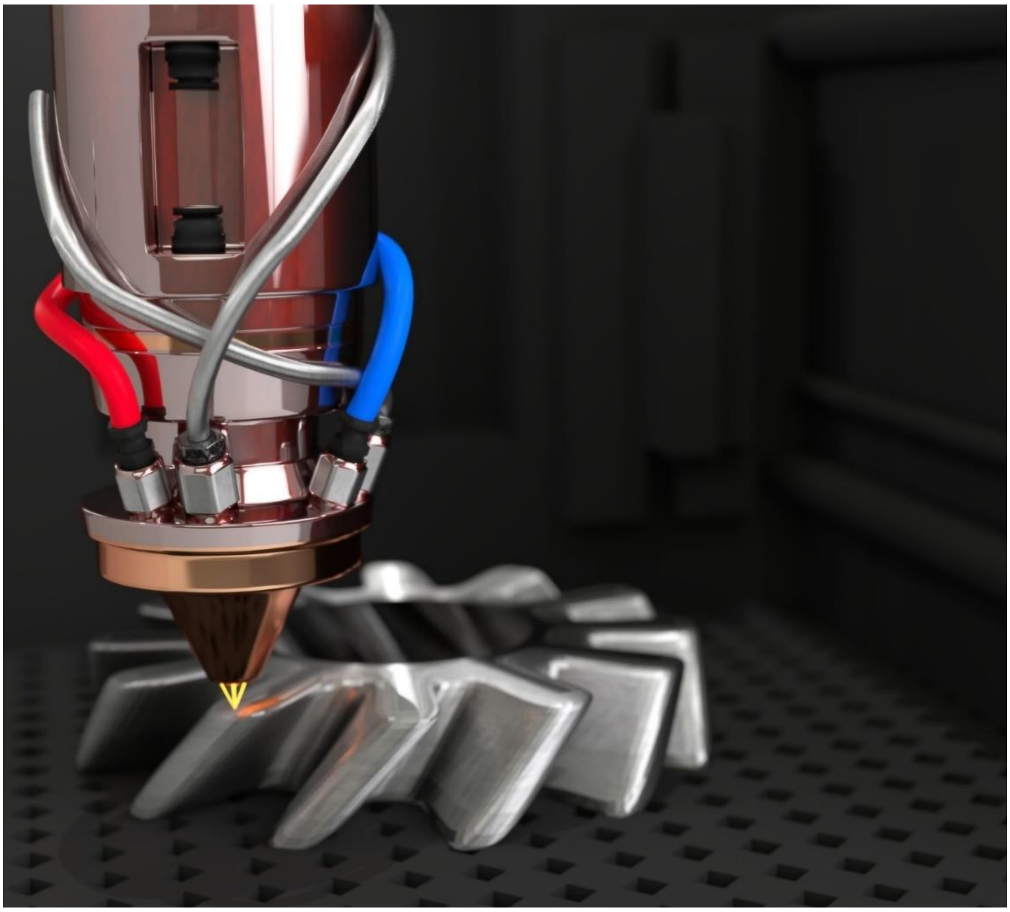
Understanding the Norwegian additive manufacturing market:

Its attractive aspects, limitations, potential and future opportunities within a circular framework.



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Preface

This master thesis marks completion of our Master's Degrees in Business Administration at the University of Stavanger. It has been a challenging yet fulfilling experience. While the work has been tough, it has also been encouraging to see how the thesis has evolved along the way. This study program has been an inspiring and enriching experience for personal, academic and professional growth. We are honoured to hopefully make a contribution towards a potential greener technology option for Norwegian manufacturing.

We would like to express gratitude towards those that have contributed and supported us along the way. We would like to use the opportunity to show appreciation for our academic supervisor Gorm Kipperberg, Ph.D., for effective guidance and support throughout our work with the thesis.
We would also like to express gratitude towards Rolf Lohne and Paul Tysse at Valvision AS, for excellent advice and insight into their work. They showed great willingness to cooperate and was always available for questions at a short notice, which we are greatly appreciative of. This is also the case for their industry partner F3nice AS, who were available for questions and provided insights into relevant data.
We are also thankful towards Jørgen Grønsund at the University of Stavanger, for informative insight in the technology and interesting work ideas.

We are also appreciative towards our interview informants, who made time for us during their busy work schedules. The informants showed great interest in our work, were informative and provided unique insights into the Norwegian additive manufacturing market.

Lastly, we would like to thank family and friends for patience, understanding and emotional support during this semester.

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Abstract

The main objective of this thesis was to shed light on the current additive manufacturing market today in Norway, and from there conduct simulations for expected demand level and profitability in a powder production. The AM market in Norway was emphasised through a specific focus on attractive aspects, limitations, opportunities and perceived barriers to entry for both the technology and the market. The research was divided into two types, both quantitative and qualitative research. The AM market of Norway and research questions regarding it was highlighted through a qualitative analysis, where relevant actors in the AM market was interviewed through the use of semi-structured interviews. This was then directly compared to relevant literature on the area in order to find any common reoccurring themes. A specific case study on powder production in Norway was conducted in its own quantitative analysis, simulating expected demand and growth for the next five years.

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List of Abbreviations

Abbreviation	Name
AM	Additive manufacturing
TM	Traditional manufacturing
CE	Circular economy
CAD	Computer Aided Design
DED	Direct Energy Deposition
IP	Intellectual property
PBF	Powder Bed Fusion
RP	Rapid Prototyping
CO_2	Carbon Dioxide
CNC	Computer Numerical Control
PLCs	Programmable Logic Controllers
STL	Standard Tessellation Language
LSL	Selective Laser Sintering
SLM	Selective Laser Melting
COGS	Cost of Goods Sold
EBITDA	Earnings Before Interest, Taxes, Depreciation and Amortisation
EBIT	Earnings Before Interest and Taxes
PPE	Property Plant and Building
TR	Tax rate?
pdf	Probability Density Function
cdf	Cumulative Distribution Function
SLR	Systemic Literature Review
MCS	Monte Carlo simulation
CAPEX	Capital related Expenditures
R&D	Research and Development
CI	Confidence Interval

1. Introduction

The additive manufacturing (AM) technology has captured the imagination of many technology observers and manufacturing professionals (Baumers and Holweg 2019). The interest in AM has seen a large growth the last decade, and the technology is said to signify a new disruptive path on how parts and products will be produced (Godina et al. 2020). Additive manufacturing was initially considered as an alternative that allowed rapid prototyping of complex parts in the design or early manufacturing stages (Arrizubieta et al. 2020). AM is a developing technology that was launched in the 1980s. Over thirty years into its development, AM is now more considered as a mainstream manufacturing process (Huang et al. 2013). The last decade has especially seen an intense increase in the sales of additive manufacturing (Pannitz and Sehrt 2020). From the emergence of the first Rapid Prototyping system (Schneck et al. 2019), AM technology has been successfully introduced in many industries such as automotive, aerospace, electronics, and medicine (Niaki and Nonino 2017).

Additive manufacturing, more commonly referred to as 3D-printing, is a method of manufacturing which involves the joining of materials layer-upon-layer to create objects from 3D model data. The main benefits of this methodology includes design freedom, removal of tooling requirements, and economic low volumes (Mellor, Hao, and Zhang 2014). The great enthusiasm around AM is its promise to replace conventional production technologies, and the numerous opportunities for business model innovation brought with it (Brecher 2015).

The additive manufacturing market is largely highlighted as a growing market. Numbers from 2011 estimates $1.614 billion in revenue globally in the primary AM market (Thomas 2013). While AM has a large set of advantages, it has not yet quite led to a large-scale adoption of the technology in the global manufacturing market. It does however have the potential of generating a change in the way manufacturing is conceived (Arrizubieta et al. 2020), and has been referred to as “The third industrial revolution" (Huang et al. 2013). The technology still at an early stage however. Although the number of parts manufactured using this technology is growing at a rate of 25% per year, they still comprise a small fraction of the total worldwide production (Arrizubieta et al. 2020). Despite its limited use in the total worldwide production, leading organisations are increasingly investing in R&D activities to better understand AM, its limitations and how to benefit from its potential (Busachi et al. 2018).

Recent times has seen an increased focus on efficient use of energy and sustainability, with an increasing number of papers covering environmental aspects, including circular economy, recycling and the life cycle assessment of materials (Colorado, Velásquez, and Monteiro 2020). In the last decades, efficient use of resources and environmental awareness has increased. Sustainable manufacturing has attracted increasing attention, and manufacturing processes nowadays are expected to ensure a minimum environmental impact (Arrizubieta et al. 2020). The layer-upon-layer method that AM use puts less requirements on the quality of material used in the production, and it can be argued that this is could be an efficient tool in a circular economy aspect. In today's markets and societies there is a growing support for protecting the environment and boost the green economy.

This thesis is based on circular manufacturing perspective. The idea was brought up by Valvision; a business located in Bergen and Stavanger and a supplier of valves and actuators to the oil and gas industry. This is on the back of their cooperation with F3nice, a business located in Italy that provide metal powder made from 100% recycled sources. They are collaborating on a new production method of circular powder and plans to build a factory in Bergen. This powder production involves a new twist on the gas atomization technique. Atomization produces fine particles from bulk material, resulting in powder which can utilized through AM production. This new prospect of F3nice is the possibly to deposit raw material directly into the atomizer, eliminating intermediate steps in metal processing, which subsequently reduces climate gas emission and results in a more circular manufacturing loop. The main perceived benefits from this would be the improvement of recycling high-quality steel, subsequent reduction of CO_2 emissions and freeing up storing capacity.

The opportunities for profit were the main area Valvision wanted to uncover. The additive manufacturing market provide a set of uncertainties however which makes this challenging. The market for AM is generally considered young in most parts of the world, and has not seen a widespread adoption in Norway. There is a large uncertainty around demand, where lack of historical data and few producing companies makes it challenging to forecast future sales levels. The market is limited by a few numbers of producers, and some hesitation from potential consumers of the technology. There is however an ever-increasing interest in AM, due to its great number of perceived benefits and opportunities to shine. Despite of this present interest, the high amount of uncertainty results in a market that is hard to asses, and risk aversion can therefore lessen external investments in the market.

These uncertainties make it challenging to directly asses the profitability of circular powder production in Norway. It was deemed more natural to first focus on the intricacies of the Norwegian Market. Based on this, the main objective of this thesis is to shed light on the current additive manufacturing market today in Norway, and from there conduct simulations for expected demand level and profitability in a powder production. The research on the AM market in Norway is done with specific focus on attractive aspects, limitations, opportunities and perceived barriers to entry for both the technology and the market.
This has led to the following main research question:

(1) *How is the current additive manufacturing market in Norway?*

Demand is an important factor for evaluation of a market. The demand for a product drives sales, and is the main contributor towards revenue. While demand is a main area of interest, it is just as important to understand the viable production levels for a product, in other words its supply. Additive manufacturing is usually mentioned in conjunction with prototyping and small to medium production levels, but its viability on large-scale production is rarely mentioned. An additional research question has therefore been targeted towards this, resulting in a complementary research question as followed:

(2) *Could additive manufacturing be relevant for large scale production?*

One of the often-mentioned benefits and selling point of AM is its opportunities to reduce CO_2 emissions and promote sustainability. A circular economy with reduced emissions is a selling point for F3nice's project. It is expected that the interest for AM could be driven further through its potential benefits in cleaner energy. A second additional research question has therefore been created, addressing the greenness of AM and whether or not this technology should be considered together with other green technologies:

(3) *Should additive manufacturing be considered as a green technology?*

The final additional research question is targeted back towards the specific project that F3nice and Valvision is researching on. It is of major interest to predict whether this type of production could be viable in today's market. The final area of interest has led to the last additional research question:

(4) *Could a circular powder production in Norway be profitable?*

This introduction serves as the first of ten total chapters. The second chapter gives a technical background for AM and a description of circular economy. The third chapter lays the theoretical foundations which the thesis is built upon. Chapter four presents the methodical approach used in this research. The fifth chapter examines previous literature related to the research questions, and consequently serves as a part of the analysis. Chapter six presents' data received through interviews with experts and actors within the AM market, while chapter seven conducts a specific case study related to third additional research question, regarding the viability of powder production. Chapter eighth presents a brief summarisation of findings, discusses research implications and presents suggestions for further research. Chapter nine concludes the thesis, while the tenth chapter serves as an appendix for additional information.

2. Background

The purpose of this chapter is to provide an insight into the world of AM without going to deeply in details and technical descriptions. This chapter consist of a total of five sub-sections. Chapter 2.1 describes how the usage of AM components has evolved through the last years. Chapter 2.2 addresses the AM process in details, from product design to post-processing procedures. The third chapter, 2.3, provides a brief overview of some relevant types of AM processes. Chapter 2.4 provides background on production and recycling of powder, while chapter 2.5 address the ambiguity of the circular economy concept.

2.1 Developments of AM Components

2.1.1 Digital Components

From its infancy, AM has been able to take full advantage of the technological developments offered by computers, both directly and indirectly such as: processing power, graphics, machine control, networking and integration (Gibson et al. 2019). Technologies such as droplet printing and inkjet printing have rapidly developed during the past years. This allows droplet deposition to be used to print photocurable and molten resins and binders for powder systems. As described: "Since print heads are relatively compact devices with all the droplet control technology highly integrated into these heads, it is possible to produce low-cost, high-resolution, high-throughput AM technology" (Gibson et al. 2019).

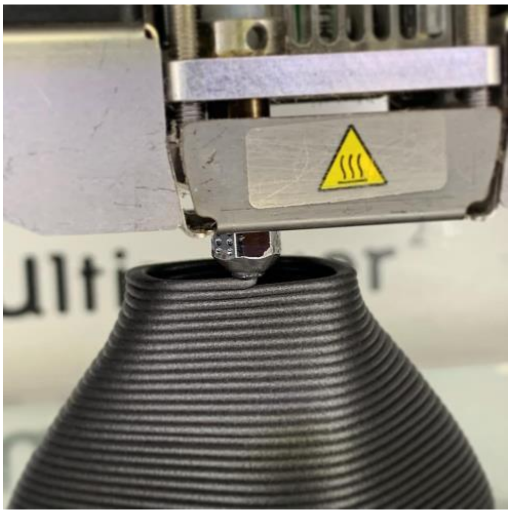
A programmable logic controller (PLC) is a digital computer used for industrial automation. It is established in order to reduce high power consumption that is rooted in the utilisation of relays to control and coordinate manufacturing processes. Large computer aided design (CAD) files serve as inputs into AM machinery are reduced into a series of process stages that require sensor input and signalling of actuators. An actuator is a component of a machine that is responsible for moving and controlling a mechanism or system, for example by opening a valve. Microcontroller systems are much better fits to carry out the previously described system and machine control than microprocessors. Industrial microcontroller systems are used to reliably control industrial processes form the basis of PLCs. Using building blocks based around modern PLCs for coordinating and controlling the various steps in the machine process makes it much easier when designing and building industrial machinery, like AM machines (Gibson et al. 2019).

2.1.2 Materials

As AM technology came into existence it used raw materials that had already been available and compatible with contemporary manufacturing processes. The uniqueness of AM technology shortly proved the urgent need for new materials that suited the AM manufacturing process better. Due to the development of raw materials, parts produced by AM technology nowadays are longer lasting, accurate and stronger (Gibson et al. 2019).

2.1.3 The Use of Layers

A 2D cross-sectional representation of a complex 3D object has long been common to several technologies apart from AM. However, slicing up an object to a finite number of 2D cross-sections is not just an optional form of representation, it is one of the key principles of AM technology (Gibson et al. 2019).



2.1.4 Computer Numerically Controlled Machining

Computer Numerically Controlled (CNC) Machining and its development is relevant due to its wide spread in TM technologies and is often brought up as a comparison to AM. The AM technology has gradually developed on the back of CNC technology did not living up to its expectations regarding time frames or yield of desired outputs. CNC machines were considered slow and cumbersome to operate. On the contrary, AM machinery was easy to set up and yielded quick results, but with poor quality and low capacity. As AM technology indicated quick development, CNC equipment vendors invested heavily in CNC technology, and it has made a dramatic improvement. Nowadays the two manufacturing technologies complement each other (Gibson et al. 2019).

2.1.5 From Rapid Prototyping to Parts-Manufacturing

Additive manufacturing was once used to be described as Rapid Prototyping (RP). The term RP covers all the printing processes in a variety of industries that aim to build a part representation before final release or commercialization. The RP process with other words is the making of a prototype that serves as a base to derive the final object from. As explained by Gibson et al. (2019); "Management consultants and software engineers both also use the term Rapid Prototyping to describe a process of developing business and software solutions in a piecewise fashion that allows clients and other stakeholders to test ideas and provide feedback during the development process" (Gibson et al. 2019)

However, the significant quality improvement of the parts built directly in the printing equipment made the products much closer to the final "real" products; hence the use of the term "prototype" has become improper. Moreover, calling the procedure RP does not consider the fact that these technologies manufacture parts using an additive approach. This does not imply that RP is no longer used for building prototypes, AM is still a perfect technology to build prototypes of real models/parts to be printed.

2.2 The AM Process

Depending on product complexity and AM technology, AM processes may vary, but most of them involve the following phases to a certain extent:

2.2.1 Design and STL File

Firstly, the desired geometry of the product is designed with a CAD. It is a detailed model of the part to be printed with a solid 3D representation. Then, the CAD is transferred to STL file format, which is accepted by most AM machines, and therefore a standard in the industry. The STL file, which stands for Stereolithography or Standard Tessellation Language, was created in 1987 by 3D Systems Inc. The STL file contains the fundament of calculations necessary to "slice up" the 3D model. The STL file is then manipulated in such a way that it matches the actual size, position and orientation for building, and the file is sent to the machine (Gibson et al. 2019). Prior to this the machine must be set up must be set up properly before the building, taking energy and raw material consumption, layer thickness, timing and other parameters into consideration.

2.2.2 Build and Removal

The building of the product takes place in the AM machine, and besides the supervision of a smooth raw material flow, software glitch-free operation and continuous energy supply, the process is completely automated.

When removing the printed product from the machine, safety regulations must be kept by taking temperature, moving parts and other factors into consideration.

2.2.3 Post-Processing

After removal of the part from the printing machine, a series of post-processing steps are carried out to meet the requirements of the finished product. Support structure needs to be removed, surfaces must be polished and finished according to product requirements, involving human labour which significantly raises related costs.

2.3 The Different Types of AM Processes

There are multiple possibilities to group and categorize AM procedures. A possible way to group the different technologies is to consider the baseline technology such as laser beam or extrusion technology. It is also possible to group the different technologies by binding mechanism, or to gather them by raw material input. Since there are processes that can be categorized into several groups based on either input material or baseline technology, there are no sterile classifications, and the different technologies might overlap with each other. Therefore, instead of trying to classify these technologies, they are demonstrated in a loose context.

2.3.1 Powder-Based Systems/ Discrete Particle Systems

Powder Bed Fusion (PBF)

PBF was among the earliest AM processes, and an extremely versatile technology well suited for polymers and metals, and to a lesser extent ceramics and composites. Two of the most relevant PBF technologies will be represented, Selective Laser Sintering (SLS) and Selective Laser Melting (SLM).

Selective Laser Sintering

Selective Laser Sintering was the procedure to first utilize PBF technology. Powder is sintered or fused by the application of carbon dioxide laser beam. The chamber is then heated to a close proximity of the materials heating point. The laser then fuses the powder at a specific location for each layer, following the design. The particles lie loosely in a bed controlled by a piston that is lowered by the same amount of layer thickness each time a layer is finished. This manufacturing procedure offers a great selection of materials that could be used: plastics, metals, combination of metals, combinations of metals and polymers, and combinations of metals and ceramics.

Selective Laser Melting

Selective Laser Melting has the potential to process near full density parts with mechanical features that can be compared to those of bulk materials. Powder particles are completely molten by a laser beam during the process; the resulting high density makes the lengthy post processing procedures possible to avoid, as it is the case with SLS (Kruth et al. 2004).

2.3.2 Direct Energy Deposition

Direct Energy Deposition (DED) is mainly used for metal powders but is widely used for polymers and ceramics. Thus, this approach is often referred to as Direct Metal Deposition (DMD).

Laser Engineered Net Shaping

During the manufacturing process, a part is built by melting metal powder that is injected into a specific location. It then becomes molten with the use of a high-powered laser beam. When it is cooled down the material solidifies. The process occurs in a closed chamber with an argon atmosphere. This process makes use of a high variety of metals and combinations like stainless steel, nickel-based alloys, etc. Alumina can be used too. This process allows manufacturers to repair parts that would be impossible to carry out by other processes or would be too expensive to perform.

Pro metal

This technology is used to build injection tools and dyes. A powder-based process that utilises stainless steel. During the printing process a liquid binder is spurt out in jets to steel powder. The powder bed - which is controlled by build pistons that lower the bed when each layer is finished and a feed piston that supplies the material for each layer - contains the powder. The residual powder is removed after finishing the product.

Electron Beam Melting

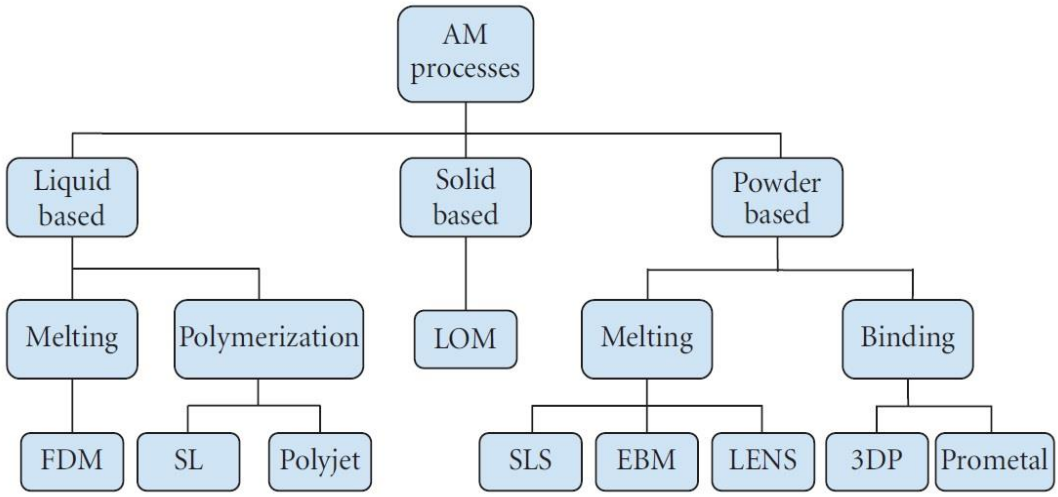
The process is relatively new but is growing rapidly. In this process, the powder is melted by an electron laser beam powered by a high voltage, typically 30 to 60 KV. In order to avoid oxidation issues the process takes place in a high vacuum chamber since the process is intended for building metal parts. Other than this, the manufacturing procedure is very similar to SLS.

2.3.3 Stereolithography

This technology has been the most widely used fabrication process for rapid prototyping. This is a liquid-based process which starts with a model In the CAD software and is from there translated into an STL file in which the pieces are cut in slices containing the information for each layer. The equipment used determines the thickness and the resolution of each layer. In order to anchor the piece and support the overhanging structures, a platform is built, which subsequently has to be removed after the building process.

Additive manufacturing has a large variety of methods not mentioned due to less relevancy. The full overview of all AM processes thus far is provided in figure 2.1.

Figure 2.1 Groups of AM processes.



Source: (Wong and Hernandez 2012)

2.4 Powder Production and Recycling

Metal powder is one of the main raw materials as input for AM and different production types are therefore briefly introduced. Any metal that is weldable should in principle be a candidate for PBF and DED. Precious metals are a growing area for AM feedstock and can be printed using PBF. Application of this is commonly seen within jewellery, as well as dental restorations, and other specialty applications (Gibson et al. 2019).

When processing powder-based metal feedstock, several physics and chemistry-related factors contribute as a limitation to the process. As explained; “Metal powder in AM processes is produced typically by the gas atomization technique. Atomization produces fine particles from bulk material by breaking them up during the liquid phase. A stream of liquid metal is hit by pressurized gas and broken up by kinetic energy, scattering the droplets. The droplets rapidly solidify, and powders are collected in an atomization tank, which is filled with inert gas. Gas atomization produces highly spherical particles" (Gibson et al. 2019). Powder production results in powder with extremely fine particle structures.

Reusing scrap metal is a promising aspect within the Circular Economy loop regarding parts manufacturing. While it reduces waste significantly, a high energy consumption is necessary in the procedure. Reuse of metal powder is possible but requires several chemical procedures to prevent conglomeration and other issues, resulting in a high cost.

2.5 Definition of Circular Economy

While the terms Circular Economy (CE) and sustainability are increasingly gaining traction with academia, industry, and policymakers, the similarities and differences between both concepts remain ambiguous (Geissdoerfer et al. 2017). The relationship between both concepts is not made explicit in the literature. Geissdoerfer et al. (2017) define the Circular Economy as a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. In their research, they contrast this to sustainability by highlighting their difference in origins, goals, motivations, timeframes and perception of responsibilities. The Circular Economy refers mostly to individual economic benefits through input reduction, efficiency gains, and waste avoidance. Murray et al. (2017) points out that Circular Economy places emphasis on the redesign of processes and cycling of materials, which may contribute to more sustainable business models. Criticism of the concept refer to circular economy as a collection of vague and separate ideas from several fields and semi scientific concepts (Korhonen, Honkasalo, and Seppälä 2018). Kirchherr, Reike, and Hekkert (2017) state that there is no common understanding on the concept of CE among market actors. For most market actors, CE encompasses some combinations of the elements of the 3R framework, reduce, reuse and recycle activities, without a deeper dimension of a systematic shift. The article emphasizes the lack of inclusion of future generations, environmental and social benefit factors. The lack of a common definition creates a challenge in distinguishing between a circular economy and other forms of recycling.

3. Theoretical Positioning

This chapter provides theories, concepts and the background for methods and analysis. This chapter consist of a total of two sub-sections. The first chapter, 3.1, provides some theoretical aspects of literature while describing different types of interviews and their usage areas. Chapter 3.2 provides theoretical background for Monte Carlo Simulations.

3.1 Interviews

3.1.1 Types of Interviews

Structured

Structured interviews are the best fit for quantitative research and analysis. It is based on developing standardised questions in the form of questionnaires, where the collected data can easily be transformed to data frames or spreadsheets to be further processed in the research.

Semi-structured

Semi-structured interviews are non-standardises interviews best suited for qualitative research due to its flexibility during the interview. It allows for deviations from pre-determined interview guides during the questioning process that can be necessary if the course of the conversation brings up non-planned topics, ideas etc. There is also more room for follow-up questions.

Unstructured

Unstructured interviews are common for informal in-depth interviews that are designed to gain in-depth information in an area. There are no pre-determined list of questions or interview guidelines, which means the interviewer must be well informed and knowledgeable on the topic to be able to guide the interview.

Table 3.1 depicts the different types of research methods and the corresponding interview types. The number of "X's" represents its level relevancy for each research type.

Table 3.1 Overview of interview types and usage areas

	Exploratory	Descriptive	Explanatory	Evaluative
Structured		xx	x	x
Semi-Structured	x		xx	xx
Unstructured	xx			x

3.2 Monte Carlo Simulation

3.2.1 Definition

One common definition of Monte Carlo simulation (MCS) is, “A Monte Carlo technique is any technique making use of random numbers to solve a problem" (James 1980). This can be demonstrated via an example. Let us assign F as result of the solution of the problem, which could be a real number, a set of numbers, a decision of binary character, etc. The Monte Carlo estimate of F will then be a function of, besides other various things, the random numbers used in the calculation. The introduction of randomness into an otherwise well-defined problem produces solutions with rather special properties which are somewhat often close to reality (James 1980).

3.2.2 Statistical Background for Monte Carlo Simulation

Law of Large Numbers and the Central Limit Theorem

The law of large numbers concerns the behaviour of sums and expected values of large numbers of random variables. This law states that by repeating the same experiment of choosing n random independent variables of function f, the sum of these variables divided by n, will converge to the expectation of the function f. Central Limit Theorem states that if X_1, X_2, X_3 … X_n is independently individually distributed stochastic variable with E[X] = μ, and var(X_i)= σ^2. Table 3.2 summarises the sum, expected value, approximation, variance and standard deviation of X provided that n is sufficiently large.

Table 3.2 Summary of Central Limit Theorem statistical features

	Approximation	Variance	SD
$\mathbf{S(X) = x_1 + x_2 + x_3 + \cdots + x_n}$	Normal	n× μ	$\sqrt{n \times \sigma^2}$
$\mathbf{E[X] = \frac{1}{n}(x_1 + x_2 + x_3 + \cdots + x_n)}$	Normal	μ	$\sqrt{\frac{\sigma^2}{n}} = \frac{\sigma}{\sqrt{n}}$

As stated, “Whereas the law of large numbers tells us that the Monte Carlo estimate of an integral is correct for ‘infinite’ n, the central limit theorem tells us approximately how that estimate is distributed for large but finite n. This very important theorem says essentially that the sum of a large number of independent random variables is always normally distributed (i.e. a Gaussian distribution), no matter how the individual random variables are distributed, provided they have finite expectations and variances and provided n is ‘large enough’” (James 1980).

Random Variables and their Probability Distribution

A random variable is a variable that takes on numerical values and has its outcome determined by an experiment (Wooldridge 2013). Another definition of a random variable says: “A random variable is a variable that can take on more than one value (generally a continuous range of values), and for which any particular value that will be taken cannot be predicted in advance. Even though the value of the variable is unpredictable, the distribution of the variable may well be known. The distribution of a random variable gives the probability of a given value “ (James 1980).

Discrete Random Variables

A discrete random variable takes on only a finite or number of values. A discrete random variable is completely described when the possible values and the associated probability belonging to each value are presented. If X takes on the k possible values $\{x_1, \ldots, x_k\}$, then the probabilities $p_1, p_2, \ldots, p_2$ are defined by

$$p_j = P(X = x_j), j = 1, 2, \ldots, k,$$

where each p_j is between 0 and 1 and

$$p_1 + p_2 + \ldots + p_k = 1.$$

The probability density function (pdf) of X accumulates the information regarding the possible outcomes of X and the corresponding probabilities:

$$f(x_j) = p_j, J = 1, 2, \ldots, k,$$

with f (x) = 0 for any x that does not equal x_j for some j. Putting it differently, for any real number x, f(x) is the probability for the random variable X taking on the particular value x (Wooldridge 2013).

Continuous Random Variables

As stated, “A variable X is a continuous random variable if it takes on any real value with zero probability" (Wooldridge 2013). The reasoning behind is that a continuous random variable X can take on uncountable many possible values that cannot be assigned positive integers, so X actually has a probability of zero. Therefore, a probability density function for continuous random variables is used, as with discrete random variables, the pdf provides information on the likely outcomes of the random variable. Since it makes no sense to identify the probability of a particular value, the pdf of a continuous random variable is used only to compute events involving a range of values. For example, if a and b are constants where a < b, the probability that X lies between the numbers a and b, P(a < X < b), is the area under the pdf between points a and b. This is the integral of the function f between the points a and b. The entire area under a pdf must always equal one. When computing probabilities for continuous random variables, it is easiest to work with the cumulative distribution function (cdf). If X is any random variable, then its cdf is defined for any real number x by

$$F(x) \equiv P(X \leq x)$$

For discrete random variables, it is obtained by summing the pdf over all values x_i such that $x_j \leq x$. For a continuous random variable, F(x) is the area under the pdf, f, to the left of the point x. Because F(x) is simply a probability, it is always between 0 and 1. Further, if $x_1 < x_2$, then $P(X \leq x_1) < P(X \leq x_2)$, that is, $F(x_1) < F(x_2)$. This means that a cdf is an increasing, or at least a nondecreasing, function of x. Two important properties of cdf's that are useful for computing probabilities are the following:

For any number c, P(X > c) = 1 - F(c).

For any numbers $P(a < X \leq b) = F(b) - F(a)$ (Wooldridge 2013)

Utilised Probability Distributions

The following distributions are going to be discussed in this chapter: Truncated Normal, Poisson, Triangular and Uniform. They are discussed in the order which they will appear in the research methodology. An argumentation for the use of a particular distribution in each simulation is provided in analysis section.

Normal and Truncated Normal Distribution

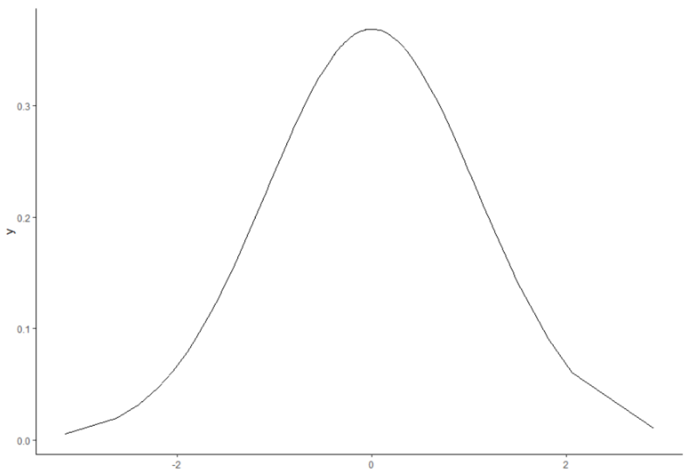
Normal distribution is the most widely used probability distribution in statistical analyses. (Løvås 2013)

Definition**;** If x is a random variable with density:

$$f(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2\sigma^2}(x-\mu)^2}, \qquad -\infty < x < \infty$$

Then x is normally distributed with expected value μ and variance σ^2. The usual form of writing the distribution is N ~ (μ, σ^2). Due to the specification of a mean and standard deviation when defining growth rate of demand, standard normal distribution (which has a μ=0 and VAR=1) is not discussed in detail nor will be the formula above since the most usual method is to use a normal distribution table. The Normal distribution has a classic “bell” shape when graphed with the mean/mode being positioned to the centre, as can be seen in figure 3.1.

Figure 3.1 Illustration of a typical Normal distribution and its bell shape



Truncated normal distribution

A special case of the normal distribution that uses as minimum and maximum boundaries, and a standard deviation.

Poisson

A Poisson distribution is a discrete probability distribution that is used to estimate the probability of an event occurring during a fixed length of time interval, such as: Number of phone calls in a call centre, average number of customers entering a shop, average number of equipment failures per day for a logistics company, or number of visitors to a web site etc.

The events that may be described by this distribution have the following characteristics (Viti, Terzi, and Bertolaccini 2015):

- The events are independent from one another,
- Within a given interval the event may present from zero to infinite times,
- The probability of the event happening is increasing when the period of observation is longer.

Definition:

$$f(x) = \frac{\lambda^x e^{-\lambda}}{x!}$$

To predict the probability, the behaviour/characteristics of the above listed events must be known. Such data can be obtained from previous or historical observations. This parameter, that is a mean of the events in a given time interval as derived from previous observations, is called λ. If lambda gets high enough, Poisson distribution has normal approximation. F(x) has a mean μ = λ and σ = √ λ, P~(λ, √ λ) so the coefficient of variation σ/μ becomes small for large λ; e is the base of the natural logarithm with value approximately 2.71828.

Triangular

A triangular distribution is a continuous probability distribution with a probability density function with a shape of a triangle. It is described with three values: the minimum value a, the maximum value b, and the peak value mode or most likely value, c. A general criterion is that $a \leq b \leq c$. A special case of the distribution when c takes the value of $\frac{(a+b)}{2}$, then the triangle is symmetric to its centre. When drawing a random variable with uniform distribution between 0 and 1 the variable can be described with the following function:

$$X = \begin{cases} a + \sqrt{U(b-a) - (c-a)} \\ b - \sqrt{(1-U)(b-a)(b-c)} \end{cases} \qquad , 0 < U < F(c) \text{ and } F(c) \leq U < 1$$

Where F(C) has a triangular distribution with parameters a, b, and:

$$F(C) = \frac{(c-a)}{(b-a)}$$

Uniform

This distribution – when being continuous - serves the bases for "random number" generation when using computer programmes. In this case the probability of a number or event occurring is within a given/specified range. An example for discrete uniform distribution is rolling a dice (unbiased), the probability of any outcome is exactly 1/6. The probability of an event with uniform distribution occurring is constant.

3.2.3 Randomness in Monte Carlo Simulation

As defined earlier, a random number is a value that a random variable may take. For Monte Carlo simulation randomness has a slightly different meaning. In this case as soon as a sequence of numbers has been generated, it has features/characteristics of some levels that can be compared to true randomness. As stated, “To be precise one must distinguish three different types of sequences: truly random, pseudo-random and quasi-random” (James 1980). Furthermore, it is common to confuse the randomness properties of a sequence with its distribution, but this is misleading because the two are largely independent. A perfectly random sequence of numbers may have any kind of distribution, whereas a perfectly uniformly distributed sequence may not be at all random. (James 1980).

True randomness is an extremely challenging task to find in nature, one cannot be sure if an observed event is truly random, unless one is able recreate the exact same conditions as at the starting point infinitely and then visualise the distribution - but it is obviously impossible — and even then, it is impossible to be sure if the sequence of results isn't "previously determined/set”. Therefore, it is challenging, impractical or expensive to carry out M.C. simulation by using physical equipment that can take care of the bias originating from the lack of true randomness. M.C simulations therefore utilise other methods to generate seemingly random numbers.

4. Methodological Approach

This chapter provides insight in the chosen research method. The chapter contains five sub-sections in total. Chapter 4.1 describes the selection of research design. The second chapter, 4.2, informs on how and why a Systematic Literature Review was used as a part of the analysis. Chapter 4.3 describes the main steps in interviews conduction, while Chapter 4.4 addresses the research credibility of the interviews. The final chapter, 4.5, describes the steps of Monte Carlo Simulations.

4.1 Selection of Research Design

When a research seeks to find answers to what is happening, looking for new insights, assess phenomena in a new light etc, exploratory research design is appropriate. It is particularly useful for clarification of understanding a problem (Saunders, Lewis, and Thornhill 2019). The main research question, understanding the Norwegian AM market, is researched through a qualitative research with an exploratory design. This is also the case for the additional research question (2) and (3), which are closely related to the first. Additional research question (4), where the profitability of powder production is addressed, is done through a separate case study with simulations. This is therefore a quantitative research with descriptive and explanatory design. The overall research method should therefore be considered as a mixed method.

4.2 Systematic Literature Review

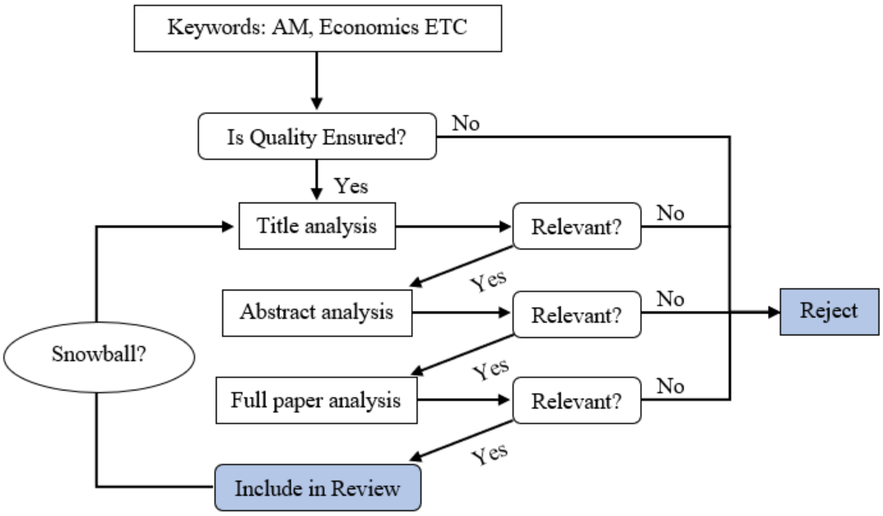
A central source of information to address the research questions have been the literature of AM. AM is a relatively young and new area of manufacturing, and historical data is therefore limited. This is especially the case for the Norwegian market, where data sources have been hard to come by. A systematic Literature Review (SLR) was employed in order to effectively address the thesis research questions, specifically the primary and two first additional research questions. A systematic literature review is a means of identifying, evaluating and interpreting available research relevant to a particular research question, topic area, or phenomenon of interest (Kitchenham 2004). Systematic literature studies have emerged as a way of synthesizing evidence and allowing researchers to come to a joint understanding of the status of a research area (Wohlin 2014). SLR is reported as a helpful tool to determine the necessary criteria for relevant research within the field of additive manufacturing (Arrizubieta et al. 2020).

The review started with a sample of relevant papers published by highly cited journals, and was then followed by a semi-structured snowballing approach (Wohlin 2014), to capture both established and emerging conceptual trends. Snowballing refers to using the reference list of a paper or the citations of the paper to identify additional papers (Wohlin 2014), which allows a wider range of searches to identify relevant publications (Arrizubieta et al. 2020). The snowballing approach can be divided into two types, backward and forward snowballing (Wohlin 2014), where forward snowballing was assumed to be most relevant for this research. Forward snowballing refers to identifying new papers based on papers cited by the examined paper. A depiction of the method on forward snowballing is provided in figure 4.1.

The first step in the search for relevant research was to identify keywords and formulate search strings. Identifying a start set of papers can be challenging when applying a snowballing approach (Wohlin 2014). The search for papers were conducted through the use of specific keywords such as: AM, AM economics, 3D-printing, AM profitability etc. These keywords were defined and used in order to limit the reference material. Recency limitation on research was also applied. Due to the rapid evolution of the technology and steadily increasing market for additive manufacturing, recent papers had to be in focus. When the additive manufacturing market is mentioned, it's usually focused on the rapid evolution the last 10 years. Early focus was as mentioned on the possibilities for non-commercial use of AM, while the latter research is on mass-production. A cut-off point of 10 years was therefore used, and research from before 2011 were not included. The oldest paper included in the literature is from 2012. Only manuscripts in English were included.

The main approach for identifying relevant literature is summarized in figure 4.1. The figure depicts the process of forward snowballing, where an article relevant to the chosen keywords where identified, checked for quality, subsequently brought through several steps to identify its relevance the research, before finally added if all the steps where passed. A snowballing approach where then used, where new literature where identify based on the "accepted literature" and then brought through the same steps as prior literature.

Figure 4.1 Flow chart for Systematic Literature Review



4.3 Interviews

4.3.1 Sample Development

Purposive Sampling

A random sample of informants was not feasible due to the limited size of the Norwegian AM market. A non-probability, purposive, heterogeneous maximum variation sample selection was therefore conducted based on recommendations from market actors and experts on the field. The interviewees were chosen with the goal of covering all aspects of the Norwegian AM market. The spread of informants includes: AM producers, prominent customers, AM partners and facilitators, research departments and academic experts.

4.3.2 Administrative Procedures

Interview Guides

According to the well diversified sample there was a need to construct customised interview guides. Two templates for interviews were created; one unique for AM producers, since they can answer production related questions with great insight, and one general for the rest of the informants.

Template for Information Letter

The template was sent to the Norwegian Centre for Research Data for approval to ensure privacy related procedures were followed up, as well as to our supervisor. The template can be found as an attachment in Appendix 1.

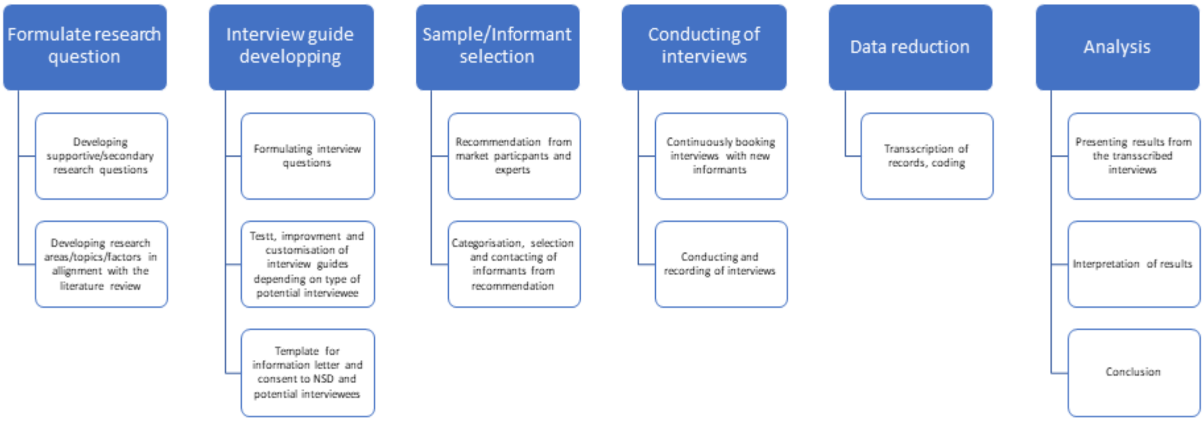
Request of Interviews

Interview requests were sent out via email. The emails contained information about us, the thesis, the rights of the interviewee and the Template for Information Letter. After receiving a sign of interest and preferred time, electronic invitation was sent out to the interview at the agreed-upon time and date.

4.3.3 The Interviewing Process

From the earlier listed types of interviews semi-structured interviews were selected to be carried out, altogether nine of them. The Covid-19 situation did not allow us to conduct any of the interviews in person, and the interviews where therefore conducted digitally through the Microsoft Teams application. The advantage of this method compared to regular type recordings is the opportunity to watch the interview repeatedly with all gesticulations, non-verbal communications etc. This was a great help during the transcription process. Both authors were present during each interview, which gave more room for follow-up questions and discussion. Figure 4.2 provides and overview of the interview conduction.

Figure 4.2 Interview conduction



4.4 Ensuring Credibility of Research

4.4.1 Reliability

Reliability refers to the consistency of findings of data collection techniques or analysis procedures. The three main aspects are:

- Measures taken will yield the same results
- Similar observations will be reached by others, and
- Transparency of how the data was made sense of.

From the listed aspects, the second one must be addressed in regard to semi-structured interviews. This technique features flexibility to a larger extent allowing the interviewer to ask follow-up questions. The advantages of this technique are discussed at the relevant chapter, while the downsides are that it limits the repeatability of the research. As (Saunders et al. 2019) lists in his work, there are three threats to reliability: participant error, participant bias and observer error.

Subject/Participant error

Involves, among others, bad timing of an interview. It has been eliminated by the requesting of interview via email; the respondents had the opportunity to choose the best fitting time for themselves. Also, video-recorded interview may allow greater flexibility and comfort regarding location by not having to find/book an appropriate meeting room in advance etc, hence reducing unnecessary extra planning and stress. The disadvantage of video recordings is that not everyone might be accustomed to talking into a tiny camera, which may be perceived as unnatural.

Subject/Participant bias

Involves potential exposure of interviewees to management style. The research must ask himself: "Is interviewees free to say what they want or could they be pressured?". This has likely been eliminated due to the promise of anonymity. Additionally, most interviewees were either in a management position in the company or not related to an AM producing firm.

Observer error

Involves low level of structure. Both authors were as mentioned present actively during the interviews, allowing greater structure for observation and more possibilities for follow-up questions.

Observer bias

Observer bias involves the possibility to misinterpret the observed phenomenon. This was addressed through cross-checking between transcriptions post-interviews.

4.4.2 Generalisability

Also referred to as external validity. Generalisability address whether a research can be reconducted on a different sample and still be applicable again. The answer to this question is that it is partly is. The methods utilised in the first two parts of the thesis can be repeated on other settings, the third part – the quantitative case study – cannot be repeated again since the dataset will be different: depending how long time would pass until the "repetition" of the research, new real-time data would be available that would alter the results.

4.5 Case Study of circular powder production

A case study to analyse the expected profit and overall profitability of a company was carried out. Valvision and F3nice provided sufficient data through a spreadsheet containing all necessary economic data to support an economic analysis.

4.5.1 Choice of Software for Monte Carlo Simulations

There are numerous Monte Carlo Simulation packages available, most of them as Excel extensions or other forms of software's. However, the nature of the task to be carried out requires a big amount flexibility, and therefore the programme of choice is R. R is a free software environment for statistical computing and graphics.

An important feature of R is that one can set the initial "seeds"/parameters of the various iterated scenarios such that it can be repeated at a later occasion with exactly the same result. This feature is crucial when one intends to present the simulation results, in alignment with the criterion of research credibility, more precisely Reliability and Generalisability.

4.5.2 Data

Description of Input Variables

An overview of the input variables from the spreadsheet is provided in table 4.1. Unit of currency is expressed in euros. The company is a start-up, and subsequently has no historical data at hand regarding sales or demand. Table 4.1 provides and overview of every input variable used in the simulations.

Table 4.1 Description of input variables

Variable	Abbreviation	Amount	Measurement	Calculation
Crucible Volume	CV	65	L	NA/Given
Average Scrap Density	ASD	6.5	kg/l	NA/Given
Crucible Max. Batch	CRMAXB	422.5	kg	CRMAXB = CV×ASD
Batch Cycle Time	BCT	8.00	h	NA/Given
Production Hours	PH	24	h/d	NA/Given
Production Days	PD	220	d	NA/Given
Annual Number of Batches	TOTB	660	#/Y	$TOTB = \frac{PH}{BCT} \times PD$
Weekly Number of Batches	WTOTB	15	kg	$WTOTB = \frac{TOTB}{44}$
TOT Powder	TOTP	278 850	kg/Y	TOTP = CRMAXB×TOTB
TOT Revenue	TOTREV	N/A	Euros	*NA/Given*

Income Statement

An income statement summarises a company's profit and loss over a period of time. It is used both in accounting and in finance; it sums up all the income and subtracts both the operating and non-operating costs. Table 4.2 presents the line items which are first defined, then the calculation is presented according to how they are made on the original statement forecast. Simulation results will be plugged in the presented formulas accordingly.

Table 4.2 Income Statement forecast

Income Statement Forecast Line Items
Scenario Demand forecast expressed in percentage. **SCENARIO(X) = Year X demand indicated in percentages**. Therefore, SCENARIO1 = demand for year 1, SCENARIO5=demand for year 5. This is because each scenario represents an outfall of the simulated demand percentage – scenario - per year, as one can read *vertically* on the income statement forecasts presented in analysis. The first year's expected/predicted demand is 40% on the original spreadsheet received.
Growth in Demand Not indicated directly on the statement forecast but this is the right place to mention them. Expected yearly growth in demand/sales in percentage, the difference between two years. From year 1 to year 3 it is estimated to be 10% and from year 3 to year 5 it is around 20% by the initial settings.
Revenue The company's revenue from sales and services. This sum serves as an input for the Cost of Goods Sold to be deducted from. Income from sales(X) = **SCENARIO(X)** × (Total Revenue)
Cost of Goods Sold Summarises all the emerging costs directly related to the revenue generating sales, such as materials, labour, parts, etc. The expression in brackets in italics is referred to as COGSB, the base of the COGS. COGS(X) = **SCENARIO(X)** × *(Staff + (Scrap Collection × Total Powder × 0.5) + Utilities (related to Atomiser) + Consumables + Maintenace + Quality Control)*
Gross Profit This line item indicates profits after COGS have been deducted from the Revenue GROSS(X) = Revenue(X) – COGS

Overhead Costs *General and Administrative Costs* Indirect administrative costs related to running a business such as renting, wages, insurance, travel related costs, and might include depreciation etc. *Marketing, Advertising and Promoting* Marketing, advertising and promotion related expenses. Overhead = Building Renting + Consultancy Fees + Marketing & Sales + Admin & Sales FTE + R&D + Utilities (related to Building)
Earnings Before Interest, Taxes, Depreciation, and Amortisation The common way to refer to this item is "EBITDA". It is the profit that remains after deduction of General and Administrative Costs and Marketing, Advertising & Promoting costs. (Or, as it stands on the received spreadsheet, "Overhead" costs). EBITDA(X) = GROSS(X) – Overhead
Depreciation & Amortisation Non-cash expenses to stretch the cost of capital assets related to Property Plant and Building (PPE) over a year. D = Straight-Line Depreciation
Earnings Before Interest and Taxes This item indicates the difference between EBITDA and EBIT that is exactly the Depreciation. EBIT(X) = EBITDA(X) – D
Interest (as Expense) This item summarises the interest a company pays on its debts regulated by the debt schedule. This post is also the difference between EBIT and EBT. Financial = (Atomiser + Ancillary Equipment + Erection & Installation)/10*0.05
Earnings Before Taxes This is the profit that one arrives at after deduction of Interest from EBIT. EBT(X) = EBIT(X) – Interest (Financial)

Financial Income Taxes 22% on income for A/S (this tax rate might not be completely appropriate but is kept for simplicity's sake in the rest of the thesis, resource: Regeringen.no) $$TR = 22\%$$ $$\text{Income Tax}(X) = EBT(X) \times TR$$
Net Income/Profit $$Net(X) = EBT(X) - \text{Income Tax}(X)$$

4.5.3 Application of Monte Carlo Simulation

General procedure

There are numerous ways to conduct a MCS in R. The simulation was conducted with random number generation functions and for-loops. Printed R-scripts are provided in Appendix 4.

Four types of simulations are run, one based on completely neutral expectations using merely random inputs for triangular and Poisson distribution based random variables, later referred to as "fully random" due to the distribution parameters being random as well. There is no assumed minimum, maximum and mode levels. In addition, to create a base for comparison with the fully random simulations, two simulations are run that relies on traceable pre-set parameters. These are called pessimistic and optimistic simulations/models in the thesis. During the simulation procedures, two random variables are simulated: the first year's demand and the growth in demand (growth factors). Demand/sales after the first year is computed by adding the corresponding growth factor to the given year. After the simulation, the variables are implemented the previously described Income Statement to produce a forecast.

Assumptions

Assumptions regarding demand simulations

1) Pessimistic

Assuming low demand levels for the first year, the modus of the random variable is set low, at the fourth of the maximum level of metal powder that can be produced.

2) Optimistic

Letting the demand for the first year to hit higher levels, the mode of the random variable is set to the three-fourth of the maximum producible powder.

Assumptions regarding Growth Factor Simulations

1) Limits of Growth Factors

The main assumption is that the growth factor takes 0 as minimum and 0.1 as maximum annual level from year one until year three. From year three until year five it has a minimum value of 0.1 and a maximum of 0.2. These limits apply for all the different distributions used to simulate growth (triangular and truncated normal). The decision to set 0.1 and 0.2 as maximum values is based on the fact that full capacity exploitation is expected at year five on the original spreadsheet, so the simulated SCENARIO5 should not exceed 1.

2) Pessimistic

Expecting slow growth in demand for the years to come, mode for the first two years is set to 0.025 and for years four and five it is 0.125.

3) Optimistic

Expecting the growth to reach higher levels, modes are set to 0.075 for the first two years and for years four and five it is 0.175.

Simulation Based Merely Upon Randomness

A) Triangular Distribution Based Simulation

Argumentation

Triangular distribution is a widely used distribution for demand simulations. As Wanke (2008) suggests in his conclusion, “Finally, as a suggestion, future research concerning the application of different probability distributions in inventory management should take into consideration the Triangular distribution, defined by mean, minimum and maximum parameters. The premise of the Triangular distribution of demand forecasts and replenishment lead times may be employed at different stages of the learning process, not only at the introductory stage.” (Wanke 2008).

Stage 1 - Sample for Demand

A possible way to produce input data for MCS when there is no historical data available is to do some research in the form of expert (employees, sales managers, etc.) interviews on what the expectable demand for a new product/company might be. Then, with the use of various types of random number generators that use statistical indicators such as the minimum, maximum, mean etc. of those educated guesses on demand as inputs, a simulation can be run, usually with thousands of iterations.

As it turns out from the interviews in previous chapters, the assessment of the AM market in Norway is challenging. It is really new, and several companies that utilise TM but are interested in AM have invested in AM machines as an experiment, or just using AM for prototyping so there are several small actors besides the biggest ones. Therefore, no guesses could be made regarding the expected demand for powder.

To "symbolise"/simulate those educated market actor guesses, the number of market actors is assessed to be approximately 20, of which there are 3-4 big producers on the market and there might be several small actors in the experimental/prototyping phase. Therefore, first a sample of 20 random numbers is generated between 0 and the annual total amount of producible powder, each number representing the expected sales of powder by producers/market actors.

Stage 2 - SCENARIO1 and Growth Factor Samples

"Raw" demand random variable, "SCENARIO" is generated by triangular distribution that takes the minimum, maximum and mode values from the random sample specified above.

The first-year scenario (SCENARIO1) is generated by taking the mean of SCENARIO. For growth factors, two sets of samples have been generated with size of n, spreading between the parameters as introduced at the assumptions. These two sets of samples are used for a minimum, maximum and a mode value to be calculated.

Stage 3 - Simulating Growth Factors per Year

Two random variables with triangular distributions use the parameters specified in the growth sample section above, producing two sets of 10 000 growth percentages. The mean of these sets are then calculated, arriving at the two growth factors, (g1 and g2.)

Stage 4 - Calculation of SCENARIOS for years 2 – 5

With a SCENARIO1 for year one, and the corresponding growth rates, SCENARIOS for the rest of the years until year five can be calculated, based on SCENARIO1. See detailed calculation of yearly scenarios (SCENARIO1, …, SCENARIO5), annual revenues (R1, …, R5), COGS (COGS1, …, COGS5) and the remaining Income Statement Forecast line items in Appendix 4.

B) Poisson Distribution based simulation

Argumentation For Poisson

Including the Poisson distribution is that it is well suited to estimate the probability of an event occurring during a fixed time period. The time frame is usually an hour, a day, or a week depending on the context and characteristics of the given event. The frequency of the event in question has to be observable for the lambda to be estimated. Due to the lack of historical data available and estimating/guessing the number of batches ordered in the first year seems challenging, the argumentation is that it may be more realistic to estimate the frequency of order batches for a week rather than for a year, based on the vague parameters of the AM market size. The number of powder batch orders can be assumed to be independent during the first couple of years of the business operations.

Argumentation against Poisson

Clearly, the assumption of the frequency of demand for powder batches remains the same throughout each week in a whole year as estimated for a single week is extremely strong or might even be unrealistic. Further, purchase orders for metal powder on a large scale for large companies do not appear just ad-hoc.

However, projecting the demand on the whole AM market and taking the small actors (who probably represent the majority) into account, there could be some reality to estimate the average number of powder batch orders during a week.

Simulation Process

Therefore, a new approach was necessary to elaborate. The production indicators had to be scaled down from yearly to weekly base by dividing them by 44 (assumed number of working weeks in a year on the initial spread sheet).

Stage 1 – Downscaling and weekly demand generation

The maximum value of TOTB is scaled down to a weekly base. Therefore, the following new variables are implemented:

$$WTOTB = \frac{TOTB}{44} = \frac{660}{44} = 15$$

AP (price of different powder types on average) = 25

Based on the same assumption regarding the number of market actors, a sample consisting of 20 random numbers generated (between 0 and WTOTB). Then the random variable using lambda as mean of the random sample is generated. This results in a sequence of weekly "raw" demand estimations, Y. To obtain the weekly average estimated demand, the mean of the sequence is computed, MY.

Stage 2 - Growth Simulation

Since random variable with Poisson distribution is not applicable for growth factor simulation, it has been substituted by a special case of normal distribution (truncated normal distribution). It takes the sd. of the samples described at the relevant section, besides the minimum and maximum limits of those sequences. The result is two sets of growth factors, dividing them by thousand yields the corresponding growth factor one gp1, and two, gp2.

Stage 3 - Implementation of Simulation Results

First year's revenue is calculated as follows:

$$R1 = (CRMAXB \times MY \times AP) \times 44$$

That is, it equals the Maximum Crucible Batches the average weekly demand the average powder price multiplied together and annualized by multiplying the result by 44. Cost of Goods Sold of the first year is

$$COGS1 = \frac{MY}{WTOTP} \times COGSB$$

Revenues had to be scaled up again to a yearly data to be able to plug them into the Income Statement forecast. It makes a crucial difference how SCENARIO is computed here; the yearly SCENARIOs are attained by dividing the yearly revenue by the total revenue. Detailed computation of the annual revenues COGS and scenarios can be found in the appendix 4.

II) Pessimistic Approach

Demand

A random variable with triangular distribution that uses zero as minimum, total producible powder as maximum, and a mode introduced in the assumptions generated.

Growth

For growth factor one a random variable generated with triangular distribution that uses the limits described in the assumption section and a mode that is set to be 0.025. For growth factor two the mode is 0.125. Computation of SCENARIO1 and the growth factors is identical with that of the previously described method of fully random triangular distributions. Further, implementation of the two random variables into the income forecast is also identical therefore not specified here.

III) Optimistic Approach

Identical method with the pessimistic one, the only difference is setting the mode of demand in triangular distribution to three-fourth of the annual powder, and 0.075 for mode of growth factor 1 and 1.175 for mode of growth factor two in the triangular distributions.

Table 4.3 and 4.4 summarises the random distributions

Table 4.3 Random distributions used for demand simulation

DEMAND				
Simulation Type	**Distribution**	**Inputs**		
Fully Random	*Triangular*	min(random)	max(random)	mode(random)
	Poisson	Lambda (random)		
Pessimistic	*Triangular*	0	TOTP	0.25*TOTP
Optimistic	*Triangular*	0	TOTP	0.75*TOTP

Table 4.4 Random distributions used for growth rate

GROWTH FACTOR				
Simulation Type	**Distribution**	**Inputs**		
Fully Random	*Triangular*	min(random)	max(random)	mode(random)
	Truncated Normal	min(random)	max(random)	SD(random)
Pessimistic	*Triangular Y1-Y3*	0	0.1	0.025
	Triangular Y3-Y5	0.1	0.2	0.125
Optimistic	*Triangular Y1-Y3*	0	0.1	0.075
	Triangular Y3-Y5	0.1	0.2	0.175

Following this, an overview of the main approach for demand and growth simulation is provided. The optimistic approach is not detailed due to the identical approach to the pessimistic simulation. Figure 4.3 contains the flow chart describing the main approach for the demand simulation of year 1, while figure 4.4 describes the approach for growth factor simulations.

Figure 4.3 Flow Chart for demand simulation Year 1

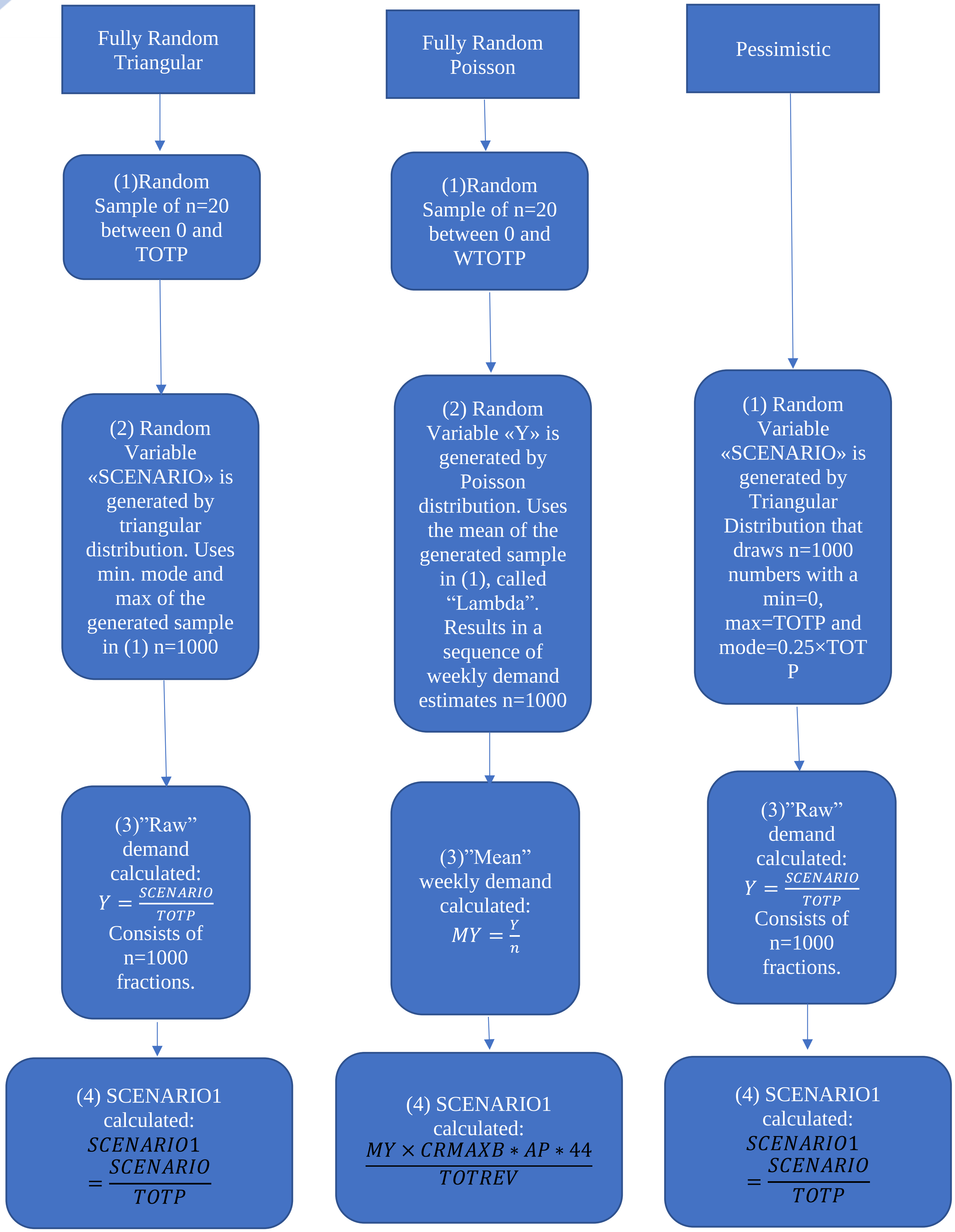
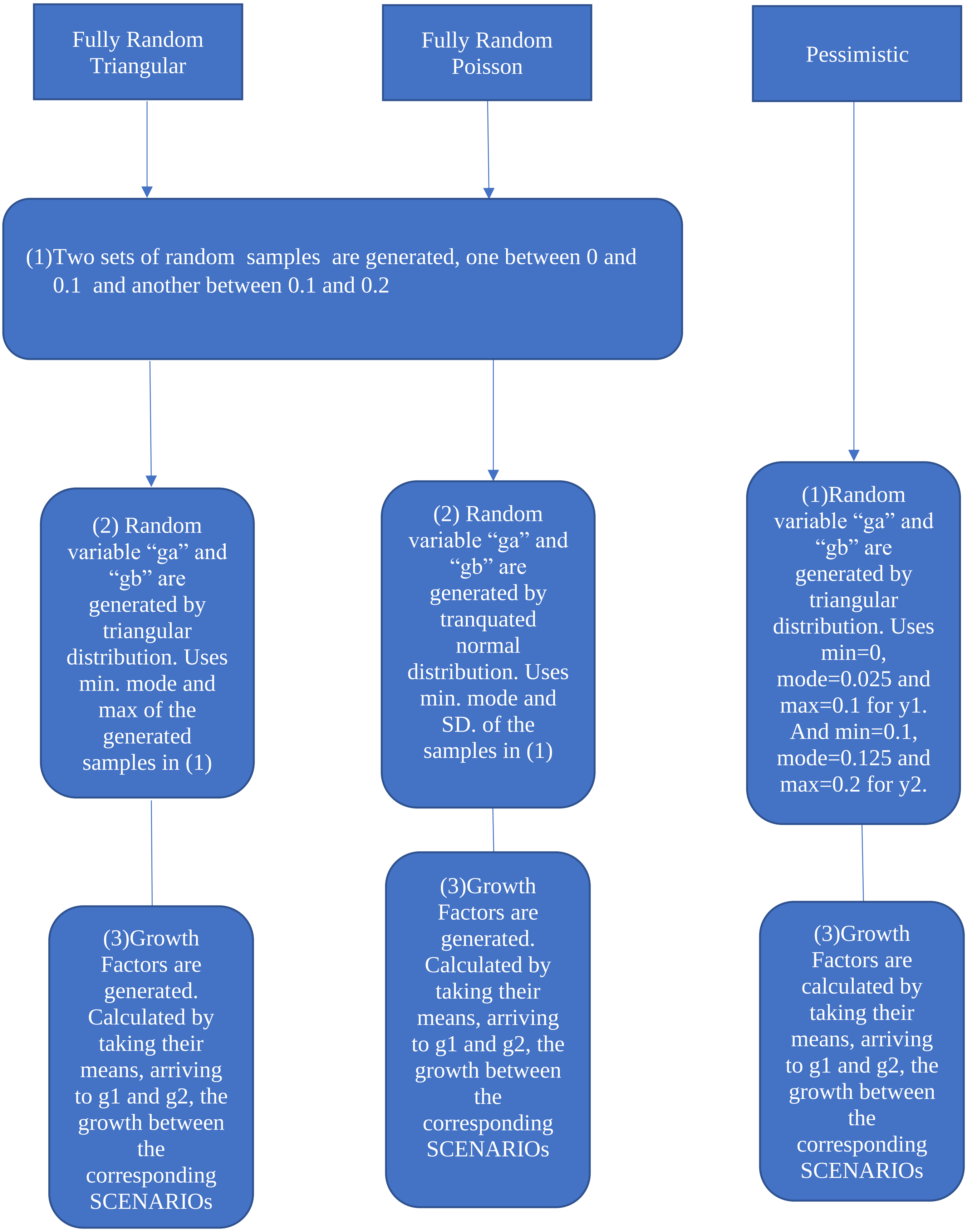


Figure 4.4 Flow Chart for growth factor simulation



5. Literature Analysis

This chapter review research related to the thesis topic. It is divided into a total of 7 sections. The first five sections, 5.1-5.5 present literature corresponding to the primary research question. Section 5.6 address the first additional research question, while the second additional research question is addressed in chapter 5.7. The literature review will in conjunction with the interview sections address these research question. The final research question regarding circular powder production is addressed in its own case study in chapter 8.

A total of 40 papers were examined for this literature analysis, mostly journal articles and some chapters from books. A tabularized summary can of this can be found in appendix 3. The table contains 7 columns. The first column informs about the authors of the article. The second column contains the full title of the of the paper, while the third column contains the published year. The fourth column explains where the paper is from. The fifth column describes what the purpose was the survey. Furthermore, the sixth column tells the methods used in the survey. The last column shows the main findings of the research.

5.1 The Market for Additive Manufacturing

The additive manufacturing technology has captured the imagination of many technology observers and manufacturing professionals (Baumers and Holweg 2019). The interest in AM has seen a large growth the last decade. The research on AM is vast, and the technology is said to signify a new disruptive path on how parts and products will be produced (Godina et al. 2020). AM is frequently referred to as one of the disruptive technologies that are changing the way products are designed and businesses established (Gibson et al. 2019). The economic analysis of AM still is scarce despite of this, especially when looking at the market as a whole. The aim of this research was to highlight the Norwegian market. The limited size of this market has made this challenging. There has not been found any literature specific to the Norwegian market. This subchapter therefore highlights the international manufacturing market, where differences to a Norwegian specific market could occur.

The additive manufacturing market is largely highlighted as a growing market. Numbers from 2011 estimates $1.614 billion in revenue globally in the primary additive manufacturing market (Thomas 2013). Additive manufacturing AM is said to be the technology that revolutionize production operations and flourish in supply chain (Sonar, Khanzode, and Akarte 2020). While additive manufacturing has a large set of advantages, it has not yet quite led to a large-scale adoption of the technology in the global manufacturing market. It does however have the potential of generating a change in the way manufacturing is conceived (Arrizubieta et al. 2020). The April 2012 issue of the Economist billed AM as the production technology of the future and called it “the third industrial revolution" (Huang et al. 2013).

Additive manufacturing was initially considered as an alternative that allowed rapid prototyping of complex parts in the design or early manufacturing stages (Arrizubieta et al. 2020). AM is a developing technology that was launched in the 1980s. Over thirty years into its development, additive manufacturing is now more considered as a mainstream manufacturing process (Huang et al. 2013). Especially the last decade has seen an intense increase in the sales of additive manufacturing (Pannitz and Sehrt 2020). From the emergence of the first Rapid Prototyping system (Schneck et al. 2019), AM technology has been successfully introduced in many industries such as automotive, aerospace, electronics, and medicine (Niaki and Nonino 2017). AM allows manufacturing of complex parts that otherwise would be impossible or too expensive to achieve (Arrizubieta et al. 2020).
The technology still at an early stage however. Although the number of parts manufactured using this technology is growing at a rate of 25% per year, they still comprise a small fraction of the total worldwide production (Arrizubieta et al. 2020). Despite its limited use in the total worldwide production, leading organisations are increasingly investing in R&D activities to better understand AM, its limitations and how to benefit from its potential (Busachi et al. 2018).

Most applications that have been reported use additive manufacturing to produce either customized parts or produce at small scale, while the volume manufacture of standard parts largely remains a conjecture (Baumers and Holweg 2019). The usage of a technology in production is dependent on its profitability, where AM is usually more profitable on smaller scales of production. Some consider business models for additive manufacturing technology to be too immature for large-scale adoption (Godina et al. 2020). The market range of AM is growing however, and is quite prominent in a number of sectors. Colosimo, Cavalli, and Grasso (2020) consider metal AM systems as suitable for not only rapid prototyping, but also for final product manufacturing in various industrial sectors, largely due to continuous technological developments.
One of the most prominent and highlighted sector is the medical sector (Sandström 2015). Sandström (2015) provides an empirical illustration of how and why the industry adopted

3D-Printing for manufacturing purposes. This is done through a specific case on the hearing aid industry. The hearing aid industry is an especial interesting case, because it has already transitioned its operations to using 3D printing (Sandström 2015). The study showed that by replacing hearing aid shell production 3D printing, hearing aid manufacturers could lower their cost significantly, improve quality and decrease return rates. In some cases, cost reductions of up to 75 percent were reported. Due to these cost reductions, the study argues that these incentives to pursue 3D printing are one of the main explanations to why adoption was swift and uniform across the industry. In addition to the hearing aids sector, successful applications have been reported across manufacturing sectors such as footwear and prosthetics (Baumers and Holweg 2019), as well as being used in multiple industry subsectors, including motor vehicles, aerospace, machinery, electronics, and medical products (Derekar 2018; Thomas 2013; Wong and Hernandez 2012). Additive manufacturing was early adopted in the aerospace industry due to its opportunities in manufacturing lighter structures, a common goal in aircraft design. AM is also quite prominent in the automotive industry, due to its advantages in reproducing difficult to find parts, often related to classic cars (Wong and Hernandez 2012).

5.2 Attractive Aspects

Research related to additive manufacturing highlights a multitude of attractive aspects. The benefits of most interest are those that help additive manufacturing be competitive with traditional manufacturing. Post et al. (2016) argues that the increase in productivity coupled with decrease in feedstock and energy costs enables AM to become more competitive with conventional manufacturing processes for many applications. Implementation of AM processes has shown to improve costs in terms of reducing stock levels, logistics cost and component cost (Handal 2017). Studies shows that 3D-printing is likely to be preferred over TM when products have a high level of complexity or customization (Pannitz and Sehrt 2020). Additive manufacturing also enable product agility, so companies that seek competitive advantages should seek product opportunities in multiple regions rather than be locked into one region as is the case with traditional mass manufacturing (Conner et al. 2014).

One of the well-known benefits of additive manufacturing is the option to launch products quickly with no custom tooling requirement, which is an economically advantageous production for smaller production volumes (Nagulpelli, King, and Warsing 2019). Handal (2017) emphasizes the flexibility of manufacturing, and the ability to respond rapidly to market demand. The level of convenience is dependent on how one utilizes these opportunities. The convenience is more evident when the freedom of design is capitalized through a proper redesign, such that one exploit the opportunities of additive manufacturing (Atzeni and Salmi 2012). Through additive techniques, several parts of the same material can be replaced in an integrated assembly, which reduces cost, time and quality problems resulting from assembling (Derekar 2018). Increased design freedom can create performance benefits, while reduced production lead times is beneficial to the after-sales service logistics (Westerweel, Basten, and Houtum 2018). AM technologies enable companies to produce products with a near infinite complexity at a lower cost than conventional manufacturing (Piller et al. 2019). Studies find that estimated manufacturing savings alone from adopting AM ranges from 36% to 46% (Baumers et al. 2017).

Several researchers highlight the absence of physical tooling in particular (Baumers and Holweg 2019; Mellor et al. 2014; Thomas 2013). The absence of physical tooling allows productions of any specific shape without any sort of commitment to machinery. This is by some mentioned as the primary feature of AM, and there is high value in the ability to produce high levels of product variety to a competitive price (Baumers and Holweg 2019). The complexity does not impact the cost in the same way that it does for traditional manufacturing.

This technology eliminates many of the restrictions of "Design for Manufacture and Assembly", enabling new possibilities for customized products at an affordable price (Thomas 2013). Higher geometric complexity on the product leads to a greater comparative advantage for additive manufacturing (Gibson et al. 2019). Customization of healthcare products is a great example of this. AM is widely used to produce customized surgical implants and assistive devices in the healthcare industry (Huang et al. 2013).

A quick response time is also a crucial aspect of AM. On the area of 3D-printing, Berman (2012) finds that 3D-printing entails relatively low fixed costs and is cost effective for small production runs. This is helped by the lessened requirement for expensive tooling, as well as less waste material, ease of product designs and modifications. AM allows factories to quickly adjust their production in order to meet dynamic object demand, without losing profitability, allowing the implementation of more efficient supply chains. (Mashhadi and

Salinas Monroy 2019). Additive manufacturing not only influences the creation and value proposition of companies, but also communication, distribution and capturing value to a greater extent (Godina et al. 2020). Godina et al. (2020) find that additive manufacturers are able to meet the market with better efficiency, higher quality, lower cost and lower delivery time. AM allows for a simplified supply chain that can increase efficiency and responsiveness in demand fulfilment (Huang et al. 2013). Busachi et al. (2018) support that AM can be preferable due to increased availability given a reduced response time, reduced supply chain complexity, reduced platform inventory levels providing more space, and reduced delivery time of the component as the production can be located near to the point of use. To achieve economies of scale, many physical products have previously been manufactured far from the site of end use (Brecher 2015). This can sometimes create high costs for the user of a physical product, due to the delay in acquiring the product. The end-products are often products that are needed as soon as possible. 3D printing shifts production locations closer to customers and leads to free-form product design as well as sustainable manufacturing (Khorram Niaki and Nonino 2017). This allows for faster delivery and more customization options for the end users, as well as containing environmental benefits. Sustainability is also a highly valued aspect of AM. AM is more efficient in terms of material consumption, water usage, as well as producing less pollution (Huang et al. 2013). Waste reduction is also tied to this. AM production uses only the necessary material to produce the required shape, which greatly improve waste management (Godina et al. 2020). Additionally, parts with defects can be completely recycled (Godina et al. 2020).

5.3 Limitations and Technological Barriers

The literature around AM is largely focused on potential limitations and areas it falls short compared to traditional manufacturing. Little focus is shown towards specific barriers to entry into the manufacturing market, and instead more so areas where the technology is inferior to TM. Limitations and barriers to entry are therefore combined in this subchapter, where the two categories largely overlap.

The most prominent limitation when looking at additive manufacturing is its profitability compared to traditional manufacturing methods; starting with lack of available materials, material costs, equipment costs and a limited range of materials (Grujovic et al. 2016). Augustsson and Becevic (2015) investigate the profitability of low turnover spare parts with AM compared to traditional manufacturing. They find that, at best, only one fifth of the sample of 30 products would be considered profitable through AM. Khorram Niaki et al. (2019) studies the sustainability of AM technology with focus on the factors that drive its supposedly superior performance compared to TM. The adoption of rapid prototyping is emphasized in this research. The researchers find that even though AM based prototyping leads to significant cost reductions, in terms of profitability of the investment it is not as good as conventional manufacturing. They also highlight how cost reduction depends on production volume, and payback period depends on the types of materials and scope of AM implementation after having controlled for firm size and experience.

The efficiency of additive manufacturing is also brought up as a potential issue. Metal powders for AM is mentioned to be expensive, in addition to AM being time consuming compared to traditional manufacturing (Fredriksson 2019). AM equipment is also considered an expensive investment. 3D-printers at an entry level averages approximately $5,000 and can go as high as $50,000 for higher-end models, not including the cost of accessories and resins or other operational materials (Huang et al. 2013). These high investments cost subsequently lead to depreciation of machines being a prominent cost. This is highlighted as prominent disadvantages and challenges for AM. Any additional expenses, such as depreciation of machines, maintenance cost and, more significantly, higher prices of the material and machines, need further development to be efficient (Niaki and Nonino 2017). The paper also emphasises the need for post-processing as a challenging aspect.

The technology strength is also brought up as a potential limitation. Berman (2012) highlights how AM technology has higher costs in large production volumes, gives reduced freedom for materials, a limited strength, less resistance to heat and a lower precision relative to other technologies. It is mentioned that these issues, primarily related to cost, accuracy and strength would need to be overcome before this technology can achieve widespread adoption, and is expected to do so in the future. Huang et al. (2013) also bring up the technology strength as a possible limitation, stating that parts produced using AM processes often possess a rough and ribbed surface finish, which results in an end product with an unfinished look.

Another limitation of AM technology is that there is often uncertainty concerning the mechanical properties of such parts (Bikas, Stavropoulos, and Chryssolouris 2016), which in turn may have a large negative effect on the maintenance and repair costs that are incurred over the course of an asset’s lifecycle (Westerweel et al. 2018). Size limitations also come into play, where large-sized objects often are impractical due to the extended amount of time needed to complete the build process (Huang et al. 2013). Traditional manufacturing is usually the preferred option in large scale production, due to AMs per-unit production costs and capacity limitations (Nagulpelli et al. 2019). Lack of knowledge is also a highly noticeable limitation related to AM. A wide range of companies are investigating if AM could bring benefits to their products and processes, but are limited by the lack of internal available knowledge (Schneck et al. 2019).

5.4 Opportunities

A large portion of the literature on additive manufacturing highlights the potential and opportunities this technology possess. Many of these opportunities are tied to overcoming and improving on its own limitations, where the main ones are cost. Additive manufacturing will as mentioned struggle in comparison to traditional manufacturing for regular products and large-scale productions. There are however some areas highlighted where additive have opportunities to combat this. Atzeni and Salmi (2012) highlights how additive technology can be economically convenient and competitive with traditional manufacturing. The potential cost reductions depend on the manufacturers ability to exploit AM potentialities, mainly the modifications of the component shape. A remarkable cost reduction can be obtained if the component shape is modified to exploit AM potentialities (Atzeni and Salmi 2012). While it requires a certain level of design maturity, additive manufacturing is mentioned to have the potential to reduce costs in production, logistics, inventories, and in the development and industrialization of a new product (Godina et al. 2020).

Khorram Niaki and Nonino (2017) identify the impacts of AM in manufacturing. Through a series of semi-structured interviews, their study reveals how the implementation of AM has boosted productivity. Westerweel, Basten, and Houtum (2018) compares AM and TM by demonstrating the production of two system components, with case studies from two different companies. They find that component reliability and production costs are crucial to the success of AM components.

Conner et al. (2014) investigates whether a product should be manufactured by TM or AM. This decision is driven by product complexity, customization, and production volume. The case studies show that 3D printing is likely to be more competitive than conventional manufacturing when it comes to fabricating products with higher levels of complexity, customization, or a combination of both. The material used can be optimized through design modifications, allowing for even stronger and lighter parts (Godina et al. 2020).

There are also opportunities to reduce weight of products, which in turn can lower costs and emissions. Studies of light metal aircraft components compiled have shown that the weight advantages of additive manufacturing compared to conventional vary tremendously depending on the specific geometries (Fredriksson 2019). Transport is closely tied to costs and emissions. Transport is closely tied to costs and emissions. The possibility of producing locally at a reduced cost is transformation of the current supply chain, where the transport needs can be greatly reduced (Godina et al. 2020). Local production might also promote innovation, new job opportunities and enable more customization tailored to the end-user (Fredriksson 2019).

Researchers also point to the potential for a digital market. Mashhadi and Salinas Monroy (2019) propose an AM Cloud, where micro-manufacturers can pool their resources and offer them in an on-demand and pay-per-use basis. This is in turn expected to facilitate the adoption of simplified supply chains. By aggregating the manufacturing resources, the AM Cloud can fulfil large orders that no micro-manufacturer could have fulfilled on its own, in addition to the possibilities to quickly scale the overall production in order to meet dynamic demand (Mashhadi and Salinas Monroy 2019). Some expect that a significant number of small/ medium enterprises will share AM production by 2030 (Li et al. 2019). As the costs of additive manufacturing systems decrease, this technology may change the way that consumers interact with producers (Grujovic et al. 2016; Thomas 2013). AM has great opportunities in responding to a dynamic demand. Due to its ability to build a wide variety of objects, 3D-printers can offer a per-unit production cost that is mostly independent of the volume of production (Mashhadi and Salinas Monroy 2019).

AM versus TM is a theme that is brought up when discussing the viability of the technology. AM doesn’t necessarily need to be a direct competitor to TM however. It is unlikely that AM technology will make traditional manufacturing processes obsolete. It is however reasonable to expect that AM processes will play an increasingly important role in manufacturing as a complementing technology (Huang et al. 2013). AM is as mentioned likely to be more competitive than conventional manufacturing when it comes to fabricating products with higher levels of complexity, customization, or a combination of both (Conner et al. 2014). A higher expertise on product design will give AM more production areas where its superior to TM. This points to the opportunities in conscious use of AM as a complementary technology. Nagulpelli, King, and Warsing (2019) highlights profit opportunities from a mixture of AM and TM. The research emphasize how AM is more effectively used as a support to the current manufacturing environment. As stated, “Only when diligent effort is made towards operating efficiently will industry be able to experience the full breadth of benefits and capabilities AM technology has to offer in addition to an existing TM production environment” (Nagulpelli et al. 2019). Due to the continuous and increasing growth experienced and the successful results up to date, there is optimism that additive manufacturing has a significant place in the future of manufacturing (Schneck et al. 2019; Wong and Hernandez 2012).

5.5 Research on Costs Factors

The adoption of AM technology heavily depends on its profitability in the current market. This area has naturally been the target for much research on AM. Costs are a key factor to analyse the economic viability of technology or product in decision making (Godina et al. 2020). Knowledge on cost drivers is essential for ensuring the profitability of a market.

Case studies on the economics of AM suggest that processing time is the dominant cost in manufacturing (Post et al. 2016). As with all new production’s method, production cost is usually high early on due to underdeveloped technology, a problem that decrease over time as technology and machine experience improves. Widespread adoption of a technology is often hampered by economics and the lack of existing supply chains, but additive manufacturing has the potential to overcome this roadblock (Manoharan et al. 2019). Baumers et al. (2016) supports these finding. Through their research they attempt to answer how the cost structure associated with AM affect the development, future diffusion and wider societal impact of the technology. Their model suggests that machine productivity is a main cost, and further highlights that this could be considered as a general cost barrier for the technology to diffuse into mainstream manufacturing. While this is the case, some expect that further developments will enable significant improvements in system productivity and thereby reduce unit costs (Baumers et al. 2016).

In addition to machine productivity, Manogharan, Wysk, and Harrysson (2016) find that batch size and AM processing-costs are the major cost factors in AM. Atzeni and Salmi (2012) expand on this by also including machine cost per part as the major term of cost;

while other cost factors affect the total cost less. Atzeni and Salmi (2012) find that the AM technology is penalized by not only the high cost for materials, but also the high cost of AM machines. They are hopeful that a more widespread adoption of AM production will lead to a decrease investment costs. A sensitivity analysis support that the raw material and initial investments on hardware and software are the main cost drivers in AM (Yang and Li 2018).

5.6 Relevant Scale of Production

Another relevant focus of research was the relevant scales of production for additive manufacturing. There is a general consensus within the literature that AM relevant for small production runs. Production cost for AM is lower when there are small batches of manufacturing compared to TM (Handal 2017). Handal (2017) also highlights how additive manufacturing technology is not always the best manufacturing system to be used when it comes to the product type and the value of its components. Their framework recommends implementing additive manufacturing when the product is complex and formed by high value components. Mass production is not considered feasible due to the time and energy consumption in additive manufacturing. Although additive manufacturing allows the manufacture of increasingly complex parts, the slow print speed of additive manufacturing systems limits their use for mass production (Thomas 2013). In the short term, specialized geometries and small-scale production will be more feasible (Fredriksson 2019). AM is not only considered not capable of competing with TM in mass production but also is not suitable for large scale production (Khorram Niaki et al. 2019). Most reported applications use additive manufacturing to produce customized parts or produce at small scale (Baumers and Holweg 2019). Atzeni and Salmi (2012) however is more optimistic on large scale production within AM. Their expectations are that once AM technologies is a more common production process, a decreased system cost could move AM towards production of larger volumes.

5.7 The Greenness of the AM

Another secondary research question was directed towards the greenness of additive manufacturing. This seems to be one of the most attractive aspects with additive manufacturing. This subchapter aims to provide insight into environmental benefits and negatives as a result of AM. This is a relevant topic area in the literature. Lately, there's been important progress in this area, with an increasing number of papers that cover environmental aspects, including circular economy, recycling and the life cycle assessment of materials (Colorado et al. 2020). In the last decades, efficient use of resources and environmental awareness has increased. Sustainable manufacturing has attracted increasing attention, and manufacturing processes nowadays must ensure a minimum environmental impact (Arrizubieta et al. 2020).

There are many arguments that support the greenness of AM, and several researchers (Arrizubieta et al. 2020; Colorado et al. 2020; Godina et al. 2020) appear to consider AM as a green manufacturing alternative. Godina et al. (2020) highlights the importance of understanding the potential environmental harms of additive manufacturing. As stated, "Achieving a manufacturing method that increasingly is less environmentally harmful than conventional manufacturing is one of the pillars of the newer sustainable business models" (Godina et al. 2020). They find two key elements that point towards AM being considered an environmentally friendly technology; waste reduction and transport. Additive manufacturing reduces waste by only employing the necessary amount of material when adding layer by layer (Godina et al. 2020). The opportunities to recycle is also relevant to this, especially plastic waste. The second key point highlighted is tied to accessibility, where production in-house or close to the use site lead to reduced travel emissions and costs (Godina et al. 2020). The increasing attention to the sustainability of AM suggests that reuse and recycling of materials will be improved in the near future (Colorado et al. 2020).

Arrizubieta et al. (2020) focuses on the implications of use of metallic powder in AM processes, and the following waste management. Their research pays special attention paid to the health risks derived from the high concentrations of certain chemical compounds existing in the typically employed materials. AM processes are shown to reduce the environmental impact compared to traditional processes, due to the mentioned more efficient use of raw materials. Arrizubieta et al. (2020) raise the point that for AM to be considered a fully environmentally friendly technology, it is also necessary to make efficient use of energy, manage industrial waste, minimize emissions and toxic materials (Arrizubieta et al. 2020). A smaller but somewhat relevant factor in sustainability is the improved life cycle of products through AM. Godina et al. (2020) highlights how a product comprised with several pieces made through traditional methods struggle with damaged part. When one of the parts are damage, generally a new product must be purchased (Godina et al. 2020). Contrary to this, additive manufacturing allows production of isolated parts, which can extend the life cycle of the product (Godina et al. 2020). This is more common for plastic AM products, but more and more researchers are exploring the opportunities in recycling metal powders. Aspects such as possibilities to create lighter parts can also be considered. Lighter parts affects the use of the object, for example through reduced fuel consumption and the emissions caused by it (Godina et al. 2020).

While there are arguments towards the greenness of the technology, most researcher are not willing to explicitly call it green. Although light weighting in the (expanding) transport and aerospace sectors will reduce fuel consumption and therefore CO2-emissions, it will not alone be enough to meet international targets for reduction of greenhouse gases, such as the Paris agreement (Fredriksson 2019). Fraţila and Rotaru (2017) find positive results indicating that AM technology has the potential to lower costs and to be more energy efficient than conventional processes. Despite of this, the possibility for the opposite is also found. The energy required in AM processes can outweigh the savings in materials used in the process. They press that the energy efficiency of AM is dependent on several variables, including materials, load and patterns used. Although Arrizubieta et al. (2020) would consider AM as an environmentally friendly technology, they stress that further studies are required to make a definitive more statement.

The main arguments against AM as a green technology refers back to the production of AM feedstock and its negative effects. With an increased powder use in additive manufacturing, Fredriksson (2019) raises concerns that metal powders for AM are expensive and that AM is time consuming compared to traditional manufacturing. As stated, "The powder use in AM leads to increased energy need in the manufacturing stage, due to energy intense powders, and laser/EBM equipment, which is also usually related to higher CO2-emissions" (Fredriksson 2019). A significant amount of energy is required to produce AM powder. There are opinions that this can be recovered from other stages of production. Through designs such as hollow products, AM has the opportunity to reduce weight of products, which can lower costs and emissions (Fredriksson 2019). Waste may also be reduced depending on the case (Godina et al. 2020).

6. Interview Analysis

This chapter will present and analyse data received from respondents through the conducted interviews. The chapter consists of eight main sections, which further contains smaller subsections discussing that particular area of research. The first chapter, 6.1, provides an overview of interview informants. This overview contains their job title, relevancy to AM and the abbreviations use to refer to each respondent. Chapters 6.2 – 6.5, in addition to 6.8, address the primary research question on the Norwegian AM market. Chapter 6.6 corresponds to the first additional research question regarding production size, while chapter 6.7 is targeted towards the second additional research question on greenness.

6.1 Overview of Informants

As mentioned, a total of 9 companies were interviewed for this research. While the informants are to remain anonymous, a brief overview of their title and relation to AM is provided in table 6.1. The table also contains the abbreviations used when referring to each informant.

Table 6.1 Overview of interview informants

Job title/ role of informant	Relation to AM	Abbreviations
Engineer	Academic specialist	A1
CTO	Research and Innovation	R1
Sales Manager	AM producer	P1
CTO	AM producer	P2
Head of Department	AM producer	P3
AM specialist	AM customer	C1
Engineer	AM customer	C2
CEO	Market partner	M1
CEO	Market partner	M2

6.2 Looking at the Norwegian AM market

This subchapter addresses the present-day circumstances on the Norwegian and International AM market based on the insights received from the interviewees.

6.2.1 Technological Strength

All together 4 informants (A1, P2, P3, M2) provided a confirmative response to technological strength. As explained by from an academic specialist, the technology is available for the interested and it is strong enough, it's tried out, tested and analysed for many years. Two producers let us know that the technology itself is getting really good and the parts that are produced now are remarkably better than those produced five or ten years ago.

> *"All the technology is there, it's ready, its strong enough, it's been tested and analysed for many years, it works. "(A1)*

6.2.2 Technology Maturity

Even though the technology is strong and is available, six of the informants agree that it is in its infancy, meaning only a handful of producers and suppliers are present in the market. It is still too early; the technology is still a bit unknown. As one of the Market Partners confirms, plastic printing has been present for some time, but there are not so many metal-printed parts in the market. This is reflected when oil and gas producers' AM production volume is compared to other international industries' production scale in aerospace or medical use.

> *"It is a growing industry which needs to set its standards" (P1)*

An informant gives insight for a likely reason why AM is not widespread in the (oil and gas) industry yet:

> *"...the large part of our industry is linked to oil and gas normally, and when you then look back at the oil and gas crisis and declining prices... you don't have a lot of R&D either, so it's sort of on a decline as well. Probably others will say different from my point of view, but from what I've experienced 2008-2009-2010 you saw a peak in the increase in industrial implementation of AM. So, if you match that with the numbers for financial crisis and actually oil and gas then that's not the best period to buy a lot of machines and start testing. You have to be rather big to do so. Probably some different reasons on the interest point." (M1)*

Still, as an interviewee sheds light on,

> *"AM has gained more and more attention also in Norway, which is also the trend globally obviously" (R1)*

6.2.3 Future Expectations for Market and Technology

Future expectations about AM are bright in terms of technology implementations and usage but are somewhat ambiguous regarding the market, according to the majority of informants. The technological improvements are expected to reduce lead time, increase efficiency, longer lifetime on products, more extensive use of digital inventories/files, etc. Market conditions are more challenging to predict, market actors like start-ups and young firms need to consolidate, some will obviously fall out in the competition, and

> *"The market leaders will remain and a larger part of the overall market".* The same informant sums it up all as *"But I expect that there will be increase in use and increase in acquisition of machines and increase in focus on recruiting and building competence level, academia and institutions etc." (M1)*

An informant provided a somewhat more detailed prediction regarding time horizon and suggests that *"It will start... takes off in 2025 in my opinion." (M2)*

Expectations from interest groups like potential customers and others generally interested in AM are expressed by an expert as

> *"There has been a lot of talk about AM, would say hype, if you go back a few years and there has been a belief that AM will revolutionise the industry, and will disrupt and will change. That hasn't happened and having worked with this for the last four years it doesn't seem like it's going to happen any time soon and like with any other industry you should be careful about talking about disruption and revolutions. It's usually more of a question of evolution, right?" (R1)*

6.2.4 Present-day Producer Experience in the Market

As an informant points out

> *"Experience and knowledge go hand in hand but it's not the same. A lot of people learn how a 3D printer works, and that something you google and all that and that's ok. But you need the experience and you need to design from bottom up and think about how you can make a part for AM" (A1) Trial and error is an inevitable part of gaining experience and master the knowledge one has learned in theory; the focus has been on developing, researching and producing perfect parts, but not on gaining a lot of experience by failing." (A1)*

Two of the informants highlight the importance of guiding and advising the suppliers and producers when evaluating the opportunities of 3D printing a part and helping them within IP rights, drawings and the related administration/bureaucracy.

One of the biggest actors in Norway has been around for 10 years, invested in their first AM machine in 2011 and in the second one in 2017.

6.2.5 Substitution or Complementary Technology?

As it is mentioned with expectations regarding the AM technology, transition from TM to AM is not a drastic and spectacular "revolution" but rather a slow evolution. Experts (A1, R1) agree upon the fact that there is never going to be a substitution of TM with AM, but the two production methods will reach an optimum balance. When and on what scale it is supposed to happen there are different opinions about. Some of the experts project the proportion for AM printed parts to be 1% in the whole production at the best-case scenario. There are parts that just do not make any sense to produce with AM, and this recognition is essential for the industry to function flawlessly; for some parts the TM methods like casting, moulding etc are just the perfect solutions. To sum it all up,

> *"…some of the things that are done by other technologies today will definitely be done by AM but it's not like it will take over for everything else." (R1)*

6.2.6 International Situation

We get a picture of a much more developed and mature international industry from the interviewees. One of them inform about that the AM industry is foremost in Europe with Germany and Centre Europe being the leading region/edge, China is copying the technology and the U.S is making its way by building up their separate leg in this. Regarding the biggest players on the market, we learn from an informant that

> *"These recent years you've had a shift where you don't have the special small companies that no one has heard of.. its GE, Xerox, HP.. the big players, and they know how the industry work. That's just something that's happened the last few years."(A1)*

Globally three industries are leading when it comes to AM, aerospace automotive and medical. Norway is lagging, but oil and gas is expected to grow in the near future.

6.2.7 Market Interest

This factor was mentioned only by a few actors, still it is important enough to be mentioned separately. Market interest in AM technology has been growing fast in the oil and gas industry - among others - as two market actors pointed out.

> *"There is definitely a lot of interest within the oil and gas, so we see that coming down quite fast. There is a clear value proposition toward supporting and improving the supply chain, both in future projects but also late life projects. So, one is for reducing the CAPEX side and reducing the volume of parts being bought and the other side is obviously sort of obsolescence late life problematics" (M1)*

Investments are growing, some start-ups have invested in AM factories, *"everybody see the benefit, everybody has the technology" (M2)*

6.2.8 Attitude Among Market Participants

Attitude of market actors in Norway is passive or rather confirmation seeking by already successful firms, as interpreted by an informant. It seems like Norway is re-discovering the AM processes again while the rest of the world has started to apply this technology. Also, production has been outsourced so manufacturing does not belong to the leading industries anymore, as in a large part of Europe.

"Manufacturing entities would sort of be a first step to introduce this technology and find values and that industry seems to be in a decline and has been in a decline for many years." (M1)

Customer attitude in oil and gas/offshore has been described by 2 informants as rather sceptical,

"3-4 years back in time, at least in oil and gas industry, because we are careful, we have a lot of people to turn to get allowed to use AM repair or Am manufactured parts, because they're "no, it can't be strong enough, no it's not good enough" and you can give them whatever paperwork and they still not … they still not believe it, even if they see and feel a part is AM produced, they can't believe it's AM produced, it's just "not"…"

Some market actors/participants are still not willing to consider the AM technology as a strong production method; two of the informants complain about it:

"But the issue is the market as X is saying that is also something that we see when we talk to companies. They are thinking of additive as a weak alternative to other production methods" (P2, P3)

6.2.9 Market competence

Competence regarding AM in the Norwegian industry is described as weak with low knowledge levels of AM.

"We find the competence of additive manufacturing in a Norwegian industry as rather weak. Low knowledge (of AM), (producers/customers) don't know the benefits of it.. *Of course you have companies that have a higher level of education in additive manufacturing, but generally in the Norwegian industry (there is) low knowledge, and ("they") don't know the benefits of taking this technology and to increase the knowledge in the Norwegian industry." (P2, P3)*

Another informant has the following opinion on customer and producer competence

> *"They don't know that they can be a customer, they don't know if they have the products, they don't know if they can strengthen their position to increase the production of their products – lower the cost – stronger products and these things.* So, *the knowledge in the industry on the engineering side is quite low.* So, *they don't know the benefits of using this additive technology. " (P2, P3)*

In order to improve the *c*ompetence level in the market, some companies are preparing to provide education and training.

6.2.10 Market Conditions

Market conditions in Norway for AM is still a challenge, a researcher lets us know that for equipment and for particular level of precision one still needs to turn to the international market, to Sweden, Netherland, Germany, Spain etc. (P1) Domestic conditions are gradually/slowly developing though. When it comes to customers' order size, one of the biggest producers wants only large orders of big parts for instance. Another big company is a bit more flexible regarding order batches, but they have big overhead costs and that drives the prices up. Small producers that utilise AM are often able to offer their products for half the price of those of the bigger producers, if not two-third of their prices. It is still difficult to figure out how to run the AM business profitable as an expert/Market Partner reflects on it: *"It's difficult to find out how we could make money out of it." (M2)*

6.2.11 Digital Inventory

Even though this factor did not emerge often during the interviews, it is a technology that is frequently mentioned together with am, often in the form of industry 4.0, etc.
Regarding digital inventories, there already exist market participant with exclusively drawing calculating and modelling in their profile. As an expert puts it,

> *"… and that's also something new that's coming now with AM rolling in Norway." (Engineer, AM Specialist). "Digital warehouses are the future of inventory; physical stock levels are expected to be almost eliminated. It may go into digital warehouse on the long run it will be cost saving; instead of having in stock." (A1), (C1)*

6.2.12 Communication

Both the Engineer and the AM Specialists point out the importance of good communication flow and trust between market participants is crucial to build up the industry. Glitches in the supply chain and part testing may have irreversible consequences like accidents and when happening offshore in oil and gas, it may lead to eliminating a supplier from “the list”. Therefore, following standards and regulation is crucial.

6.3 Attractive Aspects

6.3.1 Design Freedom

Design freedom was the most prominent when looking at attractive aspects related to additive manufacturing. Most respondents had it as their first mentioned benefit, and every respondent touched on the subject on way or another. The design freedom that one gets through additive manufacturing really shines whenever a part is complex and difficult to produce through regular machining. The interviewees highlighted the design freedom as an especially strong benefit in the areas where parts would normally not be produced with other methods. To quote:

> *"The first thing that additive normally is recognized for is the design freedom. You have a much larger design freedom compared to other manufacturing methods". (P2)*

Another respondent, R1, highlighted that it gives a massive benefit in cases where it couldn’t be made otherwise, in addition that it can also be more cost effective. In other production methods like casting for example, there is a need for more tools and moulds, which are often expensive. Additive manufacturing enables one to skip the need for new tools and developing moulds for different products, in addition to providing the opportunities for product optimization that other manufacturing methods doesn’t.

The design freedom was mostly brought up by the AM producers and other market partners / expert. Interestingly enough, the potential customers had more of a focus on the environmental and what good use they could make out of the technology. The design details, customisation options and product optimization advantages were mostly reserved to those that produced the product, not necessarily as much of a concern from those that would use the products.

6.3.2 Tooling Investments

Strongly tied with the design freedom is the reduced investment in tools. This point was highlighted by 4 of the respondents. Additive manufacturing enables one to print directly rather than investing in tools, moulds and such. This is an attractive aspect in the sense that it enables a produce instantly, and that you don't have the same start-up costs as other technologies. It's also considered a benefit due to the flexibility that the reduced tooling investment enables. One can swap from producing on type of product to another without having to change moulds or construct new ones.

6.3.3 Material Savings

Another often mentioned benefit with AM, was the material savings. AM has the added benefit where you don't use more material than necessary. It is quite resource efficient in this sense. 5 out of 9 respondents referred to the reduced materials use as a big benefit, both from a cost point of view but also in terms of a more environmentally friendly technology.

6.3.4 Reduced Stock

Reduced need for stock was mentioned surprisingly little during the interviews. This benefit was only mentioned by 2 of the market partners, and none of the potential customers pointed to this. The argument towards reduced stock put emphasis on how you could get away with having a significant smaller number of parts ready. One of the respondents indicated a belief that large costs could be saved from reduced stock alone and highlighted that this was probably one of the main reasons for large corporation's interest in additive manufacturing and other forms for digital transformation. Both respondents touched on the possibilities of digital transformation, and one of them quotes: "We are going to send files instead of parts around the world".

6.3.5 Quick Production

AM also have the added benefit that it allows quicker production compared to other production methods. This point was brought up by 4 of the companies involved in the study, both producers and potential customers. This lies in the fact that you are not required to put up a specific production line and make jigs to produce different products.

The potential customers brought up this as probably one of their main perceived benefits, the delivery time. The delivery time for AM in the oil and gas sector is usually 1/10th of the waiting time, according to one customer.

6.4 Barriers to Entry

6.4.1 Knowledge and Experience

This factor is related to the earlier discussed “Market Competence” factor. The difference is that the previous chapter discussed competence of the market actors, here the market actor experience and knowledge level of market actors are in the focus.

All informants have agreed that the main barrier to entry is the lack of knowledge of the market participants. Lack of knowledge and information on standards, advantages and limitations, what AM is really useful for and for what it is absolutely not. As highlighted by an Academic, lack of experience is tied to lack of information and knowledge:

> *“An overall lack of experience: Is it something that will stay in stock, how is the demand, how many, will it be more cost effective if you make a better design for AM. So, it’s kind of a complicated one. It’s not rocket science, but it’s something that you acquire over time like experience” (A1)*

Insecure/uneducated or overconfident customer order placements lead to very expensive manufacturing results that may lead to disappointment and frustrations:

> *“And that’s because the confidence of the people working in the industry. Because you can't take a part and say, "can you print this and it will be cheaper and stronger", (P2, P3)*

Another producer explains

> *“Because the people don’t know the … how expensive it is. Most of the people think that “oh it’s just to put it in the machine and it goes by themselves”, but there is a lot of work around it and very often the machines go for 24, 48, 96 hours or something. like that then it gets expensive. And people don’t know that before we explain them.” (P1)*

An expert/Market Partner just sums it up and says

> *"Not to be negative, but it's too immature. So, it's a lack of ordering competence and a lack of receiving competence... so, it's not ... there is a lot of entities that are trying to get going early on, so that is sort of a disturbance because it creates expectations which can't be met, and it creates misleading information or knowledge so that sort of needs to be ... take a few steps forward. It's a child sickness sort of. "(M1)*

6.4.2 Lack of Standards

Challenges regarding standardisation in the AM industry as a barrier to entry are emphasised by three informants. There are standards in the industry but as a market actor/partner explains, the problem is the lagging implementation. As we learn it from the Academic, proper standards were developed for oil and gas last year, so there is development there obviously.

> *"And with that the requirements that we add to this in terms of quality insurance, quality control... which is not resource efficient at all is a big challenge. So we need to sort of have standards and procedures that are fitting to the technology and what we can derive from it." (M1)*

> *"Of course, there are standards out there and there is a lag in implementation of standards. So, that's a challenge. This needs to sort of be implemented and accepted / utilized, but those solution also need to be ... those standards also need to evolve in the sense of "what are we trying to control and what can we derive this in a smarter and better way". "(M1)*

> *"Another thing is that because it's such a new technology and being used increasingly now but less in the past... there is much less standardization and "trust" from the industry in this technology if you compare to casting or machining where you have a large history of data that you can compare everything to." (P2, P3)*

6.4.3 Price Competitiveness

Observed price or being too expensive technology was also mentioned as barrier to entry by some informants. Raw material prices vary largely depending on if the powder is certified or not. Certified powders from EU, that are tested out and are compatible with the producers AM machines are much more expensive than non-certified powders.

> *"We are mostly buying powder from EUS the machine producer. Because than we can have the certificates and so on because they test all the powder, they send out on exactly the same machine as we have. I think we can have it for 150 euro, 120-150 from other powder producers, but we can't use it, they can't give a certificate and then it's not good enough for us." (P1)*

The other price related barrier is tied to information as described in the previous knowledge/information factor; customers may have completely unrealistic expectations when placing an order. TM production method is still much cheaper, if a part has been produced by casting, moulding etc. the same part is going to cost much more to print based on redesigning the part.

> *"To get the big big business in AM, it's the price, and it's not well enough … it's not known good enough in Norway. We see that 70%-80% of request we have for metal printing, it's much cheaper to do in the machining." (P1)*

> *"And then there are also some barriers that has been you know criticised the industry that it's too expensive. Talked about (it) before you have a part you have… are producing with casting or machining for anyone to 3D print it most likely that it would be way more expensive with 3D printing because it's not designed for 3D printing." (R1)*

6.4.4 Few Producers, Low Demand and Slow Product Development

A producer highlights that there are not enough producers in the market yet. If the supply was larger producers would be able to reach out to a much bigger range of customers.

> *"There are too few producers for metal parts in AM in Norway. There should have been 15 companies. Then we (would) have reached out to a big*

amount of customers. Uhm I am not afraid of competition here. I just want to have a lot of companies that offer 3D printing." (P1)

Low demand levels mean less machine hours and that is a problem when compared to high investment costs, as the same producer highlights.

> *"If we had enough work so the machine could go for 24/7 365 days the investment cost would not be a problem. But we, as the situation is now has been for several years, we have machines go 40% I think and 60% stands still." (P1)*

Slow pace of product development and hindered communication based on it is a limitation as a producer tells us in a "story",

> *"But we have used four years since they asked us first time. And we have been ... we are talking I don't know how many times with the customer, it's a lot of times, but now we have a good product, and we have started to produce it. And, we are waiting a lot of business in this product. We also have another product for another big customer, that we hope we go the same way but that started four years ago. It takes so long time from we start to discuss it with the customer to actually the big order come." (P1)*

6.4.5 Investment Costs

The other barrier to entry that has been mentioned by each of the informants is investment costs. AM machines are expensive, and there are costs that are tied to the investment such as education and training of the employees, and there are costs related to failure/error.

> *"For sure the number 1 is down-payment of the machine based on investment cost. That's also because the technology is constantly improving, it's constantly getting better since it's such a new technology, so we need to calculate the lifetime of the machine as much shorter than if you get machining for example. So, because the machining is improving so rapidly, we need to pay of the machine quicker, which drives up the cost." (P2, P3)*

The AM technology changes rapidly, and the recent improvements are impressive. This is very positive technology wise, but it is pushing up the costs and prices a lot before it stabilises. It leads to a faster pace of down payments which also drives up the costs.

6.4.6 Co-operation Challenges between Producers and Consumers

As we learn it from a few experts, entering the Norwegian industry is challenging because the market actors/producers don't want to share the products/technologies that they have, there should be a more open communication about their concerns. There is a need for agreements about "no trespassing" private areas/technologies/patents. As the interviewees inform us,

> *"When we come under the skin of companies it's much better. Then they trust us and can see the benefits, then it's easier. But the step into the companies is one thing and then we have barriers inside these companies, with engineers doing this... and they have a lot of power, so if they don't look into this as a good opportunity, then it comes to nothing. But if the engineer sees it, then you are not trespassing into the industry and it's easier to find the way into the company and find the products that we are going to develop and strengthen the company. "(C1), (C2)*

6.5 Limitations

6.5.1 Cost Inefficiency

Cost efficiency is mentioned by the majority of the informants as one of the dominant limitations of AM.

> *"If you have a normal part; pipe, plate.. people start printing that and it's just such a waste it's something you can go to your nearest dealer and buy very cheap and good. Aka: not cost efficient. "(M1)*

As it has been mentioned under the factor "investment costs" in Barriers to entry, high investment costs make it crucial for the producer to bring up production levels to a level where the investments are mainly covered. Till that point it is a "hefty project". TM is still cheaper, and with digital inventory one could still produce the part by machining.

"Because you could also machine probably if you do it the same, if you have a digital inventory, you could also do it by machining, you could have the same philosophy with the machining, you will have a little bit more waste but if you find a way to recycle the waste then you are also ok with doing it machine" (M2)

Cheap parts that are not complex enough, meaning that they are built with less than 18-19 phases, simple parts, are not cost efficient to produce as the two customers (C1, C2) complain about it.

6.5.2 Unrealistic Potential Customer Expectations

Customers' unrealistic expectations from AM can mean a limitation/barrier on producers' capacity.

"they want to produce parts as spare parts very quick. And, so they can build down their stock. We have to be honest and say that we don't believe it will work that way they say, maybe 20 years from now but, at the moment there is so many challenge with that. " (P1)

6.5.3 Time Efficiency

Regarding time efficiency as limitation opinions are different. All the producers claim that AM still takes too long time

"We had to make the parts, but it takes too long time" (P1) and "Yeah it is, and I mean production rate as well could be a limitation as well." (P2, P3)

On the other hand, an expert/researcher on AM means that it only takes long time, because the part was designed for TM technologies not for AM, hence the part to be made has to be redesigned. At this point we are back to the problems with not adequate information/knowledge on the potential customer side.

"And there is also another myth that it's too slow… And again, it can be if you come with a big bulky chunky part there you used a machine and want

to print it, yes, then it's very slow because your part is not made for AM." (R1)

6.5.4 Manual Post-Production Labour

Manual post-production procedures are related to cost efficiency but since it is referred to and stressed by all our informants frequently, it is discussed as a separate factor/category.

Post-production processes include all the procedures that come after removing the printed part from the machine. Such procedures are removal of the support structure, machining uneven or porous or rough surfaces etc. These procedures are very human labour intensive and increase production costs and product prices tremendously.

> *"After the process when we take the parts out of the printer there is always need for some sort of post processing. And it starts actually with removing the supports, then there might be some - which is usually manual – and there might be some surface finishing, because the surface has certain roughness maybe that's not good enough for your product, so you need to do some surface treatment or some post-machining or something like that to make it fit together with whatever part it needs to fit with." (R1)*

Support structure is not only affecting post production but since it is made of the same material (powder) as the part itself, support structure increases material cost as well.

> *"And, sometimes we got parts that is not … you have not thought good enough of the construction, and we put on support, and … if we don't need a support the part will cost 2000,- crowns, with the support it will cost 5000, because the more printing of support, then it's Parts shall use. SO, that's a cost problem." (P1)*

6.5.5 Design Requirements

Among design requirements the design of support structure is frequently referred to. As we learn from a producer, a general/overall design requirement is that if the angle of hangover is larger than 45 degrees, the part needs a support structure. As mentioned in the previous factor, support structures are printed from the same material as the part itself, therefore it is crucial to minimise/optimise its dimensions. With good design skills it is sometimes feasible to include the structure in the part itself such that it does not have to be removed.

> *"And, also this Support, if you build more than a hangover more than 45 degrees, you must have support. And, if you are good at designing the parts, you actually design the part with a support as a part of the parts. So, you do not have to remove it. But the more support you have, the more expensive will the part be." (P1)*

Another expert puts it as,

> *"Sometimes that's not possible to remove it than you need to redesign your part, so that you either don't have support structure or that in a way that you could remove the support structure. SO, the support structure is necessary when we talk about metal AM, and that can be a limitation." (R1)*

It is not only the support structure that has to be designed effectively, as another expert/Market Participant points out the whole building process/method has to be designed smartly:

> *"Yeah, you need a design, you need to know the method how they are going to print it, size of the printer... if you have that, then you need the design. But so, you could use the same design in different printers but you … I mean methods, how you print it need to be there, the size of the printing plates needs more or less similar, so … Yeah, but you cannot design parts and produce it in 316 and duplex. That's impossible. You need to have one design for 316 and design in a different way for duplex." (M2)*

6.5.6 High technical Qualification Requirements

Highly related to the same factor in "Barriers to entry". The limited availability of competent and experienced personnel has been highlighted by a Market Partner/Participant.

"Having access to and being able to recruit personnel, have expertise within this field, is obviously a downside, which is normal in a new technology... scarce resource." (M1)

6.5.7 Volume of Parts

Size as limitation was mentioned by a researcher and two producers. Building volume and part size and dimensions are limitations of AM. As the expert sums it all up,

*"When we are talking about these technologies that we can make these on, we are talking about relatively small build envelope and the machines that we see in the market they have a build chamber that is roughly 30 cm * 30 cm * 30 cm. So, that size is obviously a limitation." (R1)*

6.5.8 Collateral Expenses

As a producer claims, the documentation has a huge impact on many of the products that they are producing. If a functioning part that's going to be printed one needs some sort of certificate on that particular part. This is quite expensive at the moment, and usually due to metal powder. The powder is really fine therefore one should be careful when handling.

6.6 Production Size

6.6.1 Prototyping

A producer and a researcher stress that AM is especially well fitted for prototyping, and that it is still one of the main production profiles within AM.

"But it started out as a technology for prototyping, brilliant and still is useful for prototyping among otherer process" (R1)

"So far it has been prototyping" (P1)

6.6.2 Small

All the informants agree upon that AM technology today in Norway is best applicable for small batches, depending on the applied technology and the part to be printed.

> *"It depends a bit on the technology but low to medium scale atm." (P2, P3)*

> *"Depends on the product. For oil and gas there will be small series." (A1)*

6.6.3 Small-Medium

As four informants shed light on it, depending on the improvement of the technology, small-medium production volume may be achievable.

> *"When the technology is improving as it is everyday it is increasingly becoming more medium range production that can be beneficial" (P2, P3)*

> *"Some cases it could be medium if we find a way to design parts which not could be produced by machining. That's one of the benefits of AM, it could machine in a way you can't do with machining. That would be medium, otherwise it would only be small" (M2)*

6.6.4 Could Be Large

As soon as the technology allows it, production can reach large scales. This is supported by the majority of the informants. Most of them agreed that it could be relevant with technology improvements, and a few argued that it could be relevant at the moment with the right product fit,

> *"If you have the correct product, you can have a large production. And that is because sometimes when we are machining parts, we can machine five to ten different parts and you put them together. If we can instead of machine*

5 to 10 parts would use in one part, then there is economy in it. And then we can have a large production." (P1)

"We have for example the jetting machines that are also powder based. They can produce much larger quantities of parts more rapidly, but they have their own limitations in terms of mechanical properties and the material itself." (P2, P3)

"Depending on what you are producing you can actually produce quite big series quite large series still in a competitive way with AM compared to another process: We probably still haven't seen that development for metal but it it's coming for sure." (R1)

6.7 Discussing AM and its Green Aspects

6.7.1 Transportation Reductions

On the environmental benefits associated with AM, the reduced transport was often mentioned. 4 of the respondents mentioned emphasized the ability to produce locally and reduce a significant part of the transport. This was also tied to the possibilities of more home sourcing.

6.7.2 Supply Chain

Another aspect linked to transportation where the improvements in supply chain. Additive manufacturing enables a supply chain where there are fewer chains and subsequently less transportation required in the production. 2 respondents argued that additive manufacturing could be don't in a very localized manner with fewer steps and parties involved.

6.7.3 Recycling

Recycling was also mentioned among environmental benefits. This is mainly tied to metals in general, but are relevant and easily applicable to additive manufacturing.

6.7.4 CO_2 Footprints

Reduced Co2 footprints were brought up under the discussion of the greenness and attractive aspects with AM. This aspect was highly valued buy the potential customers, and also brought up by 2 of the producers. The green aspect on production is rather important since the larger corporations have an interest in this. Its therefore considered as a nice selling point from the producer side. The customers also highly valued green alternatives, and where particularly interest in AM due to the lower Co2 footprints. The opportunity to repair parts was also a mentioned in this regard. Quote: "AM for repair is also highly valuable part of us, both in delivery time and cost, and also in Co2 footprints".

6.7.5 On the Greenness of AM

A decent number of arguments towards AM being green was brought up during the interviews. The first argument was reduced transport. AM enables the producer to produce locally wherever, such as home sourcing production or produce near where the part is needed. This has the potential to drastically reduce transport costs and CO_2 gas emissions. 5 of the respondents argued towards AM as a greener technology due to reduced transport, and emphasized transport as a large contributor to greenhouse gas emission.

Material savings and reduced waste was also highlighted by 6 of the respondents when considering the greenness of additive manufacturing. AM has a manufacturing efficiency compared to traditional manufacturing. Producers use the exact amount of powder required to make their products. One respondent showed to some examples in the aerospace industry where they have managed an up to 90% improvement on waste materials. The benefits within waste materials can be linked to opportunities in the market chain, where an on-demand value chain can contribute to the reduction of wasted parts and material. One of the producers informed that the waste in producing additive is under 1%. They also elaborated that this was not necessarily tied to powder production, but applied for pretty much all additive techniques. One of the academic experts made the comparison with lean production, referring to AM being called a lean technology or sustainable technology, due to them only adding material where needed. There are of course some waste in additive as well, but significantly lower than other traditional production methods like milling and drilling. The material savings can even be improved further with weight optimization of parts. AM enables one to reduce the weight of product or optimize it in terms of aerodynamic or hydrodynamic properties. The same academic expert points to this aspect being where AM has the chance to become green, because you can optimize said products and use less energy.

The opportunities in recycling and its reduced Co2 footprints were also common themes throughout the interviews. One of the customers argued that a part of their AM value is the Co2 footprint not produced. This was explained on the basis that they buy and repair products in Norway, which is produced with "cleaner energy", ergo less Co2 per powder consume compared to production in for example China. To quote:

> *" We are saving a lot of CO_2 because we are not buying any product, we are repairing a product. So, you don't produce that CO2 compared, and in the future that could be a good idea to show why are we wanting to have circular economy. Like we use and reuse as long as possible, repair instead of replacement." (C1)*

The recycling factor is argued to give AM some relation to circular economy, in the sense that one can take waste products back in a "loop" and reuse it in a machine. 7 of the respondents touched on the ability to recycle products as a green aspect for the Technology. Furthermore, 3 of the respondents highlighted the possibilities of producing a more "green powder". One respondent also argued towards the greenness by pointing at the fact that they are getting funding from the Government.

There were naturally also some arguments as to why AM is not a green technology. The most common one was targeted towards powder production. Some of the respondents appeared unsure or not informed on the actual environmental costs related to this production. There was an overall lack of insight into what goes in the powder manufacturing process. One respondent highlighted that it was something that should be taken into account, but was not necessarily their focus. The focus of entities such as themselves were as to what good they could do with the technology they would assess to be green.
A respondent with more insight on this "explained" that the powder production process required a large amount of energy consumption, and for that matter AM could not in itself be a green technology. This might not be as severe for plastic AM, but for AM its quite energy intensive. Five of the respondents agreed that the powder production is the part holding AM back from being considered as a greener technology.

More difficulty to recycle was also mentioned by a producer. Parts made by powder is considered difficult to recycle, and no different from parts made in regular production.

Every respondent had an overall opinion on the greenness of AM. Most respondents consider AM as a greener alternative, but not necessarily green in itself. This is especially hampered by the production steps before the additive manufacturing, like powder production and so forth. Seven of the respondents answered that they would consider it as greener, but not necessarily green in itself. It can be used for green purposes and have a role in a green shift, but it's likely not going to be the main player. The producers differentiated from this, where two producers considered green even when considering the whole cycles together. The last producer did not consider it green at all, and was more leaning towards it being the opposite.

6.8 Future Opportunities for AM

6.8.1 Potential Cost Savings

A larger focus was put on future opportunities throughout the interviews. This seems to be an aspect that's valuable for actors in the additive market. While there are mentioned many benefits with the technology today, most of the interest lie in future opportunities. Every respondent expressed optimism towards the future opportunities with AM.

The main point that was brought up regarding future opportunities was the possibility for cost savings. One respondent highlighted that a lack of knowledge and experience is holding the technology back somewhat, where in some time the market will be better fit to produce more profitable parts. This lies in the design of the part. As highlighted by another respondent: "There is a possibility to design for additive with the aim to reduce weight for the part, which subsequently reduces cost and production time for the machine.". Optimizing a part for 3D-printing allows one to save material, reduce waste and sometimes can an even better product. This is the one of the main ways AM is considered competitive and sometimes cheaper than TM. Another respondent highlighted that when considering cost, you also have to include the added values that AM give when optimizing the product. The opportunities around product design reducing costs were mentioned by 5 of the respondents.

The future opportunities where the technology evolvement has slowed down were also mentioned. As mentioned, when discussing cost drivers, large investment costs contributed to a substantial amount of the additive manufacturing costs (about 70%). One of the producers highlighted the potential improvement in the future whenever the technology has a less rapid evolvement from year to year. This would prevent the need for a new costly machine every year, which in turn would lower the contribution margin required for each part. A lower contribution margin would in turn allow each part to be made for a substantial lower price, which makes the technology much more competitive in terms of cost with more traditional manufacturing options. The respondent was convinced that AM is not even close to realizing its potential in manufacturing.

6.8.2 More Widespread Use of Technology

Additive manufacturing sees a limited use in most market sectors today. The limited use was addressed by some informants, where they expressed optimism towards a future where more and more producers are actively using the technology. One market partner expressed optimism towards the coming years where big entities are starting to demand the use of AM, which leads to a spike in interest, and hopefully uncovers new potential utility and uses for the technology.

6.8.3 Increased Applicability

There was also expressed a possibility of expanding the use areas for AM. One producer highlighted that production of several number of the same part is not currently done with AM, and was hopeful that this could change in the future. Customers on the other hand described how the complexity of the part could help in this. As quoted by a potential customer and AM expert:

> *"The more complex a part is, the better price you will get comparing it to a traditionally manufactured part with AM". (C2)*

Parts with a higher number of "phases" / complexity is more difficult to use with traditional manufacturing. An increased use of complex parts could therefore shift more production over to AM, where chance is that its more price competitive.

6.8.4 Automated Post-Processing

The need for manual post-processing was brought up as a cost and time-deficiency for AM. 3 of the respondents implied that this was a potential area for improvement. One producer was certain that this could be changed in the future, but probably not in the coming years. Market partner was convinced that there is potential there, but not sure as to how. Apparently, companies are looking into more automated manufacturing facilities that could affect this. An academic specialist highlighted that this has been a lot of the focus the recent years. The focus has shifted over to the post processing steps and how this can be automated, or at least be more efficient. The early focus was often directed to the technology itself, while its more towards efficiency now. Automation of post-processing would allow much more efficient production. A respondent highlighted that the coming machines require much less manual handling, which allows the machines to run more or less 24/7. One producer mentioned that the machines are designed specifically with a manual post-production in mind. The argument was then that, if possible, automations are kept in mind when making the machine, then plenty of the steps could be automated in the future.

6.8.5 Digital Inventory

Digital inventory was also an interesting concept highlighted by some of the participants. One of the market partners consider AM as a close to 100% digital manufacturing technique, and envisions a future where one can trade digital representation of parts. This allows for faster transport of parts. Some of the producers were already involved in this, designing AM products that are then sold out of house.

A market partner on the question of whether there could be a market for digital inventory:

> *"That's probably how it will be in the future, where you have dedicated companies purely on design and other companies that focus on just producing the parts. The received plans are mainly developed so they can just focus on the production aspect." (M1)*

As of today, the market is too small for them to have that luxury. There is also a challenge of needing to have the right understanding and connection with process and production. The producers indicated troubles with designing a part and then not being able to validate the results with a machine. But they are convinced that in the future there will be plenty of companies that just do the design for additive manufacturing and then ship the production to other companies.

6.8.6 Home Sourcing

One of the big visions highlighted was the opportunities of home sourcing. One customer was especially interest in this topic, where they would like to home source more production from Asia. While this is often not competitive on price, the additive technology is bringing hope that one can produce better and faster with the improved technology. This opportunity was emphasized by 2 of the respondents, where they were looking at as to how AM could support, improve and reshape the way that we create transports and use goods.

7. Monte Carlo Outputs and Interpretation

This chapter presents simulation outputs and interpretations from the MCS. A total of two sub-sections are included in this chapter. The first section, Chapter 7.1, clarifies what belongs under the scope of the analysis and what does not. Chapter 7.2 presents and interprets the simulation output in the order of fully random simulation with triangular and Poisson distribution, then results from the pessimistic and optimistic models are presented and analysed.

7.1 Delimitations and Clarifications

This analysis has been carried out with the aim of simulating scenarios – "realized" (simulated) demand, indicated in percentages - to serve as a weight for the total revenues per year, and so deriving the various costs and net profits as introduced in the Theory chapter. It is important to emphasize that there is no intention whatsoever to carry out inventory management simulations with lead time, new purchase/repurchase timing, etc. Further, it is important to note that computation of all the posts in the statement forecast are based on their original form as they were carried out on the initial spreadsheet: grouping of different types of costs, etc are kept as they have been introduced to us.

The company of focus in this analysis does not possess a monopolistic market position, but expect to enjoy great competitive advantages in the domestic market. While they consider other foreign producers as competition, their expectation is that the target audience in the Norwegian market will have a preference for locally produced feedstock. There is an assumption of no seasonality in demand.

7.2 Outputs of Income Statement Forecasts

7.2.1 General Guidelines and Principles of Analysis

When analysing the simulation results and the corresponding cumulative tables, the following two indicators of interest are examined in addition to revenues and profits:

- Probability of the Break-Even Scenario (BE)
- Probability for the initial 40% scenario (SI).

Without any kinds of simulations conducted, one can simply plug in a demand scenario for the first year and see how the income statement line items react. The BE with an approximate value of 0.3434, is also easy to compute when put on the total scale that spreads from 0 to 1, the probability to earn profit is approximately 65.66%. Therefore, the overall purpose of the entire simulation procedure is to provide a “weight”, which depends on the type of simulation, so that the probabilities of BE and SI can be analysed.

The Break-Even point is assumed to remain the same regardless of simulation types and of growth or stagnation in demand throughout the five years tome horizon. This means that the same amount of powder batches needs to be sold in order for the company to prevent losses, assuming all else held constant.

The probability of BE varies according to the type of simulation. Therefore, it is analysed for each simulation to find out how big the probability is, depending on the type of simulation, to generate a large enough demand to make a profit. The SI is brought into focus to see the probability of our analysis approaching the initial expected scenario of 40%.
The cumulative probabilities for the BE and SI indicators are calculated on the random variable SCENARIO, just like SCENARIO1. The probability for the BE to happen is the accumulation of occurrences of percentages on SCENARIO until 0.3434 and for SI until 0.4, such that:

$$P(SCENARIO \leq BE) = x$$

and

$$P(SCENARIO \leq SI) = y.$$

In case the minimum value of the given SCENARIO generated by any of the simulations is smaller than the Break-Even or SI, it is not possible to calculate cumulative probability and the corresponding CI. If the probability of BE or SI is possible to compute, their magnitude only depends on the frequency of percentages until they reach 0.3434 or 0.4.

A confidence interval table has been created including two items from the income statement forecasts, and the above analysed “milestone” indicators:

- SCENARIO1,

- Net amount,
- BE (if applicable).
- SI (if applicable).

This enables one to set the above listed probabilities in "perspective" and contemplate the corresponding boundaries when making inferences.

7.2.2 Fully Random Forecasts

Triangular

Table 7 1 Income Statement Forecast Fully Random Triangular Simulation

	Year 1	Year 2	Year 3	Year 4	Year 5
SCENARIO	0.38	0.44	0.50	0.65	0.80
Revenues	2,686,162	3,110,293	3,534,424	4,594,751	5,655,078
COGS	1,070,664	1,239,716	1,408,769	1,813,399	2,254,030
Gross	1,615,498	1,870,557	2,125,655	2,763,352	3,401,048
Overhead	676000	676000	676000	676000	676000
EBITDA	939,498	1,194,577	1,449,655	2,087,352,	2,725,048
Depreciation	740333	740333	740333	740333	740,333
Financial	43900	43900	43900	43900	43900
Tax	34,158	90,276	146,393	286,686	426,979
Net	121,107	320,068	519,029	1,016,433	1,513,836

As the table 7.1 shows, demand scenario for the first year (38%) – it can be found in the first row, Year1 column - starts quite close to the expected initial probability of 40%, it is only 2 percentages lower when compared. Growth factor between the three first years is 0.06, from year three to year five it is 0.15. A "surprising" fact is that year five (80%) does not arrive at 100%, to the sales of all produced powder, but stops at 80% resulting in 1.5 million euros of profit.

Probabilities of the following milestone indicators:

- BE: $P(SCENARIO \leq BE) = 0.029$
- DS: $P(SCENARIO \leq SI) = 0.831$

The BE probability is 2.9% meaning there is a slight probability not to earn profits, or to put it the way around, there is a 97.1% chance to make a profit. For the initial scenario of 40% to happen there is an 83.1% chance, meaning there is high probability for SCENARIO1 to arrive at the 40% initial demand forecast. As an example, a cumulative probability table A1 with the first hundred observations of SCENARIO can be found in Appendix 4.

Table 7.2 Confidence Intervals

Confidence Interval	SCENARIO1	Mean NET	Break Even	SI
95 % Lower	0.35	116,672	0.0008	0.8076
95 % Upper	0.4099	125,541	0.0579	0.8543
99 % Lower	0.3405	115,278	0.0003	0.8003
99 % Upper	0.4194	126,934	0.0584	0.8616

Table 7.2 summarises the confidence intervals of the milestone scenarios and amounts. One can be 95% certain that SCENARIO1 (38%) falls between 35% and 40.99% so the interval can be interpreted as relatively tight. The “cost” for desiring more security for the estimations is wider borders, one can be 99% sure that it falls between 34.05 and 41.94 percentages. The net amount of 121,107 in the first-year falls between 116,672 and 125,541 euros with 95% confidence level.

Poisson

Table 7.3 Income Statement Forecast of Fully Random Poisson Simulation

	Year 1	Year 2	Year 3	Year 4	Year 5
SCENARIO	0.43	0.48	0.53	0.68	0.84
Revenues	3,063415	3,411,247	3,759,079	4,833,917	5,908,756
COGS	1,238,126	1,378,708	1,519,289	1,953,702	2,388,114
Gross	1,825,289	2,032,539	2,239,789	2,880,215	3,520,642
Overhead	676000	676000	676000	676000	676000
EBITDA	1,149,289	1,356,539	1,563,789	2,204,215	2,844,642
Depreciation	740333	740333	740333	740333	740333
Financial	43900	43900	43900	43900	43900
Tax	80,312	125,907	171,502	312,396	453,290
Net	284,744	446,399	608,054	1,107,586	1,607,119

Analysis by SCENARIO

As the table 7.3 shows, SCENARIO1 (43%) for the first year starts 3 percentage higher compared to the expected default probability of 40%. Growth in percentage between the first three years is 0.05, from year three to year five it is 0.15. SCENARIO5 (84%) is approaching high capacity-utilisation with 84% but still does not reach a 100% capacity exploitation.

Cumulative Probabilities of the following milestone indicators:

- BE: $P(SCENARIO \leq BE) = 0.3467$
- SI: $P(SCENARIO \leq SI) = 0.5133$

The BE Probability indicates that there is up to 34.67% chance to lose or to not earn any money, or to put it the way around, there is 65.33% probability to earn a profit in the first year. Further, there is up to a 51.33% probability to arrive at the original 40% demand or 48.67% to exceed it, meaning there is almost 50% probability to have higher demand than 40%.

Table 7.4 Confidence Intervals

Confidence Interval	SCENARIO1	Mean NET	Break Even	SI
95 % Lower	0.4026	273,694	0.3241	0.4823
95 % Upper	0.4641	295,793	0.3829	0.5442
99 % Lower	0.3929	270,222	0.3148	0.4726
99 % Upper	0.4738	299,265	0.3925	0.5539

Table 7.4 shows the boundaries of 95% level of SCENARIO1 to be 40.26 and 46.41%, 273,694 and 295,793 for the net amount of 284,744. The probability of not earning profit is between 32.41% and 38.29% for the 95% level. For the 99% level, corresponding values are slightly higher.

Analysing Weekly Batch Order Probabilities

A positive aspect of downscaled productivity parameters is that one can see the probabilities of various order sizes during a week, that can be useful in a market with several smaller actors and start-ups with smaller order sizes. Follow-up with an AM producing informant indicated that their powder usage is upwards toward 60kg a month. When scaled down to a weekly level it is a tiny amount of 0.055 batch.

The average order size is 7 batches per week when rounded up (6.6) (this is the lambda that will be used in the formula presented in the theory chapter). At this order level the revenue can be obtained by multiplying weekly mean demand (MY), the average powder price (AP) and the maximum crucible batches:

$$7 \times 25 \times 422.5 = 73{,}937$$

scaling it up to an annual base:

$$73{,}937 \times 44 = 3{,}253{,}228$$

The number of powder batches necessary to Break-Even in a week is the total number of weekly batches multiplied by BE:

$$15 \times 0.3435 = 5.2$$

batches a week. The initial 40% scenario translates to 6 batch orders a week.
Since Poisson distribution is a discrete distribution, it is possible to calculate the exact probability of an event happening.

$$P(WTOTB=BE) = 0.1422$$

$$P(WTOTB=SI) = 0.1562$$

This means that the probability to have exactly 5 orders of powder batches a week is 14.22%, however it is more informative to take a look at the "danger zone", the probability for the BE to happen and the "safety zone" where money is made. The sum of probabilities until (and including) BE is 0.3558 meaning there is an 64.42% probability of earning a profit.
The calculation of the SI probability is simple, adding the following probability to the BE (5 orders) one arrives at the 40% initial demand probability which is 6 orders, slightly lower than the lambda. The probability of receiving 6 or less orders is 51.21%. For comparison, the probability of having zero orders a week is approximately 0.14%:

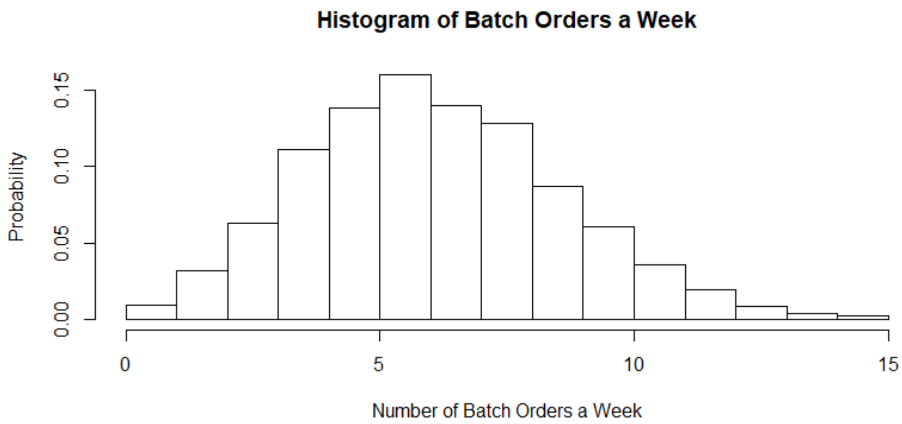
$$P(WTOTB=0) = 0.001371$$

And the probability of having ten or more orders a week is:

$$P(WTOTB > 10) = 1 - P(WTOTB \leq 9) = 0.072$$

As expected, the BE and SI cumulated probabilities are close to the probabilities obtained by examining SCENARIO1. Figure 7.1

Figure 7.1 Histogram of Batch Orders a Week



7.2.3 Pessimistic Model

As highlighted in the Method chapter, the assumption is that setting the modes of the triangular distributions of both the growth and demand to relatively low levels would result in low demand scenario and growth levels.

Table 7.5 Income Statement Forecast for Pessimistic Model

	Year 1	Year 2	Year 3	Year 4	Year 5
SCENARIO	0.42	0.46	0.50	0.64	0.78
Revenues	2,968,916	3,251,670	3,534,424	4,524,063	5,513,701
COGS	1,183,366	1,296,067	1,408,769	1,803,224	2,197,679
Gross	1,785,550	1,955,603	2,125,655	2,720,839	3,316,022
Overhead	676000	676000	676000	676000	676000
EBITDA	1,109,550	1,279,603	1,449,655	2,044,839	2,640,022
Depreciation	740333	740333	740333	740333	740333
Financial	43900	43900	43900	43900	43900
Tax	71,570	108,981	146,393	277,333	408,274
Net	253,748	386,388	519,029	983,272	1,447,516

The assumption seems to be right, as the table 7.5 shows demand scenario for the first year starts 0.02 percentage higher compared to the expected default probability of 40%. The first three years show a yearly growth in percentage at 0.04, while the two last years have growth of 0,14. SCENARIO2 (46%) is still well under 50%, only year three reaches the half of the total capacity/sales. SCENARIO5 is still below 80%.

Cumulative Probabilities of the following milestone indicators:

- BE: $P(SCENARIO \leq BE) = N/A$
- SI: $P(SCENARIO \leq SI) = 0.042$

The reason for missing probability is that the minimum value on SCENARIO is 0.3957 which is higher than the Break-Even scenario of 0.3434. This means that even though the parameters of triangular distributions were set low, the simulation produced a sequence of SCENARIO that starts slightly higher that the BE probability, therefore eliminating the possibility to not earn any profit. This may be interpreted as the results are solid and "conservative", starting low, not reaching the total capacity/sales/demand. There is 95.8% probability of the default 40% scenario to be exceeded, interestingly, since the first two years are in the region of 40%.

Table 7.6 Confidence Intervals for Pessimistic Model

Confidence Interval	Year 1 SCENARIO	Mean NET	Break Even	Default First-Year
95 % Lower	0.38942	252,397	N/A	0.00886
95 % Upper	0.45057	255,097	N/A	0.02493
99 % Lower	0.37981	251,973	N/A	0.00633
99 % Upper	0.460182	255,521	N/A	0.02746

CI table 7.6 indicates the 95% and 99% limits of the first year, break even and 40% scenarios, and the mean net. Interpretation is the same as earlier. AN interesting observation is that the Interval for the net amount is quite narrow, only a few thousands of euros.

7.2.4 Optimistic Model

The assumption is that setting the mode of the triangular distributions for both demand and growth relatively high should pull the simulation results upwards.

Table 7.7 Income Statement Forecast Optimistic Model

	Year 1	Year 2	Year 3	Year 4	Year 5
SCENARIO	0.58	0.64	0.70	0.86	1.00
Revenues	4,099,932	4,524,063	4,948,194	6,079,209	7,068,848
COGS	1,634,172	1,803,224	1,972,276	2,423,082	2,817,538
Gross	2,465,760	2,720,839	2,975,917	3,656,127	4,251,310
Overhead	676000	676000	676000	676000	676000
EBITDA	1,789,760	2,044,839	2,299,917	2,980,127	3,575,310
Depreciation	740333	740333	740333	740333	740333
Financial	43900	43900	43900	43900	43900
Tax	221,216	277,334	333,451	483,097	614,038
Net	784,311	983,272	1,182,234	1,712,797	2,177,040

The expectation that high mode values would be pulling up the simulation results seems to be fulfilled. The first year already shoots up to 58% and year five suggests that there will be demand for all the batches of powder produced.

Cumulative Probabilities of the following milestone indicators:

- BE: $P(SCENARIO \leq BE) = N/A$
- SI: $P(SCENARIO \leq SI) = N/A$

The results are not surprising, with such a high initial scenario the minimum of the random variable SCENARIO is also high, it is 0.5678. There is no danger for landing in “red”, but the results seem to be overwhelmingly optimistic.

Table 7.8 Confidence Intervals for Optimistic Model

Confidence Interval	Year 1 SCENARIO	Mean NET	Break Even	Default First-Year
95 % Lower	0.5494	783,882	N/A	N/A
95 % Upper	0.6105	784,739	N/A	N/A
99 % Lower	0.5398	783,748	N/A	N/A
99 % Upper	0.6201	784,874	N/A	N/A

From the confidence interval table 7.8 one can be 95% certain that the probability – given the same simulation type and parameters - of the first year SCENARIO to be 58% is between 54.94% and 61.05%, and 99% certain that SCENARIO1 is between 53.98% and 62.01%. NET profit can be expected to be between 783,882 and 784,739.

8. Discussion

This chapter discusses the findings relevant for this research and attempts to answer the relevant research questions. The chapter consist of a total of 6 sub-chapters. The first chapter, 8.1, discusses the primary research question of this thesis. The sub-chapter is divided in five parts, where the first four parts discuss each aspect of the market and technology in alignment to prior structure. The findings are then combined and the research question addressed. Chapter 8.2 discuss the first additional complementary research question on production scale, while chapter 8.3 address the second research question on AM as a green technology. Finally, findings from the case study on circular powder production is discussed and concluded in chapter 8.4. Section 8.5 discuss potential limitations in this research, while 8.6 provides suggestions for further research.

8.1 On the Norwegian Additive Manufacturing Market

8.1.1 The Market Today

While the market situation is somewhat challenging to predict due to the difference in data origin, namely international literature versus opinions on the Norwegian market, a decent number of common themes are still present. Both sources provided insights and opinions on AM as a strong technology but highlighted that it is still at an early stage. From the literature, AM is highlighted as a new disruptive technology (Gibson et al. 2019; Godina et al. 2020), still being at a small stage and comprising a small fraction of the total worldwide production (Arrizubieta et al. 2020; Baumers and Holweg 2019; Godina et al. 2020). Findings from the interviews support these arguments. While all producers and an academic expert stressed their opinion of the strength of the technology, nearly all of the informants agreed that it is still in its infancy stage.

As two authors point out, AM revolutionises production operations and flourishes in supply chain (Huang et al. 2013; Sonar et al. 2020). Interview findings are aligned with the literature. The expectations regarding technological improvements involve reduced lead time, increased efficiency, prolonged lifetime of products, more extensive use of digital inventories and so forth.

AM is somewhat considered a mainstream manufacturing process in automotive, aerospace, electronics and medicine (Huang et al. 2013; Niaki and Nonino 2017; Pannitz and Sehrt

2020). At an International level, the AM market is much more developed in certain market sectors. Plastic printing is more common, due to beneficial sectors such as medicine and aerospace. While metal printing is also on the rise, it is much less applied in most market sectors. The level of AM use is less relevant for the Norwegian metal manufacturing market. This was not highlighted as any common technology in the market by any of the interview informants.

AM is acknowledged as an important area for research. Research highlights how despite its limited use in the total worldwide production, leading organisations are increasingly investing in R&D activities to better understand AM, its limitations and how to benefit from its potential (Busachi et al. 2018). Two informants emphasised how knowledge is an importance factor in guiding, advising and educating suppliers and producers. The general competence in the market was described as low with corresponding low knowledge levels by most respondents, further highlighting the need for more education and research on this topic.

8.1.2 Attractive Aspects

The attractive aspects on AM had a great consistency between the literature and interview informants. Most topics were agreed upon and brought up by both sources. The most prominent where the high levels of customization and freedom of design that AM enables. (Atzeni and Salmi 2012; Berman 2012; Gibson et al. 2019; Handal 2017; Pannitz and Sehrt 2020; Piller et al. 2019; Thomas 2013; Westerweel et al. 2018). The importance of design freedom was highlighted by almost all informants, in most cases as the greatest reason for AM's existence. Its importance is reflected to when it comes to complex parts that would be difficult to machine with TM. Interview respondents also highlighted that flexibility and design freedom increases cost effectiveness through reduced need for tools, equipment, moulds and such, which aligns well with the literature. Research emphasizes how AM has the potential to increase productivity and reduce costs (Derekar 2018; Post et al. 2016; Westerweel et al. 2018).

There are two highlighted factors closely related to design freedom, reduced tooling investments (Baumers and Holweg 2019; Berman 2012; Mellor et al. 2014; Nagulpelli et al. 2019; Thomas 2013) and material savings (Busachi et al. 2018; Huang et al. 2013; Post et al. 2016). Savings due to the absence of tooling was highlighted by around half the informants, largely aligning with the opinions of international researchers. Since the need for tools between different products are almost eliminated by AM, no investments are required. The material savings from AM was also highlighted by the majority of informants. Additive manufacturing often requires less feedstock compared to traditional manufacturing (Busachi et al. 2018; Huang et al. 2013; Post et al. 2016), as well as producing less waste (Berman 2012).

Reduced stock levels (Busachi et al. 2018; Handal 2017; Huang et al. 2013; Post et al. 2016), as well as quick responsiveness and production (Conner et al. 2014; Godina et al. 2020; Handal 2017; Huang et al. 2013; Mashhadi and Salinas Monroy 2019) were brought up. Reduced stock levels were brought up by both producers, aligning well with multiple research sources. Closely related to this is the agile production, highlighted by the interviewees in conjunction with the use of digital inventory and transfer of files instead of finished products. Through this, printing has the opportunity to take place at place of consumption, allowing for efficient transfer and reduced energy and transport costs (Khorram Niaki and Nonino 2017; Post et al. 2016).

8.1.3 Limitations and Technological Barriers.

The topics of limitations and technological barriers largely overlapped in international literature and during the interviews, and are therefore combined. On the topic of limitations, the most prominent discussed by the interviewees were the lack of knowledge in the market. Coverage of this was surprisingly scarce in the literature, although mentioned in the context of companies investigating the benefits of AM. A wide range of companies are investigating if AM could bring benefits to their products and processes, but are limited by the lack of internal available knowledge (Schneck et al. 2019). The interview informants put much more emphasis on this limitation, mentioning the lack of knowledge, information on standards, information on its benefits and limitations, its use areas and where its beneficial to use alternative production methods. An issue with insecure, uneducated or overconfident customers placements was also brought up by producers, leading to overpriced and expensive manufacturing results. The lack of standards was emphasized by three informants. These standards were mentioned to be in development, although lagging behind in implementation.

Efficiency issues is also a limitation brought up by researchers. AM is in comparison to TM expensive and time consuming (Fredriksson 2019), which is by some considered the main driver of cost (Baumers et al. 2016; Post et al. 2016). Efficiency was also brought up by the majority of the informants as one of the dominant limitations of AM. Every producer expressed a dissatisfaction with the fact that AM is too time consuming, while an AM expert informs that it is often the case when the product is not tailored to utilize AM capabilities. Additionally, as with all new production methods, production cost is usually high early on due to underdeveloped technology, a problem that decrease over time as technology and machine experience improves. Manual post production is also mentioned in this context, and referred to by all informants. The need for manual post-production is tied to the requirements of design structure in AM products. This issue can be tackled by removing the need for support structure through smarter designs of products.

Additive manufacturing is also an expensive investment (Huang et al. 2013; Niaki and Nonino 2017). AM technology is penalized by not only the high cost for materials, but also the high cost of AM machines (Atzeni and Salmi 2012; Huang et al. 2013; Niaki and Nonino 2017; Yang and Li 2018). This was heavily emphasized during the interviews as well. AM machines are rather expensive, and there are additional costs tied to the investment such as education and training of employees, as well as trial and error costs during the learning phase. The high investment costs with AM are not only a large barrier to entry for start-ups, it is also a main driver of cost. The high investment costs combined with a rapidly growing technology requires fast down payment on machinery. Due to the constant research and development on AM techniques, machines are at a risk of being outdated within a somewhat short amount of time. The need for a fast down payment and change of machines results in an added fixed cost to each product. This drives up the price and harms AM's price competitiveness with other manufacturing methods, giving the impression that AM products are more expensive than they necessarily need to be.

A more technical limitation of AM is its size. Large object is not time efficient to produce through the use of AM (Huang et al. 2013). Traditional manufacturing is usually the preferred option in large scale production, due to AMs per-unit production costs and capacity limitations (Nagulpelli et al. 2019). Product size as a limitation was brought up by an academic specialist and two producers, but no heavily focused on.

Some limitations were brought up during interviews that was not mentioned much in the literature. One limitation that was brought up was the low number of producers in the market.

The AM market is still scarcely populated by producers. Both producers and market actors advocated for more additive manufacturers. The lack of mention of this in the international literature is naturally due to it not addressing AM markets for specific countries, but more on a global scale. The same is the case for limited availability of competent and experienced personnel, which was highlighted by a market actor.

There were some limitations brought up by researchers that was not brought up during the interviews. Some researchers addressed the technology strength (Berman 2012; Huang et al. 2013). Berman (2012) highlighted that AM has a lower precision relative to other technologies, has a limited strength and less resistance to heat and moisture. Huang et al. (2013) also bring up the technology strength as a possible limitation, stating that parts produced using AM processes often possess a rough and ribbed surface finish, which results in an end product with an unfinished look. Uncertainty around the strength of the technology was not brought up during any of the interviews. All informants seemed confident that this technology was up to par in terms of the quality of end products compared to traditional methods. While it could be the case that there is some informant bias due to all the informants being actors within the market, the lack of recent research mentioning these limitations suggests otherwise. The papers addressing these concerns are among the oldest ones included in the review, suggesting that these areas may have been improved in the latter years.

8.1.4 Opportunities

A large focus throughout the interviews was put on future opportunities. This seems to be one of the most important aspect for actors in the additive market. Every respondent expressed optimism towards the future opportunities with AM. The future opportunities where the technology evolvement has slowed down was especially emphasised, whenever the technology has a less rapid evolvement from year to year. This would prevent the need for a new costly machine every year, which can significantly drive down costs and make AM more cost competitive with TM. This optimism of the future is shared by some literature. Due to the continuous and increasing growth experienced and the successful results up to date, there is optimism that additive manufacturing has a significant place in the future of manufacturing (Schneck et al. 2019; Wong and Hernandez 2012). As a respondent highlighted, the lack of knowledge and experience is holding the technology back, where in some time the market will be better fit to produce more profitable parts.

The literature highlights opportunities in reducing the costs of AM. This is done through product designs. The freedom of design that AM entails allows for unique designs that can be modified to exploit AM potentialities. A remarkable cost reduction can be obtained, depending on the manufacturers ability to exploit these potentialities (Atzeni and Salmi 2012). This is further highlighted. AM is likely to be more competitive than conventional manufacturing when it comes to fabricating products with higher levels of complexity, customization, or a combination of both (Conner et al. 2014). Deliberate design modifications can allow for even stronger and lighter parts (Godina et al. 2020). This was supported by the interviews. There is the possibility to design for additive with the aim to reduce weight for the part, which subsequently reduces cost and production time for the machine. Optimizing a part for 3D-printing allows one to save material, reduce waste and sometimes even create a better product.

Design modifications also allow weight reduction of products, which in turn can lower costs and emissions. Studies of aircraft sectors have shown weight advantages of additive manufacturing compared to conventional (Fredriksson 2019). Transport is closely tied to costs and emissions. The possibility of producing locally at a reduced cost means a radical transformation of the current supply chain, where the transport routes can be greatly reduced (Godina et al. 2020). Local production might also promote innovation, new job opportunities and enable more customization tailored to the end-user (Fredriksson 2019).

Opportunities in a potential digital market is also highlighted. There are expectations that a significant number of small/ medium enterprises will share AM production by 2030 (Li et al. 2019). The idea of a digital market was shared by some of the interviewees. One market partner considers AM as a close to 100% digital manufacturing techniques and envisions a similar future where one can trade digital representation of parts. This allows for faster transport of parts. Some of the producers were already involved in this, designing AM products that are then sold out of house.

8.1.5 Overall Impressions of the Norwegian AM Market

The main objective of this thesis was to shed light on the additive manufacturing market in Norway today and to answer the main research question; *How is the current additive manufacturing market in Norway?*

While the additive manufacturing market is somewhat considered a mainstream manufacturing process in some sectors, the general status in Norway is that it is an up-and-coming market still in its infancy stage. The development of AM in Norway is slow compared to other foreign countries, and the general competence in the market was described as somewhat low.

Additive manufacturing is an interesting new technology that has its many perceived benefits, as well as some limitations. The hype for the technology is largely driven by freedom of design, reduced need for tooling investments, material savings, reduced stock levels and quick responsiveness. It is also limited by a number of limitations and barriers. The technology struggles in comparison to TM in terms of price. AM is expensive and time consuming without an optimised product design. The price of AM is largely driven by a need for manual post-production and required design structure, high investment costs, viable size productions, and has an overall lack of knowledge and experience in the market. The high investment costs combined with a rapidly growing technology requires fast down payment on machinery. This drives up the price and harms AM's price competitiveness with other manufacturing methods, giving the impression that AM products are more expensive than they necessarily need to be.

It is clear that while there are many positive aspects with AM, it also has it downsides, and is at this point not a technology that is fit for everything. Nonetheless, there are also opportunities that AM can utilise. There was a significant optimism towards the future opportunities with AM. The future opportunities where the technology evolvement has slowed down was especially emphasised, preventing the need for a new costly machine every year, which can significantly drive down costs. Cost can also be optimised through smarter design and modifications to exploit AM potential. Design modifications also allow reduced weight on products, which in turn can lower costs and emissions. Due to the increasing growth experienced and the successful results up to date, there is optimism that additive manufacturing has a significant place in the future of manufacturing (Schneck et al. 2019; Wong and Hernandez 2012). Research highlights how despite its limited use in the total worldwide production, leading organisations are increasingly investing in R&D activities to better understand AM.

8.2 Additive Manufacturing and Large-Scale Production

Both the literature and interviews showed a general consensus that AM is mainly relevant for small production runs. The literature highlighted how AM production costs are generally lower when there are small batches of manufacturing compared to TM (Handal 2017). All the interview informants agreed that AM technology today in Norway is best applicable for small batches, depending on the applied technology and the part to be printed. The interviewees put much emphasis on AM's current use areas, and didn't go in depth whether it should or should not be considered for larger scales of production. Some research from the literature on the other hand address this area, where mass production is currently not considered feasible due to the time and energy consumption in additive manufacturing. Although additive manufacturing allows the manufacture of increasingly complex parts, the slow print speed of additive manufacturing systems limits their use for mass production (Thomas 2013). AM is not only considered not capable of competing with TM in mass production but also is not suitable for large scale production (Khorram Niaki et al. 2019)

Some hope or optimism is found towards AM in large scale production. Some interviewees were optimistic that it could be a relevant technology for larger scale production, granted a perfect product fit, but in the majority of cases TM will still be the preferred option. There is also some optimism from Atzeni and Salmi (2012), that a decreased system cost could move AM towards production of larger volumes, but the overall arguments suggest that it should not be considered relevant.

The first additional research question "*Could additive manufacturing be relevant for large scale production?*", can therefore be concluded. Based on current literature and feedback from interview respondents, it seems unlikely that additive manufacturing could be a viable option in large scale manufacturing. While there are arguments that can be made towards its viability, it does not seem practical to consider this option for most types of products. AM gains its competitive advantages over TM through its flexibility and ability to produce new products lines without any required set-up and tooling, and will subsequently lose these advantages in larger scale production. Some exceptions can be made in the case of highly complex geometries, but the current situation indicates that AM will mainly be relevant for prototyping and small-scale production for the coming years.

8.3 AM as a Green Technology

There has been a decent number of arguments describing AM as a green technology. From the literature, Godina et al. (2020) find two key elements that point towards AM being considered an environmentally friendly technology; waste reduction and transport. Both these elements align well with findings from interviews. Five of the informants argued towards AM as a greener technology due to reduced transport, and emphasized transport as a large contributor to greenhouse gas emission. Arguments towards reduced greenhouse gas emissions from transport was linked to potential improvements in supply chain. AM enables a chain with fewer steps and subsequently less transportation is required. Two interviewees mentioned how additive manufacturing could be done in a localized manner. The benefits of material savings and waste reduction was also highlighted by six of the respondents. This align well with the literature, where AM processes are shown to reduce the environmental impact due to more efficient use of raw materials (Arrizubieta et al. 2020). AM also allows for creation of lighter parts. Lighter parts affects the use of an object, for example through reduced fuel consumption and the emissions caused by it (Godina et al. 2020).

A second major beneficial factor is tied to repair opportunities. Godina et al. (2020) highlights how a product comprised with several pieces made through traditional methods struggle with damaged parts, and how additive manufacturing allows the manufacturer to produce isolated parts which extends the life cycle of that product. The opportunities in recycling and its reduced CO_2 footprints were also common themes throughout the interviews. The opportunity to repair was mentioned by two producer and a potential customer. This aspect was highly valued by the potential customer, where the company was looking at reducing their CO_2 footprints.

The opportunities for recycling were surprisingly not mentioned in the literature. This aspect was touched upon in most of the interviews, where seven of the respondents touched on the ability to recycle products as a green aspect for the technology. The recycling factor was argued to give AM some relation to a circular economy, in the sense that one can take waste products back in a "loop" and reuse it in a machine.

There was on the contrary some arguments against AM and its perceived green aspects. Fredriksson (2019) raised concerns that metal powders for AM are expensive and that AM is time consuming compared to traditional manufacturing. The powder use in additive manufacturing increase energy needs due to energy intense powders. A significant amount of energy is required to produce AM powder, and it is usually related to higher CO2-emissions (Fredriksson 2019). This argument aligns well with insights received from interview informants. The most common argument against AM as a green technology was the powder used, more specifically the energy required to make said powder. This was only brought up by a few of the informants, whom subsequently were the ones questioning AM as a green technology the most. A theme emerged where the answer to whether AM should be considered green depended on how far back in the product line the informant went. Respondents who only considered the process of creating AM products out of powder were generally positive towards AM as a green technology. Those that also considered the creation of AM feedstock were more negative. There seemed to be an overall lack of information on the actual environmental costs related to this production, and a general lack of insight into what goes in the powder production process.

There was also the challenge of identifying what's green. Green technology is used to describe technologies that can create more environmentally friendly products. The level of greenness however is not specified in the term. It is for example mention that light weighting will reduce fuel consumption and therefore CO_2-emissions. While this is the case, research suggest that it will not alone be enough to meet international targets for reduction of greenhouse gases (Fredriksson 2019). Another example is the research of Fraţila and Rotaru (2017), whom find positive results indicating that AM technology has the potential to lower costs and to be more energy efficient than conventional processes. At the same time however, the possibility for the opposite is also found. The energy required in AM processes can outweigh the savings in materials used in the process and the energy efficiency of AM is dependent on several other variables, including materials, load and patterns used.

The goal of this section is to address the second additional complementary question, *should additive manufacturing be considered as a green technology?* Should this be the case, one could expect that the interest for AM could be driven further through its potential benefits in cleaner energy. Every interview informant had an overall opinion on the greenness of AM. Most respondents consider AM as a greener alternative, but not necessarily green in itself. This is especially hampered by the production steps before the additive manufacturing, like powder production and so forth. Six of the respondents answered that they would consider it as greener, but not necessarily green in itself. As stated, "It can be used for green purposes and have a role in a green shift, but it's likely not going to be the main player". Only the AM producers differentiated from this, where two producers considered green even when including feedstock production. The last producer did not consider it green at all, and was more leaning towards it being the opposite. As for the literature, a total of three researchers (Arrizubieta et al. 2020; Colorado et al. 2020; Godina et al. 2020) appear to consider AM as a green manufacturing alternative. Most papers did not outright address this question, and it is therefore difficult to predict their opinion on the matter. While the three papers mentioned AM as a green technology, some uncertainties were stressed. As stated, "Although AM would be considered an environmentally friendly technology, further studies are required to make a definitive more statement" (Arrizubieta et al. 2020).

There is an overall lack of arguents to conclude that AM should be considered a green technology. While there are many arguments that point towards how its more sustainable and cleaner than its alternatives, it is held back by its feedstock. While the additive manufacturing process is considered emission free, the production of its powder is not. AM can therefore not be considered a green technology when taking the whole cycle into account. Improvements in powder production sustainability however could reinvigorate this question at a later point.

8.4 Profitability Opportunities for a Circular Powder Production.

8.4.1 Discussion of Case Study

General Thoughts About the Simulations

When comparing the Poisson and triangular simulations with fully random settings, all conclusions must be drawn keeping in mind that these simulations are based on the fact that that demand is unknown, only two extremities are known, a worst case “scenario” when no powder batch is sold, and a best-case scenario when each produced batch is sold. When running the fully random simulations, both the Poisson and the triangular distribution used parameters drawn from a random sample that stretches between the two limits. Therefore, the outputs strongly depend on the simulation settings such as number of iterations, sample size etc. Especially the Poisson distribution seemed to be sensitive to those parameters during the simulation procedure, where too many repetitions resulted in “losing out on character”. This could be traced on the generated histograms, and as expected, tended to be normally distributed, with the variable SCENARIO1 always being close to 50%. For both the optimistic and pessimistic model, the opposite was true, with the increased number of repetitions, the results became more stable/solid. The posted outputs represent a forecast that seemed to approximate the most frequently appeared results. Still, they only represent a "snapshot" of the several possibilities.

Comparing Demand

Tables 8.1 and 8.2 are cut-outs from the analysis section and are built up in an increasing order of the corresponding SCENARIO1-s.
With pessimistic settings, the resulting demand forecast interestingly starts 4% higher than that of the fully random simulation with triangular distribution, at year three they get equal, then the pessimistic year five lands on 2% lower level than the fully random triangular estimation. This can be seen in table 8.1.

Table 8.1 Comparing Triangular and Pessimistic Simulated Demand

	Year 1	Year 2	Year 3	Year 4	Year 5
Triangular	0.38	0.44	0.50	0.65	0.80
Pessimistic	0.42	0.46	0.50	0.64	0.78

With optimistic settings, the demand forecast yields the highest estimates of all the simulations. Compared with the Poisson distribution, the differences are higher than between the fully random triangular and pessimistic simulations as can be seen in table 8.2

Table 8.2 Comparing Poisson and Optimistic Simulated Demand

	Year 1	Year 2	Year 3	Year 4	Year 5
Poisson	0.43	0.48	0.53	0.68	0.84
Optimistic	0.58	0.64	0.70	0.86	1.00

At first glance it can be inferred that the fully random simulations and pessimistic simulation yielded SCENARIO1-s that are standing relatively close to each other, and the optimistic simulation "sticking out" with almost 60%. The standard deviation of SCENARIO1-s is quite low with 0.0877, proving the first guess right.

Discussion of Break-Even and SI probabilities

The highest possibility of not making any profit was generated by the Poisson distribution with 34.67%, being the only break-even probability that expresses some levels of "threat". According to triangular distribution the chance of losing money is small at 2.9%. Neither the pessimistic nor the optimistic simulations yielded any BE probability meaning the minimum value of the random variable SCENARIO sits higher than the 0.3434 for the break-even to be calculated. This means zero probability to lose money according to those results. The simulation that got closest to the initial 40% scenario is the one based on fully random Poisson distribution. Table 8.3 sums up the results.

Table 8.3 Break Even an Initial Scenario Probabilities

Simulation Type	Distribution	BE	SI
Fully Random	Triangular	0.029	0.831
	Poisson	0.3467	0.5133
Pessimistic	Triangular	N/A	0.042
Optimistic	Triangular	N/A	N/A

Analysing Weekly Batch Orders

Regarding number of batch orders, 5.2 batches is the minimum number that F3nice should obtain a week to generate profit. This event has a probability of 35.38%. The average number of batch orders is somewhere around 6.6. The number of batches that should be ordered to arrive close to 40% demand is 6. The probability to receive more than ten orders a week is 7.72%.

A Final Comparison of Simulations

As the previous subsections of Chapter 8 have assessed the characteristics of the Norwegian AM market, the main take-aways that are relevant for assuming the demand for metal powder are:

- Present day market and the scale of production is small.
- Technology is strong but not standardised enough yet,
- If the expectations/predictions are based on firm standing data, there might be medium or even large production scale in certain sectors.

Valvision/F3nice can count on vague unpredictable demand levels and that can change for the better according to expert predictions.

The pessimistic model delivers results that seem to fit best to the above-described conditions, based on its pre-set parameters and results. Setting the modes of the triangular distributions of demand and growth quite low did not result in accordingly low SCENARIO1 but lead to lower SCENARIO5 level instead.

With the pessimistic settings, SCENARIO1 starts at an acceptable level that is slightly above 40%, and steadily increases until SCENARIO5. There has been no sign of any probability of arriving bellow the BE point.

The random Poisson simulation results must be dealt with greater care than the pessimistic ones. Being a fully random simulation has the advantage of reflecting the ambiguity of the market situation, the random sample represents the “educated guesses” of the small market. The downside is that the results have a much larger variation then the pessimistic or optimistic simulations with their fixed settings. SCENARIO1 had values between 33% and 56% most of the time. Still the presented results in the analysis captured a good average that is worth analysing. SCENARIO1 starts a bit conservative like the pessimistic one but reaches the second highest levels of demand in SCENARIO5. The great advantage of the Poisson distribution, particularly that it allows one to assess the weekly batch orders, is useful especially in the beginning of the business operations. This advantage of the distribution, however, has a cost; that it expects the pace/tact of orders remain somewhat steady during the years, and this requirement challenges the use of it. The BE probability is also the highest, indicating some level of threat of losing profits. However, this feature is not necessarily a disadvantage, it can be seen as rather realistic.

The triangular distribution is the third distribution that showed "down to earth" results, exhibiting some levels of probability of having negative profits. It is also based on fully random settings, meaning increasing the repetitions over a limit lead to the same results as for the Poisson distribution-based simulation. Obviously, there can be a reality where 50% is the actual demand. The simulation did not have a unique feature like counting the number of individual orders etc but demonstrated a seemingly solid result.

Optimistic settings resulted in suspiciously high demand levels, with zero probability of break-even and therefore is not of further interest.

As a conclusion, except for the optimistic approach, each simulation resulted in a quite similar output with further selection up to some measurements. If the assumption of the Poisson distribution that weekly orders remain at a somewhat steady level is too unrealistic, then it has to be opted out from the list of reasonable simulations. Then, the two remaining simulations are fully random triangular and pessimistic simulations. This finding is in alignment with the literature, triangular distribution is a widespread tool in the world of the MCS.

8.5 Research Limitations

Literature Limitations

There has been some challenges and limitations within the literature analysis. The main limitation is of the study market. The addressed research question was around the Norwegian market, while most of the literature is on international or foreign markets. The literature on a Norwegian market is unfortunately limited, or rather close to non-existent, which is an unfortunate by-product of the life stage of the technology. The Norwegian additive manufacturing market is still small and rather young. The literature that addresses this market sector is therefore international, with the assumption that this can in large part be relevant for Norway as well.

Limitations in Monte Carlo Simulation

The main challenge regarding the MCS was the co-existence of two factors, a complete lack of historical data accompanied by a new and small market size where the parameters are hard to assess. Therefore, no experts are able to make educated guesses regarding demand or sales. This ambiguity is reflected in the large variation of the fully random simulation results.

8.6 Suggestions for Further Research

The ways of conducting a MCS are almost unlimited, numerous demand simulations can be found in literature. A possible way of running the simulation could have been to run more simulations with pre-set parameters for the triangular distribution, for instance setting the mode to the third, half or other fraction of the maximum powder level, and then comparing the results.

Another approach could have been to examine how high the demand would have been at year five according to the simulation: then the Growth Factor parameters 0.1 and 0.2 could have been set as mean for a normally distributed random variable. Then, there had been a standard deviation around them allowing growth to either exceed or be lower than 0.1 or 0.2. If SCENARIO5 had resulted in higher that 1, it had meant that there would have been unexploited demands. Due to size limitation of this thesis, the planned net present value and internal rate of return simulations/calculations have been left out. This could have added extra value to the results, which could have further been used to compute the pay-back period of the investments.

9. Conclusion

The main objective of this thesis was to shed light on the current additive manufacturing market today in Norway, and from there conduct simulations for expected demand level and profitability in a powder production. The AM market in Norway was emphasised through a specific focus on attractive aspects, limitations, opportunities and perceived barriers to entry for both the technology and the market.

This resulted in the total four research questions:

(1) *How is the current additive manufacturing market in Norway?*
(2) *Could additive manufacturing be relevant for large scale production?*
(3) *Should additive manufacturing be considered as a green technology?*
(4) *Could a circular powder production in Norway be profitable?*

The research on the first three research questions were carried out through a qualitative analysis, where relevant actors in the AM market was interviewed with semi-structed interviews. This was then directly compared to relevant literature on the area, to see if there are any common themes emerging than one can draw conclusions from. The fourth research question was conducted in its own quantitative analysis, simulating expected demand and growth.

The main objective of this thesis was to shed light on the additive manufacturing market in Norway today and to answer the main research question; *How is the current additive manufacturing market in Norway?* The general status in Norway is that it is an up-and-coming market still in its infancy stage. Additive manufacturing is an interesting new technology that has its many perceived benefits, as well as some limitations. The attractive aspects driving its hype were identified, as well as the limitations and barriers holding the technology back. While it is clear that there are many positive aspects with AM, it also has it downsides, and is at this point not a technology that is fit for everything. Nonetheless, future opportunities for AM are highlighted.

The first additional research question "*Could additive manufacturing be relevant for large scale production?*", was concluded based on current literature and feedback from interview respondents. It seems unlikely that additive manufacturing could be a viable option in large scale manufacturing. While there are arguments that can be made towards its viability, it does not seem practical to consider this option for most types of products. AM gains its competitive advantages over TM through its flexibility and ability to produce new products lines without any required set-up and tooling, and will subsequently lose these advantages in larger scale production. Some exceptions can be made in the case of highly complex geometries, but the current situation indicates that AM will mainly be relevant for prototyping and small-scale production for the coming years.

The second additional complementary question, "*should additive manufacturing be considered as a green technology?"* is also addressed, albeit not with the same confidence. There were mixed responses from the interview informants, where most argued that AM was greener than its alternative options. Only two informants were willing to call it green however, due to the highlighted emissions in the feedstock production. As for the literature, a total of three researchers (Arrizubieta et al. 2020; Colorado et al. 2020; Godina et al. 2020) appear to consider AM as a green manufacturing alternative. There was an overall lack of arguments to conclude that AM should be considered a green technology. AM cannot be considered a green technology when taking the whole cycle into account. Improvements in powder production sustainability however could reinvigorate this question at a later point. Should this be the case, one could expect that the interest for AM could be driven further through its potential benefits in cleaner energy.

A case study was conducted in order to answer the final additional research question. It is concluded that the expected probability to earn profit is high. Each simulation resulted in a relatively low probability to lose money. Only one out of four simulations indicated a somewhat high probability for loss, with a 34.67% chance to arrive bellow the break-even level.

10.Appendices

Appendix 1: NSD Informasjonsskriv

Vil du delta i forskningsprosjektet:

Undersøkelse av sirkulære muligheter innen AM-industrien

Dette er et spørsmål til deg om å delta i vår masteroppgave hvor formålet er å kartlegge muligheter for AM produksjon gjennom en sirkulær-økonomimodell. I dette skrivet får du informasjon om målene for prosjektet og hva deltakelse vil innebære for deg.

Formål
Vi studerer master i økonomi og administrasjon ved Universitetet i Stavanger. Vi skriver vår masteroppgave for en ekstern oppdragsgiver, Valvision as. Det foreløpige forskningsspørsmålet til masteroppgaven er: Can additive manufacturing be economically beneficial in comparison to traditional manufacturing, supported by a circular business model? Prosjektets formål er derfor å kartlegge potensielle muligheter for 3D-printing innen dagens produksjonsmarked.

Hvem er ansvarlig for forskningsprosjektet?
Universitetet i Stavanger, ved Samfunnsvitenskaplige Fakultet er ansvarlig for prosjektet. Vår veileder er Dr. Gorm Kipperberg, ved Handelshøyskolen i Stavanger. Ekstern oppdragsgiver er Rolf Lohne, administrerende direktør i Valvision.

Hvorfor får du spørsmål om å delta?
Du eller din bedrift har blitt anbefalt av våre samarbeidspartnere ved Valvision og UiS som har god innsikt i 3D-printing bransjen.

Hva innebærer det for deg å delta?
Hvis du velger å delta i prosjektet, innebærer det at du svarer på et semi-strukturelt intervju. Det vil ta deg ca. 30 minutter, og vil gjennomføres via Microsoft Teams. Intervjuguiden inneholder spørsmål om anvendelsen av additive manufacturing, teknologiens lønnsomhet/økonomi, fremtidige forventninger og hindringer for teknologien. Dine svar blir tatt opp på lydbånd.

Det er frivillig å delta
Det er frivillig å delta i prosjektet. Hvis du velger å delta, kan du når som helst trekke samtykket tilbake uten å oppgi noen grunn. Alle dine personopplysninger vil da bli slettet. Det vil ikke ha noen negative konsekvenser for deg hvis du ikke vil delta eller senere velger å trekke deg.

Ditt personvern – hvordan vi oppbevarer og bruker dine opplysninger
Vi vil bare bruke opplysningene om deg til formålene vi har fortalt om i dette skrivet. Vi behandler opplysningene konfidensielt og i samsvar med personvernregelverket. Det er kun Veileder Dr. Gorm Kipperberg, Masterstudenter Hallvard Aanestad og Nimrod Szekely som vil ha innsyn i dataene underveis. For å sikre at ingen uvedkommende får tilgang til dine personopplysninger vil ditt navn og virksomhet bli erstattet med en kode som lagres på egen navneliste adskilt fra øvrige data og lagret datamaterialet på ekstern server.

Hva skjer med opplysningene dine når vi avslutter forskningsprosjektet?
Masteroppgaven skal leveres 15.06.2021. Alle personopplysninger blir slettet senest 01/09/2021. Veileder Dr. Gorm Kipperberg vil ha tilgang til dataene underveis i masterprosjektet.

Dine rettigheter
Så lenge du kan identifiseres i datamaterialet, har du rett til: innsyn i hvilke personopplysninger som er registrert om deg, å få rettet personopplysninger om deg, få slettet personopplysninger om deg, få utlevert en kopi av dine personopplysninger (dataportabilitet), og å sende klage til personvernombudet eller Datatilsynet om behandlingen av dine personopplysninger.

Hva gir oss rett til å behandle personopplysninger om deg?
Vi behandler opplysninger om deg basert på ditt samtykke. NSD – Norsk senter for forskningsdata AS vurdert at behandlingen av personopplysninger i dette prosjektet er i samsvar med personvernregelverket.

Hvor kan jeg finne ut mer?
Hvis du har spørsmål til studien, eller ønsker å benytte deg av dine rettigheter, ta kontakt med:

- Dr. Gorm Kipperberg, gorm.kipperberg@uis.no, tlf. 51833729.
  Veileder ved Handelshøyskolen i UiS, fakultet for samfunnsøkonomi og finans
- Hallvard Aanestad, hallvard.aa@hotmail.com, tlf. 93852320
- Nimrod Szekely, nimrod01@freemail.hu, tlf. 46593030

Hvis du har spørsmål knyttet til NSD sin vurdering av prosjektet, kan du ta kontakt med:

- NSD – Norsk senter for forskningsdata AS på epost (personverntjenester@nsd.no) eller på telefon: 55 58 21 17.

Med vennlig hilsen

Dr. Gorm Kipperberg	Hallvard Aanestad	Nimrod Szekely
Veileder	Masterstudent	Masterstudent

Samtykkeerklæring

Jeg har mottatt og forstått informasjon om prosjektet "Undersøkelse av sirkulære muligheter innen AM-industrien", og har fått anledning til å stille spørsmål. Jeg samtykker til:

- ☐ Å delta i semi-strukturert intervju
- ☐ Jeg samtykker til at mine opplysninger behandles frem til prosjektet er avsluttet, ca. 15. juni 2021 og slettes senest 01/09/2021.

(Signert av prosjektdeltaker, dato)

Appendix 2: List of References

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Appendix 3: Reference Table

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Arrizubieta et al.	Study of the Environmental Implications of Using Its Handling	2020	Journal Article	Studies different powder-based AM processes. Pays special attention to the health risks.	Qualitative, systematic literature review	Highlights AM as an environmentally friendly technology, while pointing to further studies being required to make a definitive statement.
Atzeni and Salmi	Economics of additive manufacturing for end-usable metal parts	2012	Journal Article	Comparison between two different technologies for metal part fabrication	Quantitative research with developing cost models	Production volume for which AM techniques result competitive with respect to conventional processes for the production of end-usable metal parts. Currently additive techniques can be economically convenient and competitive to traditional processes for small to medium batch production of metal part
Augustsson and Becevic	Implementing Additive Manufacturing for Spare Parts in the Automotive Industry A case study of the use of additive manufacturing for spare parts	2015	Master Thesis	Investigate if inventory costs for low turnover spare parts can be lowered, but still offer the same availability by using additive manufacturing	Case study	Measure the effect that additive manufacturing would have on the supply chain. Overall, somewhat negative to the current technology, but future improvements could make it profitable and worth researching further.
Baumers and Holweg	On the economics of additive manufacturing: Experimental findings	2019	Journal Article	Reports on a series of experiments designed to elucidate how quantity, quality and cost relate in additive manufacturing processes.	Quantitative analysis	Traditional economies of scale only partially apply to additive manufacturing processes. Finds no evidence of a positive effect of increased volume on unit cost.
Baumers et al.	The cost of additive manufacturing: Machine productivity, economies of scale and technology-push	2016	Journal Article	Performs an inter-process comparison of cost performance	Quantitative analysis	High specific costs, measured at £2.39 and £6.18 per cm^3 of material deposited are identified as a central impediment to more widespread technology adoption of additive systems. Reveals that economies of scale are achievable in AM.

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Baumers et al.	Informing additive manufacturing technology adoption: Total cost and the impact of capacity utilisation	2017	Journal Article	Investigate the relationship between build volume capacity utilization and efficient technology operation.	Quantitative analysis	Investigates the relationship between build volume capacity utilization and efficient technology operation in an inter-process comparison of the costs of manufacturing a complex component used in the packaging industry.
Berman	3-D printing: The new industrial revolution	2012	Journal Article	Examines characteristics and applications of 3D printing and compares it with mass customization and other manufacturing processes.	N/A	A significant advantage of 3-D printing is a firm's ability to quickly and cost-effectively supply low demand parts without the risk of carrying an unsold finished goods inventory. Focus on home-applicants
Bikas, Stavropoulos and Chryssolouris	Additive manufacturing methods and modelling approaches: a critical review	2016	Journal Article	Map available additive manufacturing methods based on their process mechanisms, review modelling approaches and identify research gaps.	Review and assessment of modelling approaches	N/A
Brecher	Advances in Production Technology	2015	Book	Provide an overview of the status of research within "The Cluster of Excellence".	N/A	N/A
Busachi et al.	Additive manufacturing applications in Defence Support Services: current practices and framework for implementation	2018	Journal Article	Studies the possibilities of implementing Am technologies in the Defence Support Services.	Quantitative analysis	MoD will benefit from the increased support to the availability given a reduced response time; from the reduced supply chain complexity given only supplies of raw materials such as powder and wire; reduced platform's inventory levels, providing more space and finally from reduced delivery time of the component as the RAS can be located near to the point of use.

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Colorado, Velásquez, and Monteiro	Sustainability of additive manufacturing: the circular economy of materials and environmental perspectives	2020	Journal Article	Seeks to develop a greater awareness in possibilities and implications in the use of the AM, as well as to encourage sustainable development.	Qualitative, systematic literature review	Research shows that significant progress has been made on several relevant issues. Using materials optimization to minimize energy and waste is still far from a global solution.
Colosimo, Cavalli, and Grasso	A cost model for the economic evaluation of in-situ monitoring tools in metal additive manufacturing	2020	Journal Article	Presents a cost model to evaluate the economic impact of defects and process instability in metal Additive Manufacturing.	Quantitative analysis with case studies	Study presented a generalized cost model formulation to determine the economic impact of defects in metal PBF processes and the economic convenience of in-situ monitoring solutions. The study identifying three categories of products in AM, namely low-, medium-, and high-value-added products.
Conner et al.	Making sense of 3-D printing: Creating a map of additive manufacturing products and services	2014	Journal Article	Investigates whether a product should be manufactured by TM or AM.	Quantitative analysis	A geometric complexity factor developed for cast parts is modified for a more general application. Parts with varying geometric complexity are then analysed and mapped into regions of the complexity, customization, and production volume model.
Derekar	A review of wire arc additive manufacturing and advances in wire arc additive manufacturing of aluminium	2018	Journal Article	A review of wire arc additive manufacturing	Quantitative analysis	A brief of WAAM history, status, advantages and constraints of the WAAM field.
Fraţila and Rotaru	Additive manufacturing - a sustainable manufacturing route	2017	Journal Article	Analyse the environmental impacts of two additive manufacturing machines and a traditional computer numerical control milling machine.	Case study	AM has the potential to lower costs and to be more energy efficient than conventional processes. The sustainability of AM vs TM depends primarily on the utilization rate of the machines.

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Fredriksson	Sustainability of metal powder additive manufacturing	2019	Journal Article	Aims to answer questions about sustainability benefits using various AM techniques	Data collection	Finds that both the metal powder production and the additive manufacturing process itself contribute considerably to total energy use and emissions.
Gibson et al.	Additive Manufacturing Technologies	2019	Book	Textbook primarily aimed at students and educators studying AM.	N/A	N/A
Godina et al.	Impact assessment of additive manufacturing on sustainable business models in industry 4.0 context	2020	Journal Article	Assess impacts of additive manufacturing technology on sustainable business models.	Qualitative analysis with framework	The effects are assessed by taking into account the social, environmental and economic impacts of additive manufacturing on business models and for all these three dimensions a balanced scorecard structure is proposed.
Grujovic et al.	Cost optimization of additive manufacturing in wood industry	2016	Journal Article	Describes the FDM and 3DP rapid prototyping technologies.	Quantitative analysis	Total costs of manufacturing related to the fabrication of sample elements and tools are analysed. One of the main recognised issues of wider application of rapid prototyping technologies is their very high costs.
Handal	An implementation framework for additive manufacturing in supply chains	2017	Journal Article	Implementation of AM from a supply chain point of view	Qualitative analysis, exploratory research with interviews	Framework recommends implementing additive manufacturing when the product is complex and is formed by high value components

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Huang et al.	Additive manufacturing and its societal impact: a literature review	2013	Journal Article	Review the societal impact of additive manufacturing from a technical perspective.	Literature review	Find promises of additive manufacturing in the following areas: customized healthcare products, reduced environmental impact for manufacturing sustainability, and simplified supply chain to increase efficiency and responsiveness.
Khorram Niaki and Nonino	Additive manufacturing management: a review and future research agenda	2017	Journal Article	Aims to investigate AM technology extending previous research results.	Quantitative article with Ordinal Logistic Regression	AM might contribute to cost reduction mostly in new product development and for low volume production. AM not only is not capable of competing with TM in mass production but also is not suitable for large scale production (more than 200 parts).
Khorram Niaki et al.	Economic sustainability of additive manufacturing: Contextual factors driving its performance in rapid prototyping	2019	Journal Article	investigate AM by studying in-depth the economic sustainability of AM technology and bringing out the contextual factors that drive performance	Survey based	AM-based prototyping leads to significant cost reduction, but not as good as conventional manufacturing in terms of the profitability of investment.
Li et al.	A dynamic order acceptance and scheduling approach for additive manufacturing on-demand production	2019	Journal Article	Introduces the dynamic OAS problem in on-demand production with PBF systems.	Quantitative with strategy-based metaheuristic decision making approach	The experimental results indicated that it is practicable to obtain promising profitability with the proposed metaheuristic approach by applying a properly designed decision-making strategy
Manogharan, Wysk, and Harrysson	Additive manufacturing-integrated hybrid manufacturing and subtractive processes: Economic model and analysis	2016	Journal Article	Study the influence of production volume, material and operating cost, batch size, machinability of material and impact of reducing AM processing time.	An experimental design	Develops and presents economic models. The developed models provide insight how variables affect costs. Batch size, AM processing time and AM processing costs were the major costs factors

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Manoharan et al.	Comparing the economics of metal additive manufacturing processes for micro-scale plate reactors in the chemical process industry	2019	Journal Article	Focus on specific AM manufacturing processes. Compares two prominent methods to produce micro-scale plate reactors.	Quantitative analysis	Not economics related may be worth mentioning
Mashhadi and Salinas Monroy	Economically-robust Dynamic Control of the Additive Manufacturing Cloud	2019	Journal Article	Investigates the possibility to develop AM cloud to pool manufacturers' resources	Quantitative analysis	Finds that it is possible to realize a profit for manufacturers' who utilize the researched business model.
Mellor et al.	Additive manufacturing: A framework for implementation	2014	Journal Article	Develops an implementation framework for AM	Qualitative analysis	Implementation of AM by five factors: Strategic, Technological, Organizational, Operational and Supply Chain factor.
Nagulpelli, King, and Warsing	Integrated traditional and additive manufacturing production profitability model	2019	Journal Article	Present research, process methodologies and a practical approach to the profit-based economic decision-modelling for production planning	Quantitative analysis with cost models	Identifies a framework for production leaders. Efficiency measures while adapting AM production. Outlines opportunities for future research toward the objective of optimizing production technology assignments within a mixed-resource environment.
Niaki and Nonino	Impact of additive manufacturing on business competitiveness: A multiple case study	2017	Journal Article	Identify the impacts of additive manufacturing in manufacturing, business strategies and business performance and determine the factors driving its performance.	Exploratory study using multiple case research methodology.	Reveals how the implementation of AM in the Rapid Manufacturing of products made of metal has boosted productivity

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Pannitz and Sehrt	Transferability of Process Parameters in Laser Powder Bed Fusion Processes for an Energy and Cost-Efficient Manufacturing	2020	Journal Article	Five metallic powders were characterized by analysing particle size distribution, morphology, flowability and absorption behaviour.	Quantitative analysis	Not economics related. Optimize exposure parameters to ensure a more sustainable and energy and cost-efficient manufacturing process.
Piller et al.	Introducing a Holistic Profitability Model for Additive Manufacturing: An Analysis of Laser-powder Bed Fusion	2019	Journal Article	Aims at developing a profitability model for a holistic assessment of Laser-Powder Bed Fusion.	Theoretical assessment	Demonstrate the impacts that L-PBF has on pricing. Confident that in the future, L-PBF will be more and more integrated in production.
Post et al. 2016	The economics of big area additive manufacturing	2016	Journal Article	Compare the cost of using traditional fused deposition modelling (FDM) with BAAM.	N/A	Changing from fibres to reinforced pellets can significantly increase production rate and part size while simultaneously reducing cost
Sandström	Adopting 3D Printing for manufacturing – The case of the hearing aid industry	2015	Journal Article	Explores how 3D Printing has been adopted for manufacturing in the hearing aid industry.	Qualitative with secondary data review	Paper suggests that the introduction of 3D Printing will not result in extensive competitive turbulence.
Schneck et al.	Evaluating the Use of Additive Manufacturing in Industry Applications	2019	Journal Article	Investigate the application purposes of additive manufacturing, showing the benefits of and additional values created by the technology.	Systematic literature reviews, expert workshops and a market study	Find two main application purposes of the AM technology: The improvement of a parts performance and a simplified manufacturing process.

Author	Title	Year	Source type	Purpose	Methodology	Main findings
Sonar, Khanzode, and Akarte	A Conceptual Framework on Implementing Additive Manufacturing Technology Towards Firm Competitiveness	2020	Journal Article	Explore essential AM implementation factors from an operational performance point of view.	Semi structured interviews	18 factors identified (The identified factors further grouped into five categories: technical, organizational, operational, supply chain and market dynamics).
Thomas	Economics of the U.S. Additive Manufacturing Industry	2013	Technical report	Examines the additive manufacturing industry in the U.S. Examines the adoption and diffusion of additive manufacturing technologies.	Quantitative analysis with cost models	Additive manufacturing may provide an important opportunity for advancing U.S. manufacturing while maintaining and advancing U.S. innovation. The U.S. is currently a major user of additive manufacturing technology and the primary producer of additive manufacturing systems.
Westerweel, Basten, and Houtum	Traditional or Additive Manufacturing? Assessing Component Design Options through Lifecycle Cost Analysis	2018	Journal Article	The article compares AM and TM by demonstrating the production of two system components	Quantitative analysis	Component reliability and production costs are crucial to the success of AM components, while AM component design costs can be overcome to a certain degree by generating performance benefits or by using the short AM production lead-time to lower the aftersales logistics costs.
Wong and Hernandez	A Review of Additive Manufacturing	2012	Journal Article	Article describes the different types of AM technologies	Qualitative with descriptive style	AM technologies systematically presented
Yang and Li	Cost modelling and analysis for Mask Image Projection Stereolithography additive manufacturing: Simultaneous production with mixed geometries	2018	Journal Article	A comprehensive cost model is established to theoretically evaluate the cost performance of the Mask Image Projection Stereolithography	Quantitative analysis with cost models and Case Study	Results show that the optimal set of the decision variables can lead to around 26% reduction in variable cost without sacrificing the yearly throughput and part surface quality. The material unit price and the initial investment are identified as the key cost drivers.

Appendix 4: Income Statement Forecast Line-Item Calculations

Fully Random Simulation Income Statement Item Calculations

$$SCENARIO2 = SCENARIO1 + g1$$

$$SCENARIO3 = SCENARIO2 + g1$$

$$\ldots$$

$$SCNEARIO5 = SCNEARIO4 + g2$$

Implementing SCENARIO and Growth

As the two random variables, SCENARIO and Growth has been simulated, they can be implemented into the initial Income Statement to create a forecast, as it has been derived in the relevant part of the theory chapter. Here only the revenues per year (R1, …, R5) and the COGS (COGS1, …, COGS5) are listed since these variables are directly depended on the SCENARIO and growth rate, the rest of the line items are only derivatives of these two. (Not numbered since they are listed here for a representative purpose).

$$R1 = TOTREV \times SCENARIO1$$

$$R2 = R1 \times SCENARIO2$$

$$\ldots$$

$$R5 = R4 \times SCENARIO4$$

$$COGS1 = SCENARIO1 \times COGSB$$

$$\ldots$$

$$COGS5 = SCENARIO5 \times COGSB$$

Computation of Income Statement Forecast Line Items for Fully-Random Poisson Simulation

The first year's revenue is computed as follows:

$$R1 = (CRMAXB \times MY \times AP) \times 44$$

Where R1 equals the Total Crucible Maximum batch, the simulated weekly demand for powder batches (MY), the average powder price (AP) and finally the number of working weeks multiplied. When plugging in the fixed variables, we have:

First year's COGS:

$$COGS1 = \frac{MY}{WTOTP} \times COGSB$$

Second year's revenue and COGS

To simplify the growth in revenue, a new variable, G, is introduced:

$$G1 = gp1 \times WTOTB$$

$$R2 = (CRMAXB \times (MY+G1) \times AP) \times 44$$

$$COGS2 = (\frac{MY}{WTOTP} + g1) \times COGSB$$

Third year's revenue and COGS

$$R3 = (CRMAXB \times (MY + 2 \times G1) \times AP) \times 44$$

$$COGS3 = (\frac{MY}{WTOTP} + 2 \times g1) \times COGSB$$

Fourth year's revenue and COGS

$$G2 = gp2 \times WTOTB$$

$$R4 = (CRMAXB \times (MY+2 \times G1+G2) \times AP) \times 44$$

$$COGS4 = (\frac{MY}{WTOTP} + 2 \times g1 + g2) \times COGSB$$

Fifth year's revenue and COGS:

$$R45= (CRMAXB \times (MY+2 \times G1+2 \times G2) \times AP) \times 44$$

$$COGS5 = (\frac{MY}{WTOTP} + 2 \times g1 + 2 \times g2) \times COGSB$$

SCENARIOS

Demand in percentage is then calculated, yearly revenue is divided by the total revenue achievable:

$$SCENARIO1 = \frac{R1}{TOTREV}, \ldots, SCENARIO5 = \frac{R5}{TOTREV}$$

Hence, scenarios are derived by "bottom-up" method from annualised revenues, unlike with the triangular distribution where they were calculated directly from yearly simulated demand, "top-down".

APPENDIX 4.A

Cumulative table to present where the BE probability is situated on the random variable SCENARIO.

A.1 Cumulative Probability Table

SCENARIO	Counts	Percent	Cumulated Count	Cumulated Percent
0,3083	1	0,1	1	0,1
0,3136	1	0,1	2	0,2
0,3211	1	0,1	3	0,3
0,3215	1	0,1	4	0,4
0,3223	1	0,1	5	0,5
0,3297	1	0,1	6	0,6
0,3314	1	0,1	7	0,7
0,333	1	0,1	8	0,8
0,3345	1	0,1	9	0,9
0,3347	1	0,1	10	1
0,3356	1	0,1	11	1,1
0,3358	1	0,1	12	1,2
0,3359	1	0,1	13	1,3
0,3372	1	0,1	14	1,4
0,3375	1	0,1	15	1,5
0,3379	1	0,1	16	1,6
0,3383	1	0,1	17	1,7
0,3384	1	0,1	18	1,8

0,3389	1	0,1	19	1,9
0,3392	1	0,1	20	2
0,3397	1	0,1	21	2,1
0,3403	1	0,1	22	2,2
0,3406	1	0,1	23	2,3
0,3409	1	0,1	24	2,4
0,341	1	0,1	25	2,5
0,3418	1	0,1	26	2,6
0,3425	1	0,1	27	2,7
0,3429	1	0,1	28	2,8
0,3433 (BE)	1	0,1	29	2,9
0,3439	1	0,1	30	3
0,3441	1	0,1	31	3,1
0,3447	1	0,1	32	3,2
0,3452	1	0,1	33	3,3
0,3453	1	0,1	34	3,4
0,3454	1	0,1	35	3,5
0,3458	1	0,1	36	3,6
0,3459	1	0,1	37	3,7
0,346	2	0,2	39	3,9
0,3464	1	0,1	40	4
0,3465	1	0,1	41	4,1
0,3468	2	0,2	43	4,3
0,3471	1	0,1	44	4,4
0,3474	1	0,1	45	4,5
0,3476	1	0,1	46	4,6
0,3478	1	0,1	47	4,7
0,3479	1	0,1	48	4,8
0,348	2	0,2	50	5
0,3487	1	0,1	51	5,1
0,3491	1	0,1	52	5,2
0,3494	1	0,1	53	5,3
0,3495	1	0,1	54	5,4
0,3497	2	0,2	56	5,6
0,3501	1	0,1	57	5,7
0,3502	1	0,1	58	5,8
0,3506	2	0,2	60	6
0,3509	1	0,1	61	6,1
0,351	1	0,1	62	6,2
0,3511	1	0,1	63	6,3
0,3515	1	0,1	64	6,4
0,3516	2	0,2	66	6,6
0,3518	1	0,1	67	6,7
0,3519	1	0,1	68	6,8
0,352	1	0,1	69	6,9
0,3521	2	0,2	71	7,1
0,3522	1	0,1	72	7,2

0,3524	1	0,1	73	7,3
0,3527	2	0,2	75	7,5
0,3531	1	0,1	76	7,6
0,3534	1	0,1	77	7,7
0,3535	1	0,1	78	7,8
0,3537	1	0,1	79	7,9
0,3538	2	0,2	81	8,1
0,3539	4	0,4	85	8,5
0,354	1	0,1	86	8,6
0,3542	1	0,1	87	8,7
0,3544	2	0,2	89	8,9
0,3546	1	0,1	90	9
0,3551	2	0,2	92	9,2
0,3552	2	0,2	94	9,4
0,3554	1	0,1	95	9,5
0,3555	1	0,1	96	9,6
0,3557	2	0,2	98	9,8
0,3558	1	0,1	99	9,9
0,3561	1	0,1	100	10
0,3562	1	0,1	101	10,1
0,3566	1	0,1	102	10,2
0,3567	1	0,1	103	10,3
0,3568	1	0,1	104	10,4
0,3569	1	0,1	105	10,5
0,3571	3	0,3	108	10,8
0,3573	2	0,2	110	11
0,3574	2	0,2	112	11,2
0,3577	1	0,1	113	11,3
0,3578	3	0,3	116	11,6
0,358	2	0,2	118	11,8
0,3583	1	0,1	119	11,9
0,3585	2	0,2	121	12,1
0,3587	2	0,2	123	12,3
0,3589	3	0,3	126	12,6
0,359	1	0,1	127	12,7

Appendix 5: R-Script

Fully Random Triangular Distribution

```
library(openxlsx)
library(tidyverse)
library(stargazer)
library(truncnorm)
library(plotrix)
library(EnvStats)
library(formattable)
library(ggplot2)

#### INPUT VARIABLES ####
## TOTAL REVENUE ##
TOTREV = 7068848
## PRODUCTIVITY ##
TOTP = 278850
## FIXED COSTS ##
OVERHEAD = 676000
## VARIABLE COSTS ##
L = 1005000
SCRAPC = 3.5 # Euro/kg
UTILITIES = 378000
CONSUMABLES = 836550
QUALITYC = 110000
## DEPRECIATION ##
DEPR = 740333
## INTEREST/FINANC ##
FINANC = 43900
## TAX RATE ##
TR = 0.22



#### SIMULATION ####
### DEMAND ###
d <- sample(0:TOTP, 20, TRUE)

# Create the mode function.
getmode <- function(v) {
  uniqv <- unique(v)
  uniqv[which.max(tabulate(match(v, uniqv)))]
}

mind <- min(d)
```

```
maxd <- max(d)
moded <- ifelse(getmode(d)==mind|getmode(d)==maxd, maxd*(3/4), getmode(d))
Y <- list()
SCENARIO <- list()
MSCNR <- list()

for (i in 1:1000)
{
  Y[[i]] <- rtri(100, min = mind, max = maxd, mode = moded)
  SCENARIO[[i]] = Y[[i]]/TOTP
  MSCNR[[i]] = mean(SCENARIO[[i]])
}

SCNR <- unlist(MSCNR)
SCENARIO1 = round(mean(SCNR), digits = 2)

## GROWTH FACTOR ##

ng1 <- list()
ng2 <- list()
g1 <- list()
g2 <- list()


ming01 <- list()
modeg01 <- list()
maxg01 <- list()

ming02 <- list()
modeg02 <- list()
maxg02 <- list()

g01 <- runif(1000, 0, 0.1)
g02 <- runif(1000, 0.1, 0.2)

ming01 <- min(g01)
modeg01 <- ifelse(getmode(g01)==0|getmode(g01)<=ming01, 0.075, getmode(g01)) # makes sure mode>min
maxg01 <- ifelse(max(g01)==0|max(g01)<=modeg01, 0.1, max(g01)) # makes sure max>mode

ming02 <- min(g02)
modeg02 <- ifelse(getmode(g02)==0|getmode(g02)<=ming02, 0.175, getmode(g02))
maxg02 <- ifelse(max(g02)==0|max(g02)<=modeg02, 0.2, max(g02))

for (b in 1:100)
  {
```

```
  ng1[[b]] = rtri(1000, min = ming01, max = maxg01, mode = modeg01) # y1 - y3
  g1[[b]] = mean(ng1[[b]])

  ng2[[b]] = rtri(1000, min = ming02, max = maxg02, mode = modeg02) # y3 - y5
  g2[[b]] = mean(ng2[[b]])
  }

g1 <- unlist(g1)
g2 <- unlist(g2)

g1 = mean(g1)
g2 =mean(g2)


### SIMUALTION PER YEAR ###
## YEAR 1 ##

SCENARIO1 = round(MSCNR, digits = 2)
R1 = TOTREV * SCENARIO1
COGS1 = SCENARIO1 * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS1 = R1 - COGS1
EBITDA1 = GROSS1 - OVERHEAD
TAX1 = (EBITDA1 - DEPR - FINANC) * TR
NET1 = EBITDA1 - DEPR - FINANC - TAX1

## YEAR 2 ##

SCENARIO2 = round(SCENARIO1+(g1), digits = 2)
R2 = TOTREV*SCENARIO2
COGS2 = SCENARIO2 * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS2 = R2 - COGS2
EBITDA2 = GROSS2 - OVERHEAD
TAX2 = (EBITDA2 - DEPR - FINANC) * TR
NET2 = EBITDA2 - DEPR - FINANC - TAX2

## YEAR 3 ##

SCENARIO3 = round(SCENARIO2+(g1), digits = 2)
R3 = TOTREV*SCENARIO3
COGS3 = SCENARIO3 * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS3 = R3 - COGS3
EBITDA3 = GROSS3 - OVERHEAD
TAX3 = (EBITDA3 - DEPR - FINANC) * TR
NET3 = EBITDA3 - DEPR - FINANC - TAX3
```

```
## YEAR 4 ##

SCENARIO4 = round(SCENARIO3+(g2), digits = 2)
R4 = TOTREV*SCENARIO4
COGS4 = SCENARIO4 * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS4 = R4 - COGS4
EBITDA4 = GROSS4 - OVERHEAD
TAX4 = (EBITDA4 - DEPR - FINANC) * TR
NET4 = EBITDA4 - DEPR - FINANC - TAX4

## YEAR 5 ##

SCENARIO5 = round(SCENARIO4+(g2), digits = 2)
R5 = TOTREV*SCENARIO5
COGS5 = SCENARIO5 * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS5 = R5 - COGS5
EBITDA5 = GROSS5 - OVERHEAD
TAX5 = (EBITDA5 - DEPR - FINANC) * TR
NET5 = EBITDA5 - DEPR - FINANC - TAX5

### INCOME STATEMENT OUTPUT ##
YEARS <- c("YEAR 1", "YEAR 2", "YEAR 3", "YEAR 4", "YEAR 5")
RNAMES <- c("SCENARIOS", "REVENUE", "COGS", "GROSS", "OVERHEAD", "EBITDA",  "DEPRECIATION",
"INTEREST/FINANCIAL", "TAX", "NET")
REVENUES <- format(round(c(R1, R2, R3, R4, R5), digits = 0), nsmall = 1, big.mark = ",")
COGSS <- format(round(c(COGS1, COGS2, COGS3, COGS4, COGS5), digits = 0), nsmall = 1, big.mark = ",")
GROSSS <- format(round(c(GROSS1, GROSS2, GROSS3, GROSS4, GROSS5), digits = 0), nsmall = 1, big.mark = ",")
EBITDAS <- format(round(c(EBITDA1, EBITDA2, EBITDA3, EBITDA4, EBITDA5), digits = 0), nsmall = 1, big.mark =
",")
NETS <- format(round(c(NET1, NET2, NET3, NET4, NET5), digits = 0), nsmall = 1, big.mark = ",")
TAXES <- format(round(c(TAX1, TAX2, TAX3, TAX4, TAX5), digits = 0), nsmall = 1, big.mark = ",")
SCENARIOS <- format(round(c(SCENARIO1, SCENARIO2, SCENARIO3, SCENARIO4, SCENARIO5), digits = 2))

STATEMENT <- rbind(SCENARIOS, REVENUES, COGSS, GROSSS, OVERHEAD, EBITDAS, DEPR, FINANC,
TAXES, NETS) %>% as.data.frame()
colnames(STATEMENT) <- YEARS
rownames(STATEMENT) <- RNAMES
### PROBABILITIES ###

SCNR <- unlist(SCNR)
SCNR <- SCNR[order(SCNR)]
```

```
SCNR <- round(SCNR, digits = 4)

ODF = OVERHEAD + DEPR + FINANC

X = ODF/GROSS1
REB = R1*X
BEGROSS = GROSS1*X
BE = round(REB/TOTREV, digits = 4)
MINSCNR = min(SCNR)

ZS95 <- qnorm(0.975)
ZS99 <- qnorm(0.995)

REV = round((TOTREV*SCNR), digits = 0)
COGS = round(SCNR * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC)), digits = 0)
GROSS = REV - COGS
NET = ifelse(FBE > SCNR, 0, GROSS - OVERHEAD - FINANC - DEPR - ((GROSS-OVERHEAD-DEPR-
FINANC)*TR))
df3 <- data_frame(SCNR, NET)
colnames(df3) <- c("SCENARIO", "NET")

## FREQUENCY TABLE ##
freqdist <- function(x, freqorder=F)
{
  counts = table(x)
  n = sum(counts)
  if(freqorder) ord=order(-counts)
  else ord = 1:length(counts)
  data_frame(row.names=row.names(counts[ord]),
             Counts=as.vector(counts[ord]),
             Percent=100*as.vector(counts[ord]/n),
             CumCount=cumsum(as.vector(counts[ord])),
             CumPercent=100*cumsum(as.vector(counts[ord]))/n)
}

dffrscnr <-freqdist(SCNR)
dffrscnr$row.names <- as.numeric(unlist(dffrscnr$row.names))
dfcumtable <- dffrscnr[1:100,]

dffrNET <- freqdist(NET)
colnames(dfcumtable) <- c("SCENARIO", "Counts", "Percent", "CumCount", "CumPercent")

## CONFIDENCE INTERVALS ##

meanSCN <- round(mean(df3$SCENARIO), digits = 4)
```

```
SEM <- round(sqrt((SCENARIO1*(1-SCENARIO1))/1000), digits = 4)
PSFC <- sum(df3$SCENARIO<=SCENARIO1)/length(df3$SCENARIO)

LOW95 <- SCENARIO1-(ZS95*SEM)
UP95 <- SCENARIO1+(ZS95*SEM)
LOW99 <- SCENARIO1-(ZS99*SEM)
UP99 <- SCENARIO1+(ZS99*SEM)

meanNET <- mean(df3$NET)
SEMNET <- std.error(df3$NET, na.rm = T)

NETLOW95 <- NET1-(ZS95*SEMNET)
NETUP95 <- NET1+(ZS95*SEMNET)
NETLOW99 <- NET1-(ZS99*SEMNET)
NETUP99 <- NET1+(ZS99*SEMNET)

PBE <- sum(df3$SCENARIO<=FBE)/length(df3$SCENARIO)
SEMPBE = round(sqrt((PBE*(1-PBE))/1000), digits = 4)

LOWPBE95 <- PBE-(ZS95*SEMPBE)
UPPBE95 <- PBE+(ZS95*SEMPBE)

LOWPBE99 <- PBE-(ZS99*SEMPBE)
UPPBE99 <- PBE+(ZS99*SEMPBE)

PD <- sum(df3$SCENARIO<=0.4059)/length(df3$SCENARIO)
SEMPD = round(sqrt((PD*(1-PD))/1000), digits = 4)

LOWPD95 <- PD-(ZS95*SEMPD)
UPPD95 <- PD+(ZS95*SEMPD)
LOWPD99 <- PD-(ZS99*SEMPD)
UPPD99 <- PD+(ZS99*SEMPD)
## CUMULATIVE TABLE ##
PSCNR <- c(LOW95, UP95, LOW99, UP99)
PNET <- c(NETLOW95, NETUP95, NETLOW99, NETUP99)
PNEGC <- c(LOWPNEG95, UPNEGNET95, LOWPNEG99, UPNEGNET99)
PBEC <- c(LOWPBE95, UPPBE95, LOWPBE99, UPPBE99)
PDC <- c(LOWPD95, UPPD95, LOWPD99, UPPD99)

clnms <- c("First-Year Scenario", "Mean NET", "Negative NET", "Break Even", "Default First-Year")
cdfivl <- c("95 Percentage Lower", "95 Percentage Upper", "99 Percentage Lower", "99 Percentage Upper")
dfconfint <- data_frame(PSCNR, PNET, PNEGC, PBEC, PDC)
colnames(dfconfint) <- clnms
dfconfint <- dfconfint %>% mutate(Confidence_Interval = cdfivl)
dfconfint <- dfconfint[,c(ncol(dfconfint),1:ncol(dfconfint)-1)]
```

Fully Random Simulation Poisson Distribution

```
library(openxlsx)
library(tidyverse)
library(stargazer)
library(truncnorm)
library(plotrix)
library(EnvStats)
library(formattable)

#### INPUT VARIABLES ####
## TOTAL REVENUE ##
TOTREV = 7068848
AP = 25
## PRODUCTIVITY ##
TOTP = 278850
CRMAXB = 422.5
TOTB = 660
WTOTB = TOTB/44
## FIXED COSTS ##
OVERHEAD = 676000
## VARIABLE COSTS ##
L = 1005000
SCRAPC = 3.5 # Euro/kg
UTILITIES = 378000
CONSUMABLES = 836550
QUALITYC = 110000
## DEPRECIATION ##
DEPR = 740333
## INTEREST/FINANC ##
FINANC = 43900
## TAX RATE ##
TR = 0.22




#### SIMULATION ####
## DEMAND ##
set.seed(0)
d <- sample(0:WTOTB, 20, TRUE)
# Create the mode function.
```

```
getmode <- function(v) {
  uniqv <- unique(v)
  uniqv[which.max(tabulate(match(v, uniqv)))]
}

medd <- median(d)
mind <- min(d)
maxd <- max(d)
### every now and then an error message appeared warning that
### the mode has to be between the min and max values. Therefore, for such a case to be avoided,
### an arbitrary set mode is used as it can be seen
moded <- ifelse(getmode(d)==mind|getmode(d)==maxd, maxd*(3/4), getmode(d))
sdd <- sd(d)
avd <- mean(d)
Y <- list()
MY <- list()
for (i in 1:100)
{
  Y[[i]] <-  rpois(100, lambda = avd)
  Y[[i]] <-  ifelse(Y[[i]]>15, (getmode(Y[[i]])-mind)/3, Y[[i]])
  MY[[i]] <- mean(Y[[i]])
}
Y = unlist(Y)
hist(Y, main = paste("Histogram of Batch Orders a Week"),
     xlab = "Number of Batch Orders a Week", ylab = "Probability", freq = F)
## GROWTH FACTORS ##
ng1 <- list()
ng2 <- list()
g1 <- list()
g2 <- list()
g01 <- list()
g02 <- list()

## SAMPLE ##
g01 <- sample(0:0.1, 100, replace = T)
g02 <- sample(0.1:0.2, 100, replace = T)

ming01 <- min(g01)
modeg01 <- ifelse(getmode(g01)==0|getmode(g01)<=ming01, 0.075, getmode(g01)) # makes sure mode>min
maxg01 <- ifelse(max(g01)==0|max(g01)<=modeg01, 0.1, max(g01)) # makes sure max>mode

ming02 <- min(g02)
modeg02 <- ifelse(getmode(g02)==0|getmode(g02)<=ming02, 0.175, getmode(g02))
maxg02 <- ifelse(max(g02)==0|max(g02)<=modeg02, 0.2, max(g02))
## GROWTH LOOP ##
```

```
for (a in 1:100)
{
  g1[[a]] = rtruncnorm(100, a = ming01, b = maxg01, mean = mean(g01), sd = sd(g01)) # y1 - y3

  g2[[a]] = rtruncnorm(100, a = ming02, b = maxg02, mean = mean(g02), sd = sd(g02)) # y3 - y5
  }
g1 <- unlist(g1)
g2 <- unlist(g2)
g1 = mean(g1)
g2 = mean(g2)

### INCOME STATEMENT LINE-ITEM CALCULATIONS ###
MY <- unlist(MY)
MY = mean(MY)

## YEAR 1 ##

R1 = (CRMAXB*AP*MY)*44
COGS1 = (MY/WTOTB) * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS1 = R1 - COGS1
EBITDA1 = GROSS1 - OVERHEAD
TAX1 = (EBITDA1 - DEPR - FINANC) * TR
NET1 = EBITDA1 - DEPR - FINANC - TAX1
SCENARIO1 = R1/TOTREV
## YEAR 2 ##
G1 = g1*WTOTB
R2 = (CRMAXB*AP*(MY+G1))*44
COGS2 = ((MY/WTOTB)+g1) * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS2 = R2 - COGS2
EBITDA2 = GROSS2 - OVERHEAD
TAX2 = (EBITDA2 - DEPR - FINANC) * TR
NET2 = EBITDA2 - DEPR - FINANC - TAX2
SCENARIO2 = R2/TOTREV
## YEAR 3 ##
R3 = (CRMAXB*AP*(MY+2*G1))*44
COGS3 = (((MY/WTOTB)+2*g1)) * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS3 = R3 - COGS3
EBITDA3 = GROSS3 - OVERHEAD
TAX3 = (EBITDA3 - DEPR - FINANC) * TR
NET3 = EBITDA3 - DEPR - FINANC - TAX3
SCENARIO3 = R3/TOTREV
## YEAR 4 ##
G2 = g2*WTOTB
R4 = (CRMAXB*AP*(MY+2*G1+G2))*44
COGS4 = ((MY/WTOTB)+2*g1+g2) * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
```

```
GROSS4 = R4 - COGS4
EBITDA4 = GROSS4 - OVERHEAD
TAX4 = (EBITDA4 - DEPR - FINANC) * TR
NET4 = EBITDA4 - DEPR - FINANC - TAX4
SCENARIO4 = R4/TOTREV
## YEAR 5 ##
R5 = (CRMAXB*AP*(MY+2*G1+2*G2))*44
COGS5 = ((MY/WTOTB)+2*g1+2*g2)*(L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS5 = R5 - COGS5
EBITDA5 = GROSS5 - OVERHEAD
TAX5 = (EBITDA5 - DEPR - FINANC) * TR
NET5 = EBITDA5 - DEPR - FINANC - TAX5
SCENARIO5 = R5/TOTREV
### INCOME STATEMENT FORECAST ###
YEARS <- c("YEAR 1", "YEAR 2", "YEAR 3", "YEAR 4", "YEAR 5")
RNAMES <- c("SCENARIOS", "REVENUE", "COGS", "GROSS", "OVERHEAD", "EBITDA",  "DEPRECIATION",
"INTEREST/FINANCIAL", "TAX", "NET")
REVENUES <- format(round(c(R1, R2, R3, R4, R5), digits = 0), nsmall = 1, big.mark = ",")
COGSS <- format(round(c(COGS1, COGS2, COGS3, COGS4, COGS5), digits = 0), nsmall = 1, big.mark = ",")
GROSSS <- format(round(c(GROSS1, GROSS2, GROSS3, GROSS4, GROSS5), digits = 0), nsmall = 1, big.mark = ",")
EBITDAS <- format(round(c(EBITDA1, EBITDA2, EBITDA3, EBITDA4, EBITDA5), digits = 0), nsmall = 1, big.mark =
",")
NETS <- format(round(c(NET1, NET2, NET3, NET4, NET5), digits = 0), nsmall = 1, big.mark = ",")
TAXES <- format(round(c(TAX1, TAX2, TAX3, TAX4, TAX5), digits = 0), nsmall = 1, big.mark = ",")
SCENARIOS <- format(round(c(SCENARIO1, SCENARIO2, SCENARIO3, SCENARIO4, SCENARIO5), digits = 2))

STATEMENTPOISSON <- rbind(SCENARIOS, REVENUES, COGSS, GROSSS, OVERHEAD, EBITDAS, DEPR,
FINANC, TAXES, NETS) %>% as.data.frame()
colnames(STATEMENTPOISSON) <- YEARS
rownames(STATEMENTPOISSON) <- RNAMES

### PROBABILITY OF BREAK EVEN SCENARIO PER YEAR ###

Y <- Y[order(Y)]
SCNR = Y/WTOTB
SCNR <- SCNR[order(SCNR)]
SCNR <- round(SCNR, digits = 4)
ODF = OVERHEAD + DEPR + FINANC
X = ODF/GROSS1
REB = R1*X
BEGROSS = GROSS1*X
BE = round(X/TOTREV, digits = 4)
MINSCNR = min(SCNR)
REV = round((TOTREV*SCNR), digits = 0)
COGS = round(SCNR * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC)), digits = 0)
```

```
GROSS = REV - COGS
NET = GROSS - OVERHEAD - FINANC - DEPR - ((GROSS-OVERHEAD-DEPR-FINANC)*TR)
df3 <- data_frame(SCNR, NET)
colnames(df3) <- c("SCENARIO", "NET")
## CUMULATIVE DISTRIBUTION TABLE ##
freqdist <- function(x, freqorder=F)
{
  counts = table(x)
  n = sum(counts)
  if(freqorder) ord=order(-counts)
  else ord = 1:length(counts)
  data_frame(row.names=row.names(counts[ord]),
           Counts=as.vector(counts[ord]),
           Percent=100*as.vector(counts[ord]/n),
           CumCount=cumsum(as.vector(counts[ord])),
           CumPercent=100*cumsum(as.vector(counts[ord]))/n)
}
dffrscnr <-freqdist(SCNR)
dffrscnr$row.names <- as.numeric(unlist(dffrscnr$row.names))
dffrNET <- freqdist(NET)

## CONFIDENCE INTERVALLS ##

ZS95 <- qnorm(0.975)
ZS99 <- qnorm(0.995)

meanSCN <- round(mean(df3$SCENARIO), digits = 4)
SEM <- round(sqrt((SCENARIO1*(1-SCENARIO1))/1000), digits = 4) # Standard Error of Mean SCENARIO1

LOW95 <- SCENARIO1-(ZS95*SEM)
UP95 <- SCENARIO1+(ZS95*SEM)
LOW99 <- SCENARIO1-(ZS99*SEM)
UP99 <- SCENARIO1+(ZS99*SEM)

meanNET <- mean(df3$NET)
SEMNET <- std.error(df3$NET, na.rm = T)



NETLOW95 <- NET1-(ZS95*SEMNET)
NETUP95 <- NET1+(ZS95*SEMNET)
NETLOW99 <- NET1-(ZS99*SEMNET)
NETUP99 <- NET1+(ZS99*SEMNET)

PBE <- sum(df3$SCENARIO<=FBE)/length(df3$SCENARIO)
SEMPBE = round(sqrt((PBE*(1-PBE))/1000), digits = 4) # SEM Beak Even
```

```
LOWPBE95 <- PBE-(ZS95*SEMPBE)
UPPBE95 <- PBE+(ZS95*SEMPBE)
LOWPBE99 <- PBE-(ZS99*SEMPBE)
UPPBE99 <- PBE+(ZS99*SEMPBE)

PD <- sum(df3$SCENARIO<=0.4059)/10000
SEMPD = round(sqrt((PD*(1-PD))/1000), digits = 4) # SEM SI

LOWPD95 <- PD-(ZS95*SEMPD)
UPPD95 <- PD+(ZS95*SEMPD)
LOWPD99 <- PD-(ZS99*SEMPD)
UPPD99 <- PD+(ZS99*SEMPD)

## CONFIDENCE TABLE ##

PSCNR <- c(LOW95, UP95, LOW99, UP99)
PNET <- c(NETLOW95, NETUP95, NETLOW99, NETUP99)
PNEGC <- c(LOWPNEG95, UPNEGNET95, LOWPNEG99, UPNEGNET99)
PBEC <- c(LOWPBE95, UPPBE95, LOWPBE99, UPPBE99)
PDC <- c(LOWPD95, UPPD95, LOWPD99, UPPD99)

clnms <- c("First-Year Scenario", "Mean NET", "Negative NET", "Break Even", "Default First-Year")
cdfivl <- c("95 Percentage Lower", "95 Percentage Upper", "99 Percentage Lower", "99 Percentage Upper")
dfconfint <- data_frame(PSCNR, PNET, PNEGC, PBEC, PDC)
colnames(dfconfint) <- clnms
dfconfint <- dfconfint %>% mutate(Confidence_Interval = cdfivl)
dfconfint <- dfconfint[,c(ncol(dfconfint),1:ncol(dfconfint)-1)]

## WEEKLY BATCH ORDER PROBABILITIES ##

WBEB = FBE*15 # weekly BE batches
lambda = MY

probs <- list()
for (p in 1:15)
  {
  probs[[p]] <- (lambda^p)/factorial(p)*(2.718281^(-lambda))
  }

probabs <- unlist(probs)
prob0 = ((lambda^0)/factorial(0))*(2.718281^(-lambda)) # probability of 0

probst5 = prob0 + probs[[1]] + probs[[2]] + probs[[3]] + probs[[4]] + probs[[5]] # probability of 5 or less orders
problt5 = 1 - probst5 # probability of more than five orders
```

```
probst6 = probst5 + probs[[6]] # probability of 6 or less orders

# probability to have more that 10 orders
ptotpois = sum(probabs)+prob0
p8 = probst6+probs[[7]]+probs[[8]]
p10 = p8+probs[[9]]+probs[[10]]
Pmt10 = 1 - p10
```

Simulation of Pessimistic Model

```
library(openxlsx)
library(tidyverse)
library(stargazer)
library(truncnorm)
library(plotrix)
library(EnvStats)
library(formattable)
library(R.utils)

#### INPUT VARIABLES IDENTICAL WITH FULLY RANDOM ####
### MODE FUNCTION ###

getmode <- function(v) {
  uniqv <- unique(v)
  uniqv[which.max(tabulate(match(v, uniqv)))]
}
#### SIMULATION ####

d <- list()
moded <- list()
mind <- list()
maxd <- list()


R1 <- list()
COGS1 <- list()
GROSS1 <- list()
EBITDA1 <- list()
NET1 <- list()
TAX1 <- list()
SCENARIO1 <- list()

R2 <- list()
```

```
COGS2 <- list()
GROSS2 <- list()
EBITDA2 <- list()
NET2 <- list()
TAX2 <- list()
SCENARIO2 <- list()

R3 <- list()
COGS3 <- list()
GROSS3 <- list()
EBITDA3 <- list()
NET3 <- list()
TAX3 <- list()
SCENARIO3 <- list()

R4 <- list()
COGS4 <- list()
GROSS4 <- list()
EBITDA4 <- list()
NET4 <- list()
TAX4 <- list()
SCENARIO4 <- list()

R5 <- list()
COGS5 <- list()
GROSS5 <- list()
EBITDA5 <- list()
NET5 <- list()
TAX5 <- list()
SCENARIO5 <- list()

g01 <- list()
g02 <- list()
ng1 <- list()
ng2 <- list()
g1 <- list()
g2 <- list()

Y <- list()
SCENARIO <- list()
MSCNR <- list()
SCNR <- list()
 ### SIMULATION GROWTH FACTORS ###

for (a in 1:100)
```

```
{

 ng1[[a]] <- list()
 ng2[[a]] <- list()
 g1[[a]] <- list()
 g2[[a]] <- list()

 for (b in 1:100)
 {
   ng1[[a]][[b]] = rtri(1000, min = 0, max = 0.1, mode = 0.025) # y1 - y3
   g1[[a]][[b]] = mean(ng1[[a]][[b]])

   ng2[[a]][[b]] = rtri(1000, min = 0.1, max = 0.2, mode = 0.125) # y3 - y5
   g2[[a]][[b]] = mean(ng2[[a]][[b]])
 }

 g1[[a]] <- unlist(g1[[a]])
 g2[[a]] <- unlist(g2[[a]])

 g1[[a]] = mean(g1[[a]])
 g2[[a]] = mean(g2[[a]])





 ### SIMUALTING DEMAND ###

 Y[[a]] <- list()
 SCENARIO[[a]] <- list()
 MSCNR[[a]] <- list()

 for (i in 1:100)
 {

   Y[[a]][[i]] <- rtri(1000, min = 0, max = TOTP, mode = 0.25*TOTP)
   SCENARIO[[a]][[i]] = Y[[a]][[i]]/TOTP
   MSCNR[[a]][[i]] = mean(SCENARIO[[a]][[i]])
 }

 SCNR[[a]] <- unlist(MSCNR[[a]])

 ## YEAR 1 ##
```

```
SCENARIO1[[a]] = round(mean(SCNR[[a]]), digits = 2)
R1[[a]] = TOTREV *  SCENARIO1[[a]]
COGS1[[a]] =  SCENARIO1[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS1[[a]] = R1[[a]] - COGS1[[a]]
EBITDA1[[a]] = GROSS1[[a]] - OVERHEAD
TAX1[[a]] = (EBITDA1[[a]] - DEPR - FINANC) * TR
NET1[[a]] = EBITDA1[[a]] - DEPR - FINANC - TAX1[[a]]

## YEAR 2 ##

SCENARIO2[[a]] = round(SCENARIO1[[a]]+g1[[a]], digits = 2)
R2[[a]] = TOTREV*SCENARIO2[[a]]
COGS2[[a]] = SCENARIO2[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS2[[a]] = R2[[a]] - COGS2[[a]]
EBITDA2[[a]] = GROSS2[[a]] - OVERHEAD
TAX2[[a]] = (EBITDA2[[a]] - DEPR - FINANC) * TR
NET2[[a]] = EBITDA2[[a]] - DEPR - FINANC - TAX2[[a]]

## YEAR 3 ##

SCENARIO3[[a]] = round(SCENARIO2[[a]]+g1[[a]], digits = 2)
R3[[a]] = TOTREV*SCENARIO3[[a]]
COGS3[[a]] = SCENARIO3[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS3[[a]] = R3[[a]] - COGS3[[a]]
EBITDA3[[a]] = GROSS3[[a]] - OVERHEAD
TAX3[[a]] = (EBITDA3[[a]] - DEPR - FINANC) * TR
NET3[[a]] = EBITDA3[[a]] - DEPR - FINANC - TAX3[[a]]

## YEAR 4 ##

SCENARIO4[[a]] = round(SCENARIO3[[a]]+g2[[a]], digits = 2)
R4[[a]] = TOTREV*SCENARIO4[[a]]
COGS4[[a]] = SCENARIO4[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS4[[a]] = R4[[a]] - COGS4[[a]]
EBITDA4[[a]] = GROSS4[[a]] - OVERHEAD
TAX4[[a]] = (EBITDA4[[a]] - DEPR - FINANC) * TR
NET4[[a]] = EBITDA4[[a]] - DEPR - FINANC - TAX4[[a]]

## YEAR 5 ##

SCENARIO5[[a]] = ifelse(SCENARIO4[[a]]+g2[[a]]>1, 1, round(SCENARIO4[[a]]+g2[[a]], digits = 2))
R5[[a]] = TOTREV*SCENARIO5[[a]]
COGS5[[a]] = SCENARIO5[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS5[[a]] = R5[[a]] - COGS5[[a]]
EBITDA5[[a]] = GROSS5[[a]] - OVERHEAD
```

```
  TAX5[[a]] = (EBITDA5[[a]] - DEPR - FINANC) * TR
  NET5[[a]] = EBITDA5[[a]] - DEPR - FINANC - TAX5[[a]]
}

R1 <- mean(unlist(R1))
COGS1 <- mean(unlist(COGS1))
GROSS1 <- mean(unlist(GROSS1))
EBITDA1 <- mean(unlist(EBITDA1))
TAX1 <- mean(unlist(TAX1))
NET1 <- mean(unlist(NET1))
SCENARIO1 <- mean(unlist(SCENARIO1))

R2 <- mean(unlist(R2))
COGS2 <- mean(unlist(COGS2))
GROSS2 <- mean(unlist(GROSS2))
EBITDA2 <- mean(unlist(EBITDA2))
TAX2 <- mean(unlist(TAX2))
NET2 <- mean(unlist(NET2))
SCENARIO2 <- mean(unlist(SCENARIO2))

R3 <- mean(unlist(R3))
COGS3 <- mean(unlist(COGS3))
GROSS3 <- mean(unlist(GROSS3))
EBITDA3 <- mean(unlist(EBITDA3))
TAX3 <- mean(unlist(TAX3))
NET3 <- mean(unlist(NET3))
SCENARIO3 <- mean(unlist(SCENARIO3))

R4 <- mean(unlist(R4))
COGS4 <- mean(unlist(COGS4))
GROSS4 <- mean(unlist(GROSS4))
EBITDA4 <- mean(unlist(EBITDA4))
NET4 <- mean(unlist(NET4))
TAX4 <- mean(unlist(TAX4))
SCENARIO4 <- mean(unlist(SCENARIO4))

R5 <- mean(unlist(R5))
COGS5 <- mean(unlist(GROSS5))
GROSS5 <- mean(unlist(GROSS5))
EBITDA5 <- mean(unlist(EBITDA5))
TAX5 <- mean(unlist(TAX5))
NET5 <- mean(unlist(NET5))
SCENARIO5 <- mean(unlist(SCENARIO5))

YEARS <- c("YEAR 1", "YEAR 2", "YEAR 3", "YEAR 4", "YEAR 5")
```

```
RNAMES <- c("SCENARIOS", "REVENUE", "COGS", "GROSS", "OVERHEAD", "EBITDA",  "DEPRECIATION",
"INTEREST/FINANCIAL", "TAX", "NET")
REVENUES <- format(round(c(R1, R2, R3, R4, R5), digits = 0), nsmall = 1, big.mark = ",")
COGSS <- format(round(c(COGS1, COGS2, COGS3, COGS4, COGS5), digits = 0), nsmall = 1, big.mark = ",")
GROSSS <- format(round(c(GROSS1, GROSS2, GROSS3, GROSS4, GROSS5), digits = 0), nsmall = 1, big.mark = ",")
EBITDAS <- format(round(c(EBITDA1, EBITDA2, EBITDA3, EBITDA4, EBITDA5), digits = 0), nsmall = 1, big.mark =
",")
NETS <- format(round(c(NET1, NET2, NET3, NET4, NET5), digits = 0), nsmall = 1, big.mark = ",")
TAXES <- format(round(c(TAX1, TAX2, TAX3, TAX4, TAX5), digits = 0), nsmall = 1, big.mark = ",")
SCENARIOS <- format(round(c(SCENARIO1, SCENARIO2, SCENARIO3, SCENARIO4, SCENARIO5), digits = 2))


STATEMENT <- rbind(SCENARIOS, REVENUES, COGSS, GROSSS, OVERHEAD, EBITDAS, DEPR, FINANC,
TAXES, NETS) %>% as.data.frame()
colnames(STATEMENTPESS) <- YEARS
rownames(STATEMENTPESS) <- RNAMES


### PROBABILITIES ###

SCNR <- unlist(SCNR)
SCNR <- SCNR[order(SCNR)]
SCNR <- round(SCNR, digits = 4)

ODF = OVERHEAD + DEPR + FINANC

x = ODF/GROSS1
REB = R1*x
BEGROSS = GROSS1*BE
BE = round(REB/TOTREV, digits = 4)
MINSCNR = min(SCNR)

ZS95 <- qnorm(0.975)
ZS99 <- qnorm(0.995)

REV = round((TOTREV*SCNR), digits = 0)
COGS = round(SCNR * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC)), digits = 0)
GROSS = REV - COGS
NET = ifelse(FBE > SCNR, 0, GROSS - OVERHEAD - FINANC - DEPR - ((GROSS-OVERHEAD-DEPR-
FINANC)*TR))
df3 <- data_frame(SCNR, NET)
colnames(df3) <- c("SCENARIO", "NET")

## FREQUENCY FUNCTION ##
freqdist <- function(x, freqorder=F)
```

```
{
  counts = table(x)
  n = sum(counts)
  if(freqorder) ord=order(-counts)
  else ord = 1:length(counts)
  data_frame(row.names=row.names(counts[ord]),
             Counts=as.vector(counts[ord]),
             Percent=100*as.vector(counts[ord]/n),
             CumCount=cumsum(as.vector(counts[ord])),
             CumPercent=100*cumsum(as.vector(counts[ord]))/n)
}

dffrscnr <-freqdist(SCNR)
dffrscnr$row.names <- as.numeric(unlist(dffrscnr$row.names))
dffrNET <- freqdist(NET)

meanSCN <- round(mean(df3$SCENARIO), digits = 4)
SEM <- round(sqrt((SCENARIO1*(1-SCENARIO1))/1000), digits = 4)
PSFC <- sum(df3$SCENARIO<=SCENARIO1)/1000

LOW95 <- SCENARIO1-(ZS95*SEM)
UP95 <- SCENARIO1+(ZS95*SEM)
LOW99 <- SCENARIO1-(ZS99*SEM)
UP99 <- SCENARIO1+(ZS99*SEM)



meanNET <- mean(df3$NET)
SEMNET <- std.error(df3$NET, na.rm = T)

NETLOW95 <- NET1-(ZS95*SEMNET)
NETUP95 <- NET1+(ZS95*SEMNET)
NETLOW99 <- NET1-(ZS99*SEMNET)
NETUP99 <- NET1+(ZS99*SEMNET)

PBE <- sum(df3$SCENARIO<=BE)/length(df3$SCENARIO)
SEMPBE = round(sqrt((PBE*(1-PBE))/1000), digits = 4)

LOWPBE95 <- PBE-(ZS95*SEMPBE)
UPPBE95 <- PBE+(ZS95*SEMPBE)

LOWPBE99 <- PBE-(ZS99*SEMPBE)
UPPBE99 <- PBE+(ZS99*SEMPBE)

PD <- sum(df3$SCENARIO<=0.4059)/1000
SEMPD = round(sqrt((PD*(1-PD))/1000), digits = 4)
```

```
LOWPD95 <- PD-(ZS95*SEMPD)
UPPD95 <- PD+(ZS95*SEMPD)
LOWPD99 <- PD-(ZS99*SEMPD)
UPPD99 <- PD+(ZS99*SEMPD)

PSCNR <- c(LOW95, UP95, LOW99, UP99)
PNET <- c(NETLOW95, NETUP95, NETLOW99, NETUP99)
PNEGC <- c(LOWPNEG95, UPNEGNET95, LOWPNEG99, UPNEGNET99)
PBEC <- c(LOWPBE95, UPPBE95, LOWPBE99, UPPBE99)
PDC <- c(LOWPD95, UPPD95, LOWPD99, UPPD99)

clnms <- c("First-Year Scenario", "Mean NET", "Break Even", "Default First-Year")
cdfivl <- c("95 Percentage Lower", "95 Percentage Upper", "99 Percentage Lower", "99 Percentage Upper")
dfconfint <- data_frame(PSCNR, PNET, PNEGC, PBEC, PDC)
colnames(dfconfint) <- clnms
dfconfint <- dfconfint %>% mutate(Confidence_Interval = cdfivl)
dfconfint <- dfconfint[,c(ncol(dfconfint),1:ncol(dfconfint)-1)]
```

Simulation with Optimistic Settings

```
library(openxlsx)
library(tidyverse)
library(stargazer)
library(truncnorm)
library(plotrix)
library(EnvStats)
library(formattable)
library(R.utils)


#### INPUT VARIABLES CAN BE FOUND IN THE FIRST SCRIPT####

### MODE FUNCTION ###

getmode <- function(v) {
  uniqv <- unique(v)
  uniqv[which.max(tabulate(match(v, uniqv)))]
}


#### SIMULATION ####
```

```
d <- list()
moded <- list()
mind <- list()
maxd <- list()


R1 <- list()
COGS1 <- list()
GROSS1 <- list()
EBITDA1 <- list()
NET1 <- list()
TAX1 <- list()
SCENARIO1 <- list()

R2 <- list()
COGS2 <- list()
GROSS2 <- list()
EBITDA2 <- list()
NET2 <- list()
TAX2 <- list()
SCENARIO2 <- list()


R3 <- list()
COGS3 <- list()
GROSS3 <- list()
EBITDA3 <- list()
NET3 <- list()
TAX3 <- list()
SCENARIO3 <- list()

R4 <- list()
COGS4 <- list()
GROSS4 <- list()
EBITDA4 <- list()
NET4 <- list()
TAX4 <- list()
SCENARIO4 <- list()

R5 <- list()
COGS5 <- list()
GROSS5 <- list()
EBITDA5 <- list()
NET5 <- list()
TAX5 <- list()
```

```
SCENARIO5 <- list()

g01 <- list()
g02 <- list()
ng1 <- list()
ng2 <- list()
g1 <- list()
g2 <- list()

Y <- list()
SCENARIO <- list()
MSCNR <- list()
SCNR <- list()


for (a in 1:100)
{

  ### SIMULATION PARAMETERS ###


  ng1[[a]] <- list()
  ng2[[a]] <- list()
  g1[[a]] <- list()
  g2[[a]] <- list()

  set.seed(0)
  for (b in 1:100)
  {

    ng1[[a]][[b]] = rtri(1000, min = 0, max = 0.1, mode = 0.075) # y1 - y3
    g1[[a]][[b]] = mean(ng1[[a]][[b]])


    ng2[[a]][[b]] = rtri(1000, min = 0.1, max = 0.2, mode = 0.175) # y3 - y5
    g2[[a]][[b]] = mean(ng2[[a]][[b]])
  }

  g1[[a]] <- unlist(g1[[a]])
  g2[[a]] <- unlist(g2[[a]])

  g1[[a]] = mean(g1[[a]])
  g2[[a]] = mean(g2[[a]])

  ### SIMUALTION PER YEAR ###
```

```
Y[[a]] <- list()
SCENARIO[[a]] <- list()
MSCNR[[a]] <- list()

set.seed(1)

for (i in 1:100)
{

  Y[[a]][[i]] <- rtri(1000, min = 0, max = TOTP, mode = 0.75*TOTP)
  SCENARIO[[a]][[i]] = Y[[a]][[i]]/TOTP
  MSCNR[[a]][[i]] = mean(SCENARIO[[a]][[i]])
}

SCNR[[a]] <- round(unlist(MSCNR[[a]]), digits = 4)

## YEAR 1 ##

SCENARIO1[[a]] = round(mean(SCNR[[a]]), digits = 2)

R1[[a]] = TOTREV *  SCENARIO1[[a]]
COGS1[[a]] =  SCENARIO1[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS1[[a]] = R1[[a]] - COGS1[[a]]
EBITDA1[[a]] = GROSS1[[a]] - OVERHEAD
TAX1[[a]] = (EBITDA1[[a]] - DEPR - FINANC) * TR
NET1[[a]] = EBITDA1[[a]] - DEPR - FINANC - TAX1[[a]]

## YEAR 2 ##

SCENARIO2[[a]] = round(SCENARIO1[[a]]+g1[[a]], digits = 2)

R2[[a]] = TOTREV*SCENARIO2[[a]]
COGS2[[a]] = SCENARIO2[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
GROSS2[[a]] = R2[[a]] - COGS2[[a]]
EBITDA2[[a]] = GROSS2[[a]] - OVERHEAD
TAX2[[a]] = (EBITDA2[[a]] - DEPR - FINANC) * TR
NET2[[a]] = EBITDA2[[a]] - DEPR - FINANC - TAX2[[a]]

## YEAR 3 ##

SCENARIO3[[a]] = round(SCENARIO2[[a]]+g1[[a]], digits = 2)

R3[[a]] = TOTREV*SCENARIO3[[a]]
COGS3[[a]] = SCENARIO3[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
```

```
  GROSS3[[a]] = R3[[a]] - COGS3[[a]]
  EBITDA3[[a]] = GROSS3[[a]] - OVERHEAD
  TAX3[[a]] = (EBITDA3[[a]] - DEPR - FINANC) * TR
  NET3[[a]] = EBITDA3[[a]] - DEPR - FINANC - TAX3[[a]]

  ## YEAR 4 ##

  SCENARIO4[[a]] = round(SCENARIO3[[a]]+g2[[a]], digits = 2)

  R4[[a]] = TOTREV*SCENARIO4[[a]]
  COGS4[[a]] = SCENARIO4[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
  GROSS4[[a]] = R4[[a]] - COGS4[[a]]
  EBITDA4[[a]] = GROSS4[[a]] - OVERHEAD
  TAX4[[a]] = (EBITDA4[[a]] - DEPR - FINANC) * TR
  NET4[[a]] = EBITDA4[[a]] - DEPR - FINANC - TAX4[[a]]

  ## YEAR 5 ##

  SCENARIO5[[a]] = ifelse(SCENARIO4[[a]]+g2[[a]]>1, 1, round(SCENARIO4[[a]]+g2[[a]], digits = 2))
  ifelse(SCENARIO5[[a]]==1, print(a), N/A)

  R5[[a]] = TOTREV*SCENARIO5[[a]]
  COGS5[[a]] = SCENARIO5[[a]] * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC))
  GROSS5[[a]] = R5[[a]] - COGS5[[a]]
  EBITDA5[[a]] = GROSS5[[a]] - OVERHEAD
  TAX5[[a]] = (EBITDA5[[a]] - DEPR - FINANC) * TR
  NET5[[a]] = EBITDA5[[a]] - DEPR - FINANC - TAX5[[a]]
}

R1 <- mean(unlist(R1))
COGS1 <- mean(unlist(COGS1))
GROSS1 <- mean(unlist(GROSS1))
EBITDA1 <- mean(unlist(EBITDA1))
TAX1 <- mean(unlist(TAX1))
NET1 <- mean(unlist(NET1))
SCENARIO1 <- mean(unlist(SCENARIO1))



R2 <- mean(unlist(R2))
COGS2 <- mean(unlist(COGS2))
GROSS2 <- mean(unlist(GROSS2))
EBITDA2 <- mean(unlist(EBITDA2))
TAX2 <- mean(unlist(TAX2))
NET2 <- mean(unlist(NET2))
```

```
SCENARIO2 <- mean(unlist(SCENARIO2))


R3 <- mean(unlist(R3))
COGS3 <- mean(unlist(COGS3))
GROSS3 <- mean(unlist(GROSS3))
EBITDA3 <- mean(unlist(EBITDA3))
TAX3 <- mean(unlist(TAX3))
NET3 <- mean(unlist(NET3))
SCENARIO3 <- mean(unlist(SCENARIO3))

R4 <- mean(unlist(R4))
COGS4 <- mean(unlist(COGS4))
GROSS4 <- mean(unlist(GROSS4))
EBITDA4 <- mean(unlist(EBITDA4))
NET4 <- mean(unlist(NET4))
TAX4 <- mean(unlist(TAX4))
SCENARIO4 <- mean(unlist(SCENARIO4))

R5 <- mean(unlist(R5))
COGS5 <- mean(unlist(GROSS5))
GROSS5 <- mean(unlist(GROSS5))
EBITDA5 <- mean(unlist(EBITDA5))
TAX5 <- mean(unlist(TAX5))
NET5 <- mean(unlist(NET5))
SCENARIO5 <- mean(unlist(SCENARIO5))

YEARS <- c("YEAR 1", "YEAR 2", "YEAR 3", "YEAR 4", "YEAR 5")
RNAMES <- c("SCENARIOS", "REVENUE", "COGS", "GROSS", "OVERHEAD", "EBITDA",  "DEPRECIATION",
"INTEREST/FINANCIAL", "TAX", "NET")
REVENUES <- format(round(c(R1, R2, R3, R4, R5), digits = 0), nsmall = 1, big.mark = ",")
COGSS <- format(round(c(COGS1, COGS2, COGS3, COGS4, COGS5), digits = 0), nsmall = 1, big.mark = ",")
GROSSS <- format(round(c(GROSS1, GROSS2, GROSS3, GROSS4, GROSS5), digits = 0), nsmall = 1, big.mark = ",")
EBITDAS <- format(round(c(EBITDA1, EBITDA2, EBITDA3, EBITDA4, EBITDA5), digits = 0), nsmall = 1, big.mark =
",")
NETS <- format(round(c(NET1, NET2, NET3, NET4, NET5), digits = 0), nsmall = 1, big.mark = ",")
TAXES <- format(round(c(TAX1, TAX2, TAX3, TAX4, TAX5), digits = 0), nsmall = 1, big.mark = ",")
SCENARIOS <- format(round(c(SCENARIO1, SCENARIO2, SCENARIO3, SCENARIO4, SCENARIO5), digits = 2))


STATEMENTOPTFULL <- rbind(SCENARIOS, REVENUES, COGSS, GROSSS, OVERHEAD, EBITDAS, DEPR,
FINANC, TAXES, NETS) %>% as.data.frame()
colnames(STATEMENTOPTFULL) <- YEARS
rownames(STATEMENTOPTFULL) <- RNAMES
```

```
write.xlsx(STATEMENTOPTFULL, file = "OPTIMISTSTATEMENT.xlsx")

### PROBABILITY OF BREAK EVEN  ###

SCNR <- unlist(SCNR)
SCNR <- SCNR[order(SCNR)]
SCNR <- round(SCNR, digits = 4)

ODF = OVERHEAD + DEPR + FINANC

X = ODF/GROSS1
REB = R1*X
BEGROSS = GROSS1*X
BE = round(REB/TOTREV, digits = 4)
MINSCNR = min(SCNR)

ZS95 <- qnorm(0.975)
ZS99 <- qnorm(0.995)

REV = round((TOTREV*SCNR), digits = 0)
COGS = round(SCNR * (L + SCRAPC*TOTP*0.5+(UTILITIES+CONSUMABLES+QUALITYC)), digits = 0)
GROSS = REV - COGS
NET = ifelse(FBE > SCNR, 0, GROSS - OVERHEAD - FINANC - DEPR - ((GROSS-OVERHEAD-DEPR-
FINANC)*TR))
df3 <- data_frame(SCNR, NET)
colnames(df3) <- c("SCENARIO", "NET")



freqdist <- function(x, freqorder=F)
{
  counts = table(x)
  n = sum(counts)
  if(freqorder) ord=order(-counts)
  else ord = 1:length(counts)
  data_frame(row.names=row.names(counts[ord]),
             Counts=as.vector(counts[ord]),
             Percent=100*as.vector(counts[ord]/n),
             CumCount=cumsum(as.vector(counts[ord])),
             CumPercent=100*cumsum(as.vector(counts[ord]))/n)
}

dffrscnr <-freqdist(SCNR)
dffrscnr$row.names <- as.numeric(unlist(dffrscnr$row.names))
dffrNET <- freqdist(NET)
```

```
meanSCN <- round(mean(df3$SCENARIO), digits = 4)
SEM <- round(sqrt((SCENARIO1*(1-SCENARIO1))/1000), digits = 4)
PSFC <- sum(df3$SCENARIO<=0.5855)/length(df3$SCENARIO)

LOW95 <- SCENARIO1-(ZS95*SEM)
UP95 <- SCENARIO1+(ZS95*SEM)


LOW99 <- SCENARIO1-(ZS99*SEM)
UP99 <- SCENARIO1+(ZS99*SEM)


meanNET <- mean(df3$NET)
SEMNET <- std.error(df3$NET, na.rm = T)


NETLOW95 <- NET1-(ZS95*SEMNET)
NETUP95 <- NET1+(ZS95*SEMNET)
NETLOW99 <- NET1-(ZS99*SEMNET)
NETUP99 <- NET1+(ZS99*SEMNET)


PBE <- sum(df3$SCENARIO<=BE)/length(df3$SCENARIO)
SEMPBE = round(sqrt((PBE*(1-PBE))/1000), digits = 4)

LOWPBE95 <- PBE-(ZS95*SEMPBE)
UPPBE95 <- PBE+(ZS95*SEMPBE)
LOWPBE99 <- PBE-(ZS99*SEMPBE)
UPPBE99 <- PBE+(ZS99*SEMPBE)

PD <- sum(df3$SCENARIO<=0.4059)/length(df3$SCENARIO)
SEMPD = round(sqrt((PD*(1-PD))/1000), digits = 4)

LOWPD95 <- PD-(ZS95*SEMPD)
UPPD95 <- PD+(ZS95*SEMPD)
LOWPD99 <- PD-(ZS99*SEMPD)
UPPD99 <- PD+(ZS99*SEMPD)

PSCNR <- c(LOW95, UP95, LOW99, UP99)
PNET <- c(NETLOW95, NETUP95, NETLOW99, NETUP99)
PNEGC <- c(LOWPNEG95, UPNEGNET95, LOWPNEG99, UPNEGNET99)
PBEC <- c(LOWPBE95, UPPBE95, LOWPBE99, UPPBE99)
PDC <- c(LOWPD95, UPPD95, LOWPD99, UPPD99)

clnms <- c("First-Year Scenario", "Mean NET", "Negative NET", "Break Even", "Default First-Year")
```

```
cdfivl <- c("95 Percentage Lower", "95 Percentage Upper", "99 Percentage Lower", "99 Percentage Upper")
dfconfint <- data_frame(PSCNR, PNET, PNEGC, PBEC, PDC)
colnames(dfconfint) <- clnms
dfconfint <- dfconfint %>% mutate(Confidence_Interval = cdfivl)
dfconfint <- dfconfint[,c(ncol(dfconfint),1:ncol(dfconfint)-1)]
```