UNIVERSITY OF TWENTE.

# Dairy side-stream valorization through the application of microbiological processes

Bachelor Thesis

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# Preface

Dear reader,

This research paper is the last part of my bachelor program Industrial Engineering and Management at the University of Twente. The company where this research has been performed is one of the largest dairy cooperatives in the world. This research called "*side-stream valorization through the application of microbiological processes"* provides the company with an analysis of their supply chain in order to make improvements that valorize their product.

Hereby, I want to take the opportunity to thank everyone who supported me the last few months throughout this bachelor thesis. I would like to thank Patricia Rogetzer and Peter Schuur, my first and second supervisor from the University of Twente, for all their time and effort to supervise this research. I appreciated the efficient and useful meetings we had together. All the tips and constructive feedback were very helpful during this process.

Furthermore, I would like to thank Peter for giving me the opportunity to perform this research in the dairy industry. The weekly meetings supporting me with a lot of feedback in combination with consequently providing me with the right connections within and without the company made him valuable during this research. Finally, I want to thank my family and friends for their support throughout this bachelor thesis.

Enjoy reading my bachelor thesis,

Kindest regards,

Sven Jeurissen

Enschede, March 2023

# Management summary

**Introduction**
The company where this research is executed is one of the biggest dairy cooperatives in the world with as main focus producing cheese. During the production of cheese different side-streams are released, these side-streams contain mainly whey. Throughout the process of producing cheese, there are three points in time where whey is released, however only in the first two cases the whey can be used as human food. These first two whey streams are for example used for infant food or sport powders and are therefore considered as high-value whey. The last whey stream instead is not usable as human food anymore, due to a low percentage of dry matter, a low pH value, and different bacteria that pollute the product. This whey, called feed whey, can only be sold as pig feed and is therefore considered low-value whey .

Currently, the company could have a better overview of their feed whey supply chain in order to valorize feed whey. In other words, the company fears a shrinking sales market of feed whey and wants to continue valorizing feed whey. This research is focused on an analysis of the current supply chain, in order to find opportunities that optimize the performance of the feed whey supply chain. The main research question of this research is:

"*How can feed whey be valorized in the long run and in a sustainable way?* "

**Methodology**
At first the current situation is analyzed through a value chain analysis in order to get an understanding of where value is created. The order data from 2021 until 2022 serves as a foundation for this analysis. This value chain analysis provides insights into where optimizations in the supply chain can be made. In addition, multiple interviews are conducted to gather knowledge about possible techniques and methods that could valorize feed whey. Based on the information that was obtained during the interviews, extensive literature research has been performed to validate techniques. Afterwards, different scorecards were developed and analyzed, resulting in an advice to the company based on the outcomes.

**Feed whey supply chain**
The feed whey supply chain consists of three main stakeholders: the producer, distributors, and consumers. In this supply chain, costs are only generated during transportation of the goods from a production plant to the pig farmers by the distributors. The costs that are incurred for transporting feed whey from a production plant to the consumers, are on average €325 per truckload. These costs are perceived as high, due to a large distance between plant and customer, and the fact that the product that is transported contains on average 96% water and only 4% dry matter, which is the valuable component of the product. Revenue is generated by the producers and the distributors who finally sell feed whey to the consumers. This market is considered to be a low value market since feed whey is sold for a few euros per ton of dry matter. This information results in the conclusion that the supply chain can be optimized by either lowering the transportation costs or increasing the sales price.

**Analysis and results**
As part of this analysis, it is questioned whether producers of feed whey are proposed to fear a decrease in feed whey sales. Market research revealed that feed whey has a 19.53% increase in sales volumes from 2015 until 2021. The increase in feed whey sales is surprising, because pig food sales volume in general, has decreased with 17.82% during the same time span. It is useful for the company to know the maximum market potential of feed whey. The maximum market potential indicates the urge to search for applications that valorize feed whey in the long run. Research turned out that feed whey has reached its maximum market potential by the end of 2028.

With the use of interviews and extensive literature research, multiple applications are found that valorize feed whey in the long run and in a sustainable way. The applications that are found are microbiological techniques. Two of these techniques are not yet applied to feed whey and are therefore new techniques in this industry. These microbiological techniques create value each in a different way:

- The application of the first technique on feed whey results in a total volume reduction without losing dry matter. In this case, a smaller number of trucks is needed to transport the product to the consumers. The transportation costs decrease if a lower number of trucks are needed. This method creates therefore value for feed whey through a reduction of transportation costs. The application of this technique on feed whey is proven by theory, we propose the company therefore to start lab experiments to prove if the technique can be applied to feed whey.

- The second microbiological technique produces proteins, increases the dry matter volume, and thus enlarge the percentage of dry matter. This leads to higher revenue for the company because price arrangements are based on the dry matter percentages in this industry. This method has already been proven on a lab scale and can be applied to feed whey on a start-up scale.

- The last method is already in use on an industrial scale and is based on a recycling method. Producers of feed whey are able to use feed whey in another, more valuable, matter through recycling their feed whey.

Subsequently, multiple scorecards are developed to analyze the performance of each application resulting in a list of main findings:

- The first two methods are new in comparison with the last method. Calculations showed that the method based on volume reduction has a better financial performance than the method that increased dry matter volume in this specific research. The company is therefore proposed to execute more research on the method which results in volume reduction.

- The recycling method that is currently used increases the financial and sustainable performance of feed whey. This technique can only be applied to production facilities that are scheduled to be built and not to existing factories.

**Recommendations**

An analysis on both the current performance of feed whey as well as the market potential has been provided to the company. The multiple scorecards show that the microbiological techniques that are found are relevant opportunities to create more value for feed whey than currently is done in the dairy industry. The recommendations to the company are to execute more research on the method that reduces total volume and to implement recycling methods in future production facilities.

The general recommendation to producers of feed whey is to actively engage in a search for technologies that create value for feed whey through total volume reduction, dry matter volume increase, or recycling methods.

**Roadmap**

Throughout this research a lot of information has been gathered regarding feed whey. This information led to a set of decisions that could be made in order to create more value for feed whey. A roadmap has been developed for the company to visualize in a schematic way the different kind of decisions they could make to valorize feed whey:

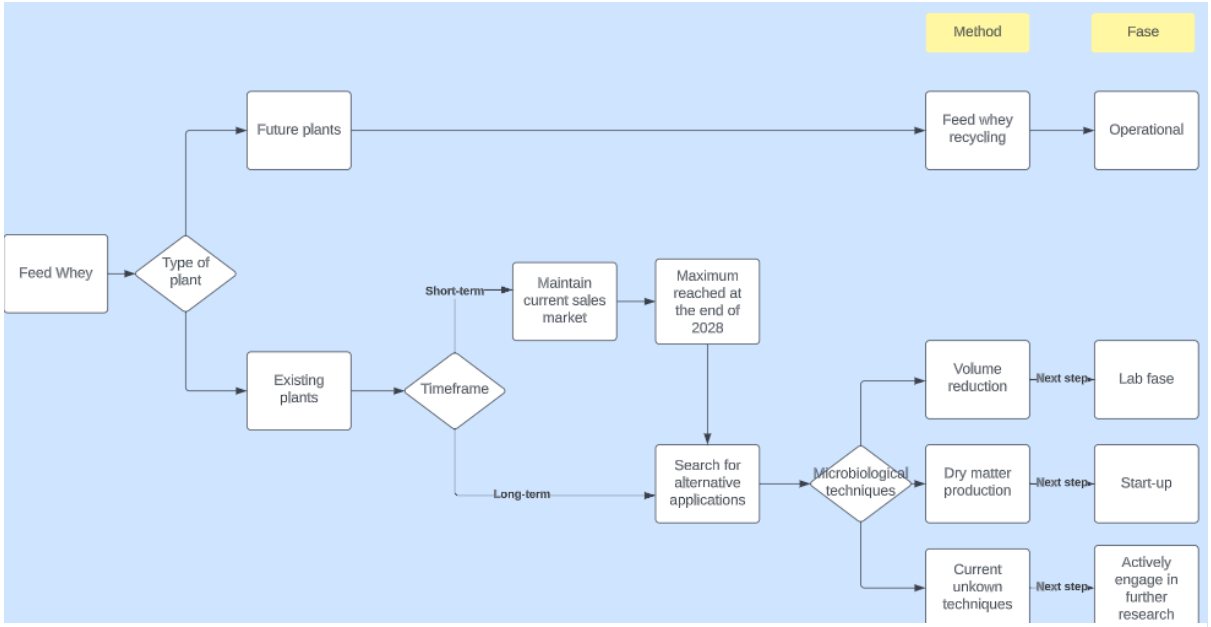


*Figure 1 Valorization roadmap for feed whey*

# Table of Contents

# 1. Introduction

This chapter provides an overview of what can be expected in this research paper. It contains the problem identification, followed by an analysis of this problem. Subsequently research questions are formulated, and the problem-solving approach is established.

### 1.1.1 The company

The company where this research has been executed prefers to stay anonymous due to confidential reasons. In this research paper is therefore often referred to “the company”, because the real name cannot be mentioned.

### 1.1.2 Management problem

During the production of cheese three different types of whey are released. The first two types of whey can be sold on the consumer goods market, for example after processing the whey into whey powder or infant food. These two types of whey are therefore seen as high-value whey. The third type of whey that is released during the production of cheese, is feed whey. Feed whey instead cannot be sold as human food due to several reasons.
Feed whey is polluted through the growth of different bacteria and a low pH-value. Furthermore, feed whey contains a low percentage of dry matter, which is mainly valuable whey. This results in feed whey being classified as animal feed. The low percentage of dry matter and the low pH-value cause that feed whey can only be sold to pig farmers that use feed whey to feed their pigs.

Nowadays the government of the Netherlands is rapidly introducing new rules and regulations regarding the nitrogen emission by farmers, which is relevant to pig farmers as well (Statistiek, 2023). They force farmers to decrease their nitrogen emission. The company fears due to this prospective that a decrease of pig farmers will occur causing a decrease of feed whey sales.

### 1.1.3 Problem Identification

The company where this research has been executed has concerns about the sales market for pig feed. This fear causes a search for possibilities that continue to valorize feed whey on the long run and in a sustainable way. The management problem is caused by several other problems leading to one core problem.

The new rules and regulations of the government cannot be influenced by the company, this is beyond their power. They can influence several other aspects of selling feed whey to pig farmers. First of all, transportation costs are perceived as high due to two reasons. The production plants are located in the north of the Netherlands while the pig farmers are located in the south of the Netherlands, this leads to a large transport distance between the plant and the pig farmers. Next to the large transportation distance, feed whey is a fluid that contains on average 96% water and 4% dry matter. In other words, a product of mainly water is transported over a large distance resulting in high perceived transport costs.

Another potential problem is that feed whey has limited applications next to being sold to pig farmers. Feed whey can currently only be sold to distributors who sell it to pig farmers and has therefore a limited sales market. Furthermore, has feed whey a low potential to be sold on other higher valued markets than the pig market, because of its nutritional values. Although the product has very unfavorable nutritional values, the company can perform a better analysis on other applications of feed whey, and on the supply chain performance of feed whey.

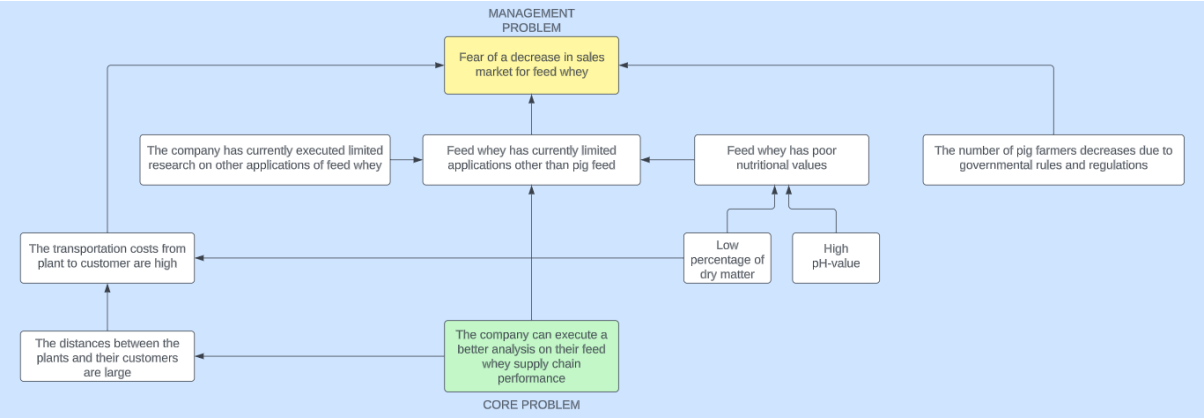


*Figure 2 Problem cluster*

**CORE PROBLEM:** The company could perform a better analysis on the supply chain performance of feed whey.

### 1.1.4 Gap between norm and reality

A core problem contains a gap between norm and reality (Heerkens and Arnold Van Winden, 2017). The company could perform a better analysis on the supply chain performance of feed whey. This analysis gives an insight into where in the supply chain opportunities exists to optimize the supply chain.

## 1.2 Research question and problem-solving approach

To solve the core problem of the company a main research question is formulated. In order to answer the main research question, sub-questions are derived from the main research question. Furthermore, in this section is the problem-solving approach elaborated and how it contributes to solving the problem of the company.

### 1.2.1 Research question

In Section 1.1.2 is discussed that the company fears a decrease of their feed whey sales market. The company gathers a lot of data about their production processes, this data helps to give an overview of their current feed whey supply chain and helps to find solutions that solve their core problem. Within this research paper the performance of the current supply chain is discussed, and microbiological techniques are identified that optimize their supply chain. Finally, their performances are visualized through weighted scorecards to provide the company with an insight into the best performing techniques.

**Main research question:** *How can feed whey be valorized in the long run and in a sustainable way?*

### 1.2.2 Sub-questions

In order to give more structure and organization to this research, the main research question is divided into three sub-questions. The following sub-questions are formulated:

**Sub-question 1:** *How is the current supply chain of feed whey organized?*

- What data can be used to quantify processes within the supply chain?
- What are the costs made when producing feed whey?
- What are the characteristics of the transportation network?
- What costs are made in the transportation network?

- Who are all the stakeholders within the feed whey supply chain?
- What revenue is made when selling feed whey?
- Which limitations can be identified in the current supply chain?

**Sub-question 2:** *How should the new feed whey supply chain be organized to meet the norm of the company?*

- What are opportunities within the supply chain for the company?
- How can the different findings be implemented in the new supply chain?
- What Key Performance Indicators are useful to assess optimizations in their supply chain?
- What are other applications of feed whey?
- Which optimization techniques are useful to improve the current supply chain?
- How can the company sell their feed whey for a maximum price?

**Sub-question 3:** *How should the performance of the improvements be visualized for the company?*

- What method is used to visualize the performance assessment of the improvements?
- What are assessment criteria in the improvement selection process?
- What assessment criteria are important and why?
- Which data is used to compare the improvements?

The sub-questions support in giving an answer on the main research question. This structured approach is beneficial during the problem-solving process. Afterwards the conclusion is drawn, as well as recommendations to the company based on the conclusion, providing an advice for a new organization of their feed whey supply chain that valorizes their product in a long-term and sustainable way.

### 1.2.3 Problem-solving approach

When considering the main research question crucial phases of the problem-solving approach are already revealed. First of all, a thorough overview and analysis of the current supply chain needs to be developed to get a better understanding of the current situation. The company has provided a data set containing all sorts of information about feed whey from the last few years. This data set is analyzed to determine where value is created in the supply chain and where could be created even more value. In order to measure the performance and efficiency of the current supply chain and its improvements, a set of KPIs need to be determined. The purpose of the analysis is to identify opportunities that optimize the supply chain on the long-term.

Performing a value chain analysis in combination with problem-solving approach mentioned in the book Managerial Problem-Solving Method (Heerkens and Arnold Van Winden, 2017) gives a proper guideline during this research.

A value chain analysis in general is used to analyze, coordinate, and optimize relationships between certain activities in the value chain of a product, by focusing on the interdependence between these activities in the value chain. A value chain gives the company a framework of their (relating) activities. Through breaking up the activities into different segments, the company achieves a better understanding of where and how value is created. This approach will make it easier to determine where in the supply chain improvements can be made (Kirli & Gümüş, 2011).

The books Managerial Problem-Solving Methods provides step-by-step a path to solve the problem. This method in combination with a value chain analysis results in the following steps that guide this research towards the solution:

**Context analysis and theoretical framework**
The context analysis summarizes all the relevant information that is necessary to understand the background of the problem. It contains information about the production region, the supply chain characteristics, and the production process. The theoretical framework includes theories regarding quantitative data, qualitative data, and sustainability. These theories from a foundation for solving the problem throughout this research.

**Data analysis**
The company provided a big data set containing information about all the incoming orders for feed whey. The dataset is prepared through removing unnecessary data and converting units to the standard units. This dataset contains information about the delivery month, feed whey volumes, and prices. Ultimately, the value of feed whey for the company is determined through different formulas that consider different prices and volumes.

**Valorization methods**
The next step is to search for methods that create value for feed whey. During the data analysis, a first insight into where improvements in the supply can be made is acquired. At first interviews are taken, to obtain a selection of possible methods that could be applied on feed whey. These methods are validated by executing literature research. The deliverable of this chapter is a selection of different microbiological techniques that create value for feed whey.

**Results**
The methods that valorize feed whey have been determined, the following step is to select the method with the highest financial and sustainable yields. Different scorecards are developed for the company in order to select the best performing solution. The outcome of these scorecards is relevant to solve the problem and finally, to do a proposal to the company how they can continue valorizing feed whey in the long-run and in a sustainable way.

### 1.2.4 Scope
In this research an overview of the current value of feed whey is provided as well as other opportunities to optimize the value of the product. These opportunities are based on data, interviews with specialists in the field, and literature research. Further research is proposed to approve the actual implementation of the improvements. Due to limited time, expertise in the field, and available resources, this is beyond the scope of this bachelor thesis.

# 2 Theoretical framework
In this research, quantitative data as well as qualitative data is gathered, processed, and finally analyzed. These two data types need to be processed according to different methods and theories since they are different data types obviously. In order to perform this analysis an understanding of the methods is required. The theoretical framework describes the chosen methods and theories for gathering, processing, and analyzing the qualitative as well the quantitative data.

## 2.1 Quantitative Data

In order to get an understanding of the current performance of feed whey, the provided quantitative data needs to be processed ,visualized and analyzed. The quantitative data is given in an Excel file containing thousands of rows with order information. These rows with order information are useful to determine the current value of feed whey. KPIs are derived from this dataset to execute an objective analysis of the situation. Multiple methods and theories are used to achieve and validate this.

### 2.1.1 Value chain analysis

The dataset provides information about all kinds of information regarding feed whey, including information about volumes, prices, and sales numbers. A value chain describes the full range of needed activities that are required to produce a product (Lazzarini et al., 2001). Part of performing a value chain analysis is a decomposition of the supply chain into single activities. This decomposition enables the company to take a closer look on the strategic cost management of each single activity. That results in a better identification of optimization opportunities per activity. This structured approach of considering single activities helps to solve the problem.

This approach fits the case regarding feed whey since the supply chain is clearly structured and therefore easy to decompose into its different activities. An overview of how this figure looks like can be found in Appendix A5. Decomposing the supply chain and identifying revenue and costs per activity in the supply chain results in a better overview of which component in the supply chain is proposed to be improved (Krmac, 2011). Through the value chain analysis, the company can perform better strategic management, resulting in better cost calculations. By continuous evaluation of the cost control and cost management, continuous optimalization can be achieved (Ruan, 2020).

### 2.1.2 Key Performance Indicators

KPIs are needed to objectively measure the performance of the current supply chain and the improved supply chain. KPIs represent a set of measures that emphasize the aspects of the performance of the company, which are the most critical for current and future success. It means that KPIs can describe how successful a company is or not (Parmenter, 2010), and in this case the performance of the feed whey supply chain.

Key Performance Indicators are developed to summarize the meaningful data for the company, they are often given as ratios, averages, or percentages. The KPIs are represented in this case through Excel spreadsheets, charts, and tables. Several aspects to consider during the usage of KPIs are the following: KPIs should show comparison over time, highlighting of values through colors and other tools, show differences between periods, and finally set thresholds, warnings, and targets for improvement (Peterson & Web analytics demystified, 2006).

### 2.1.3 Visualization

Within this research it is chosen to visualize the quantitative data that indicates the performance of each individual situation through a decision matrix analysis. This form of multiple criteria decision analysis is a process for evaluating different options through weights and criteria to select the best solution (“MindTools | Home”, 2022).

Multiple criteria decision methods have a wide range of possible features that can be included in the analysis. In the decision matrix analysis usually the obtained alternatives, type of criteria weights, degree of criteria compensation, and considering the relationships between criteria are included. This also holds in this research regarding feed whey.

## 2.2 Qualitative data

An important deliverable of this research is a range of possibilities that valorize feed whey. A foundation for these possibilities consists partly out of quantitative data. However, in order to gain a first insight into solutions, interviews were conducted with specialists in the field. These interviews narrowed down the scope until a level that only relevant solutions remained. Background information about these solutions were supported through extensive literature research using scientific articles, journals, and news articles.

### 2.2.1 Interviews

Interviews with specialists and customers from the company were performed to get a first impression of possible valorization, because the case regarding feed whey is very specific, and has not yet been extensively researched. Therefore, are employees of the company, technicians, and customers contacted and interviewed to gain more information about the topic, followed by literature research to scientifically approve the applicability of the techniques.

There exist many different methods to analyze qualitative data, in specific for interviews. In general, are two main approaches used to analyze qualitative data: inductive and deductive methods of analysis. In other words, unstructured and structured analysis. Inductive research can even be divided further into two other forms, a thematic content analysis and a narrative analysis. The method that is the most applicable in this case is a narrative analysis on the qualitative data gathered from interviews (Rev, 2022).

A narrative analysis is based on understanding the perspective on a certain topic. In this case are the interviewees' perspectives on feed whey used to get an understanding of how the supply chain is organized and to gather information about valorization techniques. Similarities between these perspectives are a foundation for literature research (Dye, 2021).

### 2.2.2 Literature research

During this research paper scientific literature is used to validate if specific microbiological techniques can be applied to feed whey. Scientific literature that is gathered through extensive literature research functionates as approval for the applicability of these methods on feed whey. *''A literature review is a type of critical review in which you analyze and evaluate many sources on a specific topic''* (UMKC Writing Studio, 2022).

This literature research on microbiological processes that can be applied on feed whey are based on the outcome of the interviews. These interviews turned out that total volume reduction, dry matter volume increase, and feed whey recycling are relevant microbiological processes that increase value. During literature research search strings as "acid whey valorization", "feed whey valorization", and "cheese whey valorization" validated that volume reduction, dry matter volume increase , and feed whey recycling are indeed methods that are applicable on feed whey. Subsequently, is investigated how the technology exactly works, and how each method can be applied to feed whey, this is kept confidential for strategic considerations.

## 2.3 Chapter 2 Summary

This chapter obtained different methods to analyze the quantitative data, and the qualitative data. The quantitative data gives consists of an Excel file with order row data. A value chain analysis helps to decompose the feed whey supply chain and to determine the financial performance of feed whey. Next to that, are Key Performance Indicators (KPIs) derived from this data set. These KPIs are used to

summarize the most meaningful data to the company. This quantitative data is finally visualized through a multiple decision matrix. This matrix helps to select the solution later in this research.

Furthermore, qualitative data is used within this research to search for opportunities that valorize feed whey. This qualitative data consists of interviews and literature research. The interviews provide a first insight into different microbiological techniques that can be applied to feed whey. Finally, literature research validates the outcome of the interviews with scientific articles.

# 3 Context analysis

This chapter contains an analysis of the problem context and describes the relevant aspects that need to be considered during the development of the supply chain overview. The context analysis provides information about the production region of feed whey, supply chain characteristics, the production process, and the sales market for feed whey.

## 3.1 Production region

The production region of cheese is mainly located in the North of the Netherlands causing high perceived transportation costs as the trucks are moving 96% water on average to the South of the Netherlands where the pig farmers are located.

In figure 3 the number of pigs per square kilometers in each municipality in 2018 of the Netherlands is shown. The difference between light blue and dark blue indicates the number of pigs per square kilometer. Light blue indicates that on average there are less than 250 pigs per square kilometer, whereas the darkest blue indicates that there are over 2,000 pigs per square kilometer. According to figures 3 it can be concluded that pig farmers are indeed located in the South of the Netherlands whereas the cheese production plants are mainly located in the North of the Netherlands. That partly proves the statement that the transportation costs are perceived as high.

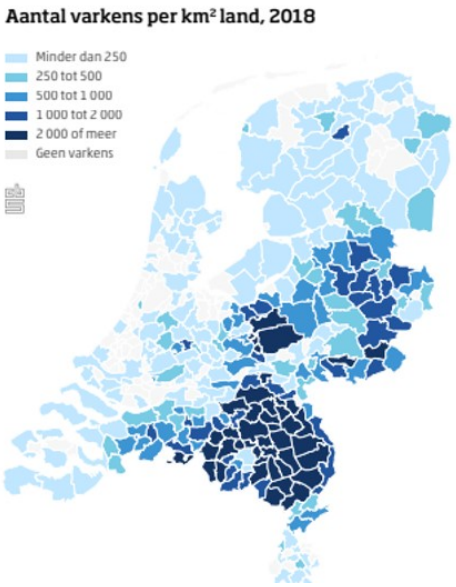


*Figure 3 Map of the Netherlands with the number of pigs per square meter in 2018 (-, 2023)*

## 3.2 Supply chain characteristics

The characteristics of the supply chain can be divided into sub-sections, the involved stakeholders, agreements, costs, and output.

**Stakeholders**

The supply chain of feed whey consists of three main stakeholders: the producer, the distributor, and the customer. The producers are dairy processing companies that produce feed whey, the distributors are transportation companies, and finally the customers which are pig farmers. The stakeholders have each different interests within this supply chain.

**Interests of the stakeholders**

The stakeholders in this supply chain all have different interests. The different interests can be split into interests about the price and the percentage of dry matter of the product for each stakeholder. Before defining the interests of each stakeholder, the assumption is made that the cheese is already saturated with whey during the production process.

The producer prefers a high percentage of dry matter. A high percentage of dry matter results in an increase in revenue as prices depend on the percentage dry matter. Furthermore, are price increases also in favor of the producer because that also results in a higher revenue.
The distributors can have 2 different opinions. Firstly, as the price increases the distributors need to pay a higher price for the product. This is not a problem if they can increase their selling price for the pig farmers. Pig farmers are not able to cope with large price increases, because the pig market is considered to be low value. In case the price increase is too high the product cannot be sold because the pig farmers will not buy the product. Distributors can therefore only aim for a small price increase.

Pig farmers prefer a low price for a high percentage of dry matter. If the price for feed whey becomes too high with a low percentage of dry matter, the pig farmers will search for alternative options to feed their pigs. When the percentage dry matter is higher, it means the liquid is more nutritious. Resulting in less needed volume for the pig farmers to feed their pigs with.
If the percentage dry matter is higher and the total volume is thus lower. It means that trucks have to drive less than they currently do. That means transportation costs decrease, and the margin increases. If the margin increases, the company can earn more profit than they currently do.

In conclusion, it is desirable for every stakeholder to have a product with a higher percentage dry matter. The producer can sell their product for a higher price, the distributor transports more valuable goods, and the pig farmer needs less volume to feed his pigs.

**Agreements**

The producer makes different agreements with every customer. The agreements are based upon the percentage of dry matter and the total liquid volume that is loaded into the truck. That means the price increases if the percentage of dry matter increases. On the other hand, decreases the price if the dry matter percentage or the total truckload decreases. There is a transportation fee for under loading the truck. This fee is charged by the distributor if the producer underloads the truck. This fee is set due to the fact that the pig farmers receive less volume and thus pay a lower price to the distributor.

The prices per percentage dry matter for feed whey are specified with limits ranging from smaller than 2% up until larger than 7%. There is no need to extend these limits, because feed whey contains only in exceptional cases dry matter percentages beyond these limits. Specific agreements about both the price per percentage dry matter as well as the truck load differ per customer.

**Costs**
Feed whey is seen as a side-stream that is released during the cheese production. This side-stream does not incur any costs, the costs of producing feed whey are therefore considered to be 0.

However, there exist transport costs obviously. The transport costs are on average €325 based on a truckload of 33 tons and a distance of 100 kilometers between plant and customer. These transport costs are included in the prices per percentage dry matter. The exact division of transport costs between the company and their distributors is unknown.

## 3.3 Production process

To understand how feed whey is produced the production process of cheese will be explained. Cheese is produced through multiple steps beginning with the ratio of milk that is needed to start the production of cheese. Ten liters of milk are needed to produce one kilogram of cheese. When the milk arrives at the factory a milk-treatment takes place which includes thermization and standardization of the raw milk to prepare the milk for cheese production. Then different starters are added before the milk enters the cheese processing machine.

After the cheese processing machine curd is separated from the liquid. This curd shrinks and leaks whey. This whey is labelled as high valuable because it is applicable in human nutrition such as enfant food and protein powders. This market has obviously a high valuable as consumer goods generate more value than animal feed, because of better product quality.

The liquid that is still in the system will be brought to the draining and shaping machine, before it enters this machine a second stream of whey is released. This whey has not made any contact with oxygen or other materials that influence the quality of the liquid in the system Therefore can this whey stream also be sold as human nutrition and be classified as high value. However, due to a lower percentage of dry matter has it a lower value than the first whey stream that is released.

In the draining and pressing machine the cheese and the shape of the cheese are formed. The last whey stream that is released and the whey stream that is the subject of this research is called feed whey. This whey stream is released when the cheese has been pressed by the pressing machine. They whey is collected in aluminum trays and will finally be saved in tanks. At this moment, the feed whey makes contact oxygen resulting in bacteria growth.

Due to the bacteria in the whey stream and the low pH-value the quality of feed whey decreases. This quality decreases till such a low level that it is not allowed to sell it on the consumer goods market. The product can only be sold to pig farmers due to its nutritional values, who use the whey stream to feed their pigs. As pigs are marked as the bottom of the feed system, the price paid for the product is also very low. This results in feed whey being a low valuable product. A detailed schedule of how and when whey is released is shown in Appendix A2.

## 3.4 Chapter 3 Summary

The context analysis described all the relevant aspects of the feed whey supply chain to gather an understanding of its organization. This chapter contains information about the production region, supply chain characteristics, and the production process. It became clear that the feed whey supply chain consists of three main stakeholders, the producer, the distributor, and the consumers. One characteristic of this supply chain is that the distance between the production plant and the consumers is large. This is caused by the fact that the plants are mainly located in the North of the Netherlands compared to the consumers, who are mainly located in the South of the Netherlands. Considering that feed whey contains on average 96% water and 4% dry matter results in high

perceived transportation costs. This is one of the main problems perceived by the company and causing this research.

# 4 Data Analysis

This chapter provides information about the provided quantitative data. It explains how the data from SAP is extracted and used in Excel, how the data has been cleansed for usage, the revenues that are made from feed whey, and finally Key Performance Indicators that are derived from the dataset.

## 4.1 Output dataset

The company has an enterprise resource system (SAP) to register all different product flows throughout the company. For this research, all single feed whey orders from 2021 and 2022 until September are extracted. This data has been transferred to Excel and contains orders per row. Every row contains information about one single order that has been sold and transported towards a customer. A snippet of this table can be found in appendix A4. This data is used for the analysis of the current financial performance of feed whey.

Below follows a brief description of the information each column gives:

Column A: plant number
Column B: plant name
Column C: delivery number
Column D: customer number
Column E: customer name
Column F: delivering month
Column G: delivering calendar week
Column H: delivering year
Column I: feed whey liquid in kg
Column J: feed whey liquid in tons
Column K: dry matter feed whey in kg
Column L: dry matter feed whey in ton
Column M: dry matter percentage
Column N: revenue order, excluding transportation costs
Column O: result, indicating the price the company receives or pays for the order
Column P: transportation costs

Order rows are gathered for the years 2021, and 2022 up until September. To complete the data of the year 2022, the assumption is made that the single orders of 2021 for the months October, November and December are the same as in 2022. The orders in 2023 are forecasted to be the same as in 2022. This assumption can be validated as the total volume of 2021 compared to 2022 shows no significant difference. The deviation in production volumes between these two years is only 4.4%.

The most important columns during the analysis are the columns J, M, N, O, P shown in the figure 10 in Appendix A4.

**Truckload**

Column J is important as it describes the total truckload. The revenue per order is based on truckload multiplied by the price per percentage dry matter. The total truckload can be a maximum of 35 tons due to governmental rules and regulations.

**Dry matter percentage**

Column M describes the percentage dry matter per truckload. This number is calculated by dividing the volume of dry matter (kg or tons) by the feed whey liquid (kg or tons). That results in a percentage dry matter which party determines the prices of a single order.

**Revenue per order**
Column N is the revenue per order, based on the percentage dry matter and the truckload. The revenue per order is calculated trough the price aligned with the right percentage of dry matter multiplied by the truckload in tons. Transportation fees are excluded.
**Transportation costs**
Column P is the transportation costs, also known as the transportation fee in this case. The transportation fee is based on the truckload. A lower truckload results in a higher transportation fee. The transportation fee differs per customer.
**Total result**
Column O is the total result which is the final price received or paid per order. This value is calculated through subtracting column N from column P. That results in the result per order feed whey.

## 4.2 Data cleansing and data preparing

The raw data gathered through extracting the single orders from SAP must be cleansed and prepared for usage. Cleansing means removing unnecessary data from the dataset such that it is prepared for the analysis.

First, before removing unnecessary data, certain data parts are split into multiple parts in order to create a better overview. The column containing posting month/year, as well as calendar year/week, are split into three different columns ensuring that single orders can be found more easily based on these details apart from each other. These two columns (month/year and year/week) are therefore divided into year, month, and week.

Furthermore, are feed whey liquid bulk and dry matter feed whey mentioned in kilograms. The company and their customers only use tons in their arrangements and calculations. The unit of this data needs therefore to be converted from kilograms into tons. This can be accomplished by dividing the number in kilograms by 1,000 resulting in the weight in tons.

The percentage of dry matter also needs to be determined because this value is important when determining the order price. The percentage of dry matter can be found through dividing the weight in tons of dry matter feed whey by the weight in tons of the feed whey liquid bulk. The value that will be returned is the percentage of dry matter feed whey.

The next step is to clean the data before any calculations can be made. The following data has been removed from the dataset:

- Test orders: at the beginning of a contract a customer performs a test order to know the circumstances at the plant. They need to know this to successfully load the feed whey into the truck and transport the feed whey from plant to customer. However, this data is not useful when making any calculations on total revenue.
- Dry matter percentages below 2% or above 10%: feed whey liquid bulk with percentages of dry matter feed whey outside these ranges are not labelled or known as feed whey anymore and are probably errors in the system. Therefore, are these order rows removed from the dataset.

### 4.2.1 Data preparation

As the data has been cleansed in the previous part, it now needs to be prepared for analysis. To measure the economic performance, the revenue per single order, the transportation costs, and the result are needed. The result is the actual paid or received price by the customer. As these values are necessary for the value analysis of feed whey it is good to develop an understanding of how these values are calculated.

**Revenue per single order**

The revenue per single order is based on the different prices per percentage dry matter and the feed whey liquid in tons. In order to calculate all the different revenues per order a universal formula has been applied. The formula checks the range of the percentage dry matter, the accompanying price will be filled in the formula, these prices can be found in tables with prices provided by the company. The formula multiplies this price with the feed whey liquid in tons resulting in the revenue per single order.

$$= IF(AND(x < n); (y * price); IF(x \geq n; x < n + 1); (y * price); IF(AND(x \geq n); (y * price))$$

With:

- x = real dry matter percentage
- n = dry matter percentage from n = 2 to 6
- y = feed whey liquid bulk in tons

**The result**

The result, the actual received or paid price, can be calculated through the formula below. At this point the transport costs are subtracted from the revenue per order (y – costs). The transportation costs that are paid, are based upon the truckload. The actual costs are determined through different ranges in truckload. The principle holds that the company pays less if the total truckload comes closer to 35 tons. These ranges regarding truckload are kept confidential by the company as they differ per customer. The ranges need to be filled in the formula per customer, the formula selects the right price when the weight fits the range. The following formula calculates the result considering transportation costs as well:

$$= IF(weight \geq x); (y - costs); IF(AND(weight \geq x; weight < x); (y - costs); IF(weight < x); (y - costs)$$

With:

- x = the range limits
- y = total revenue product
- weight = the real weight of the single order
- costs = the transportation costs aligned with the range

**Transport costs**

The actual value of the transportation fee can be determined through subtracting the result from the revenue. The returned number is the transportation fee.

## 4.3 Costs

In the business case different costs are experienced by different stakeholders. The costs for producing feed whey are negligible because it is a side stream that has not been processed any further. The first moment costs are experienced, is the moment when feed whey leaves the plant and enters the truck. The truck is owned by the distributors, so they experience depreciation and maintenance costs of the trucks. The intermediaries are also fully responsible for the carbon dioxide

emission that is released during the feed whey lifecycle, because there is considered to be no emission during the production of feed whey itself at the plant.

At this point in the supply chain there can be experienced two different costs. Transport fee and actual transport costs. The transport fee for underloading the truck are paid by the producer. Within the price per percentage dry matter costs are incurred for transporting the product from plant to pig farmers. These transport costs are mainly divided over the producer and the distributors, the exact division is currently unknown. The prices per percentage dry matter are lower when the total distance from plant to pig farmer is large.

Concluding, the costs made when underloading a truck are for the producer. The other costs, the costs for transporting the goods from plant to pig farmers are partly paid by the producer and partly paid by the distributors. These costs are found within the prices per percentage dry matter.

### 4.4 Performance measurement

The objective performance of the situation should be measured such that it can be compared to the alternative solutions that lead to feed whey valorization. This is the moment when the KPIs come in. Through selecting the right KPIs an objective measurement and an analysis of the current situation can be performed. From the provided dataset the following KPIs can be derived:

- *The average percentage dry matter*
- *Logistics costs*
- *Average result per ton dry matter*

### 4.5 Chapter 4 Summary

This chapter about the data analysis contains information about the order data to measure the current financial performance of feed whey. The data set is derived from Excel and contains information about orders from 2021 until 2023. Before the data set can be used for any calculations the data set need to be cleansed and prepared. Data about test orders and orders with dry matter percentages outside a range between 2% and 10% are removed. Furthermore, are formulas applied that calculate the transport fee, the total revenue, and the total result per year.

## 5. Valorization methods

In this chapter interviews with specialists in the field as well as extensive literature is performed to obtain new insights into feed whey applications. Possible new applications of feed whey and new sales markets for feed whey are explained in this chapter.

### 5.1 Introduction

Feed whey is currently only sold to distributors who sell it on their turn to pig farmers. Since the pig market is expected to shrink in the long-term and known as a low valuable market, there should be searched for other sales markets for feed whey. During the process of valorising feed whey several options to reach this goal appeared. These valorization opportunities are current market potential, other sales markets, recycling feed whey, volume reduction, and protein production.

### 5.2 Maintaining the current sales market

A possible solution for producers may be to maintain their current sales market and continue selling their feed whey to the distributors who sell the product to pig farmers. The figure in Appendix A3

shows that feed whey sales increase from 2015 to 2021, suggesting that the proportion of feed whey in pig feed has not reached its maximum. That means companies can still continue or even increase their sales volume according to figure 8 in Appendix A3.

**Increasing sales of feed whey**
However, the total sales in tons of feed whey are remarkably enough slowly increasing since 2015. Showing that there is still space to grow within the compound pig feed market for feed whey. Feed whey is replacing dry pig feed confirmed by the numbers shown in figure in Appendix A3. Because there is still space to gain market share for the company, maintaining their current sales market is part of the solutions. The duration of this solution is currently unknown and to be determined later on in this chapter.

**Market potential**
From 2015 until 2021 the feed whey sales in tons of product increased on average 3.45% per year, showing an increase of 19.53% in total. These production volumes are registrated by the OPNV an organization for the producers of moisture animal feeds. The volumes of moisture pig feed and compound pig feed decreased instead over the same time period with -6.45% and -17.82% respectively. Resulting in an increasing share in moisture pig feed and in compound pig feed of 5.87% and 5.73% for feed whey

According to a nutrition specialist in the pig feed market there are still opportunities the upcoming years for feed whey to expand their share in the compound pig feed market. The bigger pig farmers in the industry make use of moisture feed and especially feed whey. This happens due to the fact that feed whey is a circular product. After the production of cheese, the side stream feed whey in this case, is brought back to the origin, the farmers. Furthermore, is it attractive for the farmers to use feed whey in place of water because feed whey consists for 96% out of water and farmers are not allowed to use groundwater in all cases for their livestock. Feed whey can therefore solve this problem. The products that are mainly out competed by feed whey are yeast streams and potato steam pills.

In order to determine the maximum growth potential, the maximum proportion of feed whey in pig feed should be determined. According to an expert in the feed whey market the growth of the volume is based on the growth potential of the dry matter feed whey volume. This maximum growth potential of dry matter feed whey is 30%. Considering the production volume of feed whey in 2021, 765,000 tons with an average percentage dry matter percentage of 4%, the volume dry matter is 30,600 tons. An increase of 30% results in a maximum volume dry matter of 39,780 tons. This is a total volume of 994,500 tons feed whey. The number of years till this volume has been reached can be calculated through the following formula. During this calculations it is assumed that the statement of the nutritionist is true, linear growth of the feed whey volume with 3.45%, constant quality of feed whey, constant dry matter percentage of 4%, and all farmers are convinced of using feed whey in their compound pig feed.

The following formula calculates the number of years till market saturation of feed whey from 2021 till x years:

$$yearly\ growth\ factor^{x} * 765000 = 994500$$
$$x = yearly\ growth\ factor^{\log\left(\frac{994500}{765000}\right)}$$
$$x = 7.73520185$$

The calculations suggest that from 2021 it will take approximately 7.7 years till the maximum volume of feed will be reached. That concludes the volume will be reached in the second half of the year

2028, 5.7 years from now. This holds that maintaining the current sales market is a short-term solution.

An overview of this expected market potential is shown in Appendix A3 through a graph. This graph shows the expected sales volumes of compound pig feed, moisture pig feed, and feed whey. At the end of 2028 there can already be observed that the three lines are approaching each other and reaching their maximum. The market for moisture pig feed will absolutely collapse a few years before 2035 as their line crosses the line representing compound pig feed. Therefore, is the end of 2028 an appropriate estimation of the maximum market potential of pig feed.

## 5.3 Other feed whey sales markets

One upcoming market to potentially sell feed whey on is the insect market. Science as well as real life have proven that feed whey could be fed to insects (Rabell et al., 2021). However, the insect market is relatively small currently with only a few big competitors, for example the company Protix.

Protix is currently a fast-growing company using insects for protein production. Last year they earned a fund-raiser of 50 million euros to increase capacity and increase their performance (Protix, 2022). They feed their insects with different fluids as feed, feed whey as well according to a scientist from Nutrifeed. Although the insect market is very small right now with just a few big competitors, it may be an opportunity in the future for feed whey producers to diversify their sales market and profit from this upcoming market. Right now, it is not a relevant market to sell feed whey on as it is not able to cope with large production volumes of feed whey.

## 5.4 Feed whey recycling

A potential ideal situation regarding feed whey would be to have no feed whey at all. Feed whey is released at the end of the production cycle containing rinse water with a very low percentage of whey. The fluid is contaminated due to the rise of many different bacteria. If plants can be ahead of this occurring and returning the whey back to the cheese production process before it is contaminated the plants can earn more revenue for their product than they currently do for feed whey. This could be a high potential solution since a working example saves €600 per ton dry matter feed whey on average.

Next to the financial benefits of recycling feed whey are there also benefits regarding sustainability. Feed whey is currently used for animal feed and classified as food waste according to the food waste hierarchical pyramid (Lombardi and Costantino, 2021). Within this pyramid feed whey can currently be placed in the third top layer of the food waste pyramid, re-use of the product for animal feed. Through redirecting feed whey into the cheese production, it is used for human food again. This leads to feed whey climbing to the top layer of the food waste pyramid, prevention, and can even be classified as surplus food (Albizzati et al., 2021). Concluding that this method results in an increase in sustainability performance as well.

It is not possible to implement this technique into existing plants according to a technician that is involved in the execution of this technique. To implement this system, the whole plant needs to be reorgnized which causes to many costs and causes to much lost production time. Therefore, is this method only applicable when the company decides to build a completely new plant.

## 5.5 Volume reduction

The current transportation costs are perceived as high for feed whey. The average distance from plant to customer are 100 kilometers with an average truckload of 33 ton, the incurred costs for this type of transport are on average €325. Considering the fact that this price is paid for a transport of

96% water and 4% valuable matter leads to the conclusion that this an expensive transport. This can be solved in two ways, either way there should be paid less for the transport. That is unlikely to happen as gasoline prices are increasing rapidly per month (Statistiek, 2023). The other solution may be to decrease the number of freights, without decreasing the total volume of valuable dry matter. This can be achieved be decreasing the total volume of water in feed whey.

**The technique**
Using a technique that decreases the total water volume yields a fluid with a higher percentage of valuable dry matter. The technique that is investigated in this research can achieve dry matter percentages between the 16% and 30% currently according to microbiological scientists from the company. These dry matter percentages are achieved through a reduction in water volume.

Literature review proved that the technique can be applied to feed whey. However, these tests were performed on a small-scale level and not considering large productional scales. The assumption should be made that this technique can also be performed on a large productional scale at the production facilities

**Costs**
The Capex investment that needs to be done for this technique is 1.4 million euros, furthermore, are the yearly operational costs around €300.000 euros. These operational costs are aligned with electricity consumption, water consumption, and steam consumption. A Capex investment of 1.4 million euros combined with Opex costs of €300,000 euros are a big investment, therefore should feed whey also generate more revenue if the percentages of dry matter increase till 16% or 30% in order to gain even profit.

**Yields**
The yields of this method depend on the percentage dry matter that is obtained and the prices per percentage dry matter. In Excel, a multifunctional tool is build were the number of years and the percentage of dry matter can be changed into different values, which will return the accompanying yields. That makes it very easy to observe what the result of each different value will be. In general holds that an increase in percentage of dry matter will result in an increase in yields, an increase in volume reduction, and thus an increase in net result. In the following two sub-sections two different types of situations will be discussed based on their dry matter percentage and based on the current price for feed whey. Currently €3.95 is offered per percentage dry matter per ton fluid, this will be the price that is used for the calculation's underneath (X, 2023).

**Yields at 16% dry matter**
The feed whey liquid volume associated with the desired dry matter percentage can be derived in the following way. The new volume can be derived through dividing the volume of dry matter feed whey with the decimal number of the desired percentage, which is in this case 16% and therefore 0.16. As an example, a volume of 1,513 tons is used, this is the production volume of one of the biggest plants of the company. This value is divided over 0.16, resulting in a new volume of 9,455 tons liquid feed whey.

The most remarkable numbers that appear are the new revenue, the volume savings, the number of trucks that are saved, and the total truck savings in euro. The most outstanding results, and the results that are the most interesting during this research are the results from plants with a larger production volume. The revenue went from - €2,000 to over €500,000 by applying volume reduction in this example. Furthermore are 28,295 tons of liquid filtered resulting in 808 saved trucks and €262,740.22 euros of saved transport costs. If the company decides to invest in the system, the obviously also want to know their break-even point. At this point the cost of the investment comes

in and is set against the investment yields. the break-even point is calculated through solving the following formula with x = number of years:

$$€299258.49x - €1432400.00 = €522642.41x$$

Solving this formula results in a break-even point of 6.42 years. So after 6.42 years this example is actually profitable. That means large productional volumes are required, because it already takes more than six years for one the biggest plants of the company to reach the break-even point.

**Yields at 30% dry matter**
The maximum percentage of dry matter that can be obtained with this technique is 30%. Comparing the yields of 30% dry matter with 16% dry matter, several difference can be observed. The new volume of feed whey liquid bulk decreased which is logical since the percentage of dry matter increased. Due to this decrease, fewer trucks are needed to transport the feed whey causing a decrease in transportation costs. Since fewer trucks are needed to transport the product, more money is left for the producer of feed whey. That leads to an increase in profit. Considering the case study with 30% dry matter feed whey, the plant in this example increased their revenue with almost €40,000 and saved additionally over 100 truckloads. Based on the following formula the break-even point is calculated:

$$€299258.49x - €1432400.00 = €567665.38x$$

Solving the formula in this case results in a break-even point of 5.34 years. That means the investment is earned back 1.07 years earlier compared to the case of a fluid that contains 16% dry matter. Converted into euros is this a difference of €288,699.84 between the case study of 16% dry matter and the case study of 30% dry matter.

**Concluding volume reduction**
Based on the calculations in the previous sections it can be concluded that the company could consider investing in this technique. In both cases, 16% and 30% dry matter, the plant in the example is able to earn back the investment over 5.34 or 6.41 years, respectively. The company should strive for a dry matter percentage of 30% considering the different case studies. Assuming that the installation will work for 10 years the profit over 10 years will be 1.25 million euros for this singe plant. Dividing this profit by the working years of the machine, will this solution earn €125,000 per year at this example plant.

**Potential risks**
Potential risks that may occur are that this technique has not been tested on this product on a large scale. So, scaling up the technique may have causes on feed whey that are unknown yet. Another risk is a loss of customers if the price increases too much. Thickening the product could potentially lead to a loss of smaller customers who are not be able to feed the thicker product to their pigs.

## 5.6 Dry matter production

The other technique is focused on increasing the percentage of dry matter of feed whey through dry matter production. The total volume of the feed whey remains constant while the protein is produced. This method is based on other principles than mentioned in the previous section about total volume reduction.

**The technique**
The technique is based on microbiological principles, micro-organisms convert raw material into other nutritional components. The enzymes of these micro-organisms are able under the right

circumstances to convert the material, mostly carbohydrates or proteins, into another product (Tavares and Malcata, 2016). There exist many different enzymes, all used for different goals or end-products. Therefore, are also enzymes available that can be applied to feed whey (Chourasia et al., 2022). These enzymes can be distinguished into different types with different functionalities. Three different types of enzymes are found during this research, one of these is actually relevant for this research.

The technique that is relevant and already proven by research, turns an element of feed whey into dry matter, it produces thus dry matter. This method works on a lab scale level and has to be proven on an industrial level, however for this research the assumption is made that this method functions on an industrial level. Furthermore, is assumed that the calculations on costs and profit that has already been made by researchers, are true because there exists very few to no research the application of this technique on feed whey. This technique turning some element of feed whey into whey, is able to increase the dry matter percentage from 4% till 10%. That is a significant increase in percentage of dry matter. The difference with the previous technique is that it converts an existing component of the fluid into dry matter instead of filtering and separating the water from the fluid. In other words, this method creates new material whereas the previous technique creates value through volume reduction.

**Costs of the technique**
The installation needs a daily input of 180 tons of feed whey per day. This volume can easily be met. The CAPEX investment needed for this technique is €565,000 combined with OPEX costs of €370,000 per year. Next to these costs are also yearly costs incurred for the supply of whey and transportation. In the calculations are yearly depreciation expenses of €88,750 per year calculated for their CAPEX investment. The method will cost per year, adding up all expenses, around €1,610,000.

**Yields of the technique**
Based on the input that is used at the cost calculation, the input of 180 tons of feed whey per day the following yields are obtained. After applying the technique, a total volume of 6415.2 tons of dry matter feed whey are obtained per year. The price per kilograms of dry matter is €3 per kilogram dry matter according to research. That results in yearly yields of €924,560. Assuming that they can sell their feed whey on the PET Food industry with the obtained product.

**Concluding dry matter percentage increase**
The increase of dry matter percentage is a versatile technique with many potential applications within the dairy industry. Considering, and assuming them to be true, research found that a profit of around €310,000 could be earned. Within these calculations a deprecation time of the CAPEX investment of a bit more than six years is considered. Accumulated results this investment in a profit of €1,860,000 over six years. An important condition to notice is that this is the total profit that still has to be split over the two companies, the producer, and the inventor of this technique

## 5.7 Chapter 5 Summary

In this chapter about valorization methods different techniques are discussed that could valorize feed whey. At first is investigated if the current sales market for feed whey can be maintained, before considering microbiological applications.

Market research revealed that feed whey sales volumes are increasing from 2015 until 2021 with 19.53%. This increasing sales volume doubts whether the sales market for feed whey will decrease in the near future. The maximum growth potential has been determined to indicate the urge to

search for valorization techniques. It turned out that feed whey reaches it maximum market potential at the end of 2028. Feed whey can therefore still be sold on the short-term.

Next to the identification of the maximum market potential, has been determined if other feed whey sales markets exists. Another market where feed whey can be sold is the insect market. However, the market cap of this market is too small for the feed whey volumes produced by the company.

In order to valorize feed whey in the long-run and in a sustainable way different microbiological techniques have been found. The first method that has been found, is feed whey recycling. Feed whey recycling is already operational at an existing factory. This microbiological technique returns on average €600 per ton dry matter and leads to feed whey ending up higher in the food waste pyramid.

Another microbiological technique that has been found is volume reduction. Volume reduction is a membrane filtration technique that filters water out the product. This technique reduces the total feed whey liquid volume, while keeping the same volume of dry matter. It is focused on volume reduction, and therefore transportation costs reduction. It results in a profit of €125,000 per year at the example plant, based on the assumption that the installation lasts for ten years.

The last method that is investigated, is a method that is focused on the production of dry matter and on an increase of dry matter percentage. The technique is a microbiological process that is based on enzymes. These enzymes convert an element of feed whey into protein. This results in an increase in dry matter volume. This method is able to make a profit of €124,000,- per year at the example plant under the assumption that the installation lasts for six years.

# 6 Results

In the previous chapter the theories of the solutions have been discussed in-depth. After background information about the solutions is known, their performances are proposed to be quantified. This will be done during this chapter step-by-step resulting in multiple scorecards with a final conclusion and recommendation regarding the solution in the next chapter, Chapter 7.

## 6.1 the Key Performance Indicators

The Key Performance Indicators mentioned in Chapter 4 are in this chapter from importance as they will help in determining which solutions valorize feed whey in a long-term and sustainable way through a comparison between their performances. The KPIs that will be used during the assessment of the solutions are the following:

- *The average percentage dry matter*
- *Return on investment*
- *Logistics costs*
- *Carbon footprint of the investment*
- *Average result per ton dry matter*

## 6.2 Weights per Key Performance Indicator

A substantial component of the weighted scorecard are, as the name already suggests, weights assigned to every KPI. The importance of each KPI depends on the assigned weight, a low weight

means that the corresponding KPI is taken less into consideration than another KPI with a higher weight. These weights are determined by specialists in the field to keep the assessment as independent as possible, although this is still subjective in some manner. Each KPI has a varying weight from 0 up until 100, all the weights added up have a cumulated weight of 100%. In order to perform calculations with the weights they are turned into decimal numbers. For example, if a KPI obtains a score of 30% it will be turned into 0,3 and a score of 50% into 0,5 and so on. Finally, the weights are multiplied with the accompanying score to obtain a final score. These scores are then added up resulting in a final score.

### 6.2.1 The average percentage dry matter

The average percentage dry matter gives an indication about the composition of the product. That means that the average percentage shows the proportion of dry matter in the liquid. A very high or very low percentage results not directly in an increase or decrease of revenue. However, it will be a factor in the financial performance of the product, because prices are often based on the dry matter percentage. Therefore, will this KPI be valued with a score of 10%.

### 6.2.2 Return on investment

In order to valorize feed whey in a long-term and sustainable way certain investments might be necessary to achieve this goal. The idea behind an investment is that it makes more revenue over a certain period of time than it actually costs. The return on investment shows the ratio between the costs and revenue of the investment. It shows the potential profitability of an investment. The return on investment is usually shown through a percentage, where a higher percentage suggest the investment has high yields compared to the costs of the investment. Due to the importance of the return on investment will this KPI be assigned with a weight of 15%.

### 6.2.3 Logistics costs

The logistic costs are seen as the costs made for transporting the goods from the plant to the customer by the truck. The logistics currently account for a large share in the total incurred costs made within the feed whey supply chain. Reducing the logistics costs on the long-term could than potentially be a solution to the faced problem. Logistics costs are partly causing the management problem and thus considered as an important KPI during the assessment of the solutions resulting in a weight of 20%.

### 6.2.4 Carbon footprint of transportation

For transport big trucks are used to transport the feed whey from plant tot customer, these trucks run on diesel. Diesel is a fossil fuel causing environmental pollution through the emission of carbon dioxide. A decrease in the total number of trucks will logically contribute to a decrease in the emission of carbon dioxide. In the content of a long-term and, especially, a sustainable solution of feed whey valorization should environmental pollution through carbon dioxide emission definitely be considered. This KPI is shown in kilograms. This importance results in a weight of 20% for the carbon footprint during transportation of the product. This KPI is neither about the carbon footprint of the production of feed whey or the carbon footprint of the pig farming.

### 6.2.5 Coherence between logistics costs and carbon footprint of transportation

Between the KPIs logistics costs and carbon footprint there exists a certain coherence since they are both based on the total needed number of truckloads. The only difference is that they are multiplied with a different factor in a different unit, in euros and kilograms, respectively. However, despite their dependency they are still incorporated since they highlight two different aspects of transportation, the financial performance, and the sustainability performance.

### 6.2.6 Average result per ton dry matter

This KPI, the average result per ton dry matter, is the most important KPI to both this research and the company. It contains information about all possible costs and revenues regarding feed whey. Therefore, gives this KPI an overall indication about the financial performance of the product. This value should be as high as possible since that means feed whey has a good selling performance for the producer. This KPI is shown in euros per ton because that is the most common way of showing the financial performance of the product in the industry. Because this KPI provides the most information about the financial performance of the product is it rewarded with the highest weight of 35.

## 6.3 Quantification of the results

In this section the results of the solutions on every KPI are quantified one of the bigger plants of the company in order to make them measurable and comparable to each other. These values are subsequently used in the upcoming section during the realization of the weighted scorecard.

### 6.3.1 The current situation

Th current situation regarding feed whey will be based on the most recent numbers of an example plant from the company in the year 2022. Per KPI a brief elaboration of the score will be given. Beginning with the first KPI the average percentage dry matter

**The average percentage of dry matter**

The average percentage of dry matter feed whey in the current situation is 3.72%. This number is determined through dividing the absolute volume of dry matter feed whey over the total volume of liquid feed whey. Resulting in an average percentage of 3.72%. This score is a bit below 4%, the percentage that is assumed to be the average dry matter percentage by the company.

**Return on investment**

In the current situation no investments have been made with regards to feed whey. That means the return on investment is assigned with a score 0 for the current situation.

**Logistics Costs**

The logistics costs are the costs incurred for transporting the goods from the production plant to the customers, this is on average €325 per truckload of 33 tons. Dividing the total liquid feed whey volume by 33 results in the number of needed trucks to transport the goods. This number of trucks multiplied by the average incurred costs for a truckload, results in the total logistics costs. For the plant the logistic costs are €371,780.30 in 2023.

**Carbon footprint of the transportation**

According to a specialist in the field, the average pollution of a truck is 1.042kg carbon dioxide per kilometer. In order to keep the calculations and the comparison as uniform as possible the assumption is made that this is indeed true. That means the average carbon dioxide emission per truckload is 104.2kg. If the plant has in 2023 a total production volume of 37,750 liquid feed whey it means they have in total 1,144 truckloads a year. The total emission of carbon dioxide for the plant is taking all these factors into account, 119.2 tons a year.

**The average result per ton dry matter**

The average result per ton feed whey is on average for all the plants €2.58 in 2022. The minimum observed value in this case is - €116.84 per ton dry matter feed whey, the best performing plant generates on average €90 profit per ton dry matter feed whey. The plant that is taken as an example

during the comparison between the different situations has an average result per ton dry matter feed whey of -€ 28.32.

### 6.3.2 Feed whey recycling

This solution deviates from the other solutions in a sense that it is only applicable in case a new factory will be built. The implementation of this technique is very situation specific causing no clear vision on total costs. However, the possibility exists to implement this solution if a new factory will be built. Therefore, is this solution still taken into consideration.

**Average percentage of dry matter**

The average percentage of dry matter has still a value of 3.72%. The system collects the feed whey and leads the fluid back into the cheese production process. No adjustments will be made to the fluid, so the average percentage of dry matter still remains the same.

**Return on investment**

Too many complex operational activities are needed to implement this solution at an existing plant causing disproportionate costs. Due to all the different factors that have an influence on the costs, no clear vision on the total costs exists. The only situation where this solution can be implemented is when a new factory is scheduled to be built. Because there exists no view or indication on the total costs the return on investment will be 0.

**Logistic costs**

To calculate the logistics costs the volume savings of the plant where this technique is operational, are taken and converted to the hypothetical volumes one of the biggest plants would have. At the plant they produce in total 57.858 tons of cheese, the amount of liquid feed whey that is saved through the recycling system at this production volume is 9,969 tons. The amount of liquid feed whey that is still released is 8.520 tons. Considering the cheese production volume of both this plant and the bigger plant, the bigger would have a feed whey production of 1,670.85 tons in case they have the same system as at the existing plant. That results in total transportation costs of €174,031.09.

**Carbon footprint of transportation**

Hypothetically speaking would plant X thus produce a feed whey volume of 17,670.85 tons. Converted to truckloads would this be a total of 535.48 truckloads, causing a total environmental pollution of 55.8 tons of carbon dioxide.

**The average result per ton dry matter**

During the calculations about the average result per ton dry matter the following assumptions are made. Out of all collected whey the percentage pressing whey is considered to be 2%, resulting in a volume pressing whey of 824,103 tons per month. The average percentage dry matter of this pressing whey, known as feed whey, is 3.7%. This is the same percentage as the average percentage dry matter of feed whey. This results in a total volume of 30,379 tons per month, and thus 368,869 tons dry matter per year. The savings are considered to be €221.321. Dividing this number by the volume dry matter in tons, an average result of €600 per ton dry matter is obtained.

### 6.3.3 Other feed whey sales markets

The other known feed whey sales market where feed whey can be sold with little to no adjustments to the product is the upcoming insect market. As this a very new and upcoming market, little to no information about this market is known. Besides the fact that these insects are partly fed with feed

whey, there exists no information about volumes, prices, or market potential. This makes it impossible to answer the set of KPIs.

Although the KPIs of this solution cannot be answered or measured, the solution is still included due to the following reason. The company can keep their eyes open to eventually consequently sell rest volumes of feed whey towards this market to valorize excessive feed whey. Furthermore, should they perform research on this market for its market potential and on how to enter the market.

### 6.3.4 Volume reduction

Volume reduction is based on filtering the fluid such that it contains a higher percentage of dry matter. The potential of this solution lies in the aspect of a lower liquid volume of feed whey with the same volume of dry matter. Causing a potential lower amount of costs and therefore higher possible margin for the company.

**Average percentage of dry matter**

The average percentage of dry matter that is obtained after applying volume reduction can be regulated. The obtained dry matter percentage depends on the type of membrane that is used and the applied force on the fluid. An ideal percentage of dry matter would be 30%, because the dry matter percentage should not become too high. A very high percentage of dry matter thickens the compound feed for pigs where the feed whey is mixed with, this is not preferred by the pig farmers. Therefore, is a percentage of 30% dry matter used during the assessment of this solution.

**Return on investment**

The investment made to develop a volume reduction installation and to keep it operational from year to year is, assuming the installation lasts for ten years, € 4,424,984.90. The revenue made with this investment is € 5,676,653.79. Inserting these values into the basic formula that calculates the return on investment returns a value 28.28%

$$Return\ on\ investment = \frac{Yields - costs}{costs} * 100\%$$

**Logistics costs**

The new volume of liquid feed whey containing 30% dry matter is 5,042 tons at plant X. The old volume is 37,750 tons of liquid feed whey, causing a difference of 32,708 tons. This saves 991 trucks per year for the plant. Multiplying this number with the average truck costs of €325, yields a total savings of € 322,116.94 per year. The other way around are the actual paid logistics costs in this new situation €49,656.06. Based on the new volume of liquid feed whey, average truckload, and the average incurred costs of €325 per truckload.

**Carbon footprint of transportation**

Based on the new production volume of feed whey, 5,042 tons, a new lower volume of carbon dioxide emission is obtained. Due to volume reduction is the new carbon dioxide emission 15.9 tons.

**Average result per ton dry matter feed whey**

Assuming the installation will last for approximately 10 years, that leads to an annual profit of €125,166.89. Dividing this amount by the volume dry matter feed whey in tons results in an average result per ton dry matter of €82.73.

### 6.3.5 Dry matter production

Dry matter production is a microbiological solution that converts an element of feed whey into protein. The solution is a collaboration between the company and a research group. This technique will therefore finally result in a division of the profit.

**Average percentage of dry matter**

The average percentage dry matter that is obtained after applying the method is limited. The enzymes have a maximum that they can convert into protein. In this case study, where they have tested and proven this technique on laboratorial scale, they obtained a dry matter percentage of 10%.

**Return on investment**

T the Opex, and Capex costs should be known as well as the yields per year in order to determine the return on investment. The Opex costs are €1,521,936 per year, and the Capex costs are €565.000. The yields per year are, based on a price of €3 per kg dry matter, €1,924,560. According to the case study the solution lasts for six years. Considering the maximum duration as well as costs and revenue a return on investment of 19.08% is returned.

$$Return\ on\ investment = \frac{Yields - costs}{costs} * 100\%$$

**Logistics costs**

The logistics costs will not decrease in this case since there is no volume reduction caused by this process. The research group took a volume of 65,700 tons of liquid feed whey in their calculations. Taking into consideration again the average truckload, and the average costs per truckload results this volume in transportation costs of €647,045 per year.

**Carbon footprint**

The total volume that is considered is 65,700 tons of liquid feed whey, this equals 1,991 truckloads in total per year. One truckload causes a carbon dioxide emission of 104.2kg, resulting in a total emission of 207.4 tons of carbon dioxide.

**The average result per ton dry matter**

In Section 5.6, concerning dry matter percentage increase, is mentioned that the company earns €124,000 per year if this solution is successfully implemented. The volume of dry matter that is considered during these calculations is 6415.2 tons of dry matter feed whey. Dividing the revenue per year over this volume, an average result per ton dry matter of €19.33 is achieved.

## 6.4 The weighted scorecard

In the previous sections all the KPIs are calculated, the weights are determined, the only essential part that is missing is a scale to assign a number to each KPI. This scale will be determined in the next sub-section, followed by the scorecards in Section 6.5.

### 6.4.1 The scales

In this sub-section the scales per KPI will be determined based on the results of the solution. During the establishment of the scales, the minimum and maximum are considered followed by a logical estimation of the scale. In Appendix A6 an exact overview of the scales can be found.

**Average percentage of dry matter**
The minimum average percentage of dry matter that is observed is a dry matter percentage of 3.7%, this dry matter percentage is observed at the current situation and preventing feed whey from becoming feed whey situation. The maximum average percentage that is measured is 30% during volume reduction. During assessment, the maximum possible percentage is set to be 40, with a score of 10. The steps of the score within this range are according through the ratio 1 to 4, score to percentage.

**Return on investment**
In some cases, a significant return on investment has been measured, in case of volume reduction and in case of protein development. The maximum measured value is a 28.28% return on investment at volume reduction. Instead, in the current situation and the feed whey recycling case no investment has even been made and could therefore not been measured. These return on investments are 0%. Concerning a maximum score of 28.28% and a minimum score of 0% will the scale be defined from 0% to 40% with steps from 4% each. Each step of 4% represents a score of 1.

**Logistics costs**
The minimum observed logistics costs of all solutions are the logistics costs that are incurred at volume reduction, these logistics costs are €49,656.06 in total. The maximum observed logistics costs are charged at the dry matter production case, the logistics costs of this solution are in total €647,045. The scale will be from € to €1,000,000 with steps of €100,00 each. Each step of €100,000 is accompanied with a step 1 of the score. Within this scale the minimum value is €1,000,000 assigned with a score 0, and a maximum of €0 with a score 10.

**Carbon footprint**
Out of all cases the minimum observed value of carbon footprint is 15.9 tons caused by volume reduction. The maximum observed value is 207.4 tons caused by dry matter production. According to these values a range from 0 to 400 tons is set to be the scale. With 0 ton the maximum possible value assigned with a score of 10 and 400 tons the minimum possible score assigned with a score of 0. The ratio for every step will be 1 to 40 tons.

**Average result per ton dry matter**
The minimum measured average result per ton dry matter is -€28.32 at the current situation, instead the maximum observed value is €600 at the preventing feed whey from becoming feed whey case. Suggesting a scale of -€200 till €800 with steps of €100 each. Resulting in a ratio from 1 to €100.With a minimum score of -€200 assigned with a score 0 and a maximum score of €800 assigned with a score of 10.

## 6.5 The scores of each solution

In the previous sections all the KPIs per situation have been quantified such that a weighted scorecard can be made during this section. Along with scales made per KPI are scores from 1 up until 10 assigned resulting in a recommendation on which solution to choose.

### 6.5.1 Summarization of the results

In this section the results of each solution mentioned in Section 6.3 are summarized one more time before the actual scorecards are made in the upcoming sub-section.

| KPI | Current Situation | Recycling | Volume reduction | Dry matter production |
|---|---|---|---|---|
| % DM | 3.72% | 3.72% | 30.00% | 10.00% |
| ROI | 0 | 0 | 28.28% | 19.08% |
| Logistics costs | €371,780.30 | €174,031.09 | €49,656.06 | €647,045.00 |
| Carbon footprint | 119.2 tons | 55.8 tons | 15.9 tons | 207.4 tons |
| Avg. result/ ton DM | -€ 3.26 | €600.00 | €82.73 | €19.33 |

*Table 1 Summary of the result of each solution on the KPIs*

### 6.5.2 The final scorecards

In this final section the scorecards will be presented in two different ways, a relative version, and a weighted version. The relative version is developed with the intention to give a first impression of the results as well as first impression of the situation. The table below represents the relative results of the solution. The situations can each score a number from 1 till 4 on the different KPIs with 1 being the best possible score and 4 the worst possible score.

| KPI | Current Situation | Recycling feed whey | Volume reduction | Dry matter production |
|---|---|---|---|---|
| % DM | 3 | 3 | 1 | 2 |
| ROI | 3 | 3 | 1 | 2 |
| Logistics costs | 3 | 2 | 1 | 4 |
| Carbon footprint | 3 | 2 | 1 | 4 |
| Avg. result/ ton DM | 4 | 1 | 2 | 3 |
| TOTAL | 16 | 11 | 6 | 15 |

*Table 2 Relative scores from 1 to 4 of each solution on the KPIs*

Based on the relative score model the conclusion can be drawn, considering all the KPIs, that volume reduction is supposed to be the best solution. Volume reduction scores on almost all KPIs a score of 1 beside the average result per ton dry matter. So, if all KPIs are taken into consideration the company should choose for volume reduction. However, if only the most important KPI is considered, the average result per ton dry matter, the choice of best solution would be the recycling feed whey option. Since, that option scores the best on the KPI concerning the average result per ton dry matter. Therefore, depends the solution on preference of the company. This same condition holds for the weighted scorecard.

The table below represents the weighted scorecard. It is called a weighted scorecard since weights are assigned to every KPI. These weights ensure a division between importance of each KPI. The percentage of dry matter is less important for example than the average result per ton dry matter as far as weight concerned. In the table two different scores per situation can be observed, the raw score and the weighted score. The raw score is the score where the weight of the KPI is not considered, instead the weighted score considers the weight of the KPI as the name already reveals. The raw scores are based upon the performances of each situation mentioned in Section 6.3 and the scales mentioned in Section 6.4.1 as well as Appendix A6.

| KPI | Weight | Current Situation | | Recycling feed whey | | Volume reduction | | Dry matter production | |
|---|---|---|---|---|---|---|---|---|---|
| | | *Raw score* | *Weighted score* | *Raw score* | *Weighted score* | *Raw score* | *Weighted score* | *Raw score* | *Weighted score* |
| **% DM** | 10% | 0.925 | 0.0925 | 0.925 | 0.0925 | 7.5 | 0.75 | 2.5 | 0.25 |
| **ROI** | 15% | 0 | 0 | 0 | 0 | 7.07 | 1.061 | 4.77 | 0.716 |
| **Logistics costs** | 20% | 6.29 | 1.26 | 8.26 | 1.65 | 9.51 | 1.902 | 3.53 | 0.706 |
| **Carbon footprint** | 20% | 7.02 | 1.40 | 8.61 | 1,72 | 9.6 | 1.920 | 4.82 | 0.964 |
| **Avg. result/ ton DM** | 35% | 1.97 | 0.690 | 8 | 2.8 | 2.82 | 0.981 | 2.19 | 0.767 |
| **TOTAL** | 100% | 16.205 | 3.443 | 25.795 | 6.263 | 36.500 | 6.614 | 17.81 | 3.403 |

*Table 3 Raw, weighted, and total scores of each solution on the KPIs*

As far as the weighted scorecard is concerned the following findings are observed. The situations are ranked based on their weighted scores from worst to best, the current situation, protein development, recycling feed whey, and volume reduction.

The advice to the company on the selection of the solution can be given in three different ways:

1. Based on all the KPIs
2. Based on the most important KPI, the average result per ton dry matter
3. Based on the average result per ton dry matter and carbon footprint, considering financial performance and sustainability performance

Based on all the KPIs the advice would be to implement the volume reduction technique. Volume reduction has the best raw score as well as weighted score out of all situations. That results in the conclusion that volume reduction is the absolute winner.
Considering the average result per ton dry matter, recycling feed whey would be the solution to select. The company might base their choice only on the financial performance of the solution because they have a commercial vision regarding feed whey. If that is the only point of interest than would recycling feed whey be their selection. The only difficulty is that recycling feed whey can only be implemented if the company is scheduling to build a new plant, since this solution cannot be implemented at an existing plant.
Finally, two opportunities arise if the company takes into consideration both the financial and environmental aspect, recycling feed whey and volume reduction. The most logical way of selection would then be to consider the sum of weighted scores of the solutions on the two KPIs. This results in a selection of recycling feed whey as the most suitable solution.

Based on these findings a decision tree has been developed to give a schematic overview of the possible different decisions:

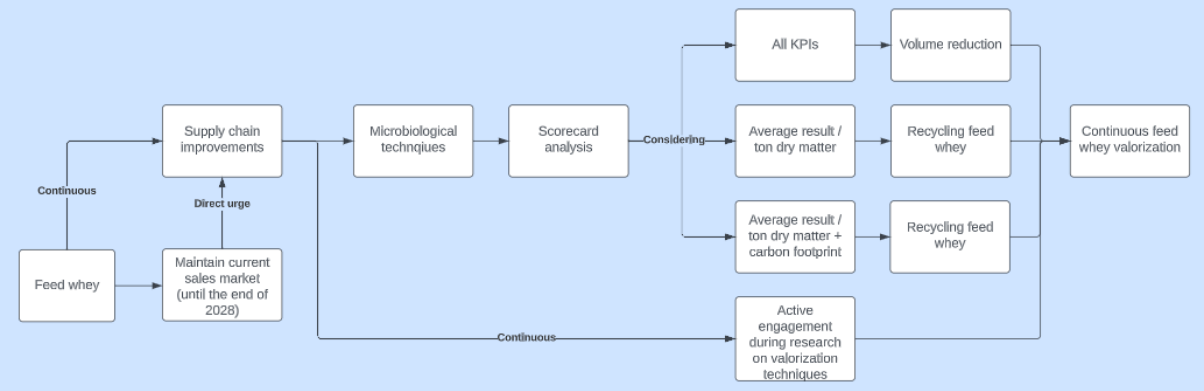


*Figure 4 Schematic overview of feed whey valorization*

## 6.6 Chapter 6 Summary

This chapter measured the performances of the current situation, and the valorization methods based on the KPIs. The KPIs are calculated per solution and resulted in different scorecards. Based on the outcome of the scorecards an advice to the company is given.

The advice to the company depends on what they find the most important KPIs. We considered that there are three ways to provide the company with a proposal on the solution to select. At first, if all KPIs are considered, volume reduction turned out to be the solution. If the company only considers the average result per ton dry matter, recycling feed whey is the best opportunity. Finally, if the average result per ton dry matter and the carbon footprint are important, we propose the company to recycle feed whey technique.

# 7. Conclusion

In the previous chapters the production process, the production region, and the transportation network (see Chapter 3) have been described. The current value of the product has been analyzed based on order data (see Chapter 4). Finally, different microbiological techniques have been found and analyzed (see Chapter 5 and Chapter 6). Based on all this information different points of interest have been gathered. In this Chapter the main findings, limitations, recommendations, scientific contribution, and future research are discussed .

## 7.1 Main findings

One of the main problems that caused this research is the fear of a shrinking sales market for feed whey. The following main research question has been derived from this problem statement:

*How can feed whey be valorized in the long run and in a sustainable way?*

At first, it needs to be clear whether the shrinking sales market for feed whey is an actual problem and not a problem caused by unfounded expectations. Therefore, is the maximum feed whey sales volume determined. It turned out that feed whey has a growing market share in both the moisture pig feed as well as the compound pig feed from 2015 until 2021, with an increase of 5.73% and 5.87% respectively. Concluding that the company has not a problem concerning feed whey valorization on the short-term, but on the long-term.
Since feed whey shows increasing sales volumes throughout the years 2015 until 2021 there seems no direct urge to search for a solution. In order to know the perspective and maximum market potential of feed whey a nutritionist and also specialist in the field has been contacted. According to

the expert the maximum volume based on 4% dry matter is 994,500 tons of liquid feed whey. This expectation is based on constant, good, delivered quality, constant supply, and a significant majority of pig farmers are convinced of using feed whey. Considering this maximum volume, the current sales volume of 765,000 tons, and the average volume increase of 3.45%, the market will reach its maximum within 7.7 years from 2021. This leads to the conclusion that the market has reached its maximum by the end of 2028.

Meanwhile the need still exists to search for alternative applications that valorize feed whey on the long-term. Before this research started dry matter production has already been proven to potentially solve the problem for the company. This research has turned out that volume reduction is a technique that could have even more potential than protein development. Volume reduction has better scores than protein development on all KPIs during the assessment. We suggest that more research should be conducted on the establishment of this technique in the future next to dry matter production and enlarge therefore their scope on different applications of feed whey.

One of the main findings of this research is that the company should aim to recycle their feed whey, because that technology has the most potential to valorize feed whey in both a sustainable and financial way. This research has proven, based on high financial yields and ending up higher in the waste pyramid as feed whey is recycled (see Section 5.2), that feed whey recycling is indeed the best way to generate the highest value for feed whey.

## 7.2 Limitations

Throughout this research several limitations occurred. Some of these shortcomings had minor impact, while other inconveniences had a significant bigger impact on the report. The following shortcomings occurred during this research:

During this research interviews with specialists and the distributors were conducted. In one of the interviews regarding volume reduction a specialist stated that feed whey with 30% dry matter can still be fed to pigs. It would have strengthened this research if a survey has been held amongst pig farmers to validate this statement.

Finally, the generalizability of this research is limited due to manual computations that were performed during Chapter 4 of this research. In this Chapter the process of data gathering and data processing that is needed to determine the value of the current situation has been explained. However, this whole process requires many different manual computations to make sure that the process is executed correctly. The Excel code is situation-specific and needs to be modified in case different data quantities are used or the price model changes. Further research could focus on automating this excel file to make it applicable to other data sets as well.

## 7.3 Recommendations

The core problem performing better research on other applications as well as opportunities within the feed whey supply chain has been solved through an analysis of the current situation in Chapter 4 and an analysis of the solutions in Chapter 6. Based on these results the following recommendations can be given to the company.

As far as their current situation is concerned, the recommendation is to better monitor their financial performances. The company currently makes decisions based on rough estimations rather than exact results from the past. Since there are major differences of thousands of euros between the estimations and the actual situation there is still space to improve for the company. A better analysis could potentially be helpful during price negotiations with their clients, because the company knows what their margins exactly are.

One of the deliverables is the prospective regarding maximum market potential of feed whey. A recommendation is to continue selling feed whey as it is currently done on the short-term, because the company already showed an increase in financial performance from the years 2021 until 2023 and the market has a positive prospective regarding feed whey volume increase. Feed whey has still potential and space to gain volume as the product has not reached its maximum sales volumes in the market. However, the company cannot wait until the market has reached its maximum. The recommendation is to actively pay attention to the situation regarding feed whey and continue performing research on feed whey valorization. During this process, we propose the company to take into consideration volume reduction and protein development in particular for existing plants.

Furthermore, a recommendation is to keep a critical look on the structure of their feed whey supply chain. To achieve a continuous valorization of feed whey the company should aim to reduce costs at transportation in the supply chain or establish a market share in a higher valued market. The cost reduction within the feed whey supply chain can only be achieved within the transportation part, as there exist no other parts in the supply chain where costs are generated. These costs can be lowered through a decrease in total needed number of trucks while keeping the same dry matter volume or increasing the dry matter volume. This can be achieved through some sort of technical application such as dry matter production or volume reduction according to this research. Both methods create value for feed whey through a different way. Volume reduction creates value based on a reduction in transportation costs, while dry matter production is based on an increase in dry matter percentage.

Value can also be created through selling feed whey for a higher price. This is only possible if the company can enter a higher valued market. The realization of an efficient process that is able to achieve this is a new research on its own. This is enough reason for the company to be ahead of their competitors and actively search for new opportunities regarding feed whey. The recommendation to the company is therefore to actively engage in scientific projects that show how to increase value for feed whey.

## 7.4 Scientific contribution

This research has a significant scientific contribution regarding different applications of feed whey. The usage of scorecards and performing a value chain analysis are extensively studied topics. However, a gap in research could be found in a matter that very few research has been done on the applications of feed whey. This research fills this gap because it describes multiple different applications of feed whey. Concluding, that it is highly relevant for the dairy industry.

## 7.5 Future research

Since this was the first time the company performed an analysis on the performance of the feed whey supply chain, there are a lot of opportunities for further research. This paper proposes different methods to valorize feed whey. Further research about the actual feasibility of the methods per plant would be relevant and important.
We also propose the company to perform future research on the effects of a long-term collaboration between them and the research group. This collaboration might be useful in a search for techniques that valorize feed whey on the long run and optimize their feed whey supply chain. Further research should find out whether collaborations like this will be profitable for the company.
In future research more variables could be added to measure the performance, resulting in more KPIs. This would expand the knowledge about the performance of the product and improves the analysis of the situation. A better analysis can subsequently even lead to a better optimization of the feed whey supply chain. It would be interesting to perform such an analysis on observe the different results compared to the results of this research

## Appendix A1 Porters Value Chain

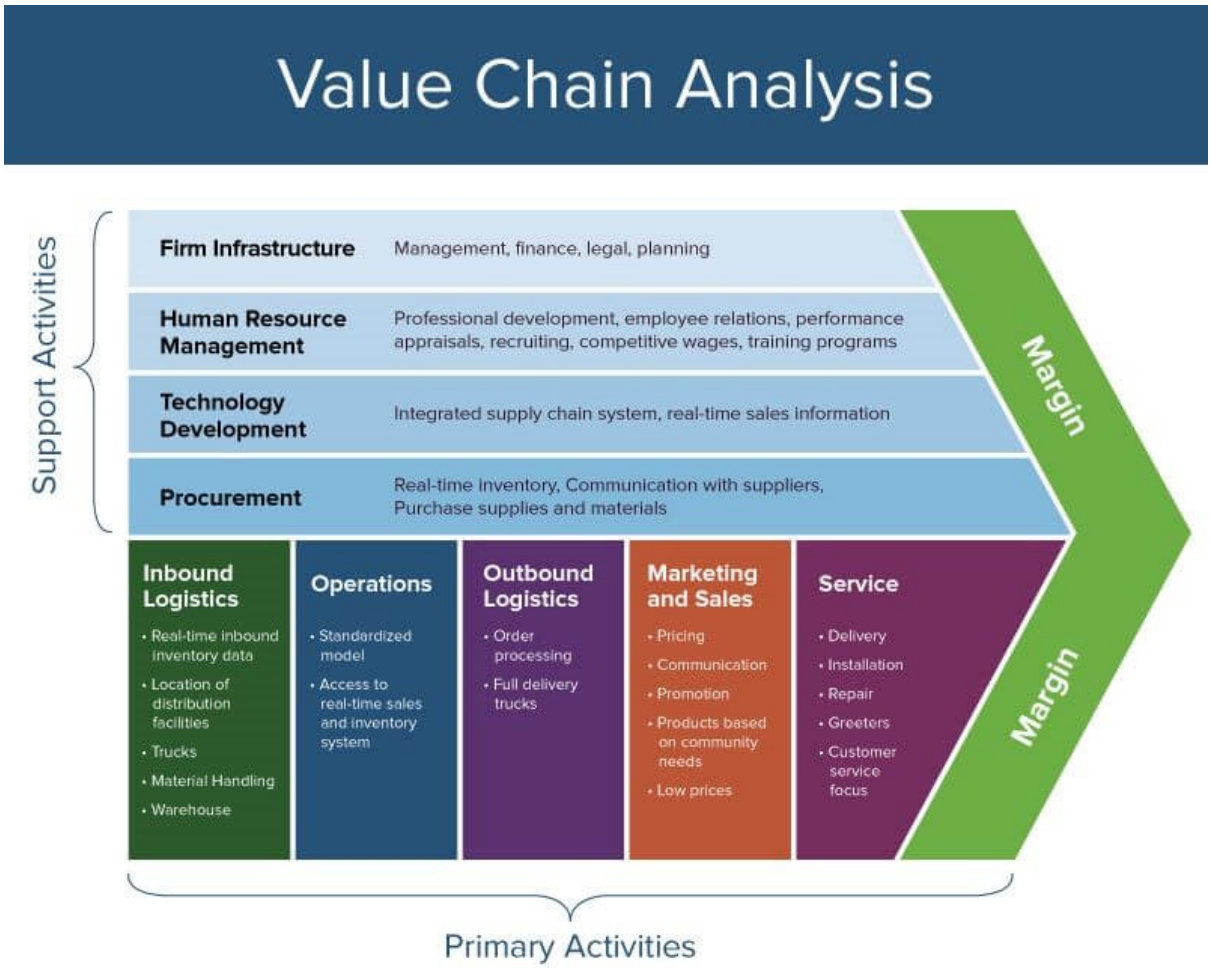


*Figure 5 Porters value chain (Eby, 2018)*

# Appendix A2 Production process of cheese

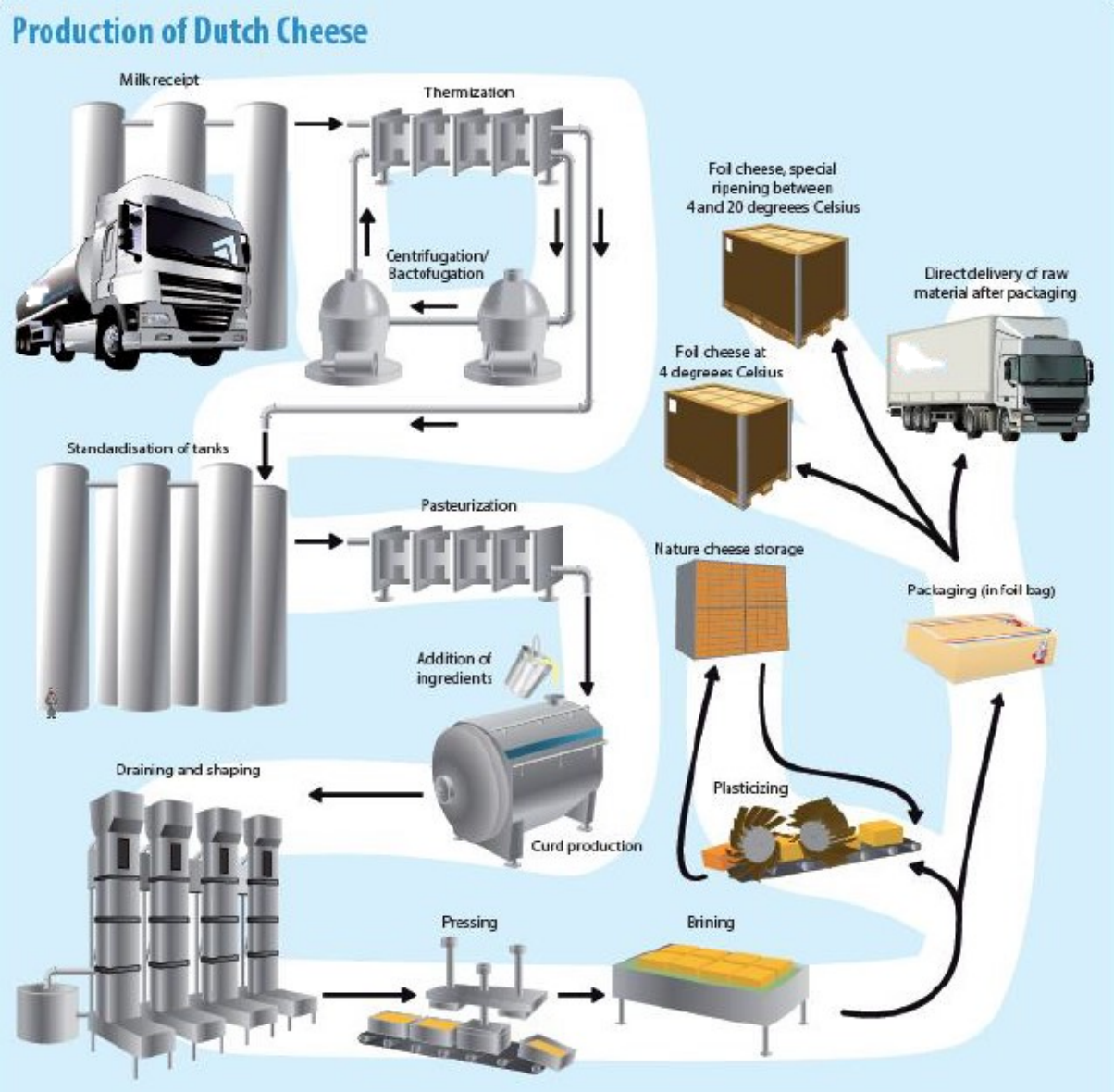


*Figure 6 The production process of cheese (-, 2019)*

# Appendix A3 Feed whey sales market

| Sales of pigfeed | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | year | Total sales of feed whey in tons | Percentage change | Total sales of moist feed materials | Procentual change | Total sales of compound feed for pigs in t | Procentual ch | Percentage feed whey of total feed market |
| | 2015 | 640000 | | 3100000 | | 4960000 | | 12,90% |
| | 2016 | 615000 | -3,91% | 3000000 | -3,23% | 4627000 | -6,71% | 13,29% |
| | 2017 | 605000 | -1,63% | 2900000 | -3,33% | 4710000 | 1,79% | 12,85% |
| | 2018 | 650000 | 7,44% | 2900000 | 0,00% | 4421000 | -6,14% | 14,70% |
| | 2019 | 590000 | -9,23% | 2700000 | -6,90% | 4327000 | -2,13% | 13,64% |
| | 2020 | 705000 | 19,49% | 2750000 | 1,85% | 4190000 | -3,17% | 16,83% |
| | 2021 | 765000 | 8,51% | 2900000 | 5,45% | 4076000 | -2,72% | 18,77% |
| **TOTAL** | | **125000** | **19,53%** | **-200000** | **-6,45%** | **-884000** | **-17,82%** | |

*Figure 7 Sales volumes of feed whey, moisture pig feed, and compound pig feed from 2015 until 2021 (Nevedi, 2022)*

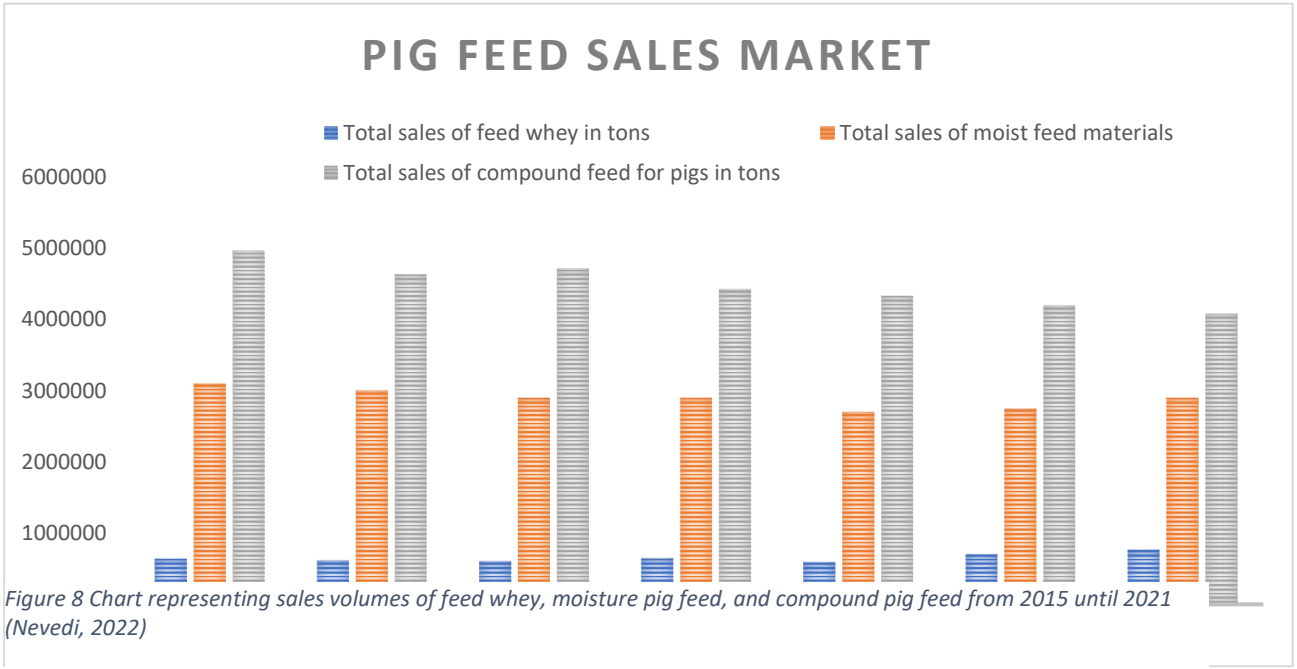


*Figure 8 Chart representing sales volumes of feed whey, moisture pig feed, and compound pig feed from 2015 until 2021 (Nevedi, 2022)*

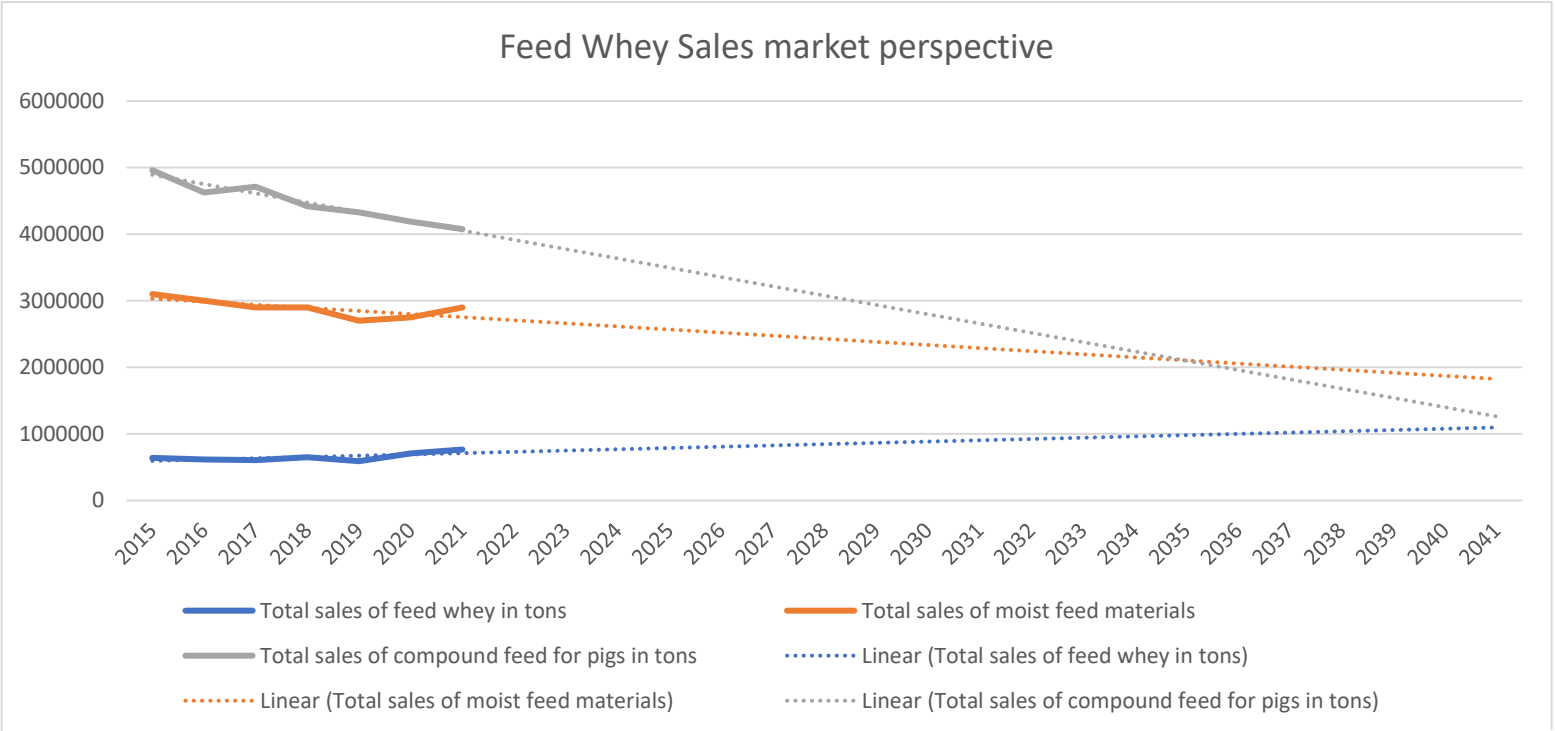


*Figure 9 Graph representing sales volumes of feed whey, moisture pig feed, and compound pig feed (Nevedi, 2022)*

# Appendix A4 output order dataset

| Posting Mo | Calendar week | jaar | Feed Whey Liquid Bulk kg | Feed Whey Liquid Bulk ton | Dry Matter Feed Whey kg | Dry Matter Feed Whey ton | drg matter % | revenue product | Result | Transpor |
|---|---|---|---|---|---|---|---|---|---|---|
| JAN | 01 | 2021 | 34.680 | 34,68 | 1.248 | 1,24848 | 3,6 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 01 | 2021 | 35.700 | 35,70 | 1.285 | 1,2852 | 3,6 | -35,70 | -€ 60,70 | -€ 25,00 |
| JAN | 01 | 2021 | 33.500 | 33,50 | 1.240 | 1,2395 | 3,7 | -33,50 | -€ 58,50 | -€ 25,00 |
| JAN | 01 | 2021 | 34.680 | 34,68 | 1.248 | 1,24848 | 3,6 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 01 | 2021 | 31.620 | 31,62 | 980 | 0,98022 | 3,1 | -31,62 | -€ 56,62 | -€ 25,00 |
| JAN | 01 | 2021 | 32.640 | 32,64 | 1.077 | 1,07712 | 3,3 | -32,64 | -€ 57,64 | -€ 25,00 |
| JAN | 01 | 2021 | 35.535 | 35,54 | 1.279 | 1,27926 | 3,6 | -35,54 | -€ 60,54 | -€ 25,00 |
| JAN | 02 | 2021 | 35.496 | 35,50 | 1.349 | 1,348848 | 3,8 | -35,50 | -€ 60,50 | -€ 25,00 |
| JAN | 02 | 2021 | 35.190 | 35,19 | 1.056 | 1,0557 | 3 | -35,19 | -€ 60,19 | -€ 25,00 |
| JAN | 02 | 2021 | 35.700 | 35,70 | 1.178 | 1,1781 | 3,3 | -35,70 | -€ 60,70 | -€ 25,00 |
| JAN | 02 | 2021 | 34.680 | 34,68 | 971 | 0,97104 | 2,8 | -104,04 | -€ 129,04 | -€ 25,00 |
| JAN | 02 | 2021 | 34.680 | 34,68 | 1.214 | 1,2138 | 3,5 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 02 | 2021 | 34.680 | 34,68 | 1.318 | 1,31784 | 3,8 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 02 | 2021 | 35.700 | 35,70 | 1.392 | 1,3923 | 3,9 | -35,70 | -€ 60,70 | -€ 25,00 |
| JAN | 03 | 2021 | 35.190 | 35,19 | 1.478 | 1,47798 | 4,2 | 35,19 | € 10,19 | -€ 25,00 |
| JAN | 03 | 2021 | 35.190 | 35,19 | 1.021 | 1,02051 | 2,9 | -105,57 | -€ 130,57 | -€ 25,00 |
| JAN | 03 | 2021 | 34.170 | 34,17 | 991 | 0,99093 | 2,9 | -102,51 | -€ 127,51 | -€ 25,00 |
| JAN | 03 | 2021 | 33.680 | 33,68 | 1.145 | 1,14512 | 3,4 | -33,68 | -€ 58,68 | -€ 25,00 |
| JAN | 03 | 2021 | 33.660 | 33,66 | 875 | 0,87516 | 2,6 | -100,98 | -€ 125,98 | -€ 25,00 |
| JAN | 03 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 03 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 04 | 2021 | 34.680 | 34,68 | 1.075 | 1,07508 | 3,1 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 04 | 2021 | 34.170 | 34,17 | 1.059 | 1,05927 | 3,1 | -34,17 | -€ 59,17 | -€ 25,00 |
| JAN | 04 | 2021 | 35.190 | 35,19 | 1.267 | 1,26684 | 3,6 | -35,19 | -€ 60,19 | -€ 25,00 |
| JAN | 04 | 2021 | 35.700 | 35,70 | 1.428 | 1,428 | 4 | 35,70 | € 10,70 | -€ 25,00 |
| JAN | 04 | 2021 | 35.700 | 35,70 | 1.071 | 1,071 | 3 | -35,70 | -€ 60,70 | -€ 25,00 |
| JAN | 04 | 2021 | 34.680 | 34,68 | 1.144 | 1,14444 | 3,3 | -34,68 | -€ 59,68 | -€ 25,00 |
| JAN | 04 | 2021 | 35.535 | 35,54 | 1.137 | 1,13712 | 3,2 | -35,54 | -€ 60,54 | -€ 25,00 |
| FEB | 05 | 2021 | 34.680 | 34,68 | 1.214 | 1,2138 | 3,5 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 05 | 2021 | 34.680 | 34,68 | 1.075 | 1,07508 | 3,1 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 05 | 2021 | 34.680 | 34,68 | 1.040 | 1,0404 | 3 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 05 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 05 | 2021 | 32.000 | 32,00 | 1.120 | 1,12 | 3,5 | -32,00 | -€ 57,00 | -€ 25,00 |
| FEB | 05 | 2021 | 34.680 | 34,68 | 1.214 | 1,2138 | 3,5 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 06 | 2021 | 35.190 | 35,19 | 915 | 0,91494 | 2,6 | -105,57 | -€ 130,57 | -€ 25,00 |
| FEB | 06 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 06 | 2021 | 33.990 | 33,99 | 1.156 | 1,15566 | 3,4 | -33,99 | -€ 58,99 | -€ 25,00 |
| FEB | 06 | 2021 | 34.680 | 34,68 | 1.075 | 1,07508 | 3,1 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 06 | 2021 | 34.680 | 34,68 | 1.248 | 1,24848 | 3,6 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 06 | 2021 | 34.680 | 34,68 | 1.248 | 1,24848 | 3,6 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 06 | 2021 | 34.170 | 34,17 | 1.333 | 1,33263 | 3,9 | -34,17 | -€ 59,17 | -€ 25,00 |
| FEB | 07 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 07 | 2021 | 34.680 | 34,68 | 1.248 | 1,24848 | 3,6 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 07 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |
| FEB | 07 | 2021 | 34.680 | 34,68 | 1.179 | 1,17912 | 3,4 | -34,68 | -€ 59,68 | -€ 25,00 |

*Figure 10 Output order data in Excel that is extracted from SAP*

# Appendix A5 supply chain overview

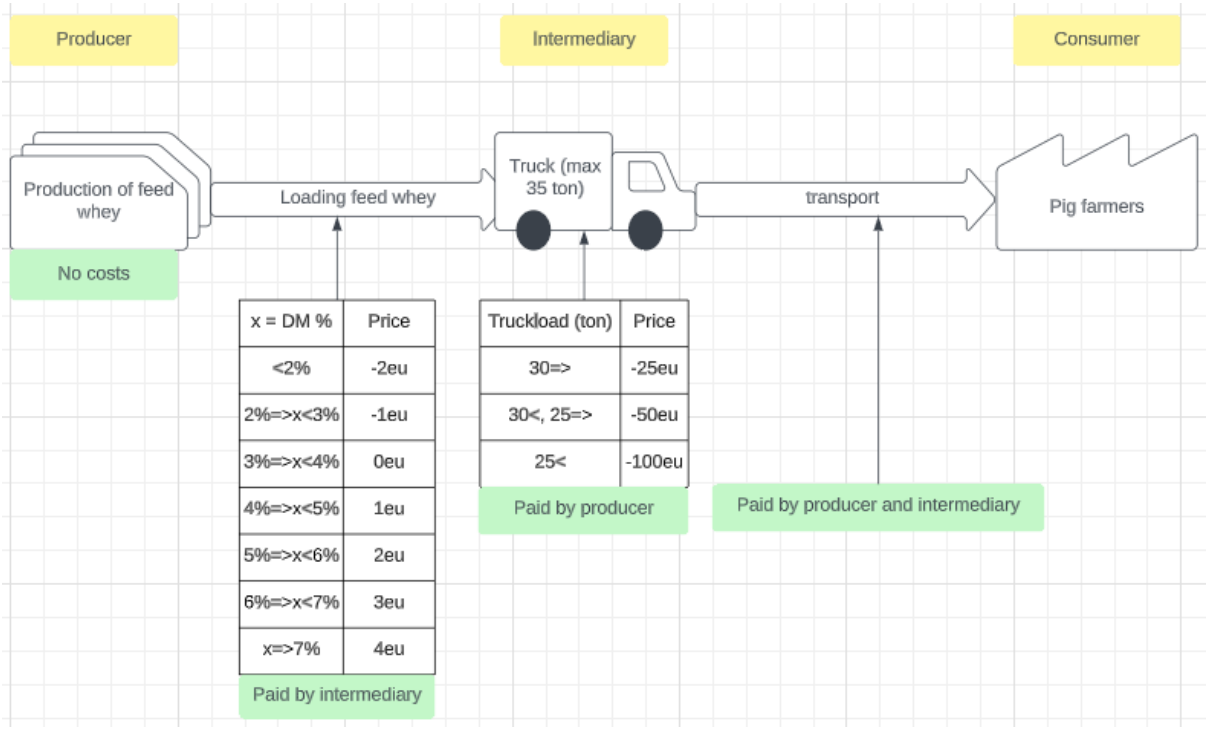


*Figure 11 Visualization of the feed whey supply chain*

# Appendix A6 Scales weighted scorecard

## Average percentage dry matter

| SCORE | % DM |
|---|---|
| **0** | 0% |
| **1** | 4% |
| **2** | 8% |
| **3** | 12% |
| **4** | 16% |
| **5** | 20% |
| **6** | 24% |
| **7** | 28% |
| **8** | 32% |
| **9** | 36% |
| **10** | 40% |

*Table 4 Scale of average percentage dry matter used during the weighted scorecard*

## Return on investment

| SCORE | ROI |
|---|---|
| **0** | 0% |
| **1** | 4% |
| **2** | 8% |
| **3** | 12% |
| **4** | 16% |
| **5** | 20% |
| **6** | 24% |
| **7** | 28% |
| **8** | 32% |
| **9** | 36% |
| **10** | 40% |

*Table 5 Scale of return-on-investment dry matter used during the weighted scorecard*

## Logistics costs

| SCORE | LOGISITCS COSTS |
|---|---|
| **0** | €0, - |
| **1** | €100.000, - |
| **2** | €200.000, - |
| **3** | €300.000, - |
| **4** | €400.000, - |
| **5** | €500.000, - |
| **6** | €600.000, - |
| **7** | €700.000, - |
| **8** | €800.000, - |
| **9** | €900.000, - |
| **10** | €1.000.000, - |

*Table 6 Scale of logistics costs used during the weighted scorecard*

## Carbon footprint

| SCORE | CARBON FOOTPRINT |
|---|---|
| **0** | 0 |
| **1** | 40 tons |
| **2** | 80 tons |

| | |
|---|---|
| **3** | 120 tons |
| **4** | 160 tons |
| **5** | 200 tons |
| **6** | 240 tons |
| **7** | 280 tons |
| **8** | 320 tons |
| **9** | 360 tons |
| **10** | 400 tons |

*Table 7 Scale of carbon footprint used during the weighted scorecard*

### Average result per ton dry matter

| SCORE | LOGISITCS COSTS |
|---|---|
| **0** | -€200, - |
| **1** | -€100, - |
| **2** | €0, - |
| **3** | €100, - |
| **4** | €200, - |
| **5** | €300, - |
| **6** | €400, - |
| **7** | €500, - |
| **8** | €600, - |
| **9** | €700, - |
| **10** | €800, - |

*Table 8 Scale of average result per ton dry matter used during the weighted scorecard*

## Appendix A7 Systematic Literature Review

| Inclusion criteria | Explanation |
|---|---|
| Studies about the application of the food waste pyramid | The functionality of the food waste pyramid is used in several sustainability issues. |
| Case studies about the valorization of feed whey, cheese whey, or acid whey | To obtain a first insight into valorization opportunities for feed whey. Feed whey can be classified as cheese whey and acid whey as well. |
| Case studies about the application of X on feed whey, cheese whey, or acid whey | Research needs to approve the applicability of X on feed whey, cheese whey, or acid whey |
| Case studies about the application of Y on feed whey, cheese whey, or acid whey | Research needs to approve the applicability of Y on feed whey, cheese whey, or acid whey. |

| Exclusion criteria | Explanation |
|---|---|
| Articles that are published before 2010 | Content from before 2010 is outdated and not relevant to this research since future solutions are sought. |
| Non-English articles | This research is executed in English, therefore is other research in another language not relevant. |
| Non-academic papers | Non-academic papers cannot approve the applicability of certain technologies. |
| Research that is out of scope | Articles that are too broad oriented about a topic or go too much in detail are not useful. |

| Key concepts | Related terms | Detailed terms | Broader terms |
|---|---|---|---|
| *Write down the key concept* | *Write down related terms or synonyms* | *Write down more detailed terms* | *Write down broader terms* |
| Food waste pyramid | Hierarchical waste pyramid, human food, animal food | Prevention, surplus food, reduce, reuse, recycle | Environment, sustainability |
| X | Filtration, ultrafiltration, microfiltration, hyperfiltration | Semipermeable membrane, higher concentration, lower concentration, pressure, demineralization | Microbiological process |
| Y | Yeast, bacteria, conversion, energy generation | Enzymes, microorganisms | Microbiological process |

| Database | Search string | Total hits | Remarks |
|---|---|---|---|
| *Write down the database* | *Write down the search string that is used* | *Write down the total number of hits* | *Write down remarks* |
| Scopus | (“Food” AND “waste” AND “pyramid”) | 4 | Relative low number of hits. However, two very useful sources. |
| Scopus | (“X” AND “filtration”) | 60 | Useful sources to validate the usage of X and filtration together |
| Scopus | (“X” AND “whey”) | 82 | Application of X and filtration on feed whey |
| Scopus | (“X” AND “cheese” AND “whey) | 28 | Application of X on feed whey |
| Scopus | (“Whey” AND “valorization”) | 90 | Whey valorization opportunities |
| Scopus | (“Acid” AND “whey” AND “valorization”) | 39 | Selection of techniques that could valorize feed whey |
| Scopus | (“Dairy” AND “wastewater” AND “valorization”) | 22 | Selection of techniques that could valorize feed whey |
| Scopus | (“Cheese” AND “whey” AND “filtration” | 300 | Application of filtration on feed whey |
| Scopus | (“Cheese” AND “whey” AND “valorization”) | 47 | Feed whey valorization opportunities |
| Scopus | (“Cheese” AND “whey” AND “Y” | 479 | Application of Y on feed whey |
| Scopus | (“Acid” AND “whey” AND “Y” | 685 | Application of Y on feed whey |

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