for the time period 2023-2028; the programme is updated every 5 years. The PPE sets two fundamental objectives: reducing energy consumption (especially from fossil fuel) and promoting the production of renewable energy. At the end of 2018, the PPE set a target for the use of solid biomass (for energy production) at 540 MWe[15] which has been met and even exceeded (590 MWe) (Ministère de la Transition écologique, 2019). The new PPE sets a target of 800 MWe for 2023 which will remain unchanged until 2028 (Ministère de la Transition écologique, 2019). However, the French Government does not provide financings for construction projects, but a 20-years-FiT is being offered for any energy installations with a power lower than 500 kW. For installations with higher capacities, additional remuneration is being offered. The *Commission de Regulation de l'Energie*[16] (CRE) is also funding projects which will benefit from a guaranteed 20 years average tariff of 113EUR/MWh (CRE, 2021).

In France, only 15% of the total biomass used for anaerobic digestion is legally allowed to be from primary agricultural resources (i.e. energy crops). Nevertheless, during interviews with a member of a monitoring association for biomethane production, it was stated that there are no strict controls for the enforcement of this limit, . (Coordinator of French vigilance of biogas association. June 15 2022) For this reason, the sector had to find alternative biomasses for the production of bioenergy (Institut de l'Elevage, 2015). However, using agricultural residues is being supported with economic incentives for biogas plants (EUR 1.5– 2.6/kWh) (Institut de l'Elevage, 2015). The French Ministry of Ecological Transition sets a guideline target to methanize biomass consisting of 40% and offers financial support for the use of biomethane produced. Nevertheless, manure and waste products are usually not sufficient to produce a profitable amount of energy and producers must find additional resources to add to the mix, one of them being food co-products. In 2015, 3% of the total amount of agricultural co-products produced nationally were used for bioenergy production (Institut de l'Elevage, 2015). The

[14] Multi-Annual Energy Plan (MAEP)
[15] Megawatts electric refers to the electricity output capability of the plant
[16] Energy Regulation Commission

main co-products used for their high methanogenic potential are mown grass and beet pulp (Institut de l'Elevage, 2015).

From information gathered from a survey conducted in 2015 (Institut de l'Elevage, 2015) and interviews with people from both industries (feed and bioenergy industry), it was interesting to see how big corporations were thought to play a big role in this competition as they have access to a higher budget. Small-scale bioenergy plants were said to be also competing with bigger producers and to have difficulties finding suppliers of coproducts.

3.5. Poland

The potential for biogas production in Poland from various substrates is as follows: '*82 million m^3 from municipal waste, 20 million m^3 from sewage sludge, 1603 million m^3 from animal droppings, 551 million m^3 from maize and 254 million m^3 from grass*' (Buczkowski et al., 2015). The use of all of Poland's biogas potential could result in achieving almost 7.5% of total Poland's energy demand (Buczkowski et al., 2015).

Although Poland owns one of the first commercial biogas plants ever built (Buczkowski et al., 2015), the country did not prioritize the development of the national bioenergy sector until recently due to its dependence on the Russian gas supply. However, in 2016 the first incentives for the development of the sector were introduced. The financial support system includes FiPs, FiTs, loans and subsidies. In 2016, Poland tried to implement tendering systems for energy supplied by bioenergy plants, but with little success. Only three out of nine of these tenders were successful, of which none in 2018. All renewable energy technologies in Poland are eligible for tax exemption (Ignaciuk, 2019). Currently, the consumption tax on electricity amounts to 20 PLN/MWh (1 Polish złoty equals 0.21 euro) (Ignaciuk, 2019). The subsidy is equal to the amount of taxes the energy generators and suppliers are exempted from.

As mentioned before, Poland receives financing from different EU organs and associations to help stimulate renewable energy production within Poland:

- **Cohesion funds:** The European Commission has set up cohesion policies in order to reduce differences between regions and are aimed at the Member States whose gross national income per inhabitant is less than 90% of the European average. Almost 9 billion euros have been given to Poland for a Shift to the Low-Carbon Economy strategy, and of this 10% is for the development of renewable energies (Groenestege, 2020).
- **EEA and Norway fundings:** Iceland, Liechtenstein and Norway are offering funding to individual projects in certain EU Member States for sustainable energy and battling climate change. Between 2014 and 2021, Poland received 411.5 million euros in Norway Grants and 397.8 million euros in EEA Grants (Groenestege, 2020).
- **Kyoto Protocol:** The European Bank for Reconstruction and Development, the Spanish and Irish governments, the Japanese Organization for the Development of New Energy and Industrial Technologies, and private Japanese entities purchased Poland's surpluses of allocated units (Groenestege, 2020). Between 2009 and 2018, the funds from the aforementioned buyers totalled 796.5 million euros PLN (Groenestege, 2020). The money was used to fund projects that were part of the national Green Investment Scheme, such as

renewable energy projects (Institute of Environmental Protection - National Research Institute, 2018). Agricultural biogas plants received 5% of the budget, while biomass-burning-based energy generation received 1% (Groenestege, 2020).

On February 2nd of 2021, the Council of Ministers adopted the Energy Policy of Poland until 2040 (EPP2040). These policies promote the development of the Polish energy sector and provide guidelines for the sustainable use of biomass for bioenergy production (Ministry of Climate and Environment, 2021). This is because it is expected an increase in the national energetic use of biomass for both anaerobic digestion and biofuel production. The reason for such development is the increasing stream of bio-waste resulting from growing consumption as well as tightening of waste management regulations which gradually limit landfilling of biowaste (Ministry of Climate Environment, 2021):

- The demand for renewable resources (biomass) will be covered at the closest possible distance from the location of biomass production.
- The energy sector should utilize waste products which cannot be used in other sectors. It refers to biodegradable municipal waste, sewage waste, forestry residues and residues from the agri-food or processing industry (e.g. furniture, paper).

Considering the fact that Poland has vast agricultural land and being the bioenergy sector still under development, there is no perception of competition between the bioenergy sector and the feed industry for the sourcing of products and co-products. During interviews with experts from the Bioenergy and Feed industry (President of the Board of a Polish methane association, 10 June 2022), (Secretary General of Grain and Feed Chamber, 9 June 2022), they agreed that they do not see a possible competition between the two sectors for at least the next 10 years and stated that it is essential for the two sectors to cooperate even in the future as the two sectors often rely on one another. Moreover, the bioenergy sector mentioned that it is possible to produce bioenergy in the country only with manure from farms. Another point which was mentioned is that some of the crops and coproducts in Poland are exported to other regions of the EU (mostly in Germany) to produce bioenergy.

4. Current and future competition for feedstock

The animal feed industry has historically used food and agricultural residues to produce feed and keep nutrients within the food chain. However, the growing second-generation bioenergy industry might also make use of an increasing part of these residues. Currently, co-products from the food and bioethanol industries make up 12% of all feed material consumed by the EU28 compound feed industry as well as 25% from cakes and meals (FEFAC, n.d.). EFFPA, estimates that, as of 2015, 5 million tons of former foodstuffs are processed into animal feed in Europe annually (EFFPA, 2022).

In this section, first, the current feedstocks used for bioenergy and biogas will be described as well as the factors that influence which feedstocks are preferred by these industries. Secondly, the current competition for feedstock will be described based on the opinions of the stakeholders that were interviewed. Thirdly, the European Biogas Association's (EBA) industry growth goals, as well as what existing literature predicts for future bioenergy and feedstock demands will be presented. Fourthly, various scenarios analysis of possible future developments of the bioenergy and feed sectors will be shown.

4.1. The current feedstocks used for bioenergy and biogas

Any biodegradable non-woody (not containing lignin) plant or animal matter is a suitable feedstock for a biogas digester. One of the most important factors for anaerobic digestors is having a secure supply of quality feedstock. Therefore, co-products are often preferred for anaerobic digestion due to their high yield, and consistent supply (NNFCC, 2022). For this reason, many food processors are also interested in creating on-site biogas plants to convert their co-products into energy for their factories.

Biogas feedstock and usage vary across different countries. In Germany, Italy and France, the biogas sector has been sourcing its feedstock primarily from the agricultural sector, whereas in Sweden, Switzerland and Finland, most of the biogas production is based on municipal waste streams such as sewage and organic waste (Gustafsson & Anderberg, 2022).

The yield of biogas from a particular feedstock varies according to the following criteria (NNFCC, 2022):

- Dry matter content
- The energy left in the feedstock (if it has undergone prolonged storage, it may already have begun to break down)
- Length of time in the digester
- The type of biogas plant and the conditions in the digester
- The purity of the feedstock

The decision of which feedstock to use usually depends on the following factors in order of most to least important: biogas yield (physio-chemical composition), price, availability, and distance (Rouille et al., 2015). *Figure 4* shows the average biogas yield-by tonne of feedstock type, where industrial waste represents food co-products. This figure shows that co-products, referred to as industrial waste, have the highest biogas yield and manure has the lowest.

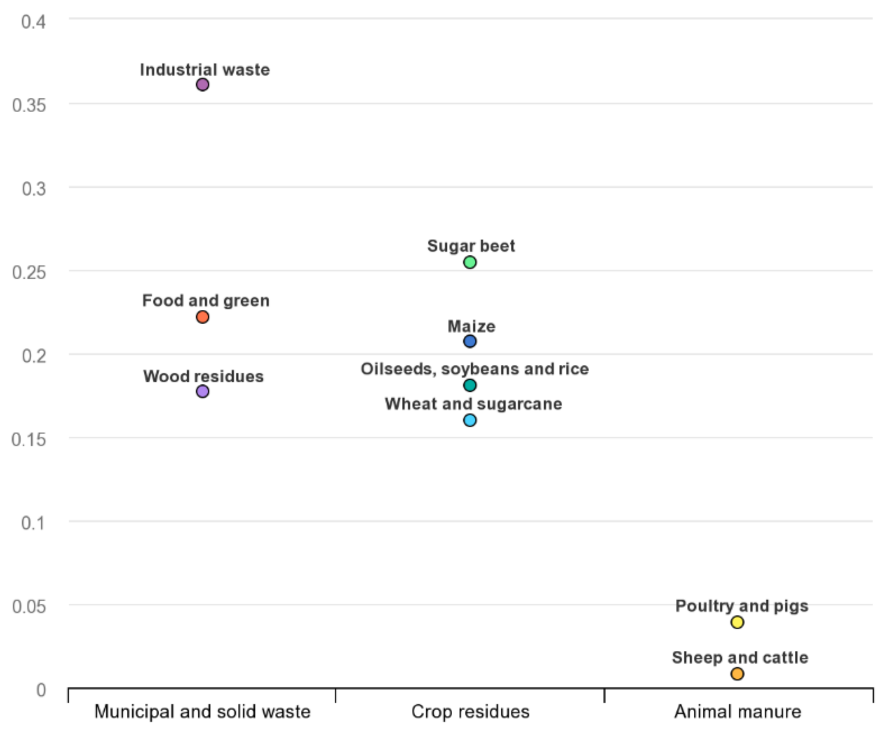

Figure 4: The average biogas yield-by tonne of feedstock type (IEA, 2020).

At the end of 2019, Europe had a total of 18,943 biogas plants and 725 biomethane plants (European Biogas Association, 2020). Anaerobic digestion plants are currently shifting from electricity production from biogas towards transforming the biogas to biomethane through a process called 'upgrading'[17]. This biomethane has gained popularity because it can be used for the same end consumer applications as natural gas (European Biogas Association, 2020). As shown in *Figure 5*, in 2018, most biomethane plants in Europe were producing energy from energy crops (33%) or agricultural residues and manure (30%). Whereas 7% of all biomethane plants in Europe produced energy primarily from industrial organic waste from the food and beverage industries (EBA & GIE, 2020).

[17] Biogas upgrading is the process of turning biogas into biomethane by removing carbon dioxide, hydrogen sulphide, water and contaminants from the biogas. The resulting biomethane can then be used for vehicle fuel or for injection into the natural gas grid network (QED, 2022).

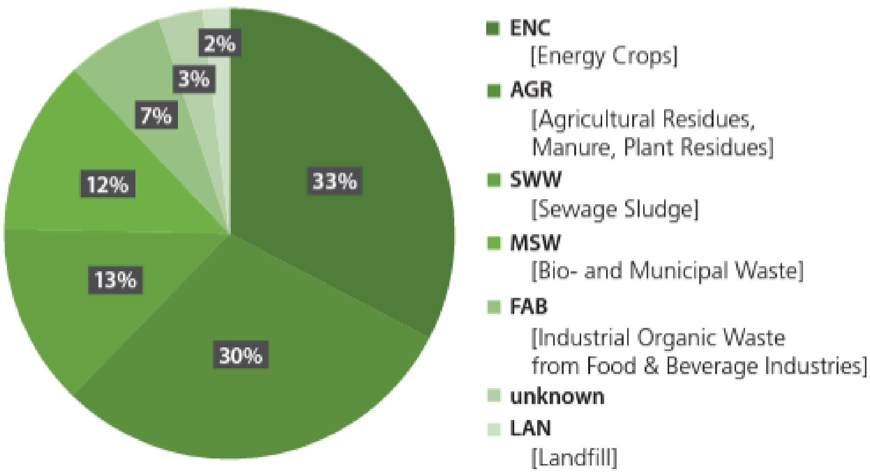

Figure 5: The distribution of biomethane plants per feedstock type within the EU in 2018 (EBA & GIE, 2020).

However, as can be seen in *Figure 6*, the number of biomethane plants using energy crops is quickly declining, while the portion of new biomethane plants using agricultural/plant residues or manure is increasing (Bioenergy Europe, 2021b); while the proportion of new biomethane plants using co-products (industrial waste) having not significantly changed. The world bioenergy association also claims that there is a clear positive global trend for the use of industrial and municipal waste for energy production. With a significant annual growth rate of 4% between the years 2000 and 2018 (WBA, 2020).

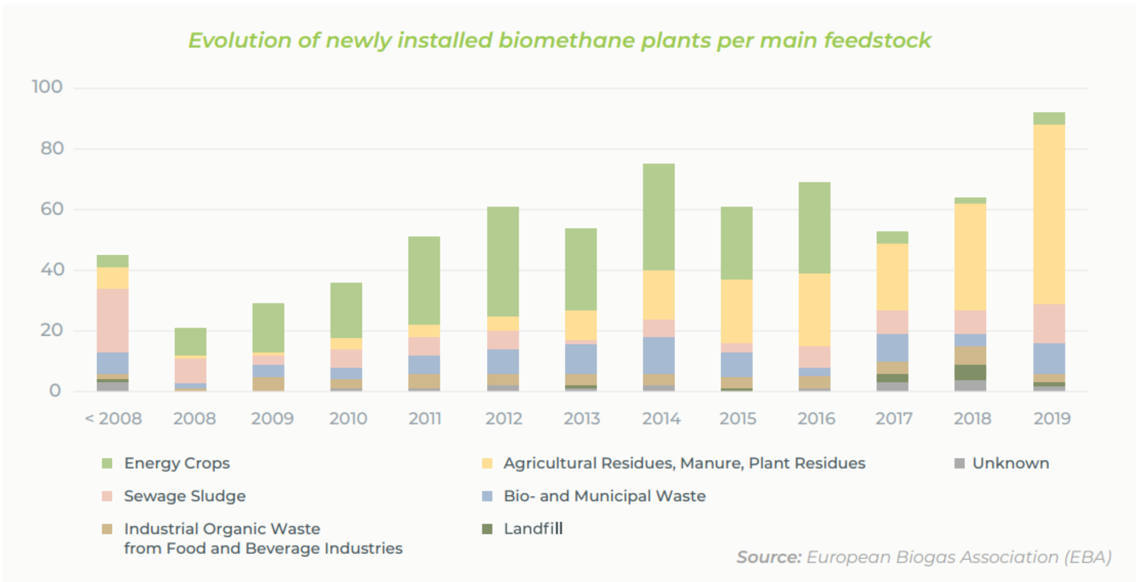

Figure 6: Evolution of newly installed biomethane plants per main feedstock. (Bioenergy Europe, 2021a)

4.2. Current competition for feedstock between the sectors

The previous section described the possible feedstock types that the bioenergy industry might use to produce biogas. However, the degree to which the biogas industry will source these feedstocks is highly dependent on the number of biogas plants within the area. The number of biogas plants per 1 million capita within various European countries can be seen in *Figure 7*.

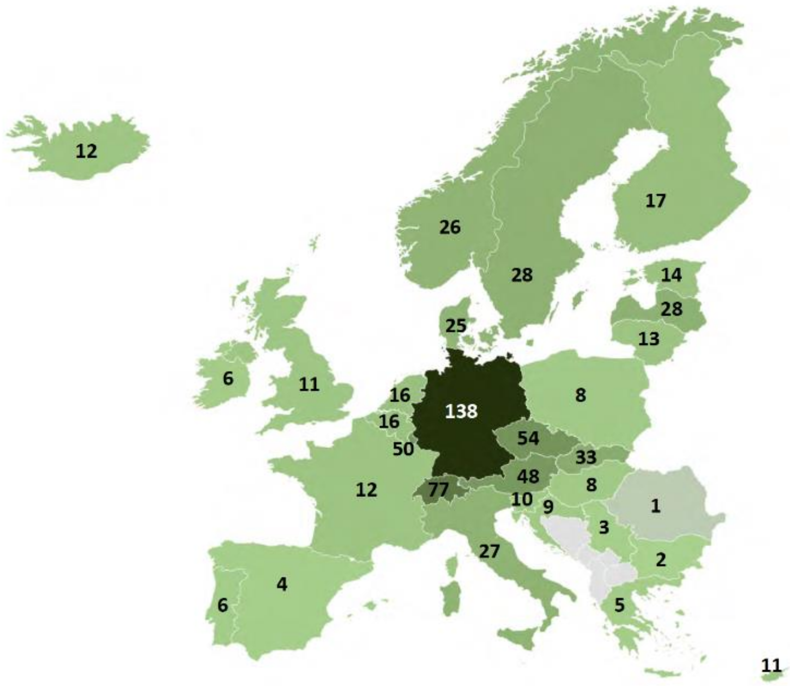

Figure 7: The number of biogas plants per 1 million capita (EBA, 2020).

In the following section, the opinions of stakeholders interviewed during our research on the current competition within various Member States are described.

Stakeholders in the Netherlands expressed that there is little competition for feedstock between the two sectors. This competition has been limited as the feed sector has been able to pay more for co-products than the bioenergy sector, which is currently interested in mono-fermentation rather than co-fermentation (Business Development Manager of Nijsen company, 17 June 2022; Founder of Top feed, June 2022; P.C.van TuiJl, June 2022). Additionally, most co-products processors within the Netherlands believe that it is best to keep their co-products within the food chain. However, if the prices offered by the bioenergy industry become higher than the prices offered by the feed industry; or if the sorting and hygiene requirements needed to sell to the feed industry are too difficult for the producer, they will often choose to sell to the bioenergy industry (Business Development Manager of Nijsen company, 17 June 2022; CEO of Stadsbrouwerij Wageningen, 7 June 2022; Founder of Top feed, June 2022; P.C.van TuiJl, June 2022). One stakeholder believed the strict quality control regulations, specifically the ones about animal products, to be one of the major factors that were limiting the feed sector's ability to source former foodstuffs. And that the biogas industry has not yet been put under sufficient environmental protection regulations with regards to their digestate because they are using new technology that still has some unknowns (Business Development

Manager of Nijsen company, 17 June 2022).

The stakeholders of the two sectors in France seemed to notice more competition than in The Netherlands, specifically in the North where biogas plants are situated closer to one another (Researcher of La Coopération Agricole Chargé de mission alternant méthanisation, 17 June 2022). The rapid expansion of France's biogas industry in the past few years has resulted in some co-products being already diverted from the feed to the biogas sector (specifically sugar beet production co-products). France currently has legislation that limits each biogas plant to have a maximum of 15% of input biomass coming from energy crops. However, it is unclear if this is being controlled (Coordinator of a French vigilance of biogas association, June 15 2022). France also has a financial bonus for biogas plants that use at least 60% manure as biomass. It was stated that in France selling feedstock that could be used for food or feed to the biogas industry is not socially acceptable (Institut de l'Elevage, 2015).

The stakeholders interviewed from Italy noticed the most competition of all the researched countries (Director General of Assalzoo. 14 June 2022; Sales Manager of Italian biogas company, 24 June 2022). The feed industry does not receive any financial help, while the bioenergy sector does. The *Decreto Tagliaprezzi* implemented in March 2022 promotes the use of co-products traditionally used for feed for the production of bioenergy. The stakeholder from the Bioenergy sector stated that competition is inevitable and that it is fairer now that co-products can be sourced by both sectors equally than it was before the decree. Moreover, he argued that one of the reasons why competition in Italy is severer compared to other countries is because no official decree about biogas was drawn up and it is thus difficult for both sectors to understand what is allowed and what is not (Sales Manager of Italian biogas company, 24 June 2022).

The Polish stakeholders that were interviewed seemed to notice the least amount of competition between the two sectors, and do not foresee there being significant competition within the next 10 years (President of the Board of a Polish methane association, 10 June 2022; Secretary-General of Grain and Feed Chamber, 9 June 2022). This is mostly because of the large number of agricultural products available and their underdeveloped biogas sector. Poland is also the largest rapeseed producer in Europe and has a lot of cooperation between the biodiesel and feed industry. The biodiesel industry supplies rapeseed meal co-products to the feed industry (President of the Board of a Polish methane association, 10 June 2022). Poland's energy policy is much more affected by Russia than western Europe. Russia's attack on Ukraine has increased Poland's desire to move away from Russian natural gas and to increase bioenergy production (President of the Board of a Polish methane association, 10 June 2022), (Secretary General of Grain and Feed Chamber, 9 June 2022). One of the Polish stakeholders involved also believes that NGOs are much more present in western Europe. Where they condemn the use of food for fuel, but also create a lot of bad publicity for the animal agriculture industry (Secretary-General of Grain and Feed Chamber, 9 June 2022).

4.3. The future competition for feedstock between the sectors

The global average annual growth rate of the bioenergy sector between 2000 and 2018 was 2%. With liquid biofuels and biogas are the fastest growing sectors with growth rates of 13% and 9% (IEA, 2018). However, the number of biomethane plants is increasing at an even higher pace. With the number of biomethane plants in Europe increased by 51% between 2018 and 2020 from 483 to 729 plants (EBA & GIE, 2020).

Europe is currently producing 3 bcm of biogas and methane combined (EBA, 2022). The European Biogas Association believes that this could increase by more than 10 times, to 35 bcm by 2030 (which is in line with the REPowerEU target of 2022), representing 10% of the total EU gas demand. And that by 2050, combined biogas and biomethane production can reach 95 bcm, representing 30-40% of the total 2050 gas demand. According to EBA there will be enough sustainable feedstock to produce biogas and biomethane in Europe. This is partially due to[18]:

- Increased supply of food waste (11 bcm)
- Unlocked potential of industrial wastewater (13 bcm)
- Wastewater sludge (3 bcm)
- Livestock manure (23 bcm)
- Agricultural residues (37 bcm)
- Big feedstock potential from the use of sequential cropping (the use of sequential crops supports soil enhancement and carbon farming). (43 bcm)
- Gasification (36 bcm)

Their estimate did not include the use of mono-crops as feedstock until 2030 (EBA, 2022). Factors influencing competition for biomass are raw material prices, prices of end products (biogas yield), policy, availability of land for feedstock or technological constraints (S2Biom, 2016).

The European Commission's mandate on the collection of biowaste starting in 2023 will create a large amount of feedstock available for the biogas industry. However, even though biowaste is cheaper than conventional feedstock, it is generally not preferred for anaerobic digestion due to the poor quality control and possibly harmful substances it contains. There is also concern that these contaminants may accumulate within the environment if the digestate will be used as fertilizer.

It is estimated that between 176 and 242 million tonnes of agricultural residues and between 144 and 242 million tonnes of biomass from crops could serve as additional sustainable feedstock in Europe by 2030. In the case of the low estimates, a scenario with strong restrictions on collection of agricultural residues was used (S2Biom, 2016).

A study conducted by GCB-Bioenergy did a scenario analysis on the bioenergy needs in Europe in 2050, in which they estimated that bioenergy will provide 27% of the total primary energy demand in Europe in 2050. Thus, increasing from 5 EJ to 18 EJ/yr. To keep up with the bioenergy needs, imports of biomass will increase from 4% to 60% (Mandley et al., 2022). In *Figure 8* the predicted first-generation bioenergy demand in the EU under different scenarios is shown. And in *Figure 9*, the predicted feedstock demand for second-generation bioenergy in Europe is shown. It can be seen that both the demand for primary and secondary bioenergy will increase dramatically. And that the majority of the

[18] The estimates of the amount of bcm that can be produced from the beforementioned feedstocks were shown on the European Biogas Association website at the time of this research project. However, after our interview with one of their representatives about this topic, these numbers were no longer visible on their website.

increase in feedstock for second-generation bioenergy will come from residues. This could threaten the animal feed industry's ability to source the portion or these residues that are still suitable for feed production.

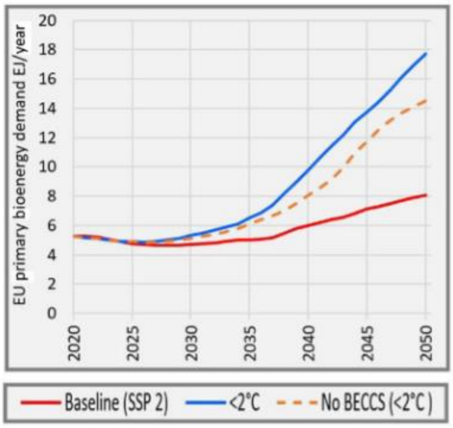

Figure 8: The predicted first generation bioenergy demand in the EU under different scenarios. (Mandley et al., 2022)..

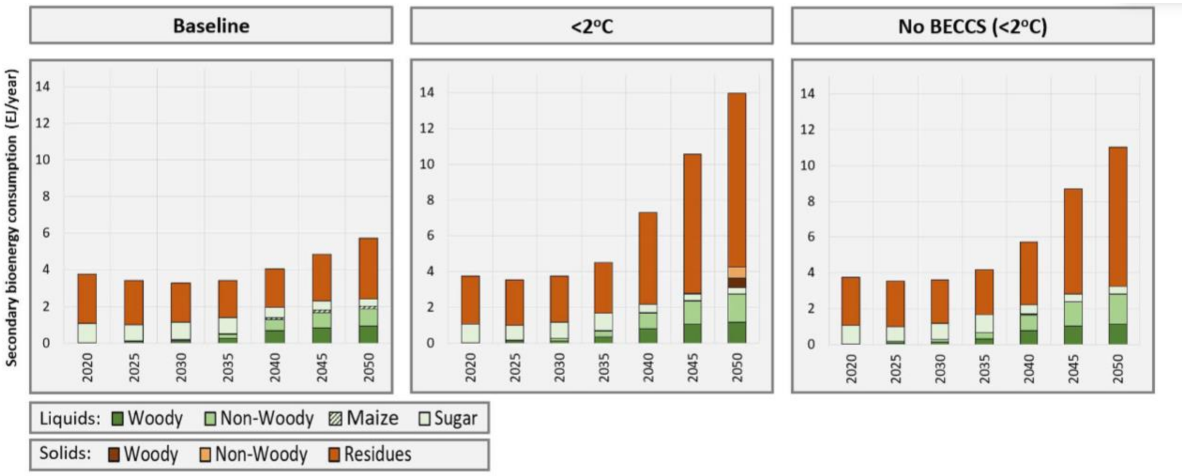

Figure 9: Demand for biomass feedstocks used to produce second-generation bioenergy in Europe (Mandley et al., 2022)

4.4. Scenario analysis of possible future developments in the bioenergy and feed sector

In this section, the results of four scenario analyses conducted by other studies will be presented. No scenario analysis specific for the competition between the biogas and animal feed sector was available. The example scenarios that are presented show the possible competition between the biofuel and agricultural residues that could also be used for feed, and the fluctuating market prices if different regulations were implemented for bioenergy. Then, scenario predictions of the competition between biogas and the animal feed sector for co-products are made, based on the application of the example scenarios and assumptions.

4.4.1. Scenario 1: agricultural residues directly to the bioenergy sector

The first scenario analysis was carried out by Schuenemann & Delzeit (2022) and shows the potential outcome of the use of agricultural residues for the production of biofuel in 2030. Although the study was specifically about biofuel, it can be still useful to predict the possible developments of the biogas industry and the course of competition for co-products with the animal feed sector. In fact, it is expected that the biofuel and biogas sectors will follow similar trends, mainly due to the overall increased interest in bioenergy in the EU. The analysis is based on the mandates of the revised Renewable Energy Directive (REDII). The REDII's objective is that 14% of transport fuel is required to consist of biofuel by 2030. The RED also states that the biofuel sector should reduce at least 35% of GHG emissions compared to the GHG emissions by fossil fuels currently (Tufvesson et al., 2013). The revised Directive highlights the importance of advanced biofuels to eliminate competition for cropland. The REDII states that biofuels and biogas produced from biomass and by-products not suitable for the food or feed chain should account for 3.5% of the total fuel utilization in 2030 (European Commission, n.d.). The regulated output cap for first-generation biofuel production in 2030 is 7% and biofuel produced from palm oil should be eliminated by 2030 (Schuenemann & Delzeit, 2022).

Two different scenarios are investigated by Schuenemann & Delzeit (2022). The first is called the '2030 base' scenario. The baseline scenario accounts for the development of the global economy from 2011 to 2030 (based on population growth and GDP). The trend of biofuel production in this scenario is based on the actual biofuel production until 2018. From 2019 onwards the 7% cap on first-generation biofuel is included. The second scenario, ´2030 RED2', accounts for the REDII obligations for advanced biofuel use. *Figure 10* shows the predicted percentages of agricultural residues that will be used for the 2030 base and 2030 RED2 scenarios and compares them to the total percentages of agricultural residues consumption in 2011.

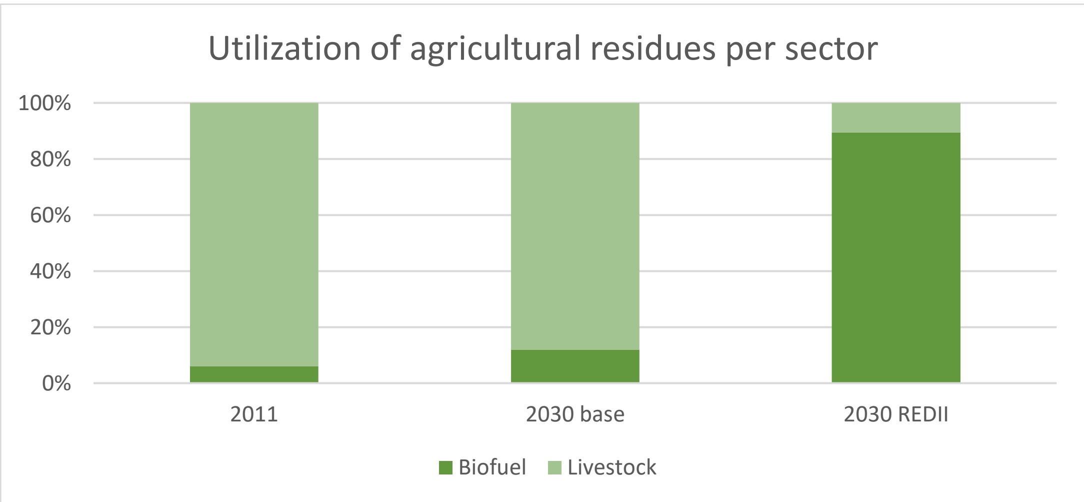

Figure 10: Percentages of agricultural residue consumption by different sectors for two scenarios and the consumption percentages in 2011 by these sectors. (Schuenemann & Delzeit, 2022)

For the RED2 scenario, the bioenergy sector becomes the main consumer of agricultural residues. *Figure 10* shows how the consumption of these residues for animal feed will largely decrease. In the RED2 scenario, the demand will possibly exceed the available products. Hence that competition can be an actual problem in the future. In the baseline scenario, the share of biofuels produced from crops does not exceed 7% of the total fuel in the transport sector.

Schuenemann & Delzeit (2022) concluded that the scenario accounting for the policies mandating advanced bioenergy would need to consume almost 90% of agricultural residues available on the market to meet the REDII objectives (see *Figure 10*). From this bioenergy scenario analysis, it can be deduced for biogas specifically that the shift towards advanced bioenergy will also cause a shift towards the production of biogas, which will likely interfere with the sourcing of co-products by the feed sector. Therefore, if this scenario is considered as a potential future outcome, it is very likely that a large extent of competition between the livestock and bioenergy sectors will occur.

Another scenario analysis (about the competition between the two sectors) conducted by Philippidis et al. (2018), shows the potential trade-offs and economic implications for different scenarios. The scenario analysis examines the share of available biomass for bioenergy and the consequent impacts on the economy for the time 2020-2030. The researched scenarios are similar to the one of Schuenemann & Delzeit (2022). The scenarios relevant for the research question are the followings: the Baseline scenario, the Advanced Biofuel Scenario (AB), the No Palm Oil Import Scenario (POE) and a scenario where all EU bioenergy support is eliminated (NoS). In the Baseline Scenario, it is assumed that conventional biofuel reaches 7% of the total energy produced in 2030, of which 1.5% is advanced biofuel. See table 1 for an overview of the energy production in percentages for each scenario. The researched scenarios are compared to the assumed market prices of the products utilized by the biogas and feed sector and the production output of both sectors. The mentioned co-products for animal feed refer to by-products of biofuels, which are particularly oilcake and DDGS. Oilcake is a co-product of energy crops and DDGS is a co-product of bioethanol.

Table 1: Percentages of energy production from biofuel in each scenario. (Philippidis et al., 2018)

	BASELINE	AB	POE	NOS
Conventional biofuel	7%	3.8%	7%	0%
Advanced biofuel	1.5%	3.6%	1.5%	0%
Palm oil imports	No restriction	Baseline EU directives	Eliminated from Asia	Baseline EU directives

For the AB scenario, it is expected that conventional biofuel production will decrease by 46.2% compared to the baseline scenario, while advanced biofuel production is expected to rise by 136.7%. The production of co-products for animal feed from conventional biofuels decreases by 8.7%. The impact on market prices for bioenergy and electricity is expected to be no greater than 2.5-5%, as trade for biomass with third-world countries satisfies the biomass demand.

For the NoS scenario, market prices for feedstocks (otherwise used for bioenergy)y fall, combined with increased availability of biomass. However, some co-products from bioenergy for animal feed will have reduced availability. And the market prices for these co-products are predicted to increase by 9.3% and 83.7%, respectively. Furthermore, the import of energy from fossil fuels is expected to be necessary to meet the EU energy demand in the NoS scenario. The energy gap created by a lack of bioenergy availability will likely be compensated by other sources of renewable energy and by fossil fuels.

In the POE scenario, palm oil imports are excluded and imports of oilseeds, sugar beet, bioethanol and, biodiesel will therefore increase, to compensate for the lack of palm oil. Since there will be a dependence on biofuel import to reach the REDII goals, export from the EU is expected to fade out.

To summarize, it is observed that the production of biofuel leads to a potential supply of co-products for the animal feed industry and that in the AB and NoS scenario this co-product supply from the bioindustry declines. Since the animal feed sector is dependent on the import of protein co-products, no large supply gaps are expected with the phasing out of (conventional) bioenergy (Philippidis et al., 2018). However, Schuenemann & Delzeit (2022) conclude that the impact of the bioenergy sector on the competition with animal feed for co-products from the food chain is still unclear since many events that can possibly take place in the future can influence the developments of both sectors.

4.4.2. Scenario 2: circular agricultural production

While the implications of the developments of the bioenergy sector have been mentioned in the scenario analyses by Schuenemann & Delzeit (2022) and Philippidis et al. (2018), the growth of the bioenergy industry could also increase market opportunities. The following scenario investigates the idea of only using non-nutritional residues and waste streams for biogas production. This promotes the idea of cascading use of biomass and circularity, which is in line with the Food Waste Hierarchy. Currently, a degree of competition between the food, feed and energy industry can already be observed, and it can be expected that the Renewable Energy Targets from the EU put pressure on this competition. However, there are also market opportunities that come with the development of the bioenergy sector (Popp et al., 2016a). One advantage of the increased biofuel production is that co-products such as oilcake and DDGS produced during the production of biofuels can be used for animal feed. This would reduce competition between the feed and food sectors predicted in the scenario by Schuenemann & Delzeit (2022). In contrast, biogas production produces a digestate that has no nutritional value for feed, but would be suitable as fertilizer for agricultural land, provided that the right technologies are developed to convert digested manure into pathogen- and micropollutant-free fertilizer. This would lead to a scenario of circular agricultural production: a principle where agricultural land is prioritized for food production first, and co-products from the food chain not consumed by humans are directed to feed production. Animal manure and rest products not suitable for animal consumption are directed to biogas production and biogas digestate can be used to fertilize agricultural land for crop production again. In this scenario, waste streams are minimized (van Zanten et al., 2016).

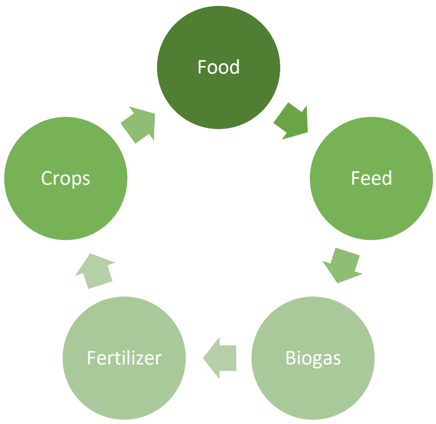

Figure 11: Model of circular use of biomass in the food-feed-energy chain (Tufvesson et al., 2013)

Figure 11*3* shows the simplified model of circular use of biomass in the food-feed-energy chain. The outcome of this scenario describes an optimistic future scenario where the competition between the feed and biogas sector is limited and environmental impacts are minimized. However, using waste streams for bioenergy may potentially not be profitable enough for bioenergy producers. In the future, it can be expected that there will be a lot of incentives to produce green energy and the energy demand for biogas might possibly outgrow the supply in this scenario (Business Development Manager of Nijsen company, 17 June 2022). In the case all agricultural land is exploited for food production, it is yet unclear whether the supply of food residues would be sufficient to meet the demand of the feed and bioenergy sector (which are dependent on these residue streams in this scenario). Evaluating the results of the scenario analysis of Schuenemann & Delzeit, (2022) it can be expected that a substantial amount of biomass from these rest streams would be necessary to produce a sufficient amount of biogas to achieve the REDII objectives. Therefore, if this circular agricultural principle will be prioritized in the future, it is likely that the competition in the food-feed-energy chain for sourcing biomass will not be entirely eradicated. However, effective national regulations, cooperation between the feed and biogas industry, and the standardization and quality control of former foodstuffs and co-products might allow more effective management of such competition (Popp et al., 2016b). Additionally, governance solutions are mentioned to be feasible types of solution: for example, policies that distribute the amount of food/co-product supply between the industries, a market structure and focus on supply chains, communication and agreements with local stakeholders (Muscat et al., 2020). In this scenario, co-existence between the sectors can be achieved, provided that the technologies necessary are developed and the policies regulate the sourcing of co-products for both sectors.

4.4.3. Application of scenarios on biogas production in competition with co-products

While there are several studies on biofuel and bioethanol, not much research is done on biogas production. Tufvesson et al. (2013) conducted a scenario analysis for the reduction of GHG emissions and benefits of biogas production when using all industrial residues (food co-products) or only using industrial residues that do not compete with the animal feed sector. It is emphasized that the potential utilization of co-products for biogas has gained interest, as this eliminates competition with the agro-food sector for cropland. However, it is predicted that the utilization of co-products to produce biogas instead of using them to produce animal feed will lead to a shift in competition between the feed and food sectors (Tufvesson et al., 2013). This is because an increased amount of cropland for the production of animal feed crops is necessary. On top of that import of animal feed protein sources will likely increase, leading to increased land use outside of the EU, causing a shift of environmental problems as well. On the other hand, prioritizing the use of co-products for the bioenergy sector is observed to potential lower GHG emissions and decrease the reliance on fossil fuels substantially (Tufvesson et al., 2013). Furthermore, using the biogas digestate as fertilizer would replace the artificial fertilizer industry, which contributes to decreasing GHG emissions even further and promotes the concept of circularity. Therefore, it can be stated that for both scenarios for the biogas industry potential benefits and tradeoffs are observed; decreasing GHG emissions in the energy sector will lead to an increase in GHG emissions in the animal feed sector instead, together with the competition with the food sector and implications, and also vice versa.

5. Environmental impact comparison

In this section, the impact on the environment of using food co-products for animal feed versus bioenergy will be discussed. The focus will be on the Global Warming Potential (GWP) because this is directly linked to climate change and GHG reduction is key to many of the EU's climate policies. In this chapter, an overview will be given of what is already known about this subject in the various industries. The studies have applied either an Attributional Life Cycle Assessment (ALCA) or a Consequential Life Cycle Assessment (CLCA) approach. A life cycle assessment is a method to assess the environmental impact of the entire life cycle of a product or human activity. (RIVM, 2018) ALCA is focused on the description of the environmental physical flows to and from a life cycle and its subsystems. CLCA is focused on how these flows will change due to different potential approaches. (Finnveden & Potting, 2014) The EU's Food Waste Hierarchy was taken as a starting point, which was already discussed in *Section 3.1.2* (Vandermeersch et al., 2014). According to this hierarchy, the use of food co-products for animal feed has a higher priority than the use for renewable energy production. And yet, this is not always met. This can be due to economical or technological reasons.

5.1. Food waste management with supermarket food products

A case study analysis was performed in Sweden (Eriksson et al., 2015). The environmental impact was calculated for the scenario of when all the food co-products of supermarkets would be used for producing animal feed in comparison with other valorization options (such as landfill or anaerobic digestion). Five types of food co-products were studied: bananas, lettuce and bread (to replace oats for their energy content), beef and chicken (to replace soy-bean for their protein content). Chicken and beef are prohibited as a protein source for animals due to their potential risks of diseases, but were used as a theoretical exercise. This study shows that bread has the lowest impact on the GWP, as shown in *Figure 12*. The rest of the products show a negligible effect on the GWP. Looking at the cases of banana, lettuce and beef, anaerobic digestion has the lowest impact on the GWP. For chicken and bread, anaerobic digestion is not the best, but still one of the best options. To conclude, anaerobic digestion has the lowest impact on the environment compared to the production of animal feed.

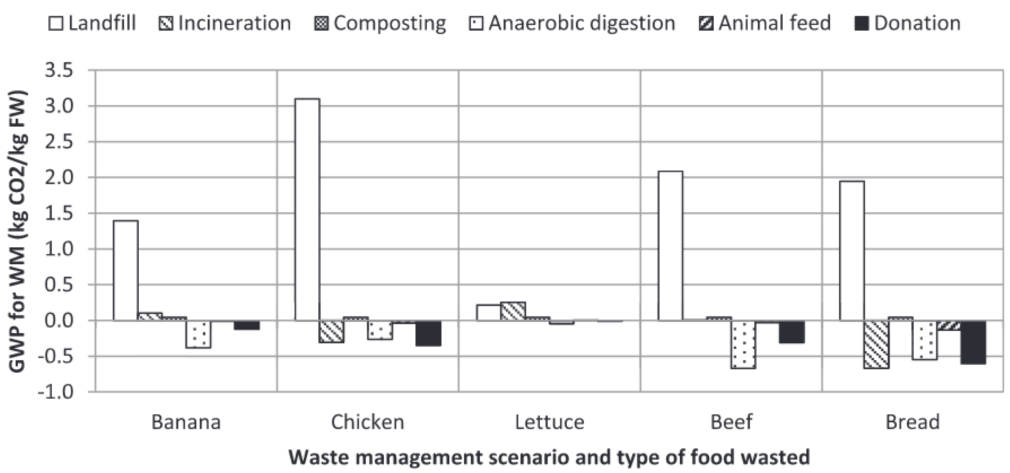

Figure 12: Global warming potential of each waste management option per food co-products (Eriksson et al., 2015).

5.2. 100% to anaerobic digestion vs. bread fraction to feed industry and non-bread fraction to anaerobic digestion

In the study of Vandermeersch et al., (2014) two scenarios on the environmental impact with an ACLA approach were compared. Scenario 1 consists of all food co-products that will be used for anaerobic digestion. In Scenario 2 this food co-products stream is separated into two streams: the bread fraction was used for animal feed production and the non-bread fraction was used for anaerobic digestion. This study is specifically done with bread as the source, hence the results obtained can only be used and extended with equal low water content sources as bread. The results of this study show that Scenario 2 is 10% more efficient than Scenario 1. As is shown in *Figure 13*, Scenario 1 performs better in eight categories i.e. climate change, ozone depletion, ionizing radiation, human toxicity, marine ecotoxicity, freshwater eutrophication, water depletion, and fossil depletion. On the other hand, Scenario 2 performs better in the remaining ten categories, i.e. metal depletion, natural land transformation, urban land occupation, agricultural land occupation, marine eutrophication, terrestrial acidification, freshwater ecotoxicity, terrestrial ecotoxicity, particulate matter formation, and photochemical oxidant formation.

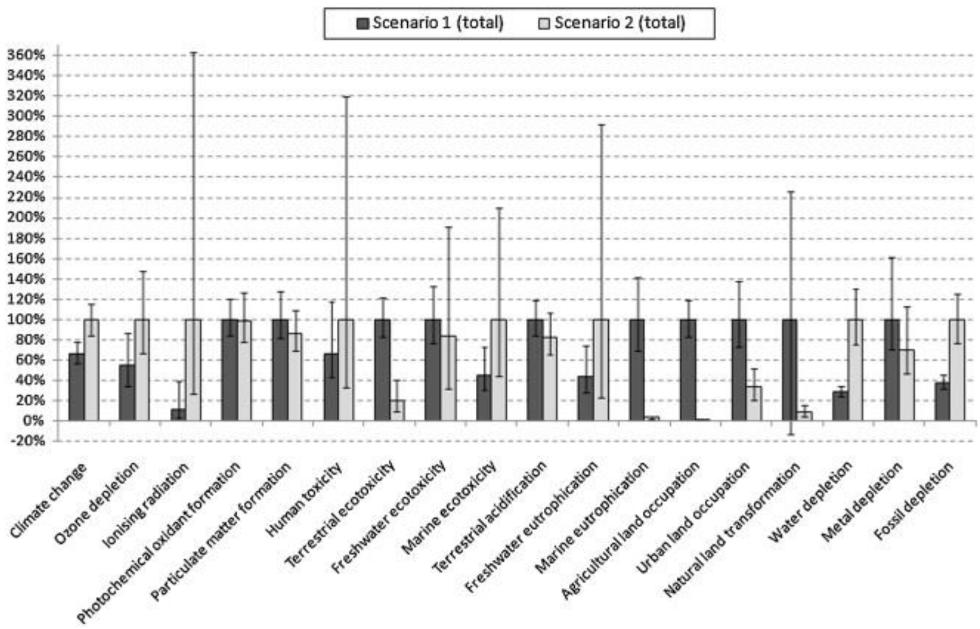

Figure 13: Environmental impact of the two scenario's on different environmental aspects (Vandermeersch et al., 2014)

5.3. The NOSHAN project

To investigate how to lower the environmental impact of the livestock, the NOSHAN project has been created. The main purpose of the NOSHAN project is to promote the recovery and reuse of food co-products (mainly dairy and plant residues) whose losses account for 8% of the global carbon footprint (European Parliament, 2017). NOSHAN aims to replace bulk feed ingredients that are about 90-95% of the total feed weight with food co-products, to lower the emissions associated with the food production chain. (NOSHAN Project, 2014) This project has come up with a special diet for chickens, the NOSHAN mix which consists primarily of processed food co-products. By using this mix with a ratio of 10% together with the standard feed, a reduction of 300 g of CO_2 emissions is accomplished for every 1000 g of only standard chicken feed. Professor Jorba, an expert in agrifood technologies, estimates a reduction of natural land transformation of 30% and agricultural land use of 12% when using this approach globally for animal feed. This project is still ongoing and is currently investigating other applications, for example in the feed for cattle, pigs and goats. (European Parliament, 2017)

5.4. Beet tails in dairy cattle diet instead of anaerobic digestion

Van Zanten et al. (2014) conducted a study in which the environmental impact has been analysed for the implementation of beet tails in dairy cattle diet instead of using it as feedstock for anaerobic digestion. The study focused on two environmental aspects: the GWP and land use (LU). According to Van Zanten et al. (2014), when using beet tails, a reduction of 239 kg CO_2-eq per ton of beet tails is achieved and the LU has a reduction of 154 m^2. Although this is quite a significant number for LU, it is important to take into consideration an uncertainty factor of about 170 tonnes of CO_2 per ha.

5.5. On-farm anaerobic digestion

Styles et al. (2015) performed a CLCA of seven scenarios, under which the scenario's: LD-SF (Imported food co-products augments slurry) and LD-SMZ (Slurry is augmented with a further 30% dry matter of fodder maize). The outcome of this study shows, as is seen in *Figure 14* and *Figure 15*, that food co-products have a high potential to lower the GWP in comparison with the use of fodder maize for augmentation of feedstock for anaerobic digestion. This study also emphasizes that using food co-products or crop types conventionally used for feed (especially maize), has an impact on the import of the soybean meal extract (SBME). Therefore, it was concluded that the co-digestion of crops is necessary to lower the GWP, but to such an extent that increasing of the international import of feedstock does not nullify the benefits of using on-farm anaerobic digestion.

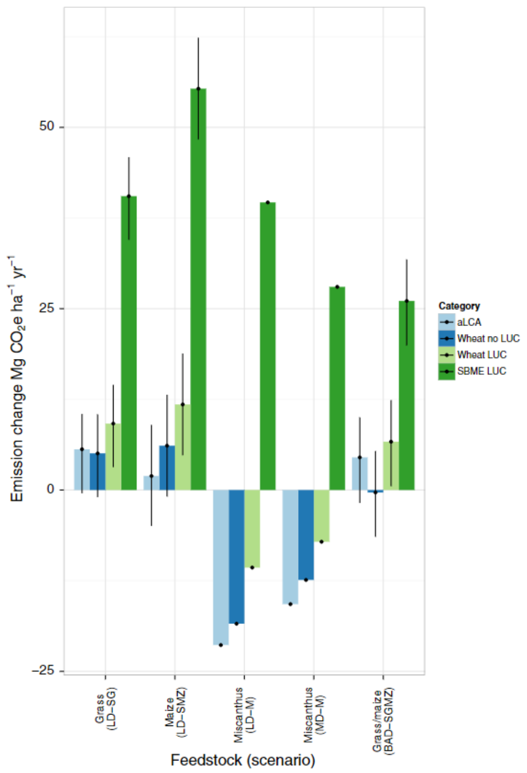

Figure 14: Effect on CO2 emissions per scenario (Styles et al., 2015)

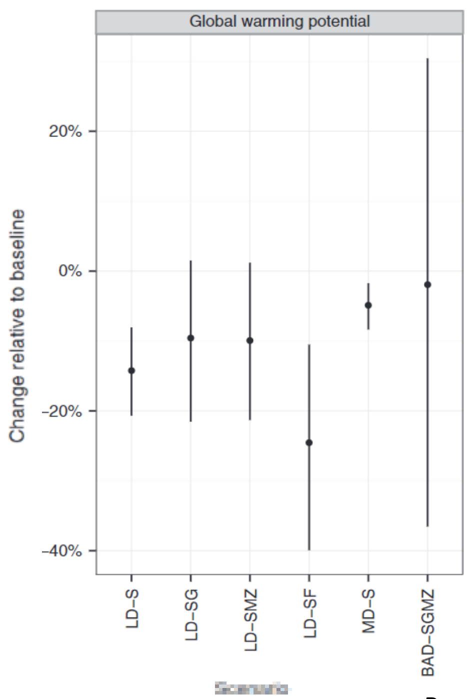

Figure 14: CLCA of the change in GWP per scenario (Styles et al., 2015)

6. Discussion

The aim of this research was to explore the development of the biogas and feed industry and the potential competition for sourcing co-products in the EU. As well as researching the environmental impact of using co-products for animal feed production versus using these co-products for biogas production.

In order to use co-products as feed ingredients, Feed Business Operators need to comply with severe hygiene requirements. This creates difficulties and additional costs for food co-products and residues manufacturers. Hence, they may opt to divert their co-products to the biogas sector, for which the requirements are much less strict. It follows that a large number of co-products, which could be re-introduced in the food chain as feed, are lost and locked in a lower level of the food waste hierarchy. Additionally, the wide heterogeneity of food co-products could render difficult the extrapolation of the potential sources for feed production. Also, the possible high transportation costs, which are strongly dependent on the size and geographical proximity of the food processing industry to the animal feed producing plant, can make food processors opt for a lower level of the food waste hierarchy as it is economically more feasible. Finally, some Member States (such as Italy) are now raising subsidies for biogas plants to comply with the REDII energy targets, which may lead to the downgrade of food residual flows at lower levels of the waste pyramid.

Due to a lack of research on the future developments of the biogas sector for sourcing co-products (otherwise suitable for animal feed), the scenario analysis for the competition between the two sectors is based on assumptions. It was assumed that the plausible development of the biogas sector will likely follow a similar trend as the development of the biofuel sector for sourcing agricultural residues in competition with the animal feed sector. Furthermore, the described scenarios covered two theoretical extremes; either all co-products are being directed to the biogas sector or all agricultural land is used for food production only, of which the rest streams are directed to the animal feed sector. In this scenario, the bioenergy sector is thus left just with non-nutritional by-products, following the circular agricultural production principle. In reality, a more balanced share of co-products is needed between the two sectors, as it is probable that either sector will eventually start competing with the food sector. If the balance is not reached, the competition between the two sectors will be an escalating issue in the future, and in order to comply with REDII, the demand of the biogas sector might exceed the available amount of co-products.

When analyzing the environmental impact of using food co-product by either the animal feed sector or the bioenergy sector, some considerations need to be taken into account. When a larger amount of food co-products is being used for anaerobic digestion, more feed ingredients will need to be imported. Thus, the environmental impact of the animal sector will likely increase, due to the higher emissions associated with the transport and storage of raw materials. Also, it has been demonstrated that certain co-products have more benefits for the environment when used for one industry instead of the other (e.g. beet tails for the feed industry). Finally, it should also be taken into account that the available literature has often been funded by companies that are in favour of one of the two industries, and thus may have resulted in a biased conclusion.

7. Limitations

During literature research, some issues were encountered relating to the taxonomy of 'co-products'. Many sources grouped co-products into categories such as 'food residue flows' or 'agricultural residues'. There was often no distinction between the portion of co-products which still had nutritional values (and could be recovered for feed) and the portion of actual waste. Some studies, especially not recent journal articles, still refer to co-products as 'food waste' which does not align with the current European revised Waste Directive. This created uncertainty as to whether the information found was relevant for the scope of the research. Therefore, any literature containing no clear categorization of co-products was excluded from the research. Especially, since the biogas industry is rapidly evolving, a study conducted a few years beforehand could have already been outdated and not applicable for 2022. On top of that, a lot of data for scenarios were about the bioenergy and biofuel industry and agricultural residues in general, rather than biogas and co-products specifically.

An additional challenge to finding relevant data was the irregularity of the past few years regarding the global pandemic and the war in Ukraine, which was not part of the scope of this research. In fact, the conflict between Ukraine and Russia and the consequent rise in prices of raw materials and the increasing demand for energy independence, show the difficulties in predicting the future developments of this competition. There are many variables to be taken into account when looking at the future, such as the increase in imports and exports of agricultural materials outside the European Union, peculiar events related to climate change or even a pandemic. These factors drastically impact the future outcome. As a result, the scenario analysis provided in the report is based on the current and past trends of the two sectors, which cannot account for abrupt changes that might take place in the foreseeable future.

By analysing the different national policies, it became clear that there is very little information on the treatment and disposal of co-products. Co-products are briefly mentioned in decrees and national legislations and it can be difficult to identify their role in the production chain of biogas and feed. Recent European and national policies encourage the use of renewable energy and have large budgets to promote the development of the sector. Being biogas a form of renewable energy, the growth of the sector is being incentivized in many Member States, especially in Italy and France where the competition for coproducts is higher. In The Netherlands the feed sector is resilient and the incentives for the use of manure in biogas plants are discouraging the competition for coproducts between the two sectors. Finally, the bioenergy sector in Poland has just started growing and although different incentives and subsidies are given for the development of renewable energy, there are enough sources for both the sectors.

To investigate the different policy instruments that regulate the two sectors, stakeholders involved in the bioenergy and feed production chain were contacted. In some cases, no answer was received. Special attention was paid to trying to ensure that sufficient stakeholders from both industries were contacted to minimize the potential biases and get a fair overview of the phenomenon. Nevertheless, the information received from the representatives of the companies did not always line up with the perception of the situation based on the information collected from the literature. For instance, the representative of the European Biogas Association (EBA) affirmed that he is not aware of concerning signals of competition between the bioenergy and feed sector in Europe. This is conflicting with most of the information collected and the viewpoints of most of the other stakeholders involved.

Furthermore, when investigating the environmental impacts of using the co-products in the two sectors, some issues were encountered when comparing different studies as there are no standardized criteria for determining the sustainability of co-products used in either the biogas or feed sector. Therefore, it was difficult to compare studies and come to a reliable conclusion. Furthermore, most of the studies were about bioenergy and not only biogas specifically. That made it difficult to know whether the literature was usable or applicable.

Finally, during research it became clear that the problem is not a two-way competition as presented in this research project. It is a three-way competition between food, animal feed and the bioenergy sector, giving a more complex framework than expected, and causing that there is not one clear solution to the stated problem.

To overcome some of the limitations, different studies were combined and an attempt was made to give a clear overview of the present and future development of the bioenergy sector and its implications on the competition with the feed industry for the sourcing of co-products. Additionally, pieces of reality through interviews with stakeholders from the two sectors that gave insights were integrated, complementing the knowledge gap from lack of literature.

8. Conclusion and Recommendations

The hypothesis of this research was, that the bioenergy sector is currently not outcompeting the feed sector, but that future developments are expected to increase the degree of competition. To answer the main research question, the main effects that are expected to be observed through competition if the biogas sector will be favoured by EU regulations, are increased prices of co-products and former foodstuffs, increased import of products necessary for animal feed production, reduction of the amount of livestock and increase in demand for agricultural land for feed crops, which causes a lower environmental impact and increased competition between the food and feed chain. On the other hand, if the European regulations prioritize the use of co-products and former foodstuffs for animal feed, which promotes a cascading use for biomass, the biogas industry could potentially increase more with the food sector for land use.

Currently, the biogas plants across Europe are using a significant number of agricultural residues but only a minimal number of co-products, as feedstock that could be used for the feed industry is more expensive than the waste feedstock. However, if governmental financial support continues to increase for this industry and the biogas targets are reached without implementation of the food pyramid into national legislation, increasing numbers of feedstock currently used for feed will be diverted to biogas, as much of these contain higher biogas yields. This is already the case for some member states within the EU.

The development of the bioenergy sector is therefore inevitable as the demand for renewable energy in the EU will rapidly increase in the next years also due to the recent conflict in Ukraine. The advantage of the sector's development is that competition between the two sectors could eventually be overcome; if a cap for the use of crops in bioenergy production will be established, there will likely be more crops available for the feed and food industry although the future population growth could pose a threat for the two beforementioned sectors.

On the other hand, in multiple studies, it is stated that using former foodstuff for anaerobic digestion has a lower impact on the global warming potential and further environmental aspects such as land use. Moreover, the implementation of former foodstuff for feed next to the use of anaerobic digestion, instead of only using former foodstuff for anaerobic digestion has a lower impact on the GWP. However, the recognized issue with bioenergy is that the use of co-products is not in line with the Food Waste Hierarchy, as this strategy prioritizes the cascading use of bioenergy. Furthermore decreasing GHG emissions in the energy sector will lead to an increase in GHG emissions in the animal feed sector instead, together with the competition with the food sector and implications, and also vice versa. From this, it can be concluded that a sustainability assessment of the two sectors is dependent on a lot of factors that influence sustainability.

The research illustrates that policy recommendations for biogas are very complex because an interconnected and coherent agricultural, waste and energy policy needs to be created. However, governance solutions are the most feasible type of recommendation for managing competition between the biogas and animal feed sectors. Governance solutions can be described as policies that distribute the amount of food/co-product supply between the industries, a market structure and focus on supply chains, communication and agreements with local stakeholders. What can help to reduce the implications of this competition are primarily specifications about what co-products must be exclusively used by the feed industry and guidelines that better explain their disposal. Sanctions for non-compliance would incentivize suppliers to carefully manage their products as well.

To conclude, this research contributed to give an overview of the extent of competition for the sourcing of co-products by the biogas and animal feed industry within the EU and provided insights on regulations, potential causes, expected trends and environmental impacts of the two sectors. Overall, this study forms a basic understanding on how to identify and manage trade-offs that cause competition between the biogas and animal feed industry, and forms a foundation for finding potential solutions that eliminate the conflict of interests between the two sectors.

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Founder, Top feed, June 2022, Correspondence with Bonnie Roefs

9. Appendix

In the following Figure 1, the FiT are shown in more specific.

Biogas	organic products	1<P<300	170
		300<P<600	140
		600<P<1000	120
		1000<P<5000	97
		P>5000	85
	organic co-products, waste not from from separate collection	1<P<300	233
		300<P<600	180
		600<P<1000	160
		1000<P<5000	112
		P>5000	-
Biomass	organic products	1<P<300	210
		300<P<1000	150
		1000<P<5000	115
		P>5000	-
	organic co-products, waste not from from separate collection	1<P<300	246
		300<P<1000	185
		1000<P<5000	140
		P>5000	-
	waste for which the biodegradable fraction is determined on a lump-sum basis according to modalities set out in Annex 2 of the decree of 6 July 2012	1<P<5000	-
		P>5000	119

Figure 1: Feed-in Tariffs in Italy: The column on the right represents the power (Kw) and the second column from the right represents the tariff (€/MWh)

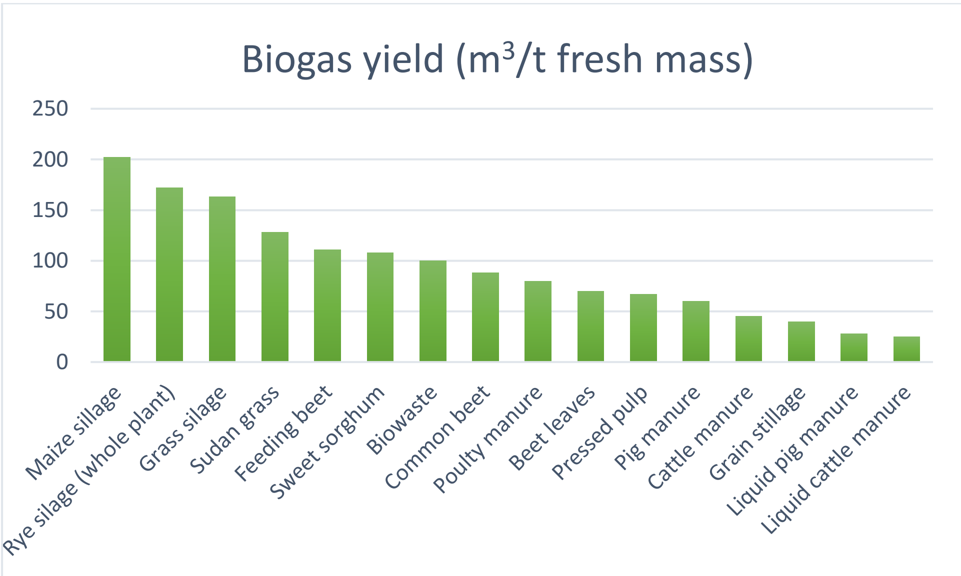
9.1. Co-products

Various food co-products (excess products generated during food production processes) can be used to produce animal feed. This includes the following examples:

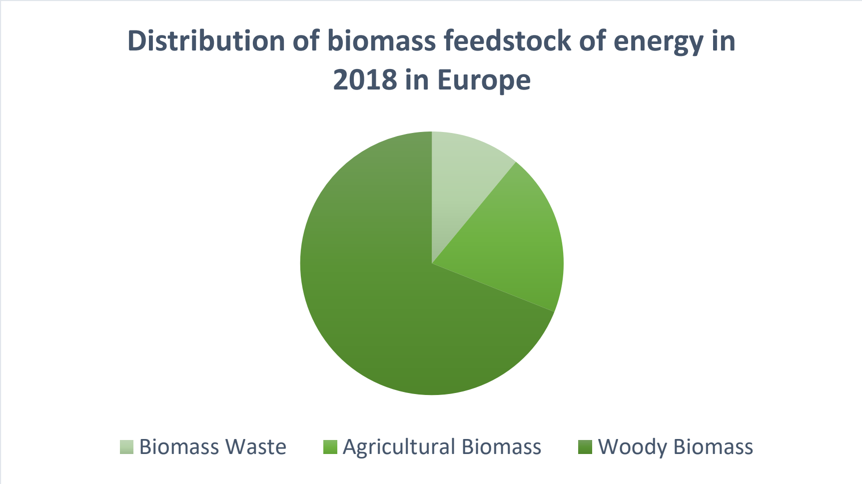
- Rice bran
- Rice wine lees
- Rice noodle debris
- Shochu dregs
- Soy sauce lees
- Starch residue
- Beer dregs
- Wheat bran
- Sesame oil residue
- Corn gluten meal
- Soybean oil residue
- Juice pulp
- Bean curd
- (tofu) Residue
- Breadcrumbs
- Cake crumbs
- Beet pulp
- Sugarcane crush residue
- Tea residue
- Molasses
- Corn steep liquor

(https://www.researchgate.net/figure/Number-of-Ecofeed-plants-by-type-of-food-waste-used-December-2007-1_fig1_43136371).

Whether or not the former foodstuffs can be used as raw materials for feed depends on the stability of supply, stability of quality and nutritional values.



(AEBIOM, 2009)



(Bioenergy Europe, 2020)

9.2. Glossary

- Acidification: The process of becoming an acid or the act of making something become an acid.
- Anaerobic digestions: The process by which bacteria act in the absence of oxygen to break down biodegradable substances. Used to generate renewable energy in the form of biogas.
- Bioenergy: It is a type of renewable energy produced with recently living organic materials called biomass, which can be used in the production of fuel, heat, electricity and transports.
- Biofuel: Fuel made from organic matter such as cow manure.
- Biogas: Gas produced when bacteria break down organic substances such as plants and animals causing their decay. It can be used as fuel.
- Biomass: Biomass is renewable organic matter derived from animals and plants. In many developed countries the use of biomass fuels for transportation and power generation is increasing to reduce carbon dioxide emissions from fossil fuels. Biomass contains the chemical energy stored from the sun through photosynthesis. Biomass can be burned directly for heat or converted into renewable liquid and gaseous fuels through a variety of processes.
- Co-fermentation: Fermentation of manure and other biomasses such as crop residues and(or food coproducts.
- Co-products: Secondary products obtained in the production of other products. In this paper it primarily refers to food co-products
- Energy crops: Crops grown to be used in the mix for bioenergy production.
- Eutrophication: The addition of nutrients to water in lakes and rivers, which encourages plant growth that can take oxygen from the water and kill fish and other animals.
- Feed in Premiums: Policy strategy aimed at supporting investments in renewable energy through an additional payment to the market price for the producers.
- Feed in Tariff: Policy strategy aimed at supporting investments in renewable energy through long-term contracts promising an above market price.
- Feedstock: material used to produce something in an industrial process.
- Former foodstuff: Food which is no longer intended for human consumption, but still have a nutritional value for animal feeding.

- Gasification: The process of converting fossil fuels and organic matter into gas that can be used as fuel.
- Landfill: The process of getting rid of large amounts of rubbish by burying it, or a place where rubbish is buried.
- Mono manure fermentation: fermentation of exclusively animal manure.
- Slurry: A mixture of water and small pieces of a solid, especially such a mixture used in an industrial or farming process.
- Tendering: Policy strategy which allows government to cosse the best or cheapest company for the supply of goods or to do a job. This is done by asking several companies to make offers for the supply of for doing a job.
- Valorization: Making something valuable from an existing substance.