Development of Internet of Things Technology and Business Model for a Centre Pivot Irrigation System (Powasave) to Optimise Power and Water Consumption

by

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Declaration

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Abstract

Agriculture is an industry that has seen a rapid increase in demand for technology innovation. With water being a limited resource, it is of utmost importance that it is well utilised. The agricultural sector is responsible for using more than 70% available freshwater and more than 40% of the global food supply is grown on irrigated croplands (Khokhar, 2017). Pivot irrigation systems experience a lot of water and power losses whilst in operation and there is a great need to reduce these losses. In this study an innovative irrigation system is designed that focuses on the reduction of water and power losses of pivot irrigations systems. The solution makes use of Internet of Things technology to determine the optimal irrigation schedules according to environmental conditions. A low-pressure irrigation sprayer (Powasave) is used to reduce the wind drift and evaporation losses. A commercialisation strategy for the solution is also developed. It was found that the solution will considerably reduce the power consumption and water losses of pivot irrigation systems, resulting in a more sustainable agricultural sector by increasing water and food security.

Opsomming

Die landbouindustrie ondervind 'n spoedige toename in die behoefte na tegnologiese innovasie. Aangesien water 'n beperkte hulpbron is, is dit van kardinale belang dat dit optimaal benut en aangewend word. Die landbousektor is verantwoordelik vir die gebruik van meer as 70% van vars water en meer as 40% van voedsel op 'n globale skaal word op besproeiide grond gekweek (Khokhar, 2017). Spilpunt besproeiingstelsels ondervind hoë water en krag verliese tydens werking en daar is 'n groot behoefte om hierdie verliese te verminder. In hierdie studie word 'n innoverende besproeiingstelsel ontwikkel wat fokus op die vermindering van water en krag verliese van spilpunt besproeiingstelsels. Die innoverende oplossing maak gebruik van "Internet of Things" tegnologie om vas te stel wat die optimale besproeiingskedules is volgens die omgewingstoestande. 'n Lae-druk sproeier (Powasave) word gebruik om wind en verdampings verliese te verminder. 'n Kommersialiseringstrategie vir die innoverende oplossing is ook ontwikkel. Dit is bevind dat die innoverende oplossing die krag verbruik en water verliese van spilpunt besproeiingstelsels aansienlik sal verminder wat dus lei tot 'n meer volhoubare landbou sektor deur water en kos sekuriteit te verhoog.

Acknowledgements

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The Lord for His unfailing love and teaching me to go from strength to strength. You are truly an ever-present help in time of need.

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Glossary

Acronyms and Abbreviations

ABS	Acrylonitrile Butadiene Styrene
CAD	Computer Aided Design
Capex	Capital Expenditure
DOI	Diffusion of Innovation
I/O	Input Output
IDE	Integrated Development Environment
IoT	Internet of Things
IP	Internet Protocol
JSON	JavaScript Object Notation
LVDT	Linear Variable Differential Transformer
Opex	Operational Expenditure
PBP	Payback Period
SAP	Soft Access Point
SSID	Service Set Identifier
STA	Station
UI	User Interface
UX	User Experience
WS%	Water Saving Percentage

Nomenclature

Symbol	Description	Units
A	Area	m^3
AR	Application rate	m/s
C	Pumping cost	
C_d	Drag coefficient	-
₵	Currency, current South African ZAR equivalent cost	ZAR
D	Depth	m or mm
F	Force	N
H	Pressure head	m
H_g	Geodetic pressure head	m
I	Current	A
K	Loss coefficient	-
L	Length	m
P	Power	W
Q	Volume flow rate	m^3/s
R	Radius or Resistance	m or Ω
Re	Reynolds number	-
S	Displacement	m
T	Temperature	°C
V	Volume or Voltage	m^3or V
c	Electricity cost per kilowatt hour	¢/kWh
¢	Cent, current South African ZAR equivalent cost of a Cent	ZAR
d	Diameter	m
f_i	Darcy friction factor	-
g	Gravitational acceleration	m/s^2
h	Pressure head	m
h_L	Head loss	m
k_o	Orifice loss coefficient	-
m	Mass	kg
p	Pressure	Pa
t	Time	s
u	Velocity	m/s

Greek Symbols

α	Angle	° or rad
β	Angle	° or rad
Δ	Change	-
η_p	Pump efficiency	-
η_m	Motor efficiency	-

ρ	Density	$\mathrm{kg/m^3}$
θ	Field Slope angle	° or rad
μ	Dynamic viscosity	$\mathrm{kg/ms}$
v	Velocity	$\mathrm{m/s}$

Subscripts

a	Air	-
b	Buoyancy	-
d	Droplet	-
dr	Drag	-
g	Gravity	-
p	Pressure	Pa
r	Radial direction	-
res	Resultant	-
w	Water	-
z	z direction	-

Chapter 1

Introduction

"There is a way to do it better – find it"

- Thomas Edison

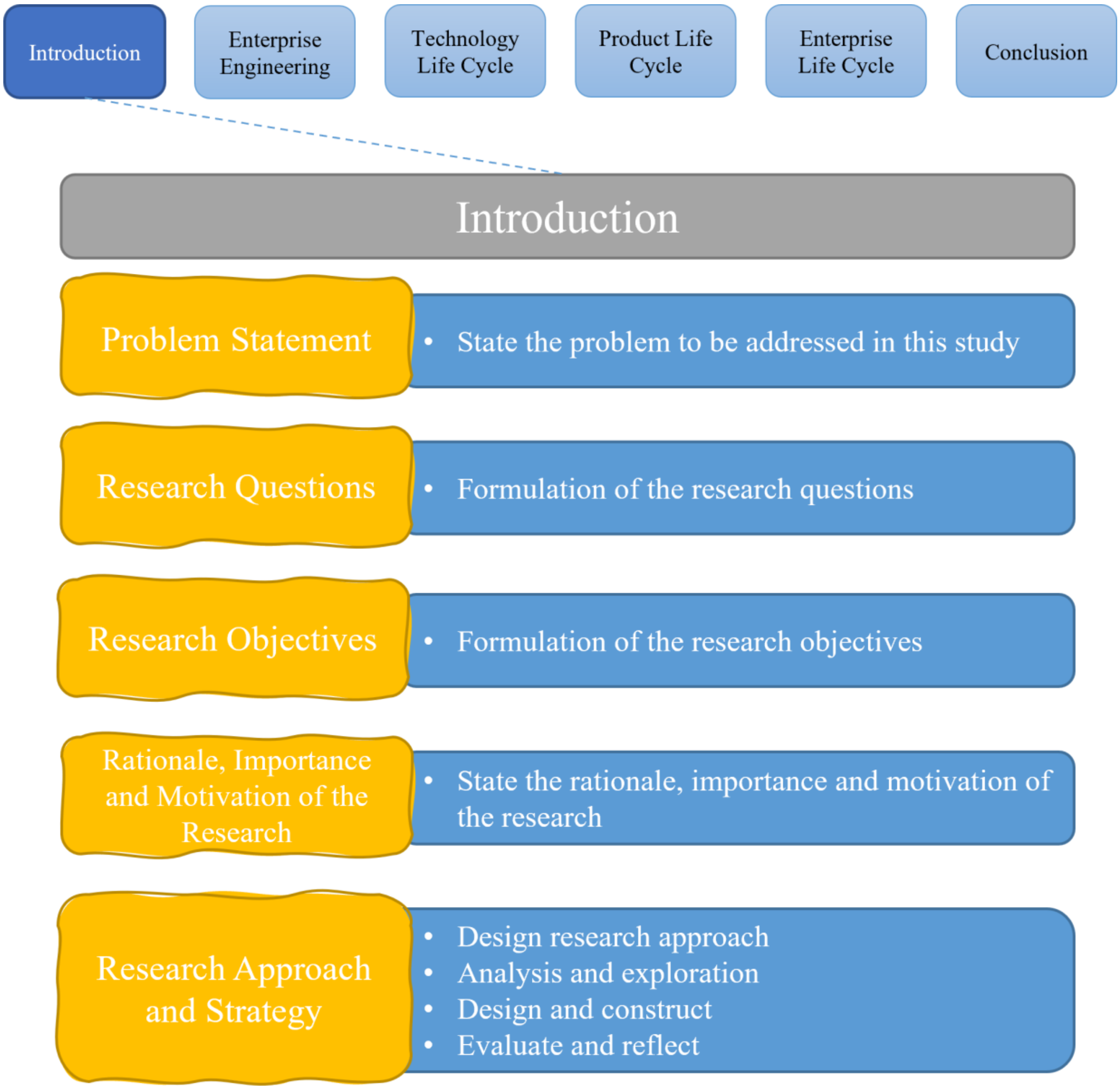


Figure 1: Navigation Structure of Chapter 1

1.1. Introduction

Technology is constantly evolving, and with the onset of the 5th industrial revolution, innovation is more important than ever before. The Internet of Things (IoT) is becoming an increasing necessity in all industries. Businesses might become irrelevant if these organisations do not start implementing IoT technologies to improve services and keep the competitive advantage.

Agriculture is an industry that has seen a rapid increase in demand for technology innovation. According to Ku (2019), there has been an increase in investment in agricultural technology over the last decade. With increased challenges such as rising cost of supplies, skilled labour shortages, climate change and overall sustainability there is a larger demand for innovative solutions to ultimately reduce costs and negative environmental impacts.

It is a well-known fact that the availability of water is a limited resource in the agricultural sector. According to Khokhar (2017), over 70% of freshwater is used for Agriculture globally and 40% of the global food supply is grown on irrigated croplands. Thus, it is of utmost importance that the water resources are managed well when it comes to irrigation and farming with crops. To increase the sustainability of crop farming, innovative water saving solutions in the agricultural sector are in high demand.

Pivot irrigation systems is a very popular form of irrigation. According to Folnovic (2020), most crops can be irrigated with them including field crops, cereals, legumes, vegetables, and fruit trees. There is a major reduction in irrigation efficiency due to wind drift and evaporation losses that occur when irrigation systems are in operation. Wind drift losses are the water losses that occur when wind blows the irrigation droplets out of the targeted irrigation area. Evaporation losses are the water losses that occur due to the evaporation of the irrigation droplets during flight and from the ground surface. These losses are especially high in areas that have high wind speeds. According to Sadeghi et al. (2016) over 30% of water losses occur due to wind drift and evaporation losses.

By reducing the wind drift and evaporation losses of pivot irrigation systems it can result in a major reduction in water losses in the agricultural sector. With the help of IoT technologies where sensors are used to monitor the environmental conditions, the optimal irrigation state can be detected. Irrigation systems can thus be programmed to take environmental factors into account to reduce water losses when in operation.

1.2. Problem Statement

Pivot irrigation systems experience high water losses and power consumption whilst in operation. In typical irrigation systems a high pressure is used to produce small droplets to irrigate crops and to spray the water over a larger area in order to reduce the water loading to avoid soil compaction. Weather conditions have a considerable effect on the efficiency of water usage of pivot irrigation systems. Once the wind speed increases, wind drift losses take place, which are the water losses that occur when the wind blows the droplets out of the targeted irrigation area. Furthermore, small irrigation droplets evaporate more than larger drops especially when the ambient temperature is high and relative humidity is low. In addition, power is required to produce the high water-pressure requirement of current pivot irrigation systems.

Pivot irrigation systems experience high water losses and power consumption whilst in operation that can be reduced if appropriate technologies are developed to make irrigation more efficient resulting in a more sustainable agricultural sector.

1.3. Research Objectives

The project is aimed at analysing the technological maturity of current irrigation systems in the agricultural sector and further developing an irrigation system that reduces the water losses and power consumption by incorporating IoT technologies on pivot irrigation systems. Further it aims to develop a commercialisation plan for the developed product. The objectives of this study are to:

- Understand Enterprise Engineering
    - Understand the Enterprise Engineering Life Cycles

- Understand the context of the Technology Life Cycle
    - Understand the maturity of the technology used in current pivot irrigation systems.
    - Understand the maturity of IoT technologies.

- Develop the Product
    - Develop a product that reduces the **water** losses and **power** consumption of pivot irrigation systems that adheres to design requirements and that gives farmers more control over pivot irrigation systems by incorporating IoT technologies.
    - Test the developed product.
    - Perform a cost analysis on the developed product and compare it to existing products on the market.

- Propose the Enterprise

- Design an Enterprise by generating a business model that can commercialise the developed product.

1.4. Research Questions

The following research questions are derived from the problem statement and research objectives.

- Enterprise Engineering
  - What are the Enterprise Engineering Life Cycles?
- Technology Life Cycle
  - What is the Technology Life Cycle?
  - What is the maturity of technologies currently used in irrigation systems and is there room for innovation to improve irrigation systems?
  - What is the maturity of some IoT technologies?

- Product Life Cycle
  - What are the design requirements for an improved irrigation system that reduce water losses and power consumption?
  - How does an improved water and power efficient irrigation system compare to current systems on the market?

- Enterprise Life Cycle
  - How can the innovative irrigation system be commercialised?

1.5. Rationale, Importance and Motivation of the Research

With the ongoing drought that Southern Africa is facing, food security has become a great concern. With the increase in population and food demand, the sustainability of crop farming is under question. Southern Africa is facing a climate-driven food crisis and it is reported that 45 million Southern Africans are facing food insecurity (World Food Program, 2020). Affected coutries are Zimbabwe, Mozambique, Zambia, Madagascar, Namibia, Eswatini, Lesotho, Malawi, Angola, Botswana, the DRC, Tanzania and South Africa (Reliefweb, 2020). Thus, it is a necessity to develop innovative water saving technologies that can reduce water wastage.

According to Sentlinger (2019), water shortages present a threat to the agricultural sector and food security and this study will address this problem. The study has the potential to solve a huge challenge that the agricultural sector is facing by saving a considerable amount of water and power in the agricultural sector and ultimately reducing crop production costs and negative environmental impacts.

The **benefactors** of this research are the agricultural sector and all of mankind who are dependent on the food supply of the agricultural sector.

1.6. Research Approach and Strategy

This is a study to identify where innovation, with regards to irrigation, is required in the agricultural sector, and how IoT technology can be implemented in this sector. This is done by using Enterprise Engineering approaches by:

1. Identifying a major technology issue in the agricultural sector that needs to be addressed, and by **studying the current technologies** that are available that partly address the problem and what the advantages and shortcomings of these current technologies are.
2. **Developing an innovative solution** to solve the problem.
3. **Developing a commercialisation strategy** to implement the innovative solution in the agricultural sector.

A design research approach is followed to complete the study. According to Lee (2012) design research is research that is based on creating a product, service or systems that satisfies a human need to improve livelihoods. The primary goal of design research is to generate value or utility for the end user. The result of design research is a developed solution that meets identified needs.

The study will follow the design research process as defined by Mckenny et al. (2012) and seen in Figure 2. This design research process comprises of the following:

- **Analysis and exploration** which entails doing a literature review on pivot irrigation systems and identifying the needs that current irrigation systems do not meet. Once this is done the design requirements of the novel pivot irrigation systems can be formulated.
- **Design and construction** which entails the detailed design, manufacture and construction of the novel pivot irrigation system.
- **Evaluation and reflection** which will entail the testing of the developed product, comparing it to conventional irrigation systems that are currently on the market.

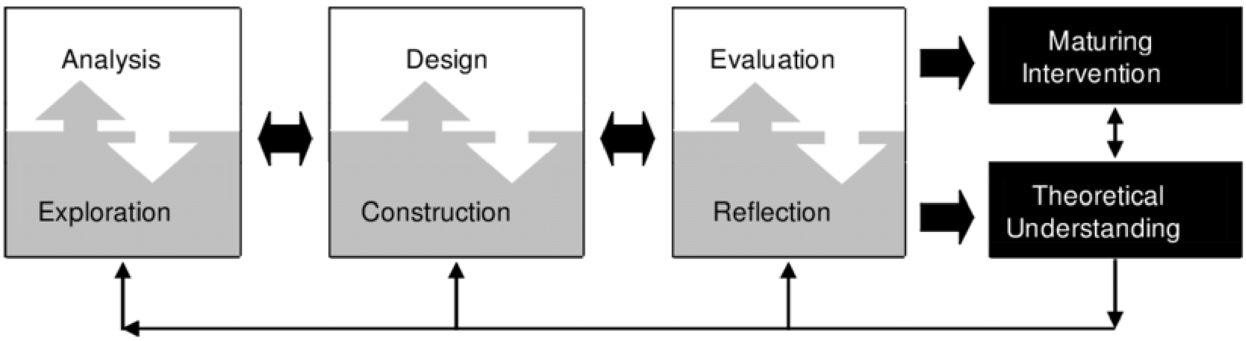


Figure 2: Generic Model for Design Research (Mckenny et al., 2012)

The study will apply Enterprise Engineering approaches and will develop the Technology Life Cycle, Product Life Cycle and Enterprise Life Cycle. The structure of the study and the interaction between the research approach and Enterprise Engineering can be seen in Figure 3.

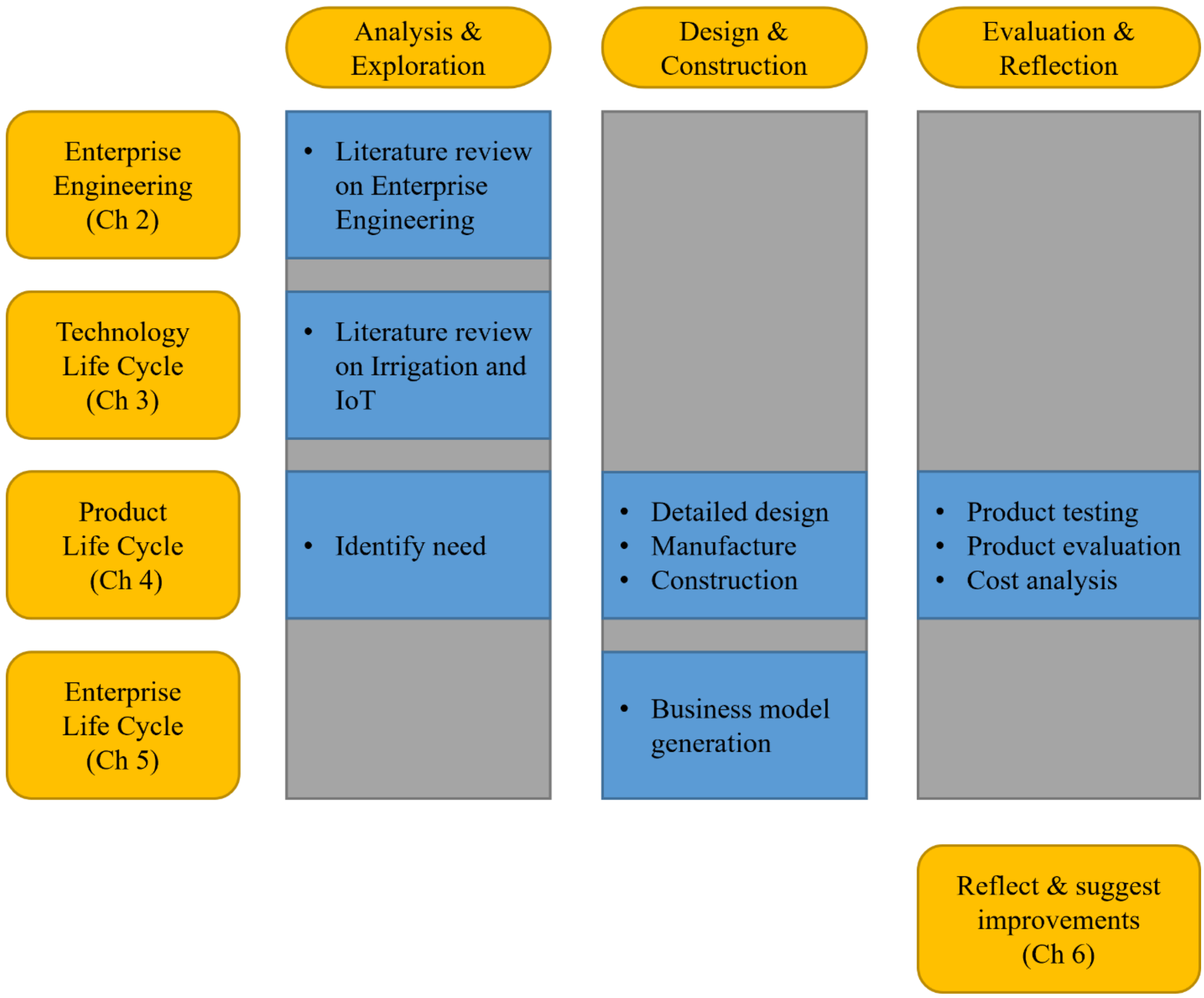


Figure 3: Research Methodology Overview

1.7. Document Structure

This document has 6 Chapters the first being the Introduction. Chapter 2 discusses Enterprise Engineering and what the three Enterprise Engineering Life Cycles are: Technology Life Cycle, Product Life Cycle, and Enterprise Life Cycle. Chapter 3 is a more in-depth study of the Technology Life Cycle of pivot irrigation systems and IoT technologies. The Product Life Cycle of a product is developed and discussed in Chapter 4. In Chapter 5 an Enterprise Life Cycle is developed for an Enterprise that will commercialise the product developed in Chapter 4. Chapter 6 is the concluding discussion.

Each Chapter starts with a Navigation Structure that states the specific topics discussed in the respective Chapters. Further, the research objectives and research questions of this study is addressed in the Chapters and Sections as summarised in Table 1.

Table 1: Thesis Objectives

Chapter	Primary Objective	Research Objectives	Research Questions	Section
Chapter 2 Enterprise Engineering	Understand Enterprise Engineering.	Understand the Enterprise Engineering Life Cycles.	What are the Enterprise Engineering Life Cycles?	Section 2.2 to 2.5
Chapter 3 Technology Life Cycle	Understand the context of the Technology Life Cycle	Understand the maturity of the technology used in current pivot irrigation systems.	What is the maturity of technologies currently used in irrigation systems and is there room for innovation to improve irrigation systems?	Section 3.2 to 3.4
		Understand the maturity of IoT technologies.	What is the maturity of some IoT technologies?	Section 3.5
Chapter 4 Product Life Cycle	Develop the Product	Develop a product that reduces the water losses and power consumption of pivot irrigation systems that adheres to design requirements and that gives farmers more control over pivot irrigation systems by incorporating IoT technologies.	What are the design requirements for an improved irrigation system that reduce water losses and power consumption?	Section 4.2 and 4.3
		Test the developed product.	Does the developed product adhere to the design requirements?	Section 4.4 and 4.6

Chapter	Primary Objective	Research Objectives	Research Questions	Section
		Perform a cost analysis on the developed product and compare it to existing products on the market.	How does improved water and power efficient irrigation systems compare to current systems on the market?	Section 4.7
Chapter 5 Enterprise Life Cycle	Propose the Enterprise	Design an Enterprise by generating a business model that can commercialise the developed product.	How can innovative irrigation systems be commercialised?	Section 5.2

Chapter 2
Enterprise Engineering Life Cycles

"You can't use up creativity. The more you use, the more you have."

- Maya Angelou

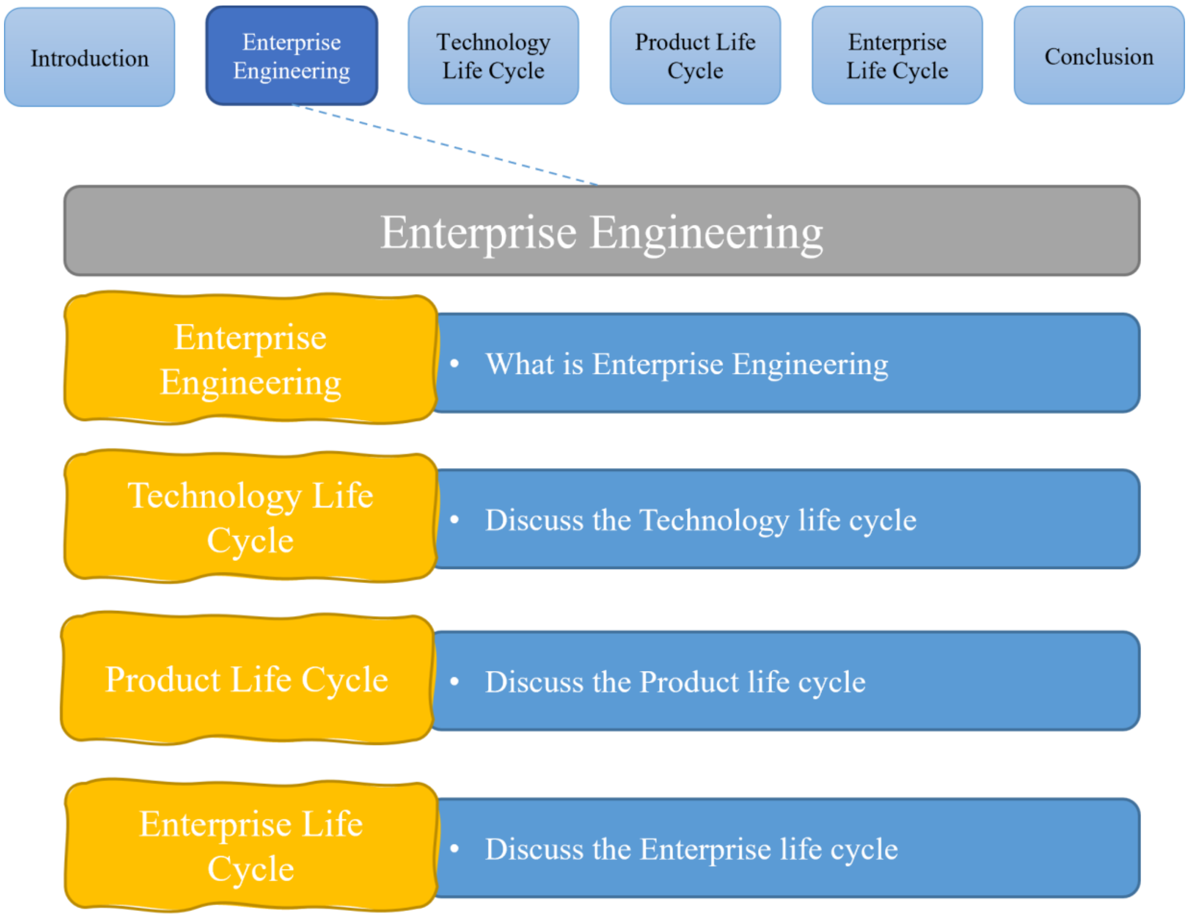


Figure 4: Navigation Structure of Chapter 2

The research objectives and research questions addressed in Chapter 2 are summarised in Table 2.

Table 2: Chapter 2 Objectives

Primary Objective	Research Objectives	Research Questions	Section
Understand Enterprise Engineering.	Understand the Enterprise Engineering Life Cycles.	What are the Enterprise Engineering Life Cycles?	Section 2.2 to 2.5

2.1. Introduction

Enterprise Engineering is the design or re-design of either an entire enterprise or part of an enterprise (Giachetti, 2010). It consists of the practices and principles to develop business processes and organisational structure (Dietz, 2006).

An enterprise must be a dynamic organisation that constantly applies changes to adapt to the ever-changing world. To keep the competitive advantage enterprises must innovate and continuously develop improved solutions to ensure that customers are satisfied, thus enterprises must constantly re-design products and business processes. The competitive advantage is the enterprises' ability to be the best, to develop the best product or service and to satisfy the customer needs better than other competitors in the industry.

The Enterprise Engineering process is a tool that enterprises can use to facilitate changes in the enterprise to either keep or obtain the competitive advantage. Competitiveness and innovation go hand in hand. According to Du Preez et al. (2007) the competitiveness of a company or industry is dependent on its capability to innovate. Since innovation is a requirement to stay competitive in the industry, innovation must be a top priority when one wants to effectively operate and manage a profitable enterprise. Within Enterprise Engineering three life cycles are developed. These life cycles are the Technology Life Cycle, the Product Life Cycle, and the Enterprise Life Cycle.

The Enterprise Life Cycle is a model that can be used to develop an enterprise. Enterprise design is a means to supporting the technology and product design life cycle. An enterprise is the vehicle in which new technologies ride to secure their spot on the global market. New technologies will not exist if there are no enterprises that drive the development of new products and technologies.

2.2. Technology Life Cycle

The Technology Life Cycle is used to describe the maturity of a certain technology that is used in a product or service. Technologies that were once successful can become outdated and replaced once new technologies are developed.

Before investing in a new technology, it is important to determine if the technology has the potential to thrive in the future. According to Gao et al. (2012) the current life cycle stages of the technology must be investigated to estimate if the technology has the potential to thrive in the future.

When a new technology is developed, for it to be successful, it must be adopted and used by society. According to LaMorte (2019) the Diffusion of Innovation (DOI) Theory, that was developed by E.M

Rogers in 1962, is a social science theory of how a new idea or product is adopted by a society. Researchers have found that the characteristics of people who are quick to adopt to a new idea or technology is different than the characteristic of people who adopt later. Thus, the maturity of a technology can be described based on the type of user that utilises the technology. There are 5 established categories of people who adopt new technologies that can be seen in Figure 5.

The first category is **innovators and technology enthusiasts**. These users are usually venturesome and is intrigued with the advances of technology and realises the potential of a technology. According to the DOI theory this category is only 2.5% of the society and are usually willing to spend money and take a risk on new innovative technology.

The second category is **early adopters and visionaries**. These are users who usually take the technology further and are interested in the technology, because it presents an opportunity to gain the competitive advantage and can have a large return on investment. According to the DOI theory this category is approximately 13.5% of the society.

The third category is **early majority pragmatists**. This group represents the first majority of society that will adopt the technology. According to the DOI theory this category is approximately 34% of the society.

The fourth category is the **late majority conservatives**. This group represent the second majority of the society that will adopt the technology. These are users who need to be convinced and usually utilise the technology just to get on par with the rest of the world. According to the DOI theory this category is approximately also 34% of the society.

The last category is the **laggards and sceptics**. These users are last to adopt and are usually older or uneducated who will only utilise the technology once it is well-established. According to the DOI theory this category is approximately 16% of the society.

Between the early adopter’s category and the early majority pragmatists category the chasm will exist. The chasm represents the transition from the early market to the mainstream market and the difficulty of getting the majority of a society to accept and utilise the technology.

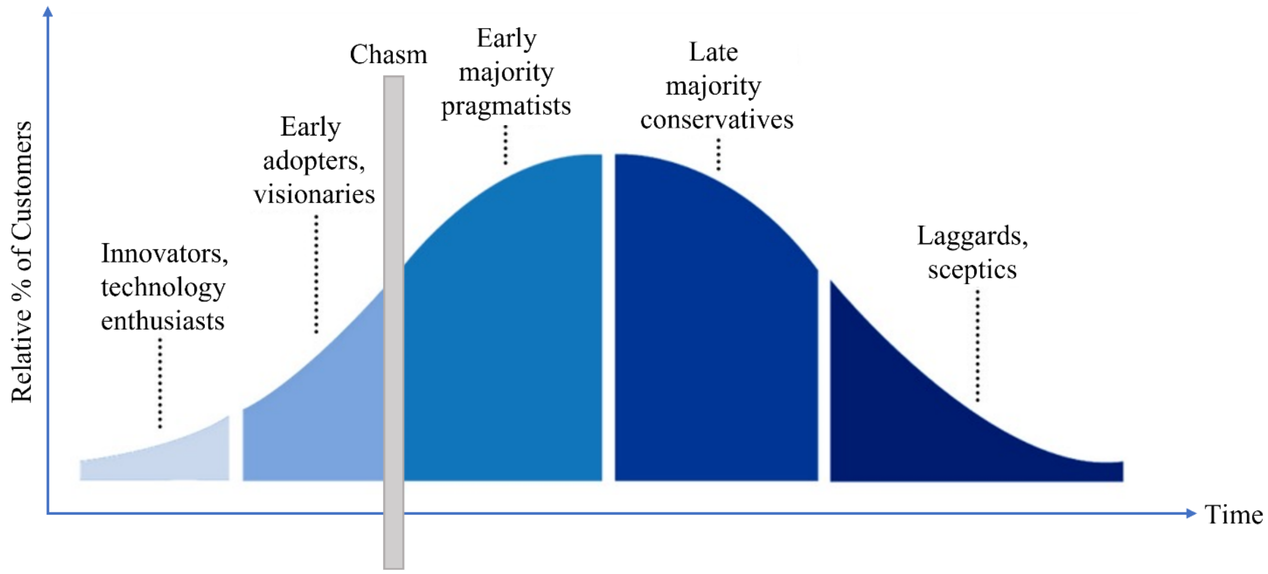


Figure 5: Technology Adoption Life Cycle (Moore, 1991)

A technology passes through different phases during its life cycle. As seen in Figure 6 the six main phases that a technology will pass through are identification, solution architecture, development or acquisition, implementation, exploitation, and decommission. The identification phase, this is when a problem is identified that does not have a solution yet. The solution architecture, this is the process of producing a solution to the identified problem. The development or acquisition phase, this is the phase of developing the solution. The implementation phase, this is when the solution is implemented once it has been developed. The exploitation phase, an enterprise will want to innovate the solution before it reaches the decommission phase. The decommission phase, this is once a product is no longer competitive, and it has to be decommissioned.

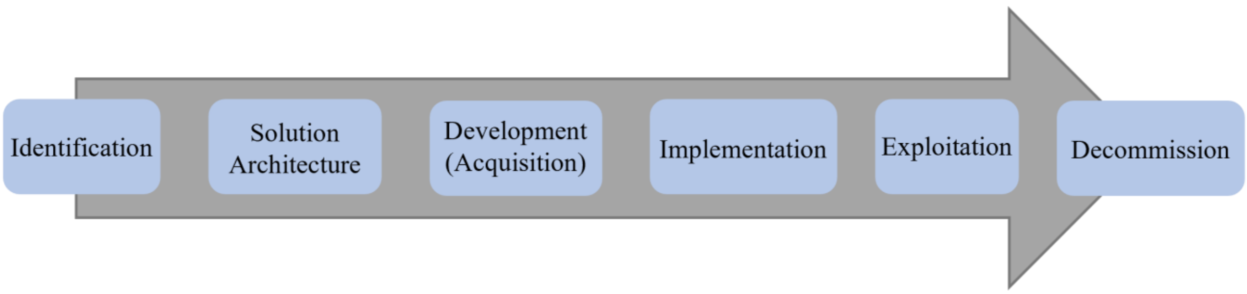


Figure 6: Technology Life Cycle (Adapted from Du Preez *et al.*, 2009)

In the industry, technologies do not necessarily follow a linear sequence as seen in Figure 6. It will follow a cyclic sequence as some technologies might have to go back to the development phase if new needs are identified (Du Preez *et al.*, 2009).

2.3. Product Life Cycle

The Product Life Cycle is the phases that a product will go through throughout its life. The typical Product Life Cycle phases can be seen in Figure 7. The Technology Life Cycle will usually fall within the Product Life Cycle.

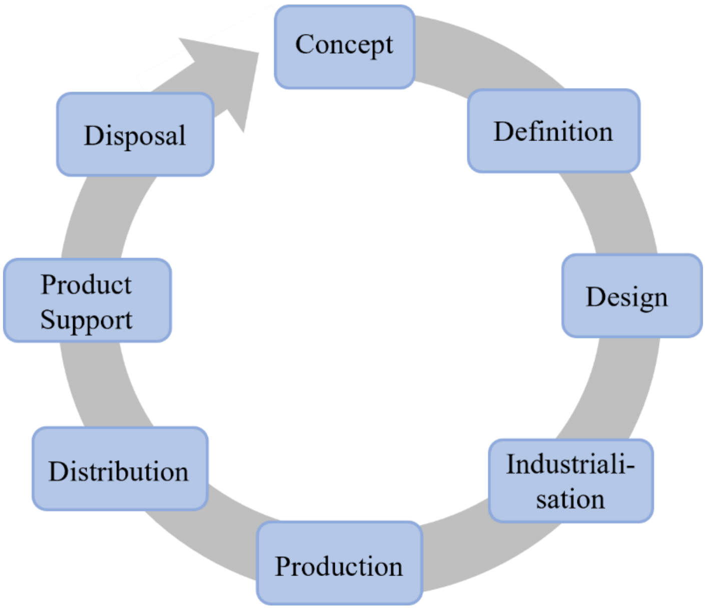


Figure 7: Product Life Cycle (Noyan, 2004)

The concept phase, this is when many different concepts are produced to solve an identified problem. The definition phase, this is the step of defining all the product requirements once a concept is chosen. The design phase, this is the whole design process that a product undergoes to ensure that the design requirements are satisfied. The industrialisation phase, this is the process of ensuring the solution can be industrialised. The production phase, once the product is developed it can be produced on a large scale. This stage included developing cost-effective production processes. The distribution phase, this is the development and implementation of a strategy to distribute the solution to the end user. The product support phase, this is the phase where support is provided to the end user. The disposal phase, this is the process of disposing of the entire product and production processes once the product is no longer on the market.

Figure 7 represents an iterative life cycle since a product will undergo re-engineering and will jump back to previous phases during the iterative process. For example, it might be identified in the production phase that a product must be altered to improve the ease of production, and thus the product will go back to the design phase to be re-engineered.

A product also has a product maturity life cycle as seen in Figure 8. The product maturity life cycle is well known and was developed by Raymond Vernon in 1966 and is still widely used by many organisations when developing new products (Indeed, 2021).

Understanding the product maturity life cycle is important for marketing strategies and according to Brady (2019) it can also help organisations that are developing new product to understand the current competitors on the market and help form a pricing strategy. The product maturity life cycle consists of 5 phases namely: the introduction, growth, maturity, decline and withdrawal phases.

The **introduction phase** is when the product is just introduced to the market. The acceptance and sales are low, and the product can still change to enhance the performance and customer acceptance. According to CFI Education (2015) this is the phase where the costs are usually the highest since economies of scale cannot be implemented yet.

A product enters the **growth phase** once the product is known and accepted, and the sales of the product increases. CFI Education (2015) also states that it is in this stage that economies of scale can be implemented as the sales and profitability increase.

The **maturity phase** is when the product is well known, and sales are stable. According to Dieter and Schmidt (2013), during the maturity phase a product will usually experience a lot of competition and, attempts should be made to innovate and introduce new features of the product to increase competitiveness and prolong the total life cycle of the product.

The **decline phase** is when the sales decrease and the product has lost the competitive edge. According to Hofstrand (2017) the decrease in sales is due to the fact that users have started buying other products that are more competitive.

The **withdrawal phase** is when the product is taken off the market (Dieter and Schmidt, 2013).

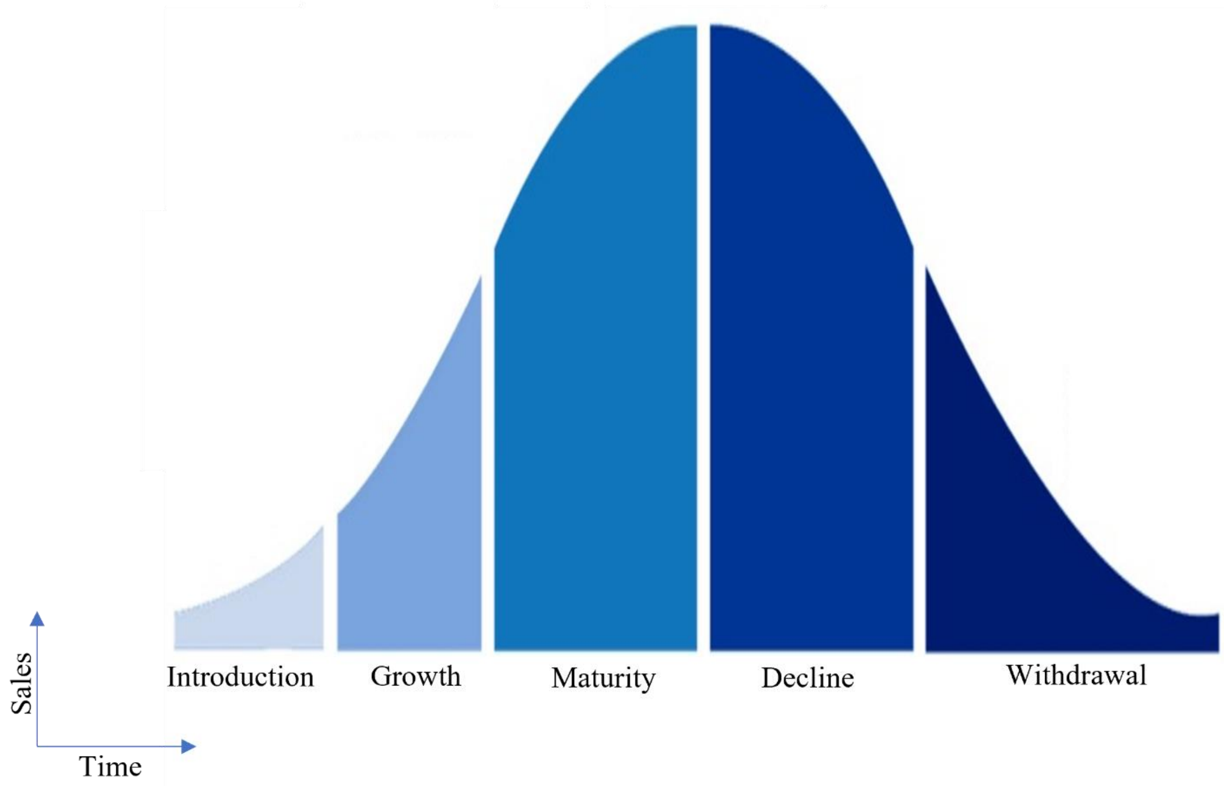


Figure 8: Product Maturity Life Cycle (Adapted from Marketing Teacher, 2014)

Within the design phase of the Product Life Cycle there exists a sub-life cycle called the product **design** life cycle. This is the process that is followed to develop a new product and typically consists of a concept design, preliminary design, detailed design, and manufacture and support.

2.4. Enterprise Life Cycle

For a product to be successful an enterprise is required to develop, manage, and sell the product. Thus, a well-defined Enterprise Life Cycle is crucial for the success of a product or service. The Enterprise Life Cycle is the life cycle that an enterprise will go through. It is typically much more complex than the technology and Product Life Cycles. The Product Life Cycle will usually fall within the Enterprise Life Cycle as seen in Figure 10 (Du Preez *et al*., 2009).

The typical phases of the Enterprise Life Cycle, as seen in Figure 9, consists of identification, concept, the design phase that includes preliminary design and detailed design, implementation, operation, and decommission.

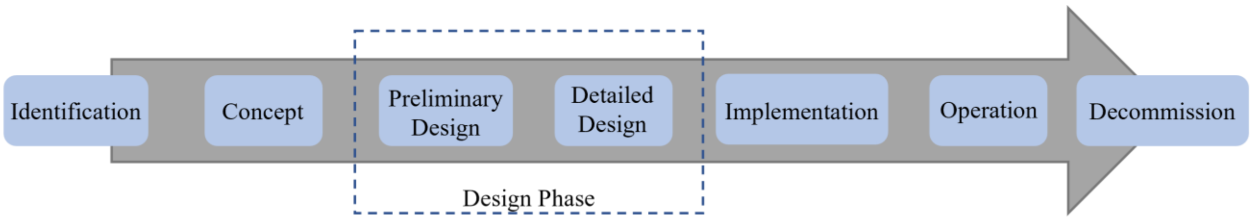


Figure 9: Generic Enterprise Life Cycle (Adapted from Du Preez *et al*., 2009)

This is similar to the Product Life Cycle where the identification phase to implementation phase of the Enterprise Life Cycle correspond to the concept phase to production phase of the Product Life Cycle.

During the Identification phase the need for an Enterprise is identified. This is usually when a new product or service is developed, and it requires a fully functioning Enterprise to run the operational activities involved with developing and commercialising the new product or service.

The concept phase is when different enterprise ideas and business models are generated and explored. This usually involved many brainstorming sessions and market research on how the new product or service can be commercialised.

The design phase is once a concept has been selected a preliminary and detailed design of the proposed Enterprise is developed. This includes developing a business model and forming partnerships with other enterprises or organisations that provide needed resources.

The implementation phase in when the developed Enterprise and business model is put to practice and the Enterprise becomes operational.

The operation phase consists of all the operations that must be executed within the enterprise to ensure that the organisation is operational and can make a profit. The decommission phase is the closing down of an organisation, once it is no longer competitive and does not make a profit.

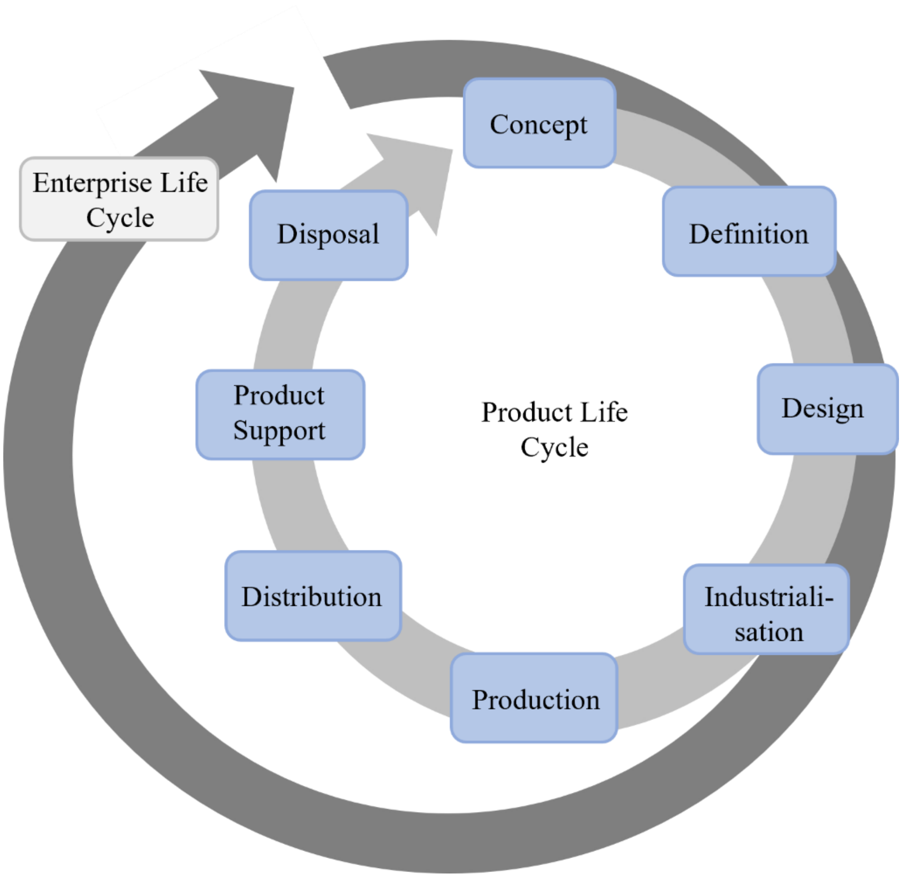


Figure 10: Product Life Cycle executed within Enterprise Life Cycle (Adapted from Du Preez *et al*., 2009; Noyan, 2004)

2.5. Chapter Summary

The research objective of understanding the Enterprise Engineering Life Cycles is achieved and the research question of what the Enterprise Engineering Life Cycles are is answered.

Enterprise Engineering is the design or re-design of an enterprise or part of an enterprise. The three life cycles of the Enterprise Engineering process are the Technology Life Cycle, the Product Life Cycle and the Enterprise Life Cycle.

The Technology Life Cycle is the phases that a technology goes through throughout its lifetime. A technology also has a technology adoption life cycle. This is an indication of how society adopts a new technology based on the type of person that utilises the technology.

The Product Life Cycle is the phases that a product goes through throughout its lifetime. The Technology Life Cycle is integrated into the Product Life Cycle. A product also has a product maturity life cycle that is an indication of the maturity of a product and is a function of sales over time, the phases are introduction, growth, maturity, decline, and withdrawal.

The Enterprise Life Cycle is the phases that an enterprise will go through throughout its lifetime. The Product Life Cycle is integrated into the Enterprise Life Cycle.

Chapter 3

Technology Life Cycle

"If I have seen further than others, it is by standing upon the shoulders of giants."

- Isaac Newton

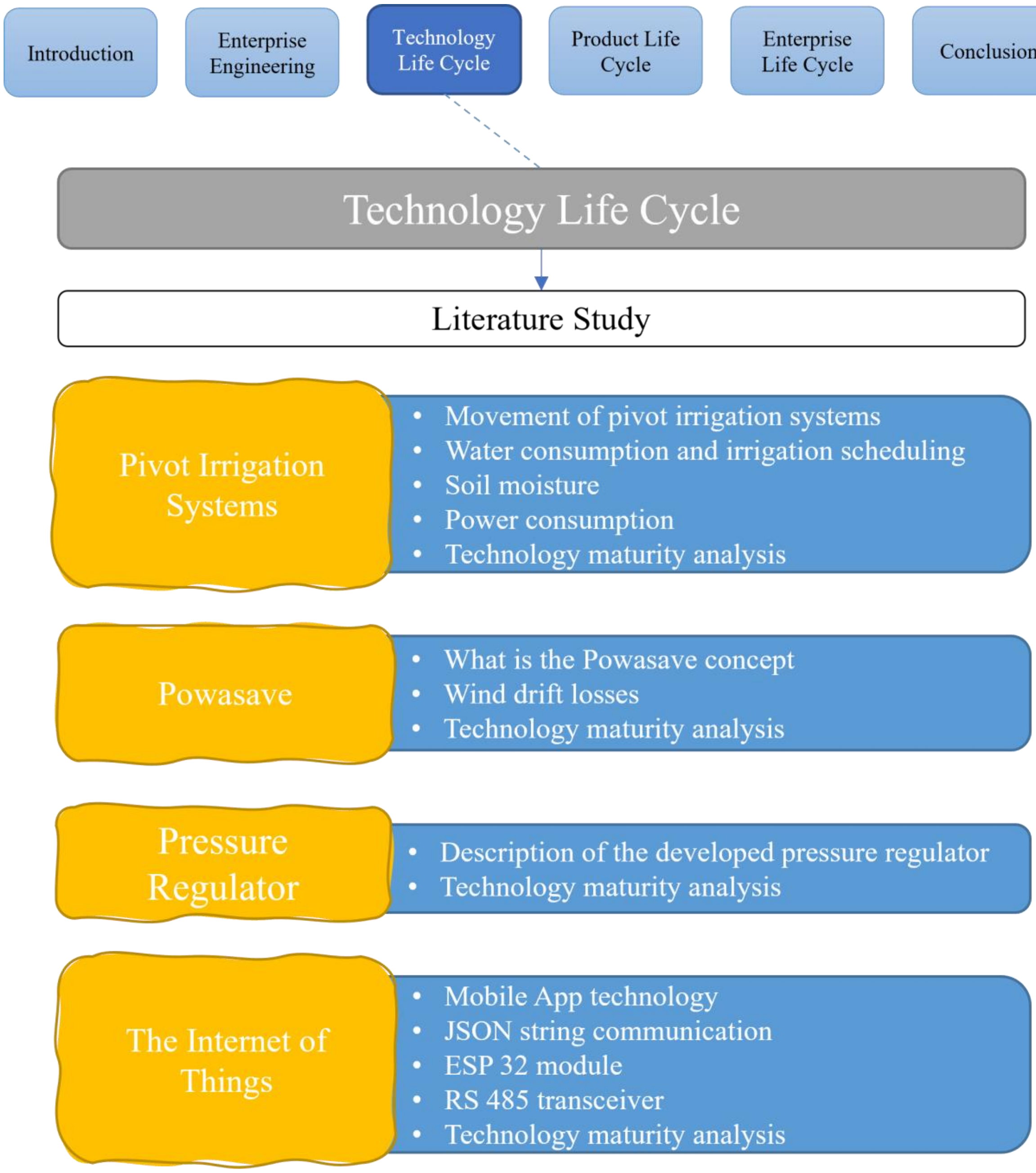


Figure 11: Navigation Structre of Chapter 3

The research objectives and research questions addressed in Chapter 3 are summarised in Table 3.

Table 3: Chapter 3 Objectives

Primary Objective	Research Objectives	Research Questions	Document Structure
Understand the context of the Technology Life Cycle	Understand the maturity of the technology used in current pivot irrigation systems.	What is the maturity of technologies currently used in irrigation systems and is there room for innovation to improve irrigation systems?	Section 3.2 to 3.4
	Understand the maturity of IoT technologies.	What is the maturity of some IoT technologies?	Section 3.5

3.1. Introduction

Chapter 3 is a literature study on the different technologies that are currently developed and on the market. Firstly, pivot irrigation systems are discussed. This includes the movement of pivot irrigation systems, the water and power consumption involved with pivot irrigation systems and the soil moisture requirements. Secondly, the Powasave concept is discussed along with the wind deflection model that was developed by Budler (2017). Thirdly, the pressure regulator that is developed for the Powasave is discussed. Lastly, IoT technologies are discusses which include Mobile App technology, JSON string communication, the ESP 32 module and RS485 Transceivers. Further a technology maturity analysis is performed on all the various technologies discussed in this Chapter.

3.2. Pivot Irrigation Systems

Pivot irrigation systems are used to irrigate crops using sprayers that are attached to a rotating tower that pivots around a centre point. Pivots have been a popular choice to irrigate crops over the past few decades due to the large area they can efficiently and uniformly irrigate with a reduced labour requirement.

As seen in Figure 12, a pivot irrigation system is a series of lateral towers that are made up of a network of trusses. The main parts are a fixed central tower, a control panel, drive units that are driven by geared motors, spans that carry the weight of the lateral water pipeline and sprayers that uniformly distribute the irrigation water over the crops.

The fixed central tower is the pivotal point of the pivot that anchors the structure to a fixed position. The lateral water pipeline is connected to a main water supply at the fixed central tower. The drive unit drives the wheels of the pivot in one direction causing the lateral structure to rotate around the central tower. The control panel controls the movement and water supply of the pivot.

While pivot irrigation systems are in operation, wind drift and evaporation losses occur. Wind drift losses are the water losses that occur when wind blows the irrigation droplets out of the targeted irrigation area. Evaporation losses are the water losses that occur due to the evaporation of the irrigation droplets during flight and from the ground surface. According to Sadeghi et al. (2016) an average of up to 18% of daily water applied to crops are lost during irrigation due to wind drift and evaporation losses. Sadeghi et al. (2016) further states that the variance of these water losses is between 0 to 36% depending on the design characteristics of the system like the required spray pressure, and weather conditions like the ambient temperature and wind speeds. The wind drift and evaporation losses are further dependant on the size of the droplet diameter. The smaller the droplet diameter the more susceptible the droplet is to wind drift and evaporation losses (Budler, 2017).

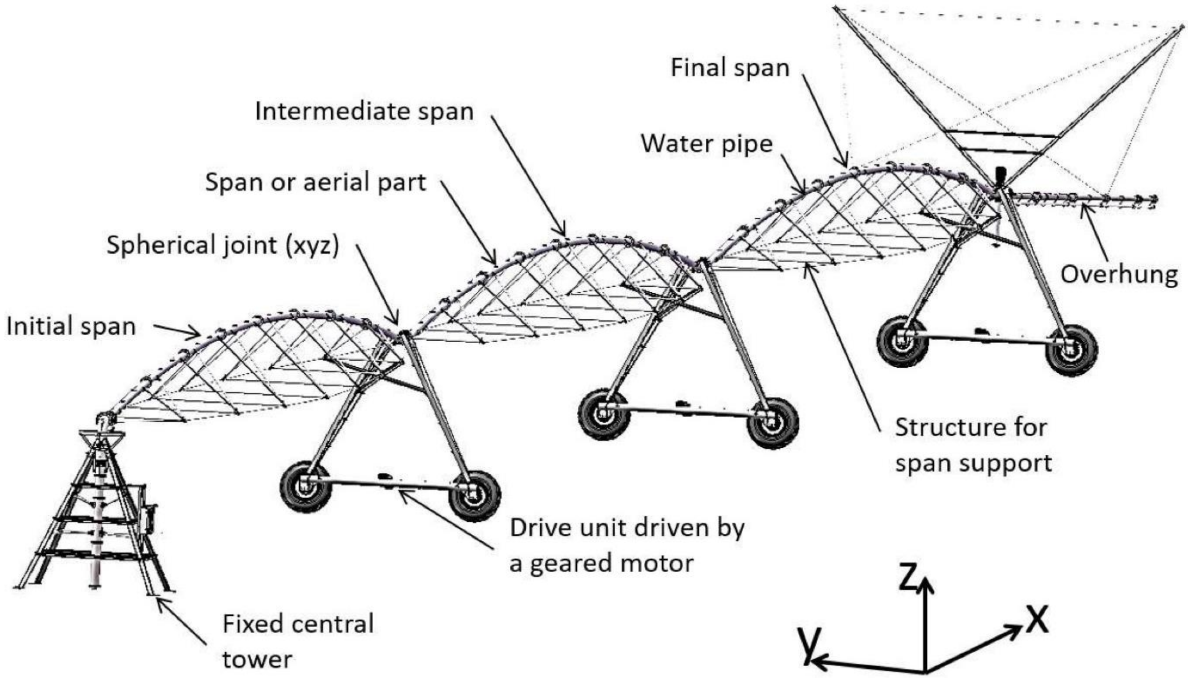


Figure 12: Pivot Irrigation System (Schmidt et al., 2019)

The droplet diameter is dependent on the irrigation pressure and nozzle size of the sprayer. With the same nozzle size, the higher the pressure the smaller the droplet diameter will be, and the lower the pressure the larger the droplet diameter will be. Thus, to produce a large droplet, a low irrigation pressure is required.

According to Martin et al. (2017) a large portion of the operating cost of pivot irrigation systems is the pumping cost involved to pump water to the desired pivot location and to pressurise the water to the desired nozzle inlet pressure. If the pumping cost can be reduced, the overall cost of operating pivot irrigation systems will reduce.

Due to the conservation of mass, once water has sprayed out of a nozzle the mass flow rate in the radial water pipe will decrease. If the mass flow rate decreases the volume flow rate will decrease. This will result in a reduction in the dynamic presses along the length of the radial pipeline. To compensate for the effect of the decrease in dynamic pressure along the radial length of the pipe, the diameter of the radial water pipe is reduced along the radial length of the pipe (Budler, 2017).

The Pressure at the inlet of the nozzles, expressed in Equation (1), depends on the pressure of the water supply at the pivot inlet, the velocity of the water, the change in elevation due to the slope of the field being irrigated, and the pressure losses due to friction in the pipe.

$$p_{Ti} = p_i + \frac{1}{2}\rho_w v_{wi}^2 + \rho_w g H_i = p_n + \frac{1}{2}\rho_w v_{wn}^2 + \rho_w g H_n + \Delta p_{losses} \qquad (1)$$

where

$$\Delta p_{losses} = \sum_i^n \frac{f_i L_i}{d_i}\frac{1}{2}\rho_w v_{wi}^2 + \sum_i^n K_i \frac{1}{2}\rho_w v_{wi}^2 \qquad (2)$$

is the sum of the major and minor pipe losses.

In Equation (2), $\frac{1}{2}\rho_w v_{wi}^2$ is the dynamic pressure, f_i is the Darcy friction factor and K_i is the loss coefficient.

The geodetic pressure, H_g varies with the slope of the field being irrigated and can be calculated with Equation (3)

$$H_{g,max} = 2R\sin\theta \qquad (3)$$

where R is the distance along the radius of the pivot and θ is the slope of the irrigation field. When the irrigation field has a slope, the geodetic pressure fluctuates as the pivot executes its consecutive cycles and the larger the slope the larger the geodetic pressure fluctuation.

3.2.1. Movement of Pivot Irrigation Systems

The movement of a pivot is a chain reaction. The movement of the last tower determines the movement of all the other towers in the pivot. It works as follows: the last tower moves causing the rest of the towers to be out of alignment. As the last tower moves a micro switch is triggered on the second last tower due to the misalignment. Once the microswitch is triggered it energises the drive unit of the second last tower causing it to move and come in alignment with the last tower. This chain reaction then continues throughout all the towers until all the towers are in alignment again and the sequence is repeated.

3.2.2. Water Consumption and Irrigation Scheduling

Irrigation systems are designed to have a constant flow rate. The water consumption of pivot irrigation systems depends on the water requirement of the crop being irrigated and how water efficient the system is. Crops require a specified amount of water application to grow. According to Leib and Grant (2019), the water application is measured based on the depth, D of water applied to the ground as seen in Figure 13. The flow rate and application depth are related to each other with Equation (4),

$$AD = Qt \tag{4}$$

A is the area of the field being irrigated, Q is the flow rate and t is the irrigation time. Thus, if the crop specific application depth, the irrigation area and the flow rate is known the irrigation time can be calculated.

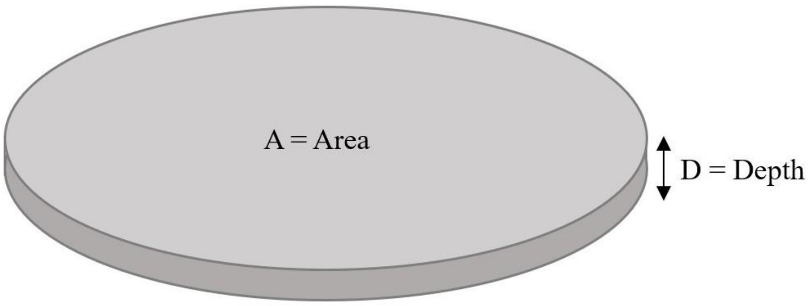


Figure 13: Free Body Diagram of the Irrigation Area

The rate at which application takes place is called the application rate, AR and can be calculated with Equation (5)

$$AR = \frac{Q}{A} = \frac{D}{t} \tag{5}$$

Thus, once the application rate of the specific pivot is known the irrigation time can easily be calculated with Equation (6).

$$t = \frac{D}{AR} \tag{6}$$

The percent timer is a setting that determines how long it will take a pivot to make a full revolution and it effects how much water is applied to the soil. The faster the pivot moves, the less water is applied per revolution and the slower a pivot moves, the more water is applied per revolution. A 60 second timer controls the movement of the last tower by controlling how long the pivot moves during 60 seconds. If the percent timer is set to 100% the pivot will be moving for the full 60 seconds. If the percent timer is set to 50% the pivot will be moving for 30 seconds of the 60 seconds. 75% is equivalent to 45 seconds and 25% is equivalent to 15 seconds.

3.2.3. Soil Moisture

Water is the most important factor to ensure crop growth. Each crop has a specific amount of water requirement to be healthy and to ensure the optimal crop yield. The soil moisture is an indication of how much water is available to the crop. According to Zhang et al. (2018), if there is not enough moisture in the soil the crops risk death and if there is too much moisture in the soil the crops can develop root diseases and water waste will occur.

The soil moisture can be used to make irrigation decisions since it can indicate if the crop is under or over irrigated. This is done by ensuring that the measured soil moisture at the root zone is between the upper and lower water limit that the specific crop requires. The Root Zone Summary represents the average soil moisture at the root zone of the crop. As seen in Figure 14, the upper limit is defined as the “Full” point and the lower limit is defined as the “Refill” point. If the Root Zone Summary is above the Full point the crops risk root diseases and water waste occurs. If the Root Zone Summary is below the Refill point the crops risk death. (Zhang et al., 2018)

3.2.4. Power Consumption

The largest power consuming factor of pivot irrigation systems is the pumping power. The higher the required irrigation pressure the more power is required to pressurise the irrigation water. The pumping power consumption P in [W] can be calculated using Equation (7),

$$P = \frac{\rho g Q H}{\eta_p \eta_m} \tag{7}$$

where ρ is the density of the fluid being pumped, g is gravitational acceleration, Q is the volume flow rate of the fluid and H is the pressure head, η_p is the pump efficiency and η_m is the motor efficiency.

From Equation (7) it is evident that the power consumption is directly proportional to the pressure head. Thus, by reducing the pressure head the power consumption will also reduce.

The pumping cost per hour, C can be calculated with Equation (8),

$$C = Pc\Delta t = \frac{\rho g Q H c \Delta t}{\eta_p \eta_m} \tag{8}$$

where c is the power cost per kilowatt hour, P is the pumping power consumption, and Δt is the total time the pump is switched on.

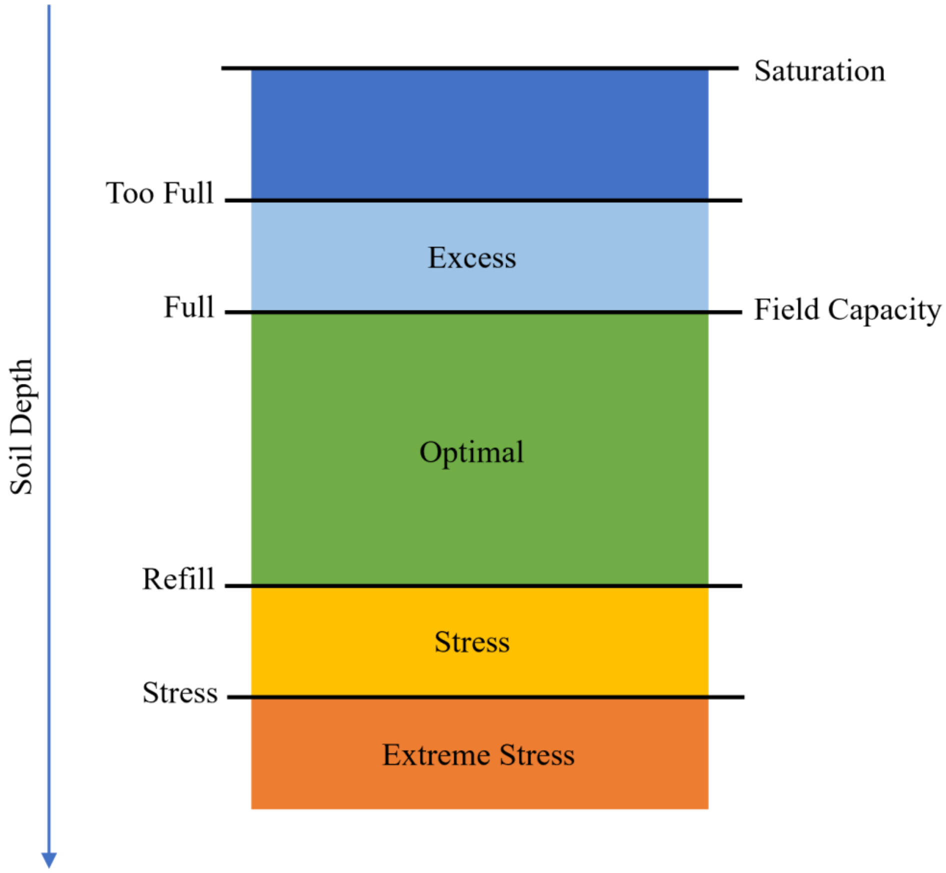


Figure 14: Soil Moisture Management Lines

3.2.5. Technology Maturity Analysis

Pivot irrigation systems have been used for decades and is a relatively mature technology. The majority of farmers have adapted to using pivot irrigation systems to irrigate and also spraying fertilizers, chemicals, and herbicides onto crops. But there is still room to improve the water and power efficiencies of pivot irrigation systems. According to Reuben et al. (2010) the low yield of sugarcane in Tanzania is due to the poor performance of pivot irrigation systems. Thus, by improving the performance of pivot irrigation systems by designing more water and power efficient solutions the crop yield will increase and/or operating costs will reduce.

An identified innovation opportunity is in the control of the pivot. Many pivot irrigation systems are still manually switched on and off and based on an estimated “gut feeling” of when it is needed to irrigate. There is a gap in the market to automate the process of when irrigation must take place and automatically switching the system on and off.

The water efficiency of pivot irrigation systems can also be improved by reducing the water losses that occur due to evaporation and wind drift losses during operation. The water efficiency of pivot irrigation systems is also dependant on the weather conditions. The higher the windspeeds, the more wind drift losses will occur and the higher the outside temperature the larger the evaporation losses. There is a gap in pivot irrigation technology to develop a system with IoT technologies that take the weather conditions into account to irrigate under optimal weather conditions.

Another area for innovation is to develop the function that the farmer is notified if the pivot irrigation system has malfunctioned. The farmer does not always know if the irrigation system malfunctioned or stopped. Pivots are usually isolated and remote, and depending on the technology used, it could take days for a farmer to realise if a pivot has malfunctioned, or that a pipe has burst.

3.3. Powasave

The Powasave is a novel low-pressure irrigation sprayer, as seen in Figure 15, that was developed at the University of Stellenbosch as part of a study done by Budler (2017). The Powasave sprayer is protected by patents in Australia with patent nr. AU2015348985 and in South Africa with patent nr 2017/03431. The sprayer consists of a PVC pipe with closed ends and multiple orifice sets attached to it.

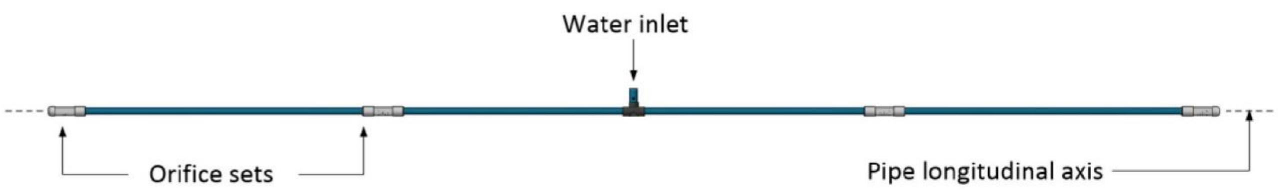


Figure 15: Powasave Sprinkler Pipe (Budler, 2017)

The orifice sets, as seen in Figure 16, have various holes machined through the wall of the orifice pipe which allows water to exit the sprayer allowing irrigation to take place. The positions of the machined holes are as seen in Figure 16 and the hole sizes range from 0,75 mm to 2 mm in diameter. (Budler, 2017)

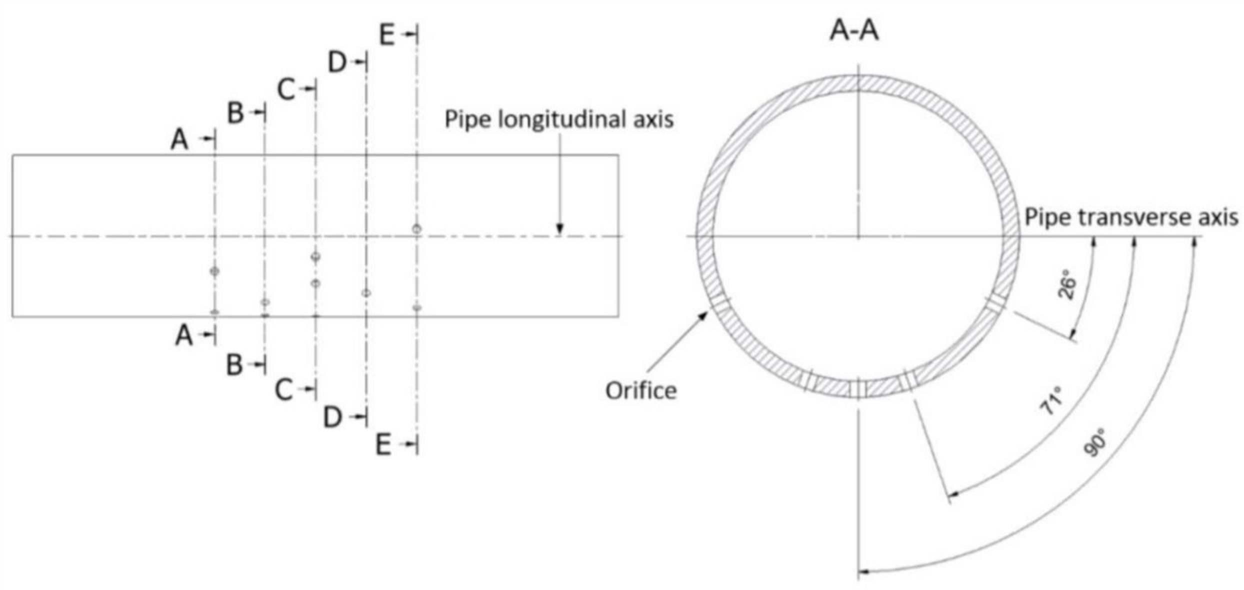


Figure 16: Powasave Irrigation Nozzle Orifice Set (Budler, 2017)

The Powasave sprayer is designed to irrigate with a larger droplet diameter than typical irrigation systems. The larger the droplet diameter the larger the mass of the droplet and thus the less susceptible the droplets are to wind drift and evaporation losses. This results in a reduction of water losses since the wind drift and evaporation losses are reduced. To produce a large droplet a low irrigation pressure is required. Thus, the pumping costs are also reduced due to the lower pressure requirement.

According to Budler (2017) the inlet pressure requirement of the Powasave sprayer is as low as 5 kPa with a design flow rate of 6,29 L/min. According to Nelson (2021) typical irrigation sprayers irrigate at pressure ranges of 10-40 PSI which is equivalent to a pressure range of approximately 70-275 kPa. This is considerably more than the pressure requirement of the Powasave sprayer.

The spray distribution profile of the Powasave sprayer was obtained by Budler (2017) and can be seen in Figure 17 and the spray distribution profile of the Nelson Spinner sprayer can be seen in Figure 18. It was found that although the spray distribution profile of the Powasave sprayer performed poorly compared to commercially available sprayers it does have a lot of potential in reducing the water and power losses of pivot irrigation systems.

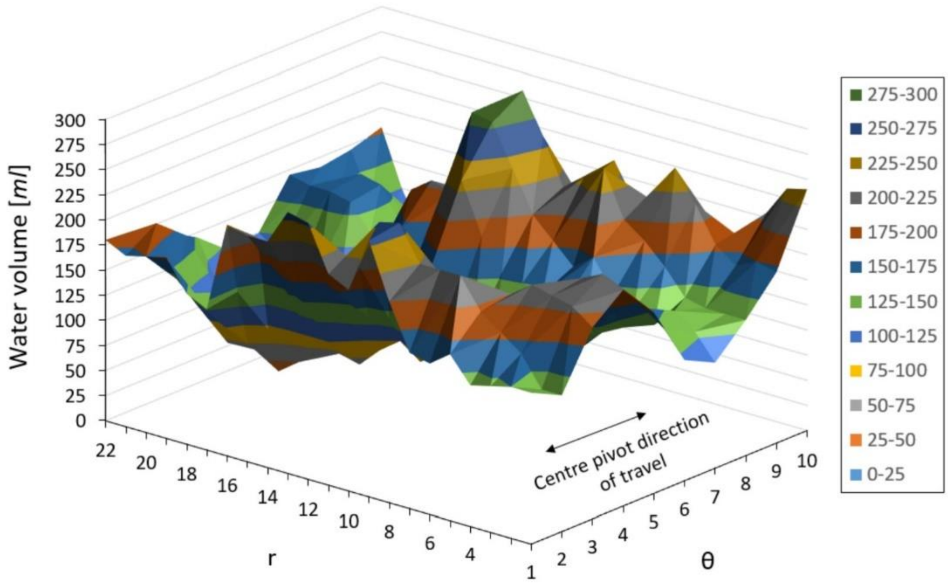


Figure 17: Powasave Sprinker Distribution Profile (Budler, 2017)

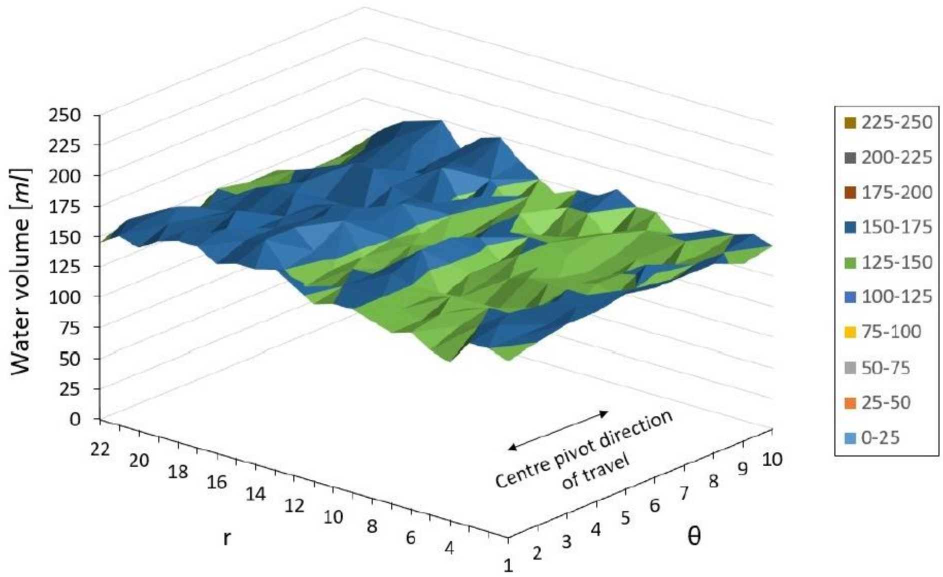


Figure 18: Nelson Spinner Sprinkler Distribution Profile (Budler, 2017)

The distribution profile of the Powasave can be improved by modifying the design of the Powasave to have multiple orifices equally spaced in a line as seen in Figure 19. The sprinklers will have to be mounted like the dotted lines at angles α_1, α_2 and α_3 as seen in Figure 20 to compensate for the new design.

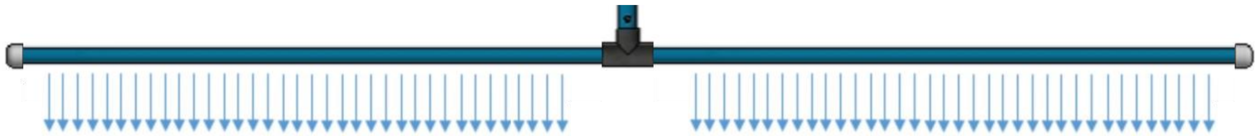


Figure 19: Powasave Sprinkler Pipe with Multiple Equally Spaced Orifices

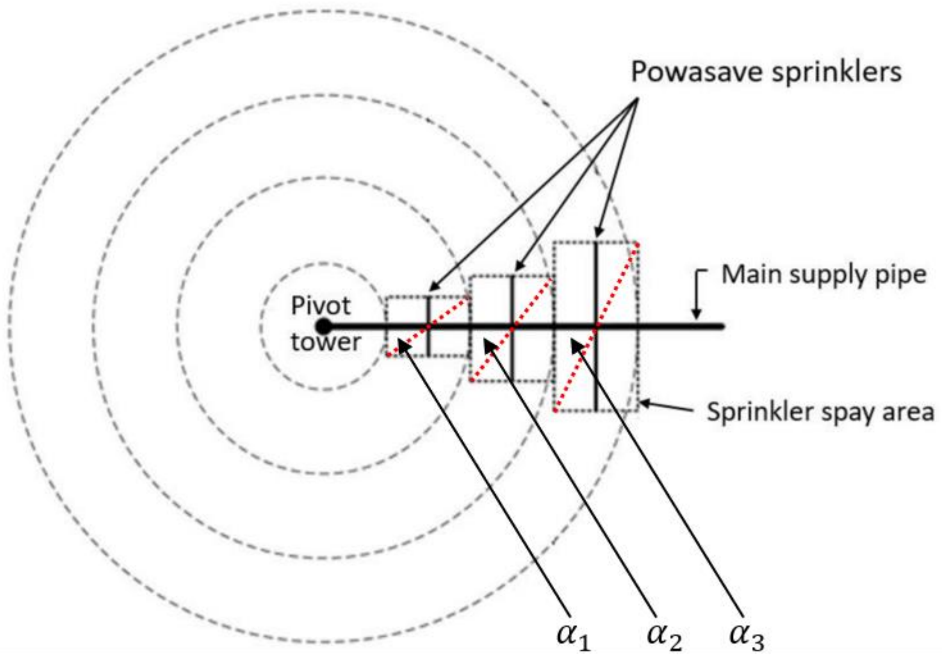


Figure 20: Annular bands irrigated by consecutive Powasave sprinklers installed on a centre pivot system with a different configuration

3.3.1. Wind Drift Losses

As stated before, the wind drift losses are the losses that occur when the wind blows the droplets out of the targeted irrigation area.

The following Equations are the mathematical model that Budler (2017) developed to describe the motion of an irrigation droplet and the effect that the wind has on the droplet.

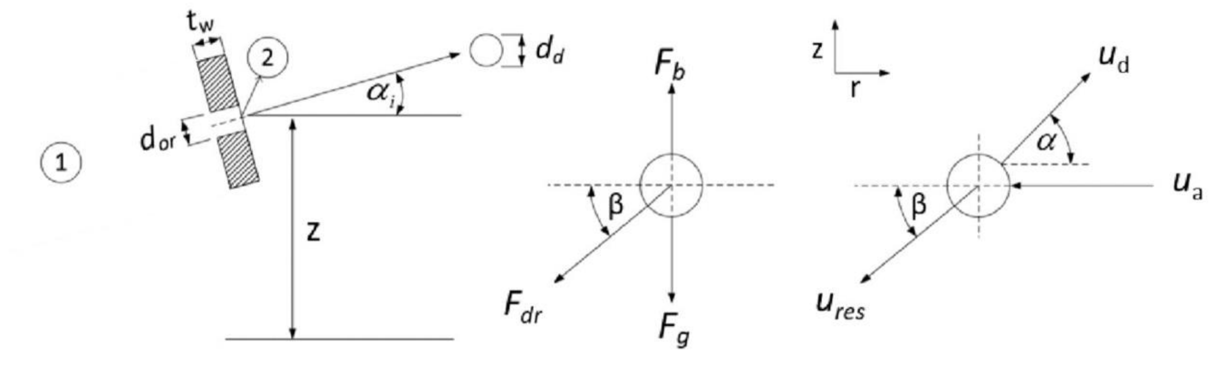


Figure 21: Droplet Exiting the Nozzle with kinetic and kinematic conditions (Budler, 2017)

According Budler, (2017) the exit velocity of the water droplet exiting the nozzle chamber is defined by Equation (9).

$$u_{d_0} = \sqrt{\frac{2g\Delta H}{1 + k_o}} \tag{9}$$

In Equation (9), g is the gravitational acceleration, ΔH is the gauge pressure head inside the nozzle chamber and k_o is the orifice loss coefficient.

The forces acting on the droplet are gravitational force, F_g, buoyancy force, F_b and a drag force, F_{dr} as seen in Figure 21. These forces are defined by Equations (10), (11) and (12).

$$F_g = \rho_w g V_d = \frac{\pi}{6}\rho_w g {d_d}^3 \tag{10}$$

$$F_b = \rho_a g V_d = \frac{\pi}{6}\rho_a g {d_d}^3 \tag{11}$$

$$F_{dr} = \frac{1}{2}\rho_a C_d A_d {u_{res}}^2 = \frac{\pi}{8}\rho_a C_d {d_d}^2 {u_{res}}^2 \tag{12}$$

According to Turton and Levenspiel (1986), C_d is the drag coefficient over the droplet defined by Equation (13).

$$C_d = \frac{24(1 + 0{,}173Re^{0{,}657})}{Re} + \frac{0{,}413}{1 + 16300Re^{-1{,}09}} \tag{13}$$

Re is the Reynolds number defined by Equation (14).

$$Re = \frac{\rho_a u_{res} d_d}{\mu_a} \tag{14}$$

ρ_a is the density of the air, u_{res} is the resultant droplet velocity, d_d is the diameter of the droplet and μ_a is the dynamic viscosity of air.

The relationship between d_d, the diameter of the droplet, and d_n, the diameter of the nozzle is as follows defined by Equation (15) according to Rayleigh (1878) and Roux (2012).

$$\frac{d_d}{d_n} \approx 1.8 \tag{15}$$

The velocity of the droplet in the r-direction is defined by Equation (16)

$$u_{d_r} = u_d \cos\alpha \tag{16}$$

The velocity of the droplet in the z-direction is defined by Equation (17)

$$u_{d_z} = u_d \sin\alpha \tag{17}$$

In Equations (16) and (17), α is the angle relative to the horizon as seen in Figure 21. The velocity of the wind is u_a and thus the resultant air velocity over the droplet in the r-direction is:

$$u_{res_r} = -(u_{d_r} + u_a) \tag{18}$$

The resultant air velocity over the droplet in the z-direction is:

$$u_{res_z} = u_{d_z} \tag{19}$$

The speed of the resultant air over the droplet is thus defined by Equation (20).

$$u_{res} = \sqrt{{u_{res_r}}^2 + {u_{res_z}}^2} \tag{20}$$

The relative angle β is:

$$\beta = \tan^{-1}\frac{u_{res_z}}{u_{res_r}} \tag{21}$$

The drag force in the r-direction is:

$$F_{dr_r} = F_{dr}\cos\beta \tag{22}$$

The drag force is the z-direction is:

$$F_{dr_z} = F_{dr}\sin\beta \tag{23}$$

Applying Newtons Second law the motion of the droplet is described by Equation (24).

$$\sum F_r = \frac{d}{dt}(m_d u_{d_r}) = m_d\frac{d}{dt}(u_{d_r}) + u_{d_r}\frac{d}{dt}(m_d) \tag{24}$$

It is assumed that the mass, m_d, of the droplet remains constant and thus Equation (24) simplifies to:

$$\sum F_r = -F_{dr_r} = m_d\frac{d}{dt}(u_{d_r}) \tag{25}$$

By applying a second order truncated Taylor series the derivative of velocity with respect to time can be approximated to:

$$\frac{d}{dt}(u_{d_r}) = \frac{{u_{d_r}}^{t+1} - {u_{d_r}}^{t}}{\Delta t} \tag{26}$$

Thus, by combining Equations (25) and (26) the motion of the droplet in the r-direction is described by:

$${u_{d_r}}^{t+1} = {u_{d_r}}^{t} - \frac{F_{dr_r}\Delta t}{m_d} \tag{27}$$

Similarly, the motion of the droplet in the z-direction is described by:

$$u_{d_z}{}^{t+1} = u_{d_z}{}^{t} + \frac{(F_b - F_g - F_{dr_z})\Delta t}{m_d} \tag{28}$$

The speed of the droplet at any given time is described by:

$$u_d = \sqrt{u_{d_r}{}^2 + u_{d_z}{}^2} \tag{29}$$

at an angle α relative to the horizon

$$\alpha = \tan^{-1}(\frac{u_{d_z}}{u_{d_r}}) \tag{30}$$

The displacement of the droplet can be obtained by integrating the velocity with respect to time. The displacement in the r-direction is described by:

$$u_{d_r} = \frac{d}{dt}(S_{d_r}) \tag{31}$$

$$\int_t^{t+\Delta t} u_{d_r}\, dt = \int_{r_1}^{r_2} dS_{d_r} \tag{32}$$

For a small time step the velocity can be approximated to be the average velocity over the interval thus,

$$\int_t^{t+\Delta t} u_{d_r}\, dt \approx \frac{u_{d_r}{}^{t} + u_{d_r}{}^{t+\Delta t}}{2} \Delta t \tag{33}$$

By combining Equation (32) and (33) the displacement in the r-direction is:

$$S_{d_{r2}} = S_{d_{r1}} + \frac{u_{d_r}{}^{t} + u_{d_r}{}^{t+\Delta t}}{2} \Delta t \tag{34}$$

Similarly, the displacement in the z-direction is:

$$S_{d_{z2}} = S_{d_{z1}} + \frac{u_{d_z}{}^{t} + u_{d_z}{}^{t+\Delta t}}{2} \Delta t \tag{35}$$

3.3.2. Technology Maturity Analysis of the Powasave Concept

The Powasave is a new technology that is not yet available on the market. It is still in the innovators and technology enthusiast's category of the technology adoption life cycle of Figure 5. The competitive advantage that this technology has to offer is the considerable reduction in water losses and power consumption of pivot irrigation systems resulting in crop farming being more profitable. This product also has the potential of enabling farming in arid areas where crop farming was not previously an option. This technology also has the potential of being taken further into the early adopters' and visionaries' category due to the competitive advantage that this technology has to offer. This technology has the potential of expanding the current life cycle of pivot irrigation systems. Due to the desire of having water efficient irrigation systems new technologies like vertical farming, etc is being developed that is threatening the life of pivot irrigation systems. Vertical farming solutions are more competitive when it comes to water efficiency, and it could be a disruptive technology. By improving the water efficiency of pivot irrigation systems with technologies like the Powasave concept, the life cycle of pivot irrigation systems could be expanded.

3.4. Pressure Regulator

The challenge with the low-pressure Powasave sprayer was that there was no pressure regulator available on the market that could regulate the low-pressure requirement. A pressure regulator as seen in Figure 22 that can accurately regulate the low nozzle inlet pressure requirement of the Powasave with an accuracy of 0,34% was developed by De Wet (2018). The main components of the pressure regulator are a gate valve, a servo motor, an Arduino nano, a pressure sensor, and a 3D printed motor housing.

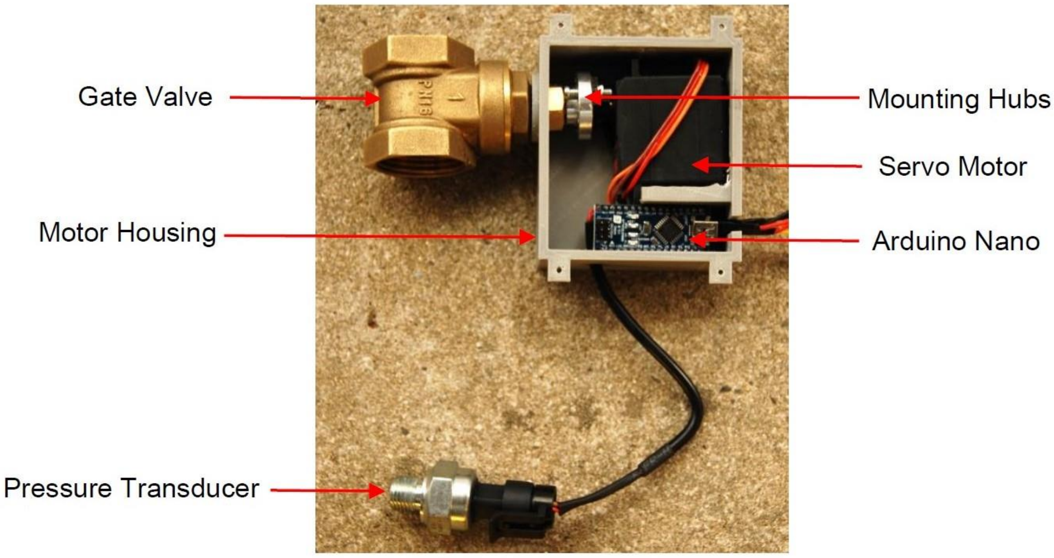


Figure 22: First Prototype of Pressure Regulator (De Wet, 2018)

The control system can be seen in Figure 23 and works as follows. Water flows through the valve, the water pressure is measured by the pressure sensor at the outlet of the valve. The measured pressure is compared with a set valve. If the outlet pressure is too high the controller sends a command to the actuator (servo motor) to rotate and partially close the gate valve, decreasing the flow area, decreasing the outlet pressure until the outlet pressure is equal to the desired pressure. If the outlet pressure is too low, the controller sends a command to the servo motor to rotate and open the gate valve, increasing the flow area, increasing the outlet pressure until the outlet pressure is equal to the desired outlet pressure. Once the outlet pressure is equal to the desired outlet pressure the servo motor becomes stationary.

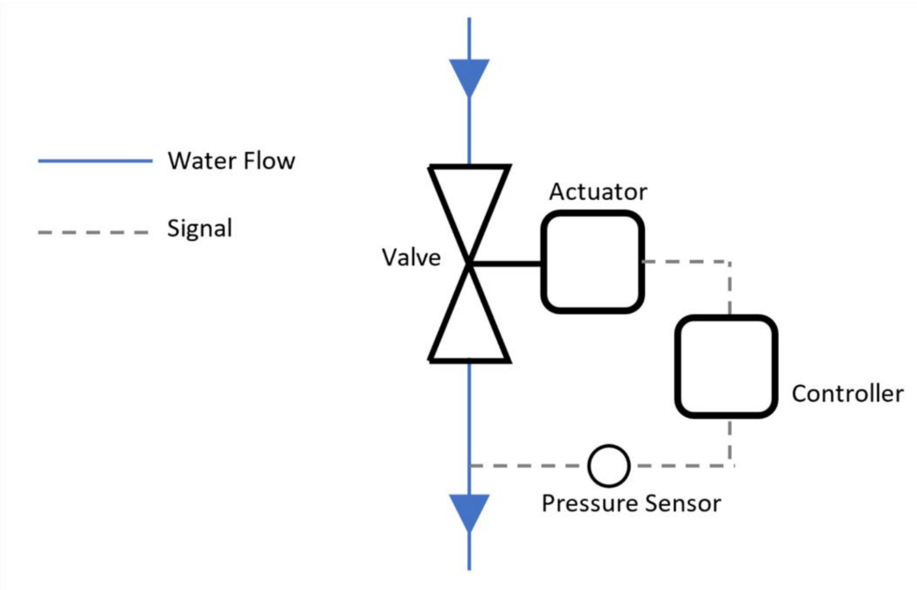


Figure 23: Pressure Regulator Control Line Diagram (De Wet 2018)

3.4.1. Technology Maturity Analysis of the Pressure Regulator

The various components of the pressure regulator are relatively mature technologies. It is the combination of these technologies that comprises a new product. Thus, the pressure regulator is in the innovators and technology enthusiast's category of the technology adoption life cycle of Figure 5.

This product can be improved to include more functions and better user interfaces. One of the changes that can be made is that this version of the product only allows for one pre-set pressure valve that must be programmed onto the device before it is installed on the pivot. The product can be further developed to incorporate IoT technologies to enable the user to change the pre-set pressure values with a mobile App.

3.5. The Internet of Things

The Internet of Things (IoT) is the idea of connecting "things" to the internet. These things are devices that can connect to the internet and communicate with other devices over the internet. It is the constellation of a network of connected devices and people that send and receive data about the environment around them and how they must respond in this environment. The IoT platform is where data from different devices are gathered and analysed to meet a specific need. (Clark, 2016)

IoT technologies is a disruptive technology. Disruptive technologies are technologies that 'disrupt the normal operation of a market or industry' (CFI, 2021). These technologies become so competitive that it replaces the existing technologies.

According to Hobbs (2018) IoT technologies are reshaping business in the following ways. IoT can improve business insight and customer experience, reduces costs and downtime, increases efficiency and productivity. Further it enables asset tracking and waste reduction, and ultimately it creates opportunities for new business models since IoT technologies enable businesses to make more informed decisions based on analysed data.

Currently all industries are under pressure to develop and incorporate IoT technologies to stay competitive. This includes the Agricultural Sector, and the impact of IoT on Agriculture can be significant. IoT Technologies can be used to optimise water usage, improve crop yield and many other factors like improving the supply chain of agricultural goods, and enable people in the agricultural sector to monitor their business from a mobile device. Smart farming is a new way of farming where IoT technologies are used to enable farmers to farm at optimal conditions to ensure maximum crop yield.

The IoT technologies that are used in this study are discussed in Sections 3.5.1 to 3.5.4. This includes Mobile App Technologies, JSON String communication, the ESP32 Wi-Fi module, and the RS485 Transceiver.

3.5.1. Mobile App Technology: Ionic

Ionic is an open-source software development kit to develop hybrid mobile Apps that are compatible with IOS, Android and web application platforms. The software was developed by Max Lynch, Ben Sperry, and Adam Bradley. The first release of the App development platform was in 2013 and is currently on its fifth release.

Ionic is very competitive due to is its ability to interface with a variety of platforms using the same development code. It makes use of web technologies like HTML, CSS, and JavaScript. Ionic is mainly used to develop the front-end user experience and user interface of mobile Apps.

Ionic has a wide variety of user interface (UI) and user experience (UX) designs allowing for customised Apps that have multiple functions. Ionic also has good customer support. This ensures that developers will be notified if corrections or updates are required in the App. This results in the App always being updated with little to no downtime.

Ionic can be classified as a relatively mature technology due to its popularity and ease of use, many software development organisations have been using the platform since 2013. Currently there are more than 5 million Apps developed with Ionic (Altexsoft, 2019).

3.5.2. JSON String Communication

JavaScript Object Notation (JSON) is a format of text file that can be understood by all computers. It is used to store, send, and receive structured data. JSON strings are compact, can map data structures of numbers, strings, Booleans, nulls, and arrays. What makes JSON very user friendly is that almost all programming languages have libraries or functions that can read and write JSON structures. One of the most common applications of JSON strings are to send data from the server to the browser in web applications. It can also be used to send data from the browser to the server.

The syntax of JSON strings are as follows. If the JSON string is an array of values the structure will be surrounded by square brackets, [ ], and the list of values are separated by a comma. If the JSON string is an object the structure will be surrounded by curly brackets, { }, and the list of "name": value pairs, otherwise called properties, are separated by a comma. A "name": value pair syntax consists of the name in double quotes. " ", thereafter a colon, :, thereafter the value.

{"Soil Moisture": 200, "Flow Rate": 10, "Wind Speed": 20, "Temperature": 21, "Rainfall": 15, "Pressure": ["node 1": 5, "node 2": 4.9, "node 3": 5.1]}

In the above JSON string an object is defined by the first and last curly bracket. Inside the object there are six properties, Soil Moisture, Flow Rate, Wind Speed, Temperature, Rainfall, and Pressure. Inside the "Pressure" array there is an object consisting of three properties, node 1, node 2, and node 3.

3.5.3. ESP 32 Module

An ESP 32 module, as seen in Figure 24, is a hybrid Wi-Fi and Bluetooth chip. It is a low power chip that is designed to be used in a variety of Internet of Things applications. The ESP 32 has an input voltage of 5-12 V and an operating voltage range of 2.2-3.6 V with 3.3 V being the optimal operating voltage. It has multiple Digital and Analog I/O pins, eighteen 12-bit Analog to Digital converters and two 8-bit digital to Analog converters. The ESP 32 can be powered by either a USB connection, a 5-12 V unregulated power to the 5V pin and ground, or a 3.3 V regulated power to the 3.3V pin and ground.

Figure 24: ESP 32 Wi-Fi Module

The ESP 32 technology supports station and soft access point. The Station (STA) mode is when the ESP 32 is an external device connected to the router. In soft access point (SAP) mode the ESP 32 is the centre of the network providing connections for other external devices. In STA mode the ESP 32 obtains its IP address from the router. In SAP mode the ESP 32 assigns an IP address to the external devices and it supports a maximum of 5 external devices in SAP mode. In both STA and SAP mode the ESP 32 acts as a Web Server.

With SAP mode the ESP 32 has a Web Server with its own unique IP Address. The ESP Web Server can be accessed by entering the ESP's IP Address into the Web Browser of a local network. Once the IP address is entered into a Web Browser a connection request is made. The ESP 32 has a unique service set identifier (SSID), the name of the network, and password. Once the correct SSID and password is entered the connection is established.

3.5.4. RS485 Transceiver

An RS485 transceiver, as seen in Figure 25, is a serial communication transmitter and receiver. It can communicate over distances of up to 1200 m and has good noise immunity. It has a maximum speed of 35 Mbs over a distance of 12 m and a 100 kbs a distance of 1200 m.

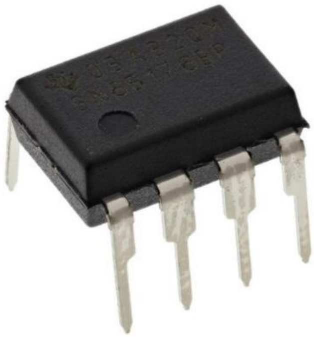


Figure 25: RS485 Transceiver (RS Components, 2021)

3.5.5. Technology Maturity Analysis of IoT Technologies

IoT technologies is a relatively mature technology. According to Technative, (2019) more than 30% of businesses have adapted to IoT technologies and 60% of these businesses claim that IoT technology has disrupted their industry. Technative, (2019) further states that 95% of IoT investors have already achieved a return on investment. Thus, IoT technology can certainly be seen as a disruptive technology that is in the early majority pragmatists stage of the maturity life cycle of Figure 5.

3.6. Chapter Summary

This Chapter examines the technology maturity of different technologies used in pivot irrigation systems. It also discussed the novel Powasave irrigation system that is designed to operate at a low pressure resulting in less power consumption and water losses. The pressure regulator that was developed for the Powasave sprayer is also discussed. The chapter ends off by exploring some IoT technologies used in this study. Emphasis is placed on the importance of IoT technology in all types of organisations and how the agricultural sector can benefit from IoT technologies is discussed.

The research objectives are achieved by answering the research questions of what the technology maturity of pivot irrigation systems and IoT technologies are. It was found that there is room for innovation to improve current irrigation systems and that mature IoT technologies can be used to improve it.

Chapter 4

Product Life Cycle

"Success consists of going from failure to failure without loss of enthusiasm."

- Winston Churchill

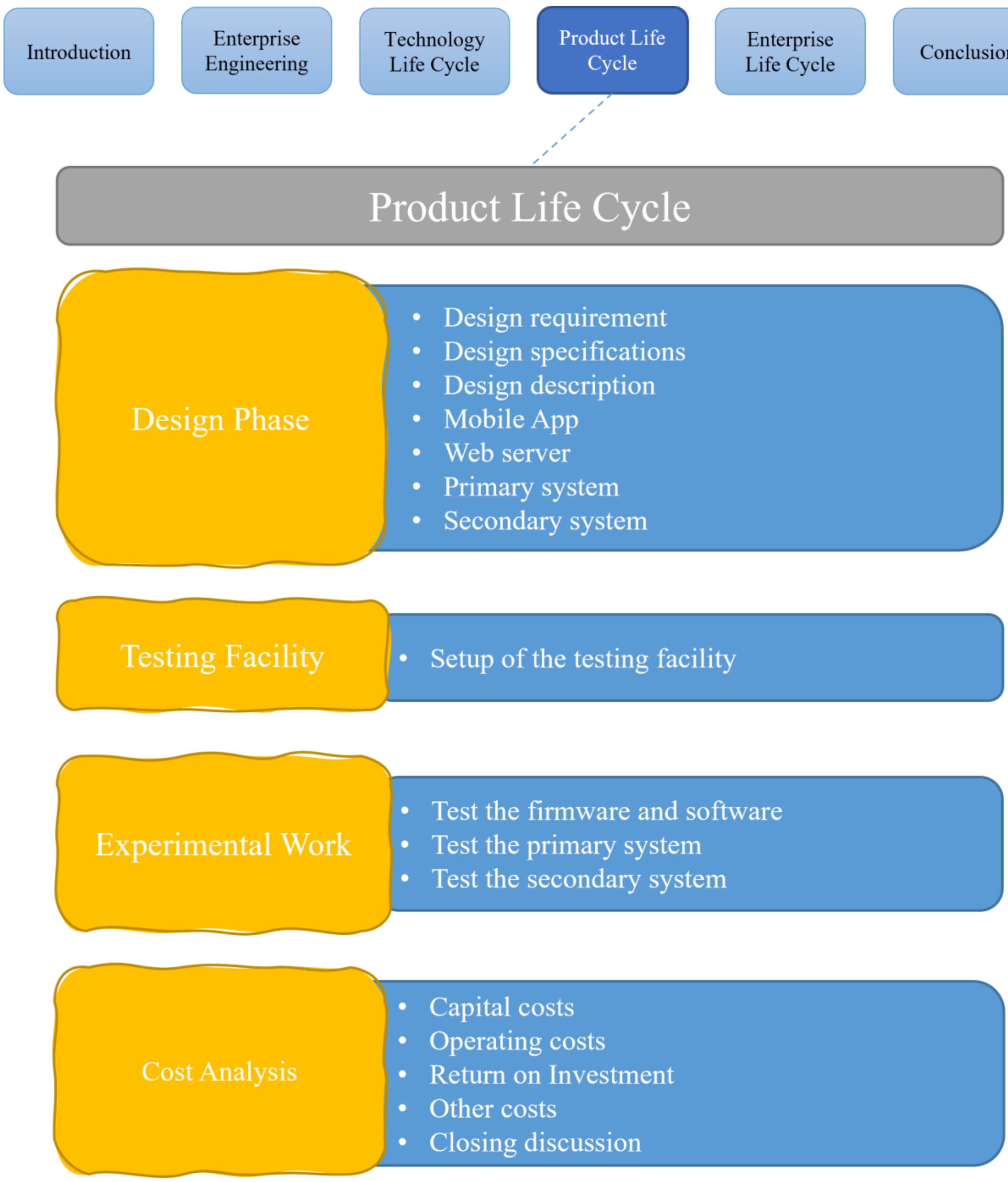


Figure 26: Navigation Structure of Chapter 4

The research objectives and research questions addressed in Chapter 4 are summarised in Table 4.

Table 4: Chapter 4 Objectives

Primary Objective	Research Objectives	Research Questions	Document Structure
Develop the Product	Develop a product that reduces the water losses and power consumption of pivot irrigation systems that adheres to design requirements and that gives farmers more control over pivot irrigation systems by incorporating IoT technologies.	What are the design requirements for an improved irrigation system that reduce water losses and power consumption?	Section 4.2 to 4.4
	Test the developed product.	Does the developed product adhere to the design requirements?	Section 4.5 and 4.6
	Perform a cost analysis on the developed product and compare it to existing products on the market.	How do improved water and power efficient irrigation systems compare to current systems on the market?	Section 4.7

4.1. Introduction

In Chapter 4 the Product Life Cycle is developed. The Product is in the Design phase of the Product Life Cycle as seen in Figure 27. The design of the product is based on concepts that are previously generated and examined. Thus, for the sake of this study it can be assumed that the concept and definition phase of the Product Life Cycle is completed. The only phase that will be discussed in Chapter 4 is the Design phase of the Product Life Cycle. The phases that come after the Design phase is not part of the scope of this study and will not be discussed. As part of the design phase the design specifications are defined. Each individual component of the product is discussed and the interface between all the components are explained. The testing facility and experimental procedures and results are also discussed. Lastly a cost analysis is performed, and the payback period is calculated and discussed.

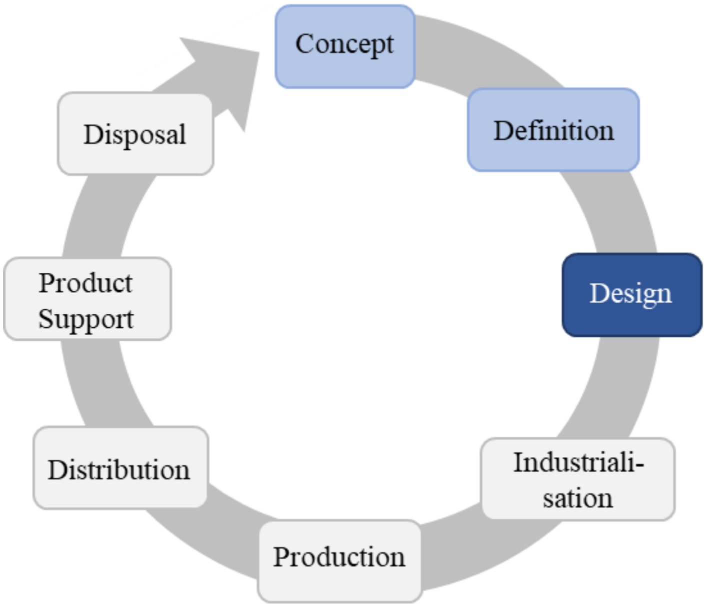


Figure 27: Product Life Cycle Progress

Since this is a new product that has just been developed it is in the 'innovators and technology enthusiasts' phase of the Technology Life Cycle. Although many of the technologies used in the product are relatively mature technologies the developed product is in the first phase of its maturity. As for the Product Maturity Life Cycle of Figure 8, the product in is the introduction phase.

4.2. Design Methodology

The design phase is a series of steps that are followed to develop a novel solution that meets certain requirements. In this study an adaption of the design methodology of Dieter and Schmidt (2013) is followed to design a product that solves the identified problem. The design methodology process can be seen in Figure 28.

Step 1 of defining the problem has already been completed in Chapter 1. The problem statement states that: ***Pivot irrigation systems experience high water losses and power consumption whilst in operation that can be reduced if appropriate technologies are developed to make irrigation more efficient.***

Step 2 of conducting research has also been addressed in Chapter 3 where a literature study is done on pivot irrigation system and IoT technologies.

Step 3 to Step 8 is further discussed in Chapter 4. Firstly, the design requirements are stated and then the design specifications are derived from the design requirements. Secondly a prototype is developed and the detailed description of the developed product is discussed in Section 4.3.3 to Section 4.3.7.

Thirdly the developed product is tested, and the results of the tests are discussed. Lastly a cost analysis is performed on the developed product.

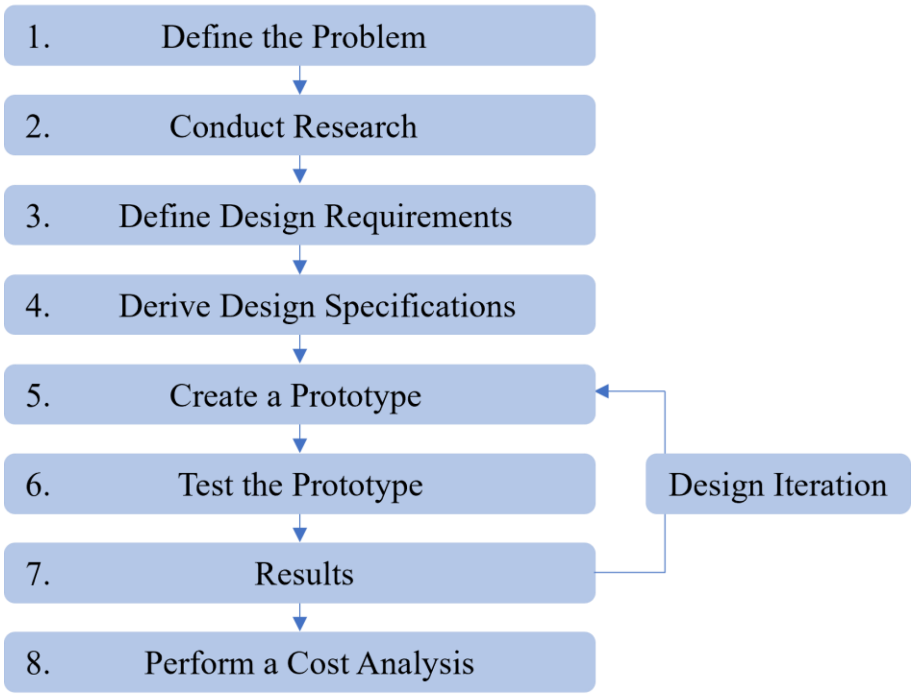


Figure 28: Design Methodology Process

4.3. Design Phase

4.3.1. Design Requirements

The design requirements are all the identified requirements that the product must adhere to, and it is as follows. The system must be able to regulate pressures of up to 1000 kPa to any desired pressure range where the minimum is as low as 5 kPa. The effect of the weather conditions must be taken onto account and the system must respond according to the weather conditions. The system must be able to read the soil moisture, wind speeds, rainfall, flow rate, and ambient temperature. The system must be able to withstand harsh weather conditions thus it will have to be water resistant and be able to operate at high ambient temperatures.

The irrigation must switch on and off depending on the wind speed. Off if the wind speed is too high and on if the windspeed is within the desired range. The irrigation must also switch on and off depending on the soil moisture. The user must be able to read irrigation and weather conditions, set the desired irrigation pressure to any value, and read the current pressure from a remote location using a Mobile App. The system must be affordable and small enough not to influence the mobility of the pivot irrigation system. According to De Wet (2018) the maximum torque required to open and close the gate valve is 13,3168 kg·cm. Thus, the servo motor must have a minimum torque of 13,3168 kg·cm. To ensure this the minimum torque requirement of the servo motor is 13,5 kg·cm.

4.3.2. Design Specifications

The design specifications are a list of specific criteria that the product must adhere to. The design specifications are derived from the design requirements are listed in Table 5.

Table 5: Design Specifications

Design Specification	Description	Parameter	Units
Outlet Pressure Range	The outlet pressure must be adjustable depending on the pressure desired by the user.	0-100	kPa
Inlet Pressure Range	The system must be able to operate under high inlet pressures.	Up to 1000	kPa
Wind Speed	The wind sensor must be able to measure the horizontal wind speeds	-	-
Soil Moisture	The moisture sensor must be able to measure the soil moisture	-	-
Flow sensor	The flow sensor must be able to measure the flow of the water entering the irrigation system	-	-
Rain meter	The rain sensor must be able to measure the rainfall over a specified time	-	-
Temperature sensor	The temperature sensor must be able to measure the ambient temperature	-10 - +50	°C
Pressure Sensor	The pressure sensor must be able to measure the sprayer inlet pressure	0-1000	kPa
Servo Motor Minimum Torque Requirement	The servo motor must be able to open and close a gate value	1.32	N·m
Gate value	The gate valve must be able to regulate the sprayer inlet pressure to a desired setpoint value.	0-1000 (PN10)	kPa
Weather resistant rating	The products must be weather resistant. Thus, it must be able to withstand water and heat exposure.	-	-
Sprayer flow rate	Flow rate through the sprayer at 5 kPa	24.6	L/min

4.3.3. Design Description

The system consists of a Mobile Application, Web Server, Primary System, and a network of Secondary Systems. The command flow of the overall system can be seen in Figure 29. The Primary System is the central control unit that measures the weather conditions and controls the network of Secondary Systems. The Secondary Systems are the respective pressure regulators that regulate the inlet pressure of the Powasave sprayers. The mobile App is installed on the users' smart device and is used to control the setting of the system and to receive data from the system. The Web Server is a mid-way communication between the Mobile App and the Primary System.

The Mobile App sends commands to and receives data from the Primary System via a Web Server with a Wi-Fi connection and an ESP 32. The Secondary Systems receive commands from the Primary System via an Ethernet cable connection. The weather station measures the weather conditions and sends the measured data to the Primary System. The communication between the Mobile App, the Web Server and Primary System is with Wi-Fi a connection. The communication between the Primary System and the network of Secondary Systems is via an Ethernet Cable and RS485 transceivers.

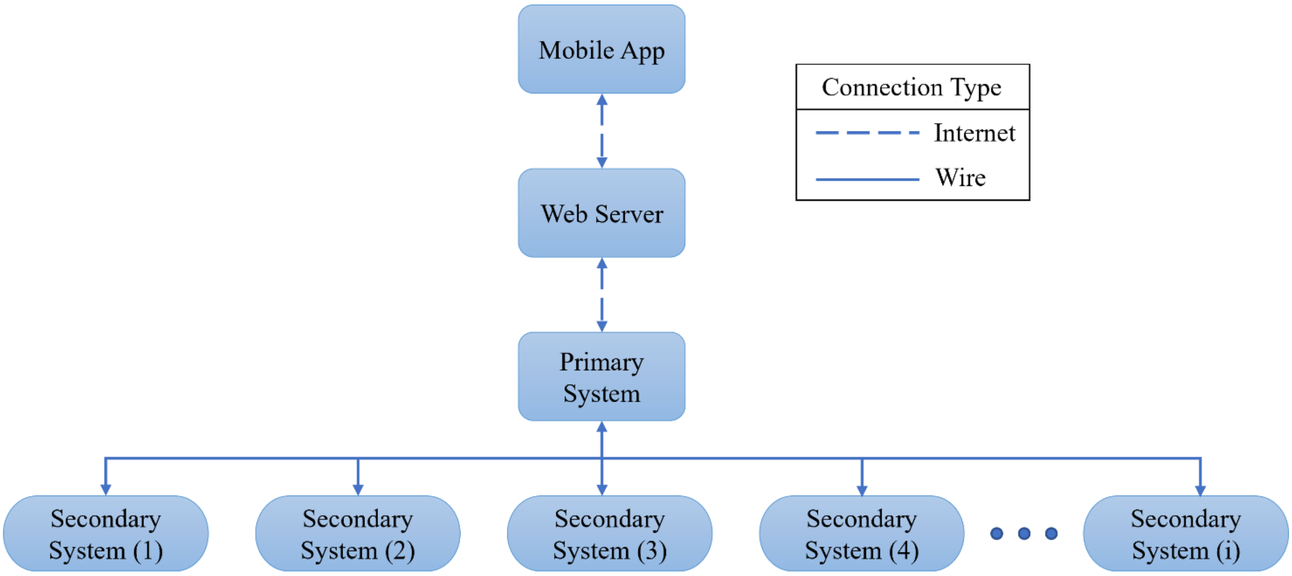


Figure 29: Control Flow Diagram

4.3.4. Mobile App

In this section the design requirements of the mobile App are stated, and the detailed design description of the mobile App is discussed.

4.3.4.1. Mobile App Design Requirements

The wireframe showing the design requirements of the mobile App can be seen in Figure 30. There must be a login page where the username and password are inserted. After the login page a home page must appear displaying all the current conditions of the system. This includes the power status, current pressure in the system, the soil moisture, flow rate, wind speed, temperature, and rainfall.

There must also be navigation buttons that navigate to pages where the pressure, moisture, wind, and temperature settings can be set. Two additional navigation buttons must be included, the first navigating to a general settings page and the second navigating to a nozzle nodes settings page.

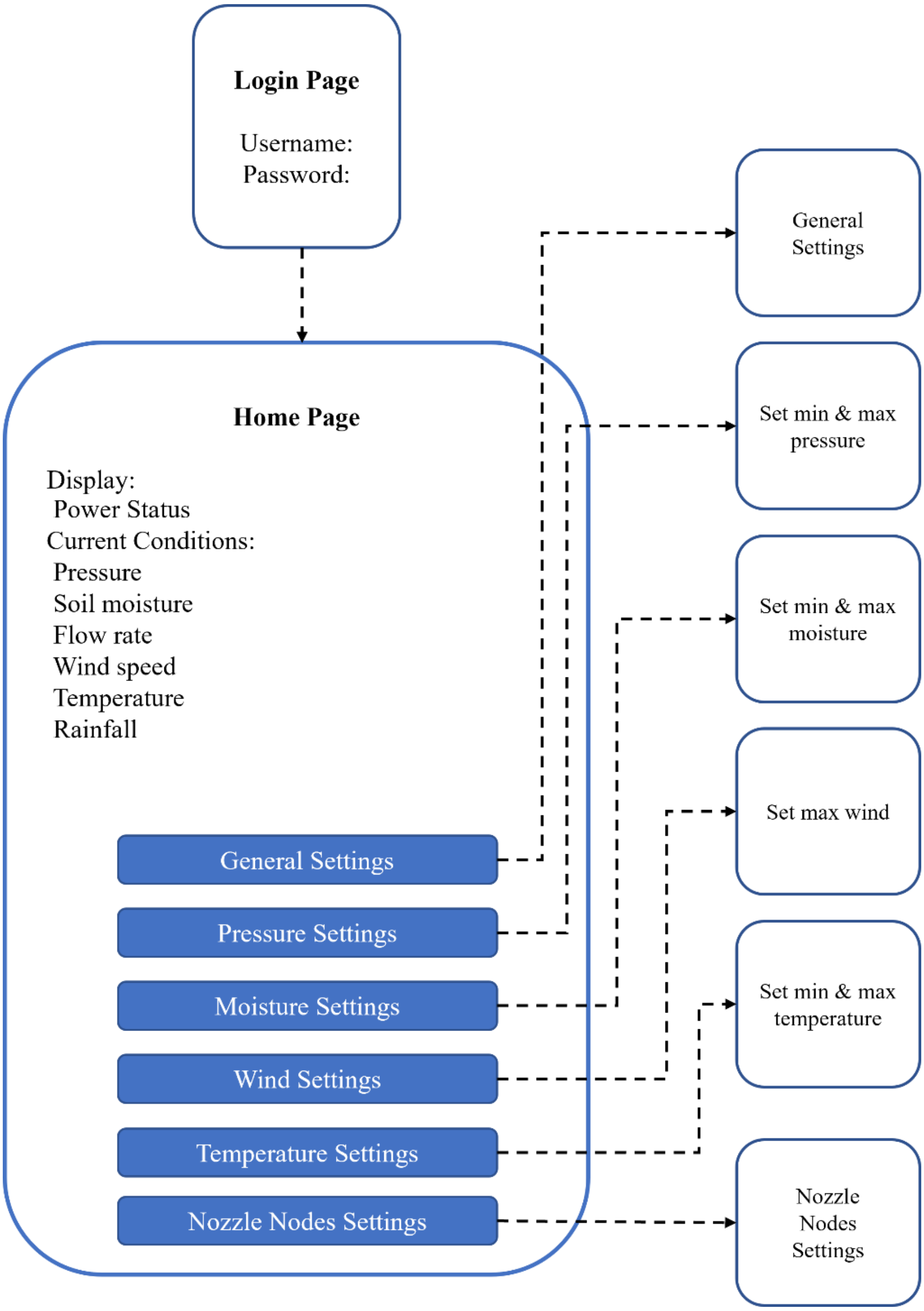


Figure 30: Wireframe for Mobile App Design

4.3.4.2. Mobile App Detailed Description

The Mobile App is developed in Ionic, an open-source software development kit for developing hybrid Apps that is compatible with IOS and Android devices. The communication between the Mobile App and the Web Server is with JSON string communication via a Wi-Fi connection. The user level flow of the Mobile App can be seen in Table 6.

Table 6: Mobile App User Level Flow

Level 1	Level 2	Level 3	Item
Login Page	**Home Page**		
	Power		Toggle button
	System Status		Display badge
	Current Conditions		
	Pressure		Display badge
	Soil moisture		Display badge
	Flow rate		Display badge
	Wind speed		Display badge
	Temperature		Display badge
	Rainfall		Display badge
	Update Conditions		Button
	Settings		
	General	Rename the board	Input
	Pressure settings	Set desired pressure	Input
	Moisture settings	Set the max and min moisture values	Input
	Wind settings	Set the max wind speed or droplet deflection	Input
	Temperature settings	Set the max and min temperature values	Input
	Nozzle Nodes	Add or delete nozzle nodes.	Input

A screen shot of each page of the mobile App can be seen in Figure 31 to Figure 39, with the description of what each item in the App does.

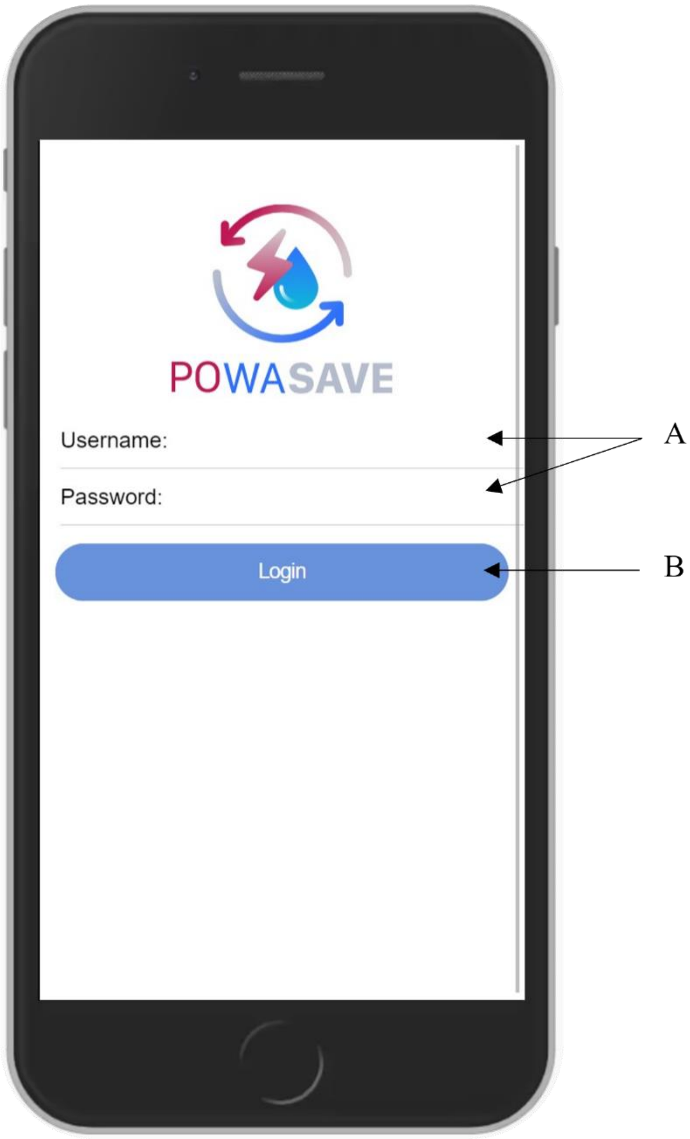


Figure 31: Powasave App Login Page

A – This is where the user must type in the username and password to get access to the system.

B – Once the username and password is entered and the login button tapped, the App will login and navigate to the home page if the username and password is correct.

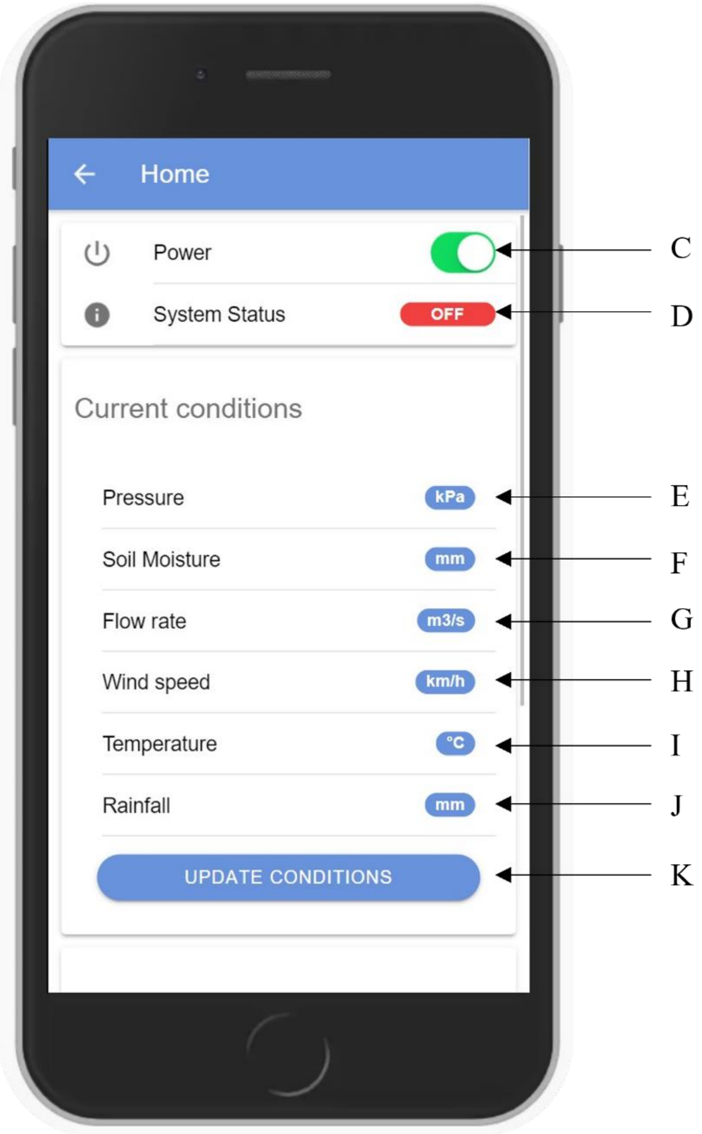


Figure 32: Powasave App Home Page 1

C – This is the power toggle. Once the power toggle is switched on the whole system is powered.

D – The system status shows if the system is activated or on standby. Thus, if all the conditions are satisfied the pivot can irrigate and the system will be activated. If one of the conditions is violated, the pivot must stop irrigating and the system will go on standby. If the Power toggle is switched off the whole system will be switched off.

E – J This is where the current conditions are displayed. The current pressure, soil moisture, flow rate, wind speed, temperature, and rainfall that the sensors are measuring are displayed here. Once the update conditions button is tapped the App will read the most current conditions that the respective sensors are measuring.

K – When the update conditions button is tapped the latest conditions is obtained and displayed.

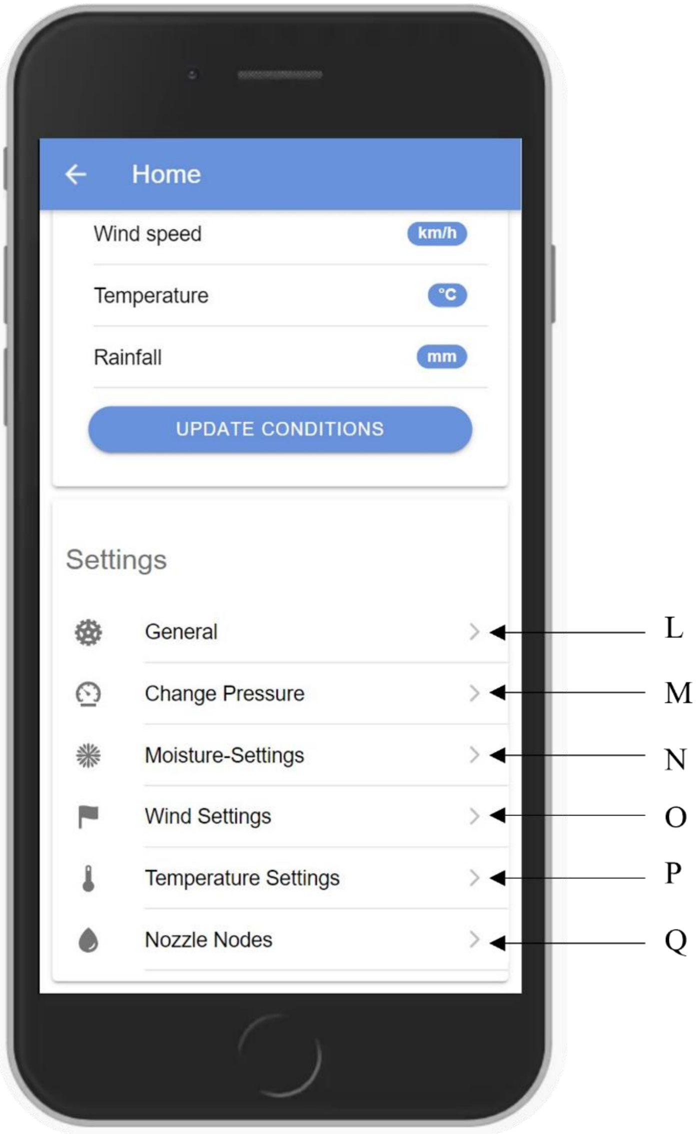


Figure 33: Powasave App Home Page 2

L – Q The settings section of the home page is there to navigate to the condition's settings. The first item (L) is to navigate to the general settings page. The second item (M) is to navigate to the pressure settings page. The third item (N) is to navigate to the moisture settings page. The fourth item (O) is to navigate to the wind settings page. The fifth item (P) is to navigate the temperature settings page. The sixth item is to navigate to the nozzle nodes page.

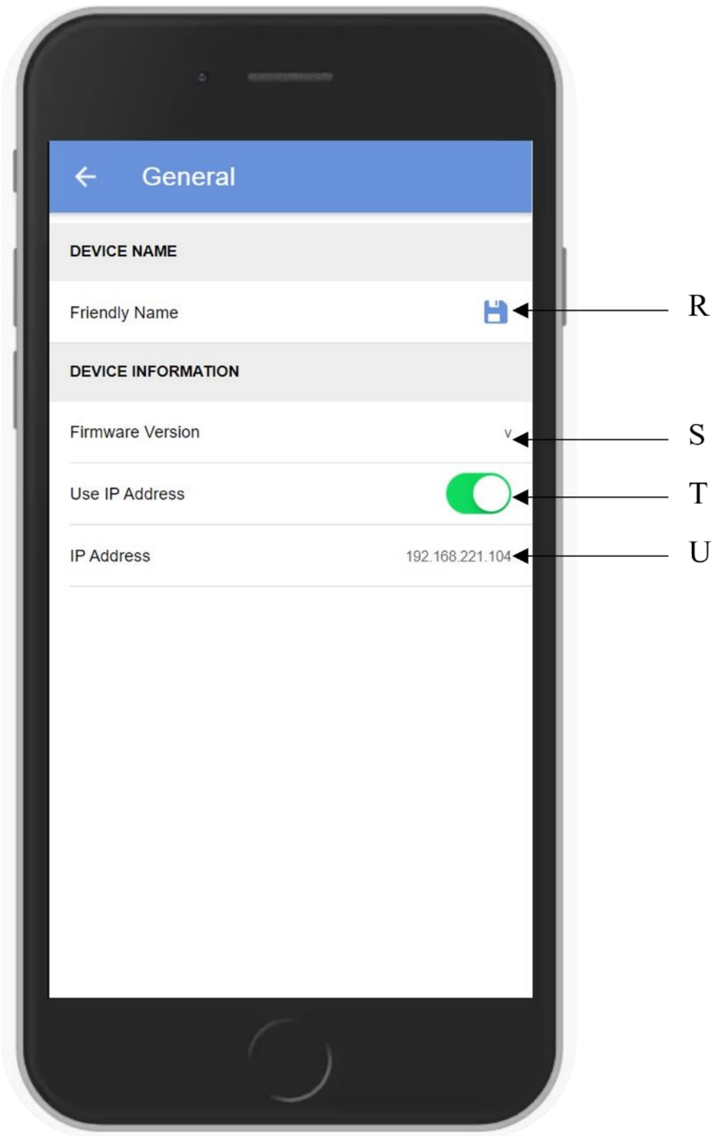


Figure 34: Powasave App General Settings Page

R – This is where the name of the primary system being connected to is displayed. It can be renamed and saved.

S – This is where the firmware version of the system is displayed.

T – This is a setting to switch between the IP Address and a local network.

U – This is where the name of the local network or IP address is displayed.

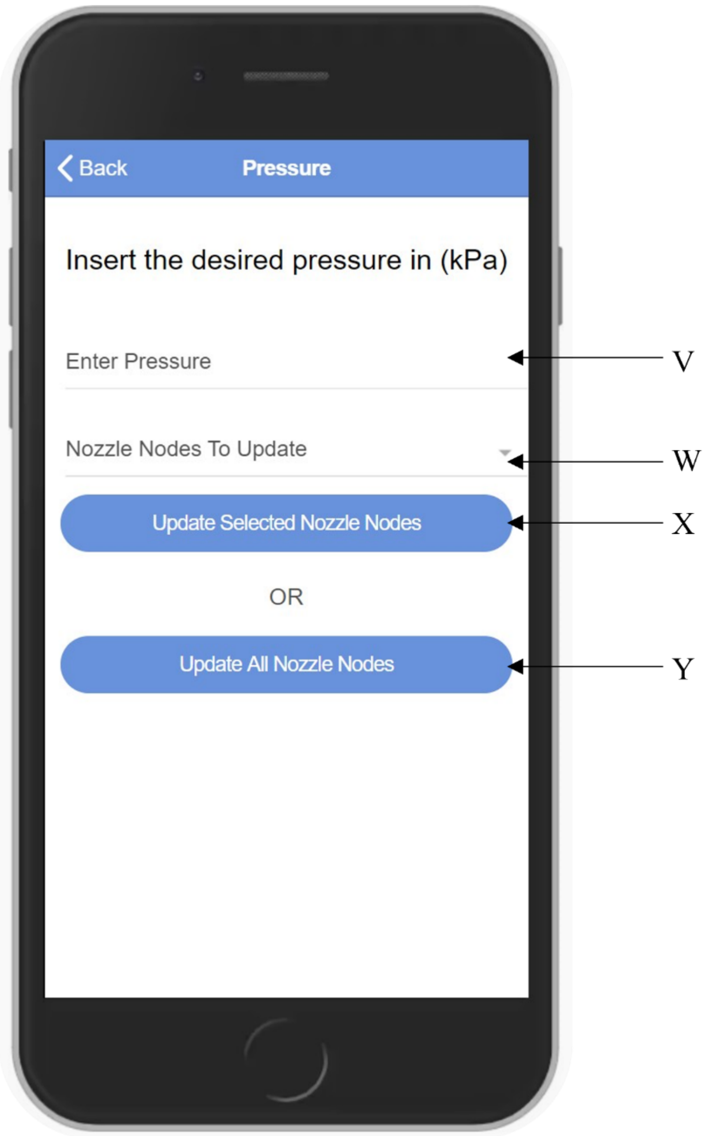


Figure 35: Powasave App Pressure Settings Page

V – This is where the user enters the desired pressure in (kPa).

W and X – The user can choose to set the pressure of one or more selected pressure regulators. In this drop-down menu the user can select which pressure regulators pressure must be set. Once the selected pressure regulators have been selected the "update selected nozzle nodes" button can be tapped and only the selected pressure regulators pressure will be set.

Y – Alternatively the user can choose to update all the pressure regulator pressure values to one value. This can easily be done by inserting the desired pressure in (kPa) and tapping the "update all nozzle nodes" button.

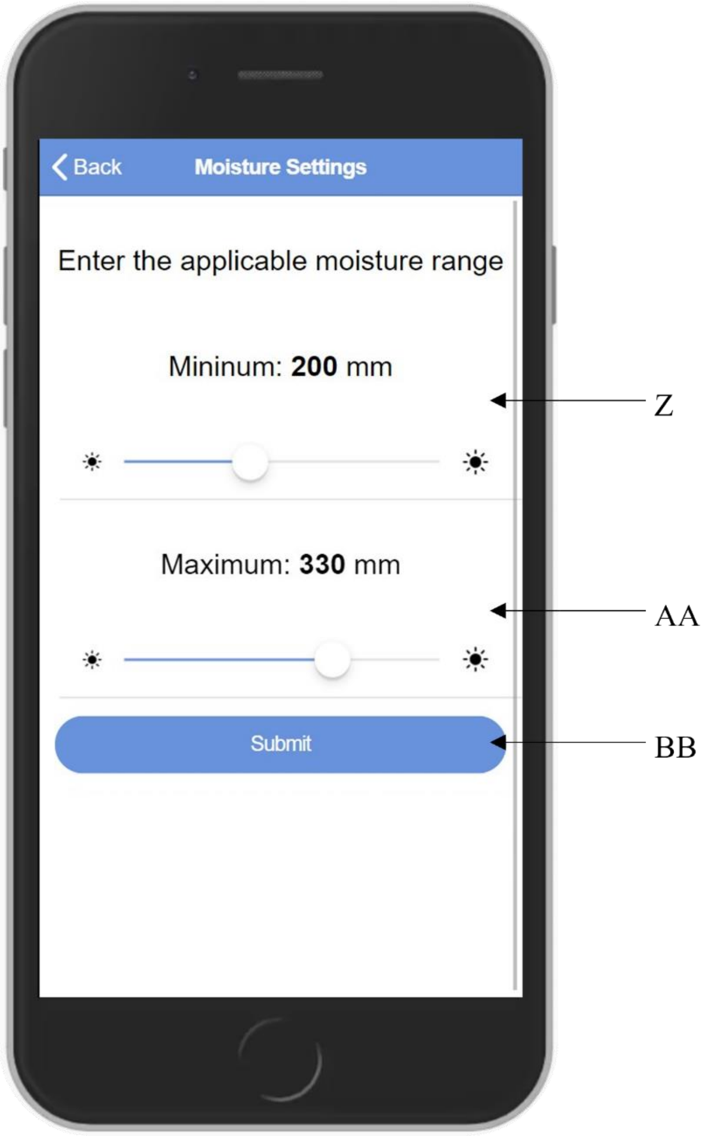


Figure 36: Powasave App Moisture Settings Page

Z and AA – This is where the user must set the minimum and maximum allowable moisture value.

BB – Once the Minimum and Maximum moisture values are entered and the submit button is tapped, the values will be updated, and the App automatically navigates back to the home screen.

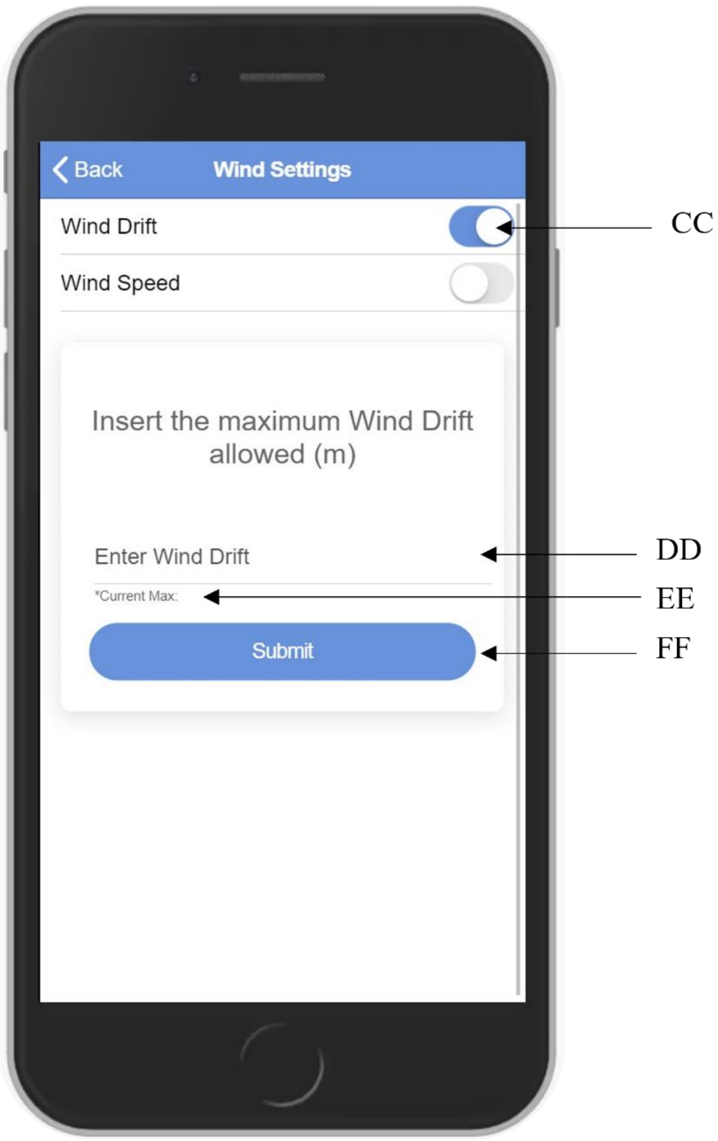


Figure 37: Powasave App Wind Drift Settings Page

CC – This is to enable the wind settings to be based on the wind drift. The App is designed to choose between setting either the maximum wind drift allowed or the maximum wind speed.

DD – This is where the user inputs the maximum allowable wind drift

EE – This is where the current Maximum wind drift value is displayed.

FF – Once the Submit button is tapped the new maximum value is updated and sent to the Primary System and the App automatically navigates back to the home screen.

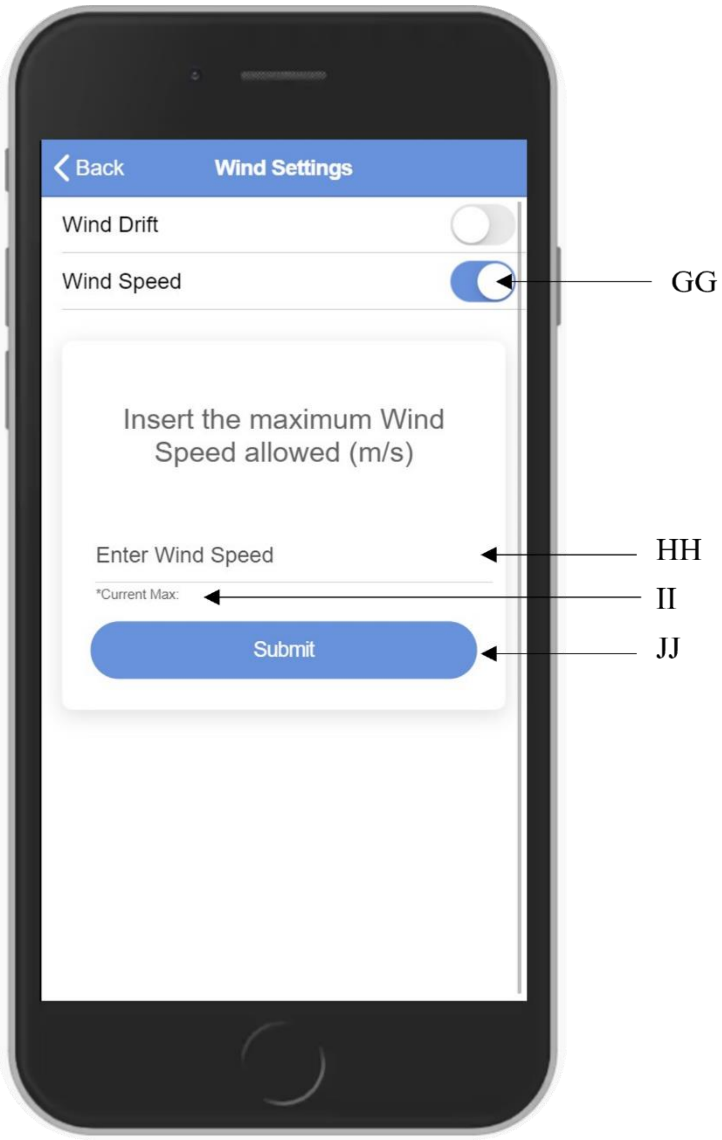


Figure 38: Powasave App Wind Speed Settings Page

GG – This is to enable the wind settings to be based on the wind speed. The App is designed to choose between setting either the maximum wind drift allowed or the maximum wind speed.

HH – This is where the user inputs the maximum allowable wind speed.

II – This is where the current Maximum wind speed value is displayed.

JJ – Once the Submit button is tapped the new maximum value is updated and sent to the Primary System and the App automatically navigates back to the home screen.

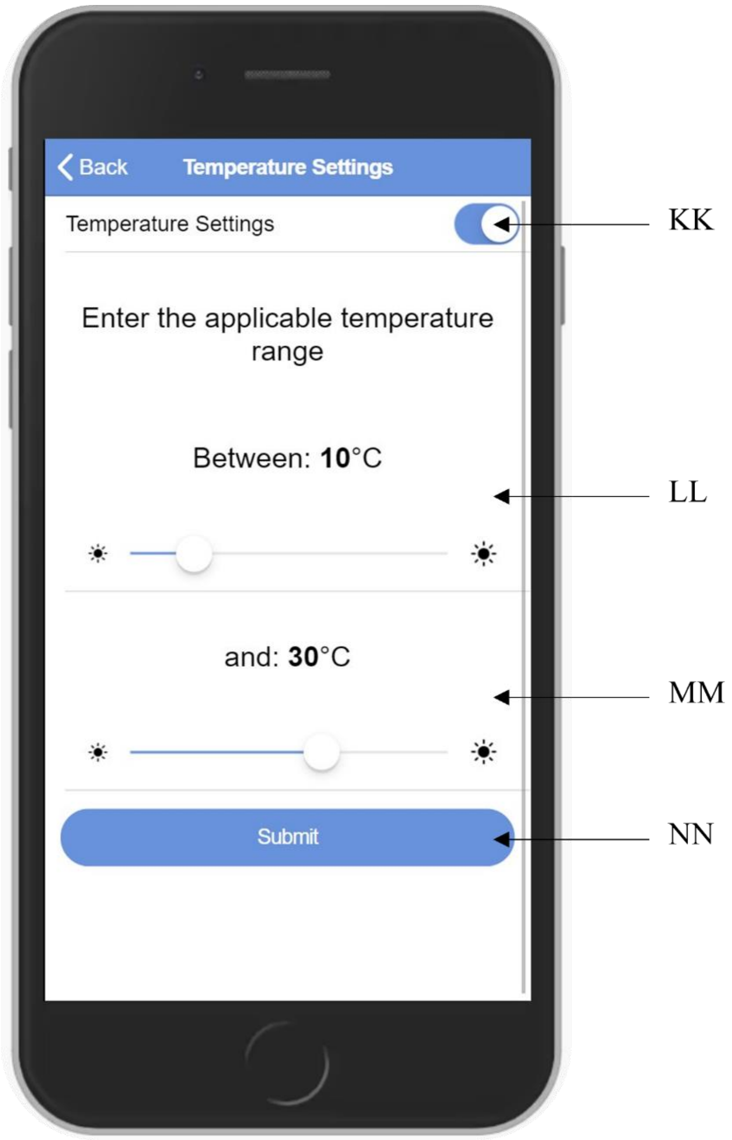


Figure 39: Powasave App Temperature Settings Page

KK – The user can choose to activate the temperature settings. This is done by sliding the toggle button to the right.

LL and MM – This is where the user must set the minimum and maximum allowable temperature value.

NN – Once the minimum and maximum temperature values are entered and the submit button is tapped, the values will be updated, and the App automatically navigates back to the home screen.

4.3.5. Web Server

Platform IO is an open-source integrated development environment (IDE). It is a cross platform source code editor and is used to develop the Web Server of the system. A screen shot of the Web Server that is developed can be seen in Figure 68 in Appendix A.

The ESP 32 is used in SAP mode. Thus, the ESP 32 is the centre of the network providing a Web Server and IP address for the users' device to connect to. The ESP Web Server can be accessed by entering the ESP's unique IP Address into the Web Browser of a local network. Once the IP address is entered into a Web Browser a connection request is made. If the correct SSID and password is entered the connection is established.

The Ionic App and Web Server communicate with JSON strings. The data structure of the JSON string can be seen in Appendix B.

4.3.6. Primary System

The Primary System, as seen in Figure 40, is the central control unit of the entire system. The Primary System receives commands from the Web Server and sends data to the Web Server with JSON strings via a Wi-Fi connection. The Primary System then sends commands to and receives data from the network of Secondary Systems via an Ethernet connection cable.

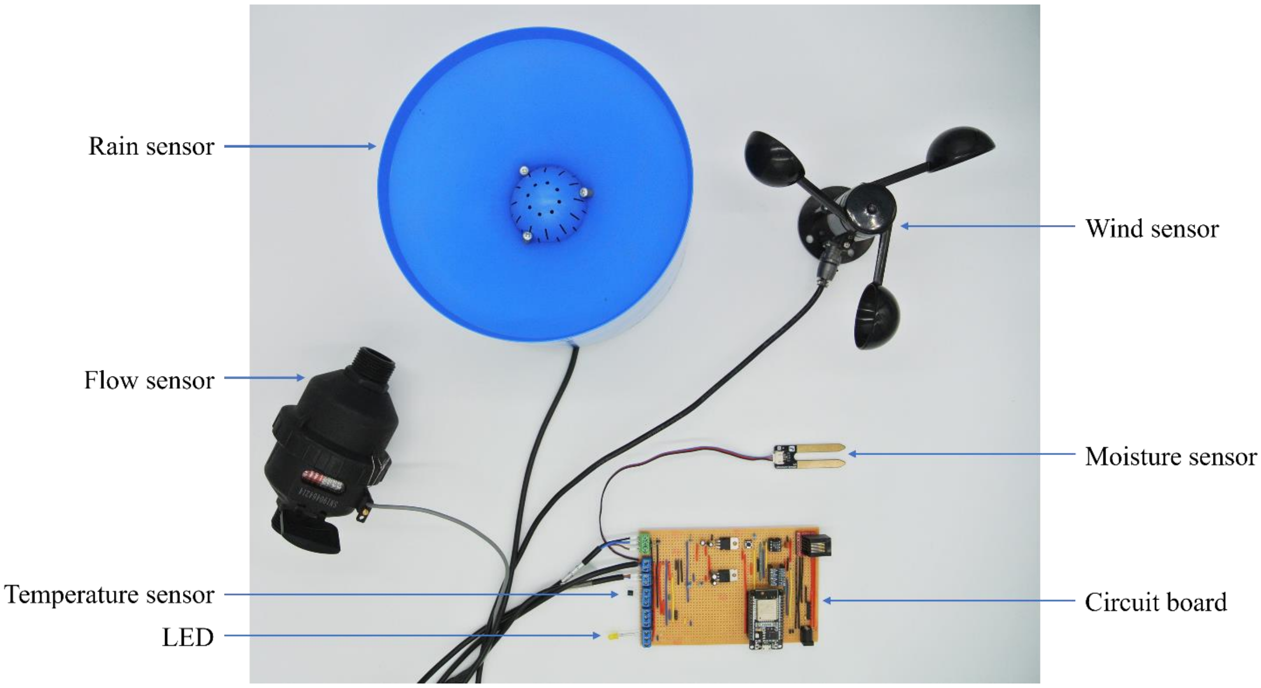


Figure 40: Primary System Prototype

The Primary System consists of a circuit board that is enclosed with a 3D printed housing, a moisture sensor, wind sensor, temperature sensor, rain sensor, and flow sensor. The parts list can be seen in Appendix C. For the purpose of this study the circuit board of the primary system is built on a strip board to show a proof of concept and to reduce the cost of the study. In future development the circuit board can be printed on a PCB board.

4.3.6.1. Primary System Control

The control logic of the Primary System is as follows:

Soil Moisture: There is a lower and upper bound soil moisture value, the Refill and Full points as discussed in Chapter 3, Section 3.2.3. The lower bound value is the lowest the soil moisture is allowed to be before harm comes to the crops and the upper bound value is equal to the suggested crop specific soil moisture. The soil moisture is constantly measured. If the actual soil moisture is lower or equal to the lower soil moisture limit the irrigation system is switched on. Once the actual soil moisture is equal to the upper limit the irrigation is switched off.

Wind: The wind speed is measured and compared to the maximum allowed wind speed. If the current wind speed is larger than the maximum allowed wind speed the irrigation is switched off. While the wind speed is too high the moisture sensor continues to measure the soil moisture. If the irrigation remains switched off for too long and the soil moisture has reached the lower bound limit the system will override the decision and the irrigation will switch back on even if the wind speed remains too high. The cost and risk of losing the whole crop is greater than the water losses that will occur during this period. The same principle is applied when the maximum wind drift is an input instead of the maximum wind speed.

Temperature: If the ambient temperatures are high, the rate at which evaporation will take place is larger. The soil moisture sensor will take the effects of evaporation into account. Thus, it will sense once the soil moisture has reached its lower limit and will switch the irrigation on. The user can input the maximum and minimum temperature values into the mobile App. This setting can be used to ensure that the system is switched off once the ambient temperatures are too low and prohibit the system to operate if the water in the system is approaching freeze point. This will reduce the potential damage to the irrigation pipes and pump due to freezing water conditions. If the temperature it too high the system will switch off provided that the soil moisture is above the lower limit.

Rain: The rain sensor will sense if it is raining or not. Since the moisture sensor will take the effect of the rain into account the rain meter is only used to measure how much it has rained over a specified time.

Flow: The flow sensor is used to measure how much water flows into the irrigation system over a specified time.

4.3.6.2. Primary System Circuit Board

The main component of the primary circuit board, as seen in Figure 41, is an EPS 32 Wi-Fi module, an RS485 Transceiver and a logic level converter. The ESP 32 Wi-Fi module has a supply voltage range of 2,2 V to 3,6 V and has 36 GPIO pins.

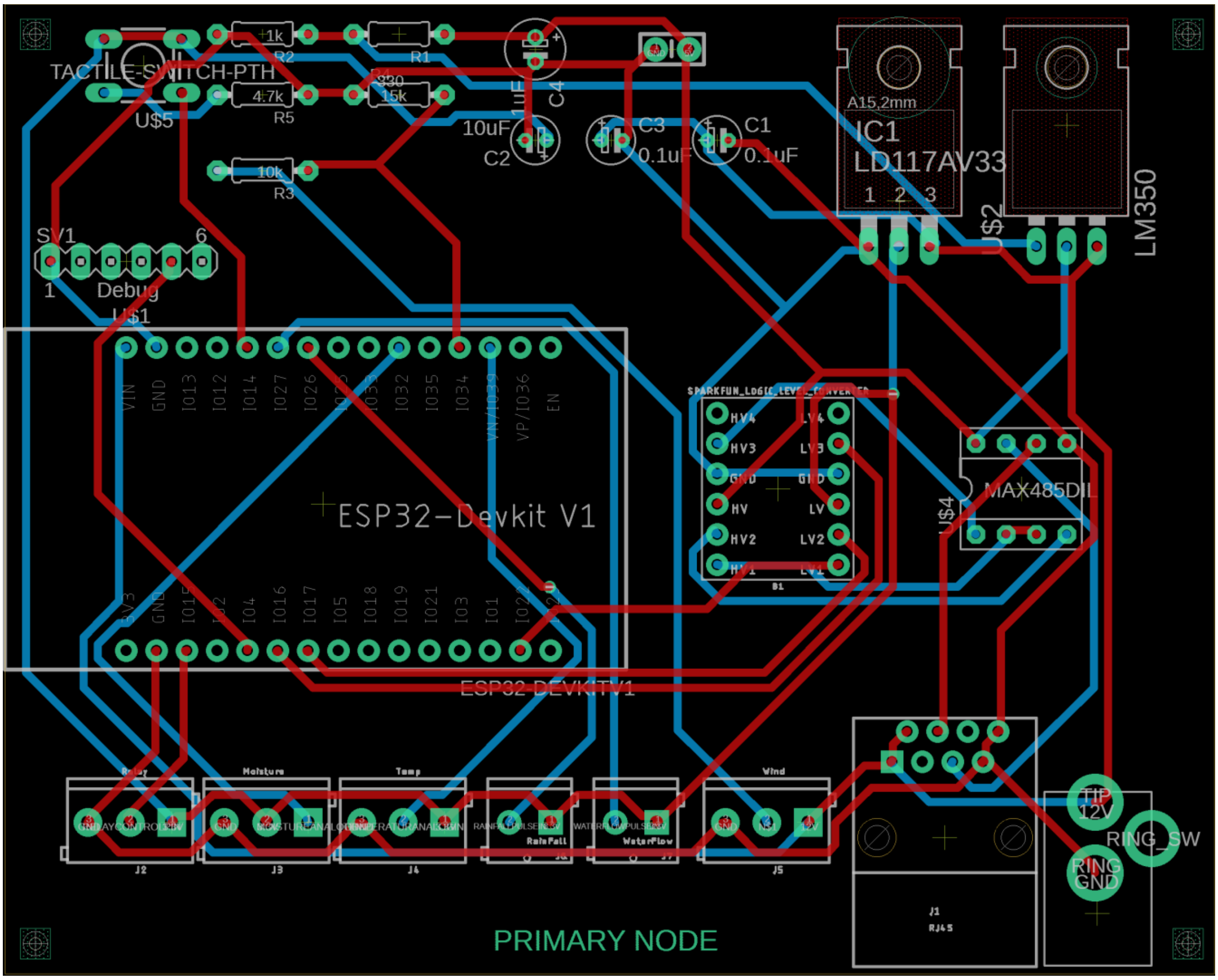


Figure 41: Primary System Circuit Board

The Schematic of the Primary System circuit board can be seen in Appendix D.1.

4.3.6.3. Moisture Sensor

A soil moisture sensor, as seen in Figure 42, is used to measure how moist the soil is.

Figure 42: Soil Moisture Sensor

The soil moisture sensor is a variable resistor that measures the volumetric content of water that is present in the soil. The resistance of the device varies according to the moisture of the soil. Water is a good conductor of electricity. Thus, the more water that is present in the soil the more electricity can be conducted through the soil and the resistance level of the moisture sensor decreases.

$$V = IR \tag{36}$$

According to Ohms law, as defined in Equation (36), if the current, I, remains constant and the resistance, R, increases the voltage, V, will also increase. The same is true if the resistance decreases, with a constant current, the voltage will also decrease. This change in voltage can be monitored and calibrated to represent the soil moisture.

4.3.6.4. Wind Sensor

A QS-FS wind sensor, as seen in Figure 43, is used to measure the horizonal wind speed. The wind speed is measured and sent to the ESP 32 via Analog communication and has a supply voltage of 7-24 V. The wind speed is calculated with Equation (37) that is obtained from the wind sensors data sheet (Lollette, 2021).

$$wind\ speed\ = \frac{(output\ voltage - 0.4)(32.4)}{1.6} \tag{37}$$

Figure 43: Wind Sensor

The wind settings can be based either on the maximum wind speed or based on the maximum allowed wind drift based in the distance of the droplet deflection. The user can choose between these two types of wind settings.

Figure 44 represents the relationship between the wind speed and the droplet deflection of a single irrigation droplet. The droplet deflection is the distance the droplet travels from the targeted mark due wind forces. Figure 44 was developed by applying Equations (9) to (35) and using $\Delta H = 0.5\ m$, $k_o = 0$, $\rho_w = 1000\frac{kg}{m^3}$, $\rho_a = 1.225\frac{kg}{m^3}$, $\alpha = 30°$, $d_d = 1.8\ mm$, and $\mu_a = 1.81 \times 10^{-5}\frac{kg}{ms}$.

The equation that represents the relationship between the wind speed and the droplet deflection is found to be

$$y = 0.411x - 0{,}4876 \tag{38}$$

If the user decides to choose the wind setting based on the wind drift, the user inputs the maximum deflection allowed in the mobile App. Equation (38) is then used to calculate the allowable wind speed.

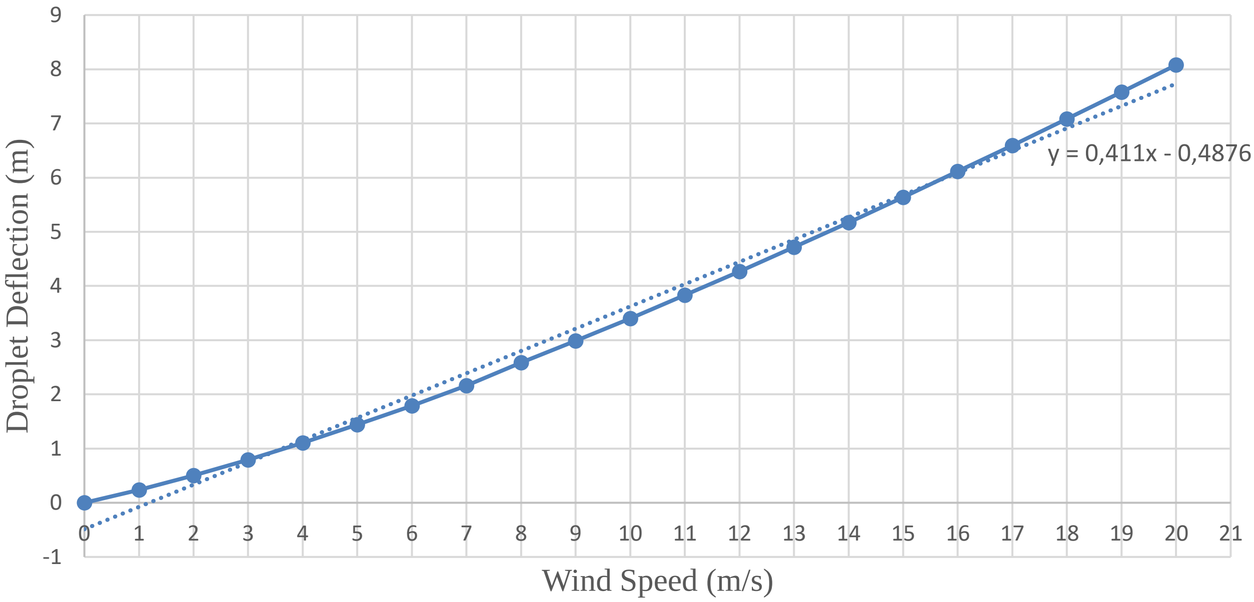


Figure 44: Wind Speed vs Droplet Deflection with $\alpha = 30°$

The same relationship was obtained for the new design of the Powasave, as seen in Figure 19 with $\alpha = -90°$. The equation that represents the relationship between the wind speed and the droplet deflection is found to be

$$y = 0.1134x - 0,2932 \quad (39)$$

Figure 45 represents the relationship between the wind speed and the droplet deflection of a single irrigation droplet with $\alpha = -90°$.

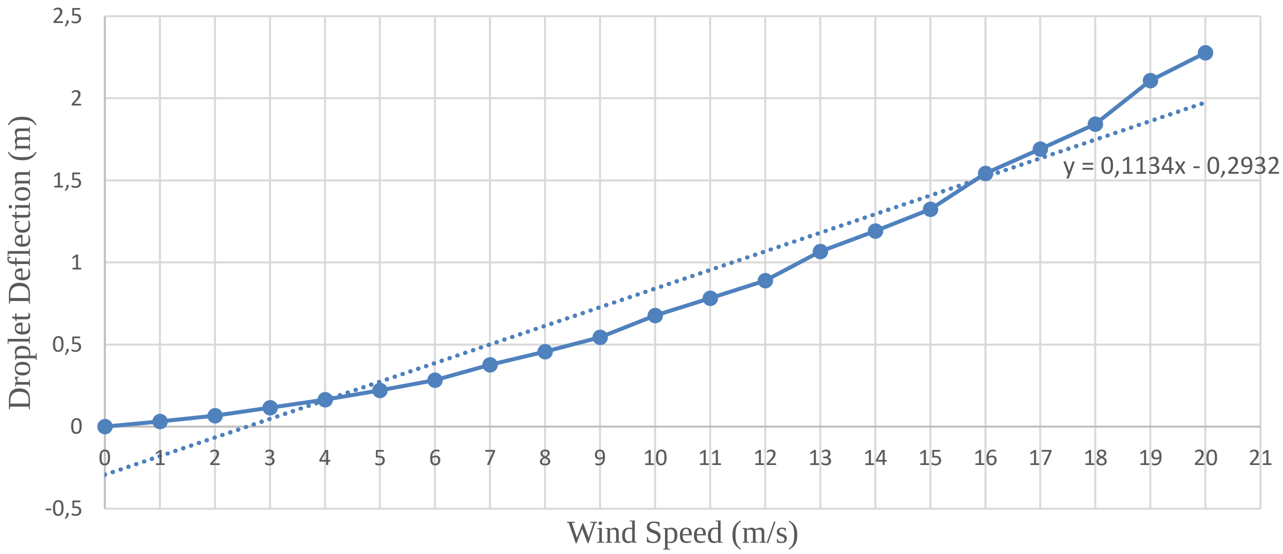


Figure 45: Wind Speed vs Droplet Deflection $\alpha = -90°$

Note that the deflection displayed in Figure 45 is based on a sprayer height of 1 m above the ground. The actual water deflection will still have to be calculated based on the height that the sprayer is from the ground on the actual pivot irrigation system in the field.

4.3.6.5. Temperature Sensor

A TMP 36 temperature sensor, as seen in Figure 47, is used to measure the ambient air temperature. The sensor has an operating temperature range of -40°C to 125°C. The sensor has an input voltage range of 2.7-5.5 V making it applicable to use with the Primary System that operates at 3.3 V. The temperature value in °C is calculated with Equation (40)

$$Temperature = \frac{(output\ voltage - 5.2)}{0.0096} \qquad (40)$$

Equation (40) is obtained from Figure 46, that represents the relationship between the temperature sensor and the voltage signal value (Analog Devices, 2015).

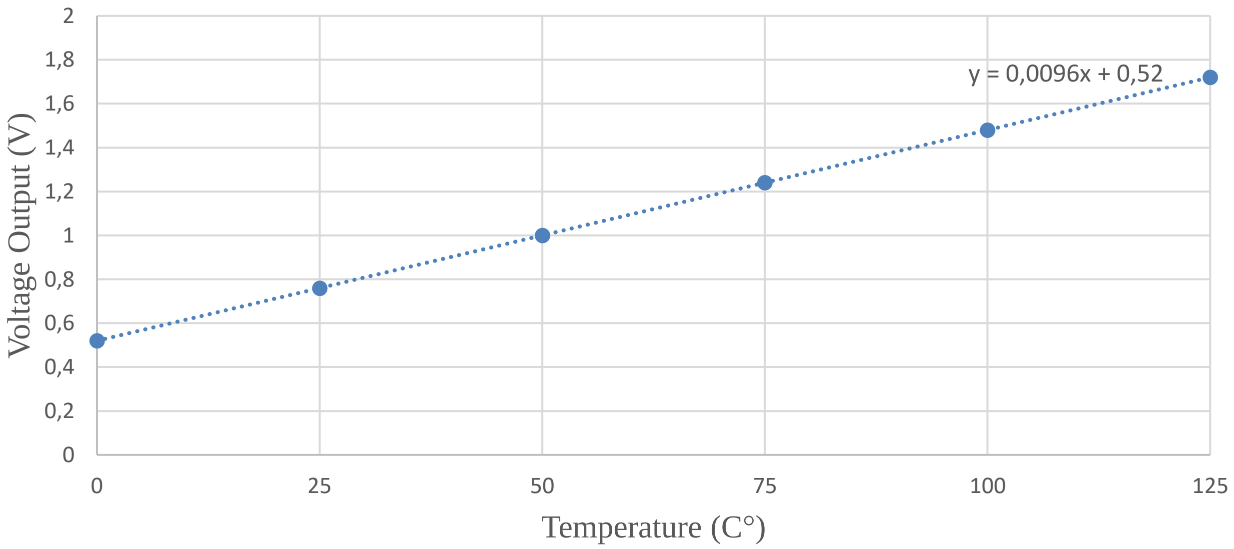


Figure 46: Temperature vs Output Voltage for the temperature sensor

Figure 47: Temperature Sensor

4.3.6.6. Rain Sensor

An electronic pulse communication rain sensor, as seen in Figure 48, is used to detect when it is raining and to measure how much it has rained. The sensor consists of two ‘cups’ that pivot around a centre stand. Once it starts raining, cup 1 fills up and reaches full capacity and pivots around the centre post causing cup 2 to be perpendicular to the sky. The water in cup 1 is allowed to drain out and cup 2 is allowed to be filled. This process repeats itself again once cup 2 reaches full capacity.

Each time the cup tips over a pulse is recorded. Each pulse is equivalent to 0.2 mm rain. Thus, the rainfall in mm is calculated with Equation (41). In the system the rain sensor is operating at an input voltage of 3.3 V.

$$Rainfall = 0.2(number\ of\ pulses) \tag{41}$$

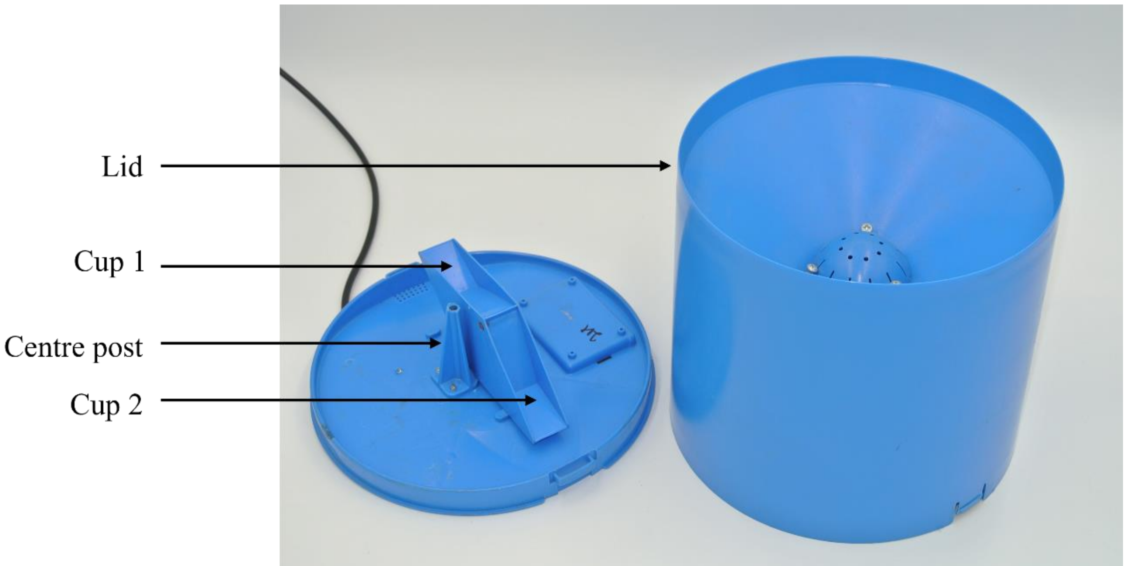


Figure 48: Rain Sensor

4.3.6.7. Flow Sensor

An electronic pulse communication flow sensor, as seen in Figure 49, is used to measure the water flow into the system. Each pulse is equivalent to 500 ml.

Figure 49: Flow Sensor

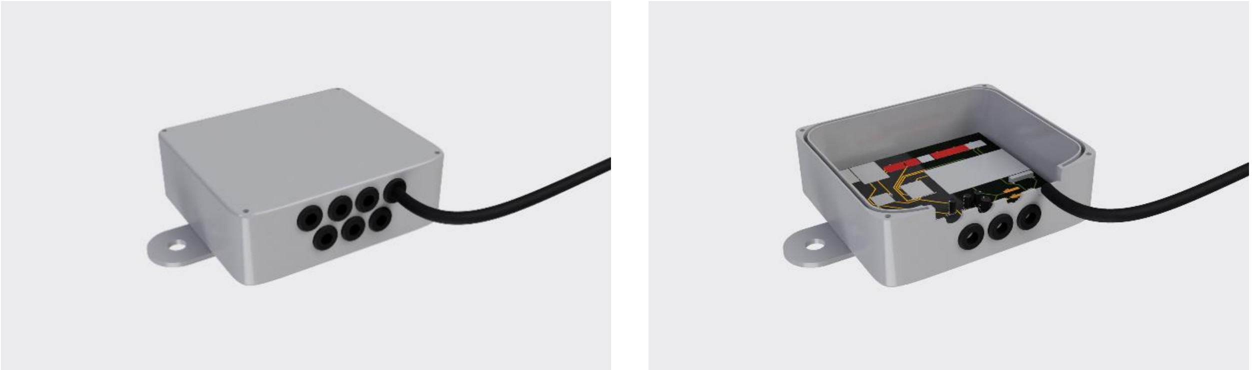
The flow rate in $\frac{\mathrm{m}^3}{\mathrm{s}}$ is calculated with Equation (42).

$$Flow\ rate\ = \frac{0.0005(number\ of\ pulses)}{t} \qquad (42)$$

Where t, is the time over which the pulses are measured.

4.3.6.8. Primary System Housing

The Primary System housing, as seen in Figure 50, is 3D printed with Acrylonitrile Butadiene Styrene (ABS) plastic filament. The CAD drawings can be seen in Appendix E.1 and Appendix E.3.



(a) Assembled (b) Unassembled

Figure 50: Primary System Housing

The housing is waterproof with a rubber seal placed between the top wall of the housing and the lid. There are also rubber seals around the opening where the electronic cables enter the housing, and these openings are sealed off with silicone once the electronic cables have been attached to the circuit board.

4.3.7. Secondary System

The Secondary System, as seen in Figure 51 is responsible for the regulation of the sprayer inlet pressure at each individual sprayer. It receives commands from the Primary System and sends data back to the Primary System via an Ethernet cable connection and RS485 Transceiver. The pressure regulator consists of a circuit board, gate valve, servo motor, pressure sensor, and 3D printed housing. The control of the Secondary System works as described in Section 3.4. For the purpose of this study the circuit board of the secondary system is built on a strip board to show a proof of concept and to reduce the cost of the study. In future development the circuit boards can be printed on PCB boards.

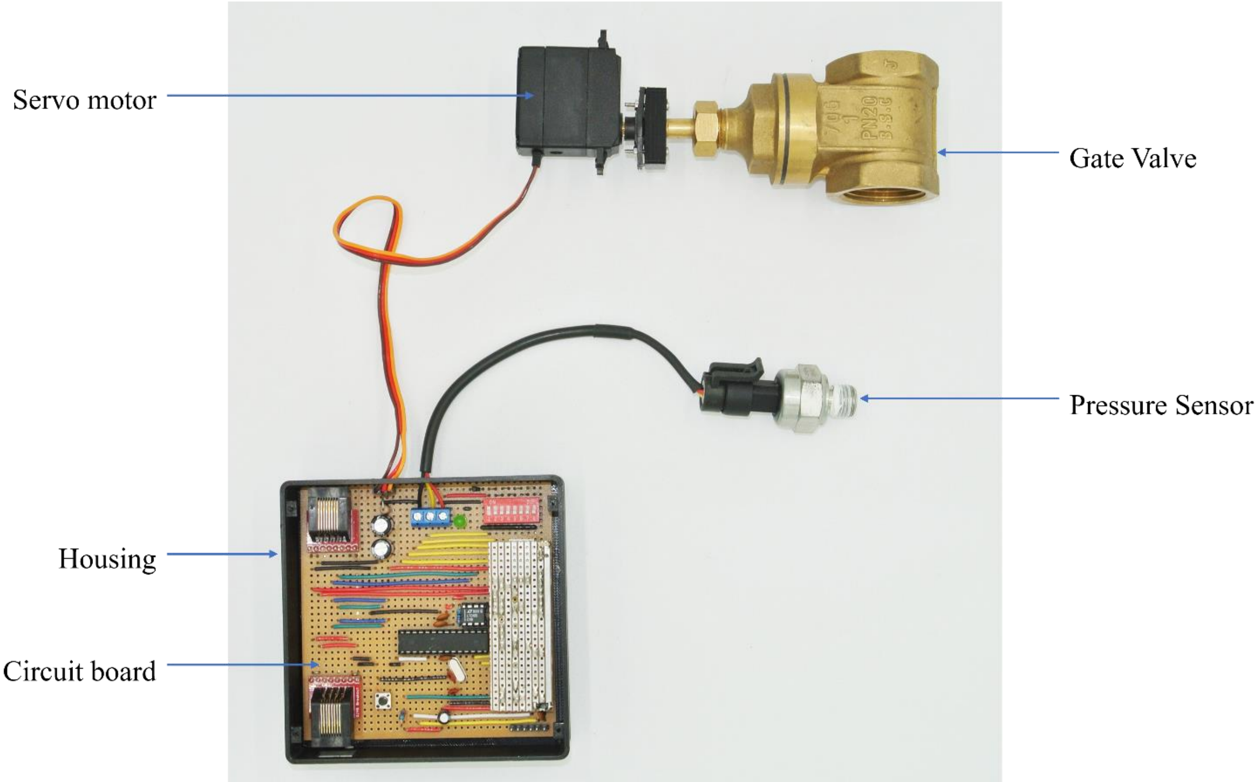


Figure 51: Secondary System Prototype

4.3.7.1. Secondary System Circuit Board

The Secondary System circuit board can be seen in Figure 52. The main components are an ATmega328 controller, a RS485 Transceiver, and a Dip Switch.

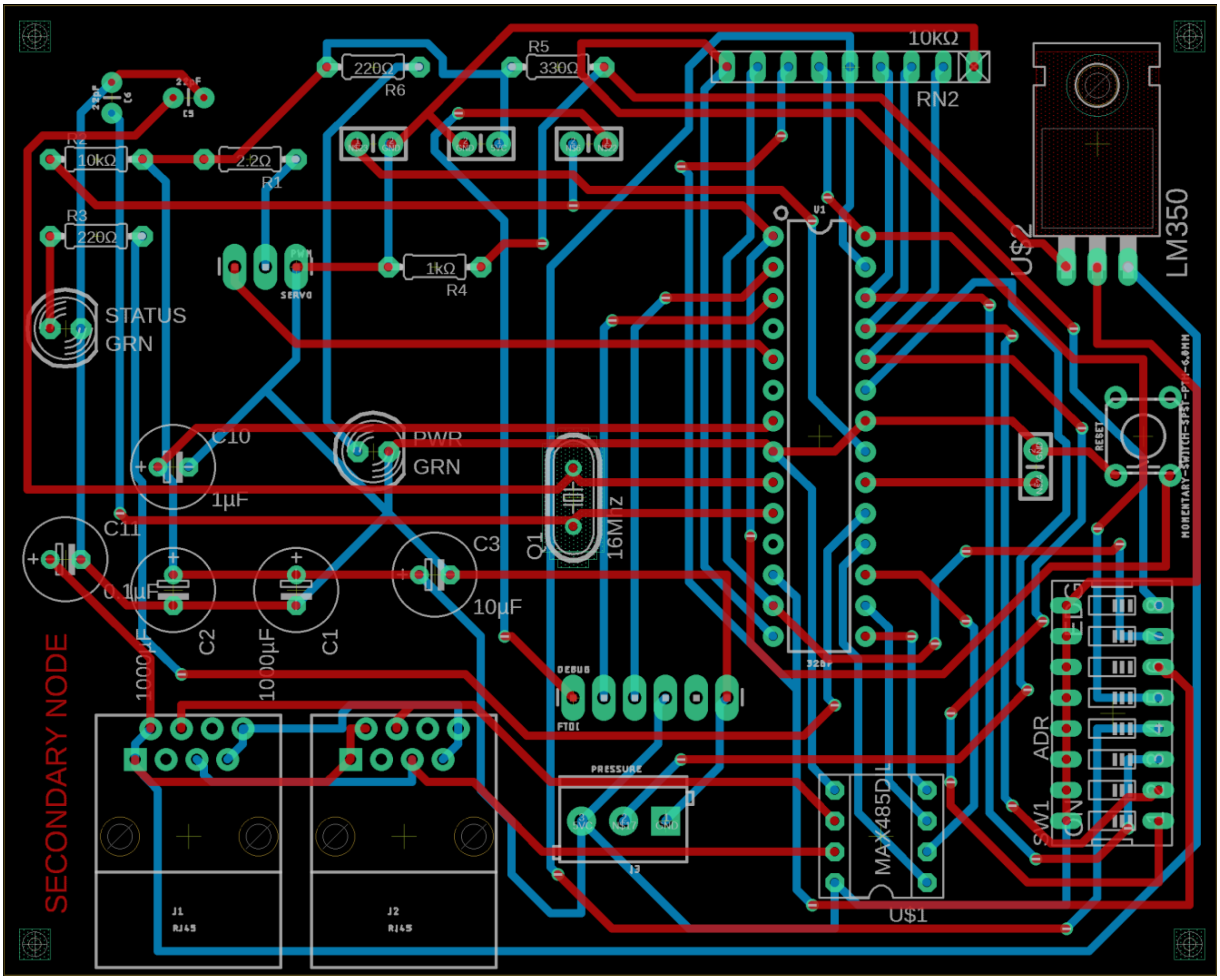


Figure 52: Secondary System Circuit Board

The Schematic of the Secondary System circuit board can be seen in Appendix D.2

4.3.7.2. Gate Valve

The gate valve selected to be used in the Secondary System is a 1 Inch, PN16 gate valve. This is the same gate valve used in the first prototype of the pressure regulator. According to De Wet (2018) at a maximum inlet water pressure of 1000 kPa, a maximum torque of 0.5 N·m is required to fully open or close the gate valve.

4.3.7.3. Servo Motor

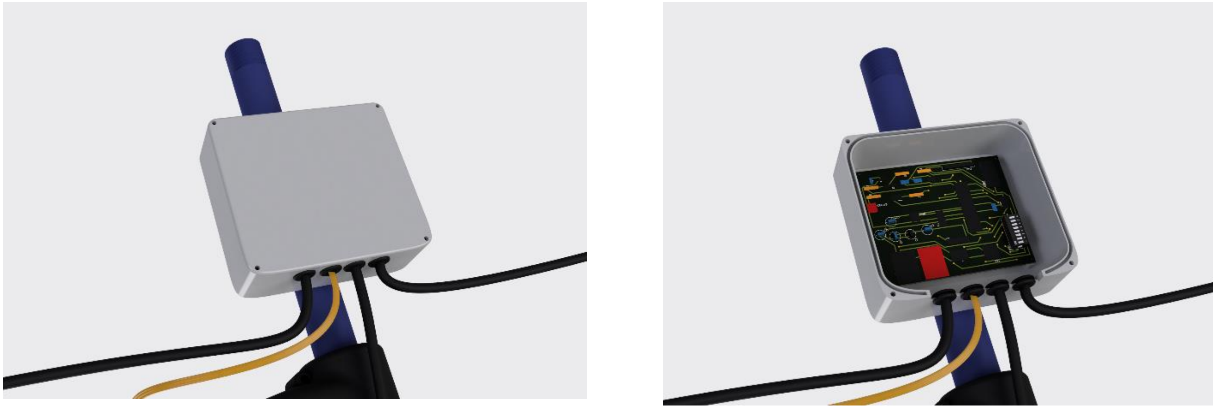
A 360-degree, 15 kg·cm DS3115-360 servo motor is selected to be used in the Secondary System. This is the same servo motor used in the first prototype of the pressure regulator. According to De Wet (2018) it has a 3-pin power and control cable, and the motor speed is 0.14 sec/60°.

4.3.7.4. Pressure Sensor

A 5V SKU237545 pressure sensor, LVDT type pressure transducer, is selected to be used in the Secondary System. This is the same pressure sensor used in the first prototype of the pressure regulator. According to De Wet (2018) it can operate under a pressure range of 0-1,2 MPa.

4.3.7.5. Secondary System Housing

The housing and lid of the Secondary System, as seen in Figure 53 and Figure 54, is 3D printed with ABS plastic filament. The CAD drawings can be seen in Appendix E.2 and Appendix E.3.



(a) Assembled (b) Unassembled

Figure 53: Secondary System Circuit Board Housing

The housing is waterproof with a rubber seal placed between the top wall of the housing and the lid. There are also rubber seals around the opening where the electronic cables enter the housing. These openings are sealed off with silicone once the electronic cables have been attached to the circuit board.

(a) Assembled (b) Unassembled

Figure 54: Secondary System Motor Housing

The servo motor housing and the gate valve cover can be seen in Figure 54 and the CAD drawing can be seen in Appendix E.4 and Appendix E.5. The Secondary System circuit board housing and the servo motor housing are separate to ensure that the circuit board housing is water resistant. The motor housing is water resistant with a rubber seal placed between the top wall of the housing and the lid, and there is an O-Ring placed around the shaft of the motor where the shaft exits the motor housing.

4.4. Integration with Existing Pivot Irrigation Systems

The integration of the Powasave system with exiting pivot irrigation system will vary depending on the setup of the Pivot Irrigation System in the field.

4.4.1. Power Source

The power source of the Powasave system will make use of the same power source of the pivot irrigation system. Pivot irrigation system are either powered by a generator or a public power source to power the pump and pivot motors (drive units) to move the system. According to Irrigation Education (2016) pivot irrigation systems use 120 and 480 volts of alternating current. The control circuit is powered with the 120 VAC and the 480 VAC is used to power the pivot drive units.

The power supply of the ESP 32 in the primary system is 12 V and the power supply of the servo motors in the secondary system is 5 V. Thus, it is expected that the power usage of the primary and secondary system will be minimal when compared to the power saved due to the reduction in water pressure.

4.4.2. Wi-Fi Connectivity

For the Mobile App to be used from a remote location a Wi-Fi Router can be placed at the pivot, suppling the Primary System with an Internet connection. Port Forwarding can be configured on the router to enable communication between the primary system and the mobile App. Port forwarding is when a router is configured to make a device that is connected to it accessible to other network devices outside of the local network. The only limitation to using a router is that internet connection is not always available in all areas where pivot irrigation systems are located. For areas with cell phone coverage APN Sim Cards can also be used.

In scenarios where it is not possible to install a Wi-Fi Router, the mobile App will still be able to connect and communicate with the primary system provided that the user is in a close enough proximity.

4.4.3. Software Security

The ESP 32 supports Hypertext Transfer Protocol Secure (HTTPs). HTTPs is a secure method for sending data between a webserver and a web browser by making use of encryption. Another security protocol that is in place is that the user must enter the correct login credentials to be able to access the mobile App.

4.5. Testing Facility

A testing facility is designed and built to test the developed product. A schematic of the Testing Facility can be seen in Figure 55. Since a high pressure is present a bypass system is required for safety purposes to ensure that the system is not over pressurised. The bypass valve is also used to change the pressure in the system.

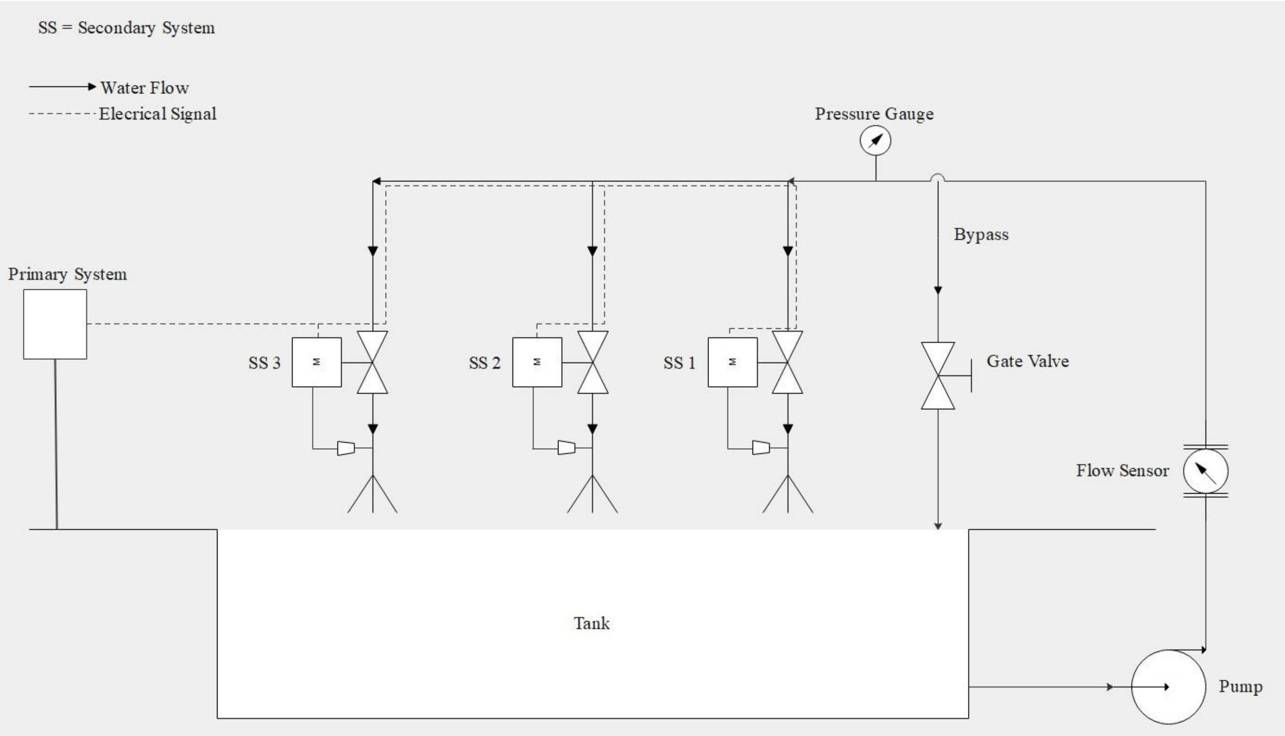


Figure 55: Schematic of the Testing Facility

The pump used in the testing facility is a stainless-steel vertical centrifugal pump. All the components of the testing facility can be seen in Table 7.

Table 7: Testing Facility Components

Component	**Quantity**	**Function**
Pump	1	Simulate the pivot pressure
Tank	1	Store the water
Bypass System	1	To set different pressures in the system

Component	Quantity	Function
Pressure Gauge	1	Measure the inlet pressure of the pressure regulators
Flow Sensor	1	Measure the total flow rate
Nozzle	3	Generate back pressure
Primary System	1	Control the Secondary Systems
Secondary System	3	Regulate the nozzle inlet pressure
Ethernet Cable	3	Connect the Primary System with the 3 Secondary Systems
PVC Pipe and connectors	-	Connect the water flow to the consecutive components

4.6. Experimental Work

This Section of the Chapter documents all the experimental work that was conducted during the study. This includes firstly, testing the software and firmware of all the sensors used in the design. Secondly, testing the Primary System, and thirdly testing the Secondary System.

4.6.1. Experiment 1: Testing the Software and Firmware of the Weather Sensors

The following experiment was executed to test the developed software and firmware of the sensors that measure the weather conditions before it could be included in the code of the Primary System. The test is conducted using an Arduino as a substitute for the Primary Node.

4.6.1.1. Experimental Setup

The experimental setup consists of the parts listed in Table 8. A Laptop was used to upload the code onto the Arduino and to read the Analog feedback from the sensors. A LED was used to simulate the state of the Pivot. Thus, if the LED is on, it indicates that the Pivot is turned on and if the LED is off, it indicates that the Pivot is turned off.

Table 8: Experiment 1 Parts List

Part	Value/Model
Arduino Uno	-
Relay	5V DC
Temperature sensor	-
Wind sensor	-
Moisture sensor	-
Battery	9 V
Resistor	1K
Resistor	220 Ω
Diode	1N4007
Transistor	2N2222
Bread board	-

Part	Value/Model
Connection cables	-
Laptop	-
USB cable	-

A schematic for the electronic setup for Experiment 1 can be seen in Figure 56.

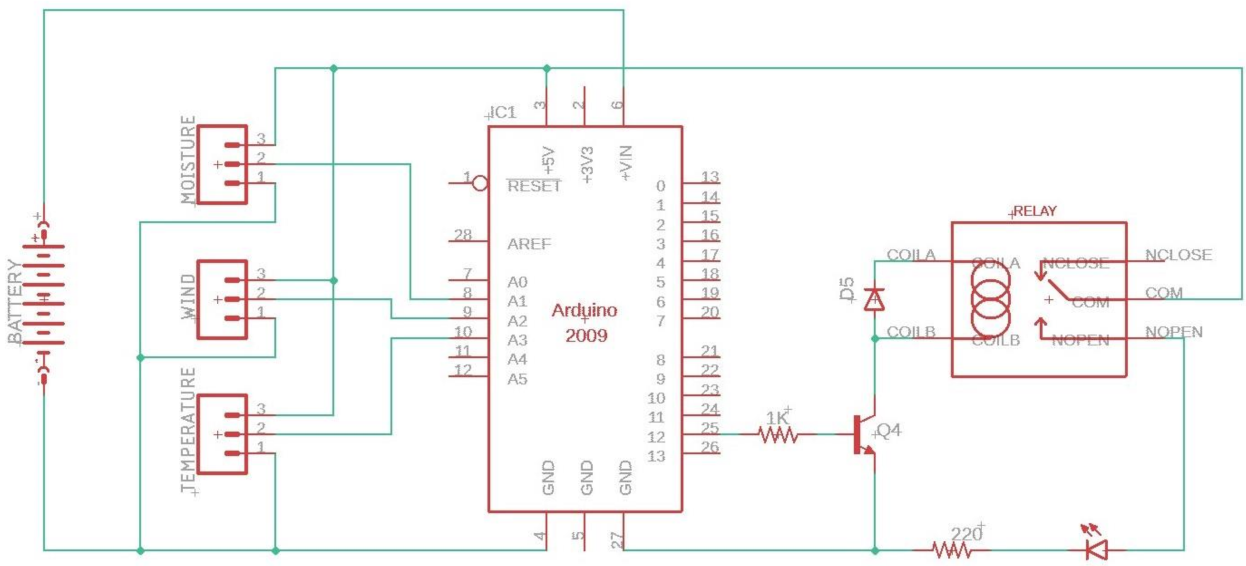


Figure 56: Schematic of Experimental Setup for Experiment 1

4.6.1.2. Measuring Devices

A Laptop is used to run the Arduino software. From the Arduino software the Analog output signals of the wind, temperature, and moisture sensor could be obtained.

4.6.1.3. Experimental Procedure

The following procedure is performed to execute Experiment 1:

Step 1: On a bread board, setup the electronics in the configuration as seen in Figure 56.

Step 2: Upload the code onto the Arduino using a Laptop and USB cable.

Step 3: Observe the Status of the LED with the conditions of Test 1 listed in Table 9

Step 4: Repeat step 3 with the conditions of Test 2 to Test 18 listed in Table 9.

Table 9: Weather Station Code Conditions

Test	Temperature	Moisture	Wind	Expected status of LED
1	Too High	Too High	Too High	OFF
2	Too High	Ideal	Too High	OFF
3	Too High	Too High	Too Low	OFF
4	Too High	Ideal	Too Low	OFF
5	Too High	Too High	Ideal	OFF
6	Too High	Ideal	Ideal	OFF

Test	Temperature	Moisture	Wind	Expected status of LED
7	Too Low	Too High	Too High	ON
8	Too Low	Ideal	Too High	ON
9	Too Low	Too High	Too Low	OFF
10	Too Low	Ideal	Too Low	OFF
11	Too Low	Too High	Ideal	ON
12	Too Low	Ideal	Ideal	ON
13	Ideal	Too High	Too High	OFF
14	Ideal	Ideal	Too High	OFF
15	Ideal	Too High	Too Low	OFF
16	Ideal	Ideal	Too Low	OFF
17	Ideal	Too High	Ideal	OFF
18	Ideal	Ideal	Ideal	OFF

4.6.1.4. Experimental Results

The experimental results can be seen in Table 10. The LED Status expected represents the expected state of the system under the specified conditions. The LED Status Actual represents the actual observed state of the LED under the specified conditions.

Table 10: Experiment 1 Results

Test	Specified Conditions			LED Status	
	Moisture	Wind	Temperature	Expected	Actual
1	Too High	Too High	Too High	OFF	OFF
2	Too High	Ideal	Too High	OFF	OFF
3	Too High	Too High	Too Low	OFF	OFF
4	Too High	Ideal	Too Low	OFF	OFF
5	Too High	Too High	Ideal	OFF	OFF
6	Too High	Ideal	Ideal	OFF	OFF
7	Too Low	Too High	Too High	ON	ON
8	Too Low	Ideal	Too High	ON	ON
9	Too Low	Too High	Too Low	OFF	OFF
10	Too Low	Ideal	Too Low	OFF	OFF
11	Too Low	Too High	Ideal	ON	ON
12	Too Low	Ideal	Ideal	ON	ON
13	Ideal	Too High	Too High	OFF	OFF
14	Ideal	Ideal	Too High	OFF	OFF
15	Ideal	Too High	Too Low	OFF	OFF
16	Ideal	Ideal	Too Low	OFF	OFF
17	Ideal	Too High	Ideal	OFF	OFF
18	Ideal	Ideal	Ideal	OFF	OFF

It was observed that for Test 1 to Test 6 the LED was off. For Test 7, 8, 11 and 12 the LED turned on. For Test 13 to Test 18 the LED turned off.

4.6.1.5. Discussion of Results

The results prove that the software, firmware and hardware of the weather sensors are working and that the observed status of the LED matched the expected status of the LED for all the 18 different conditions.

4.6.2. Experiment 2: Primary System

Experiment 2 is the testing of the Primary System.

4.6.2.1. Experimental Setup

The test was conducted using the Testing Facility as seen in the Schematic of Figure 55. An image of the Testing Facility can also be seen in Figure 57.

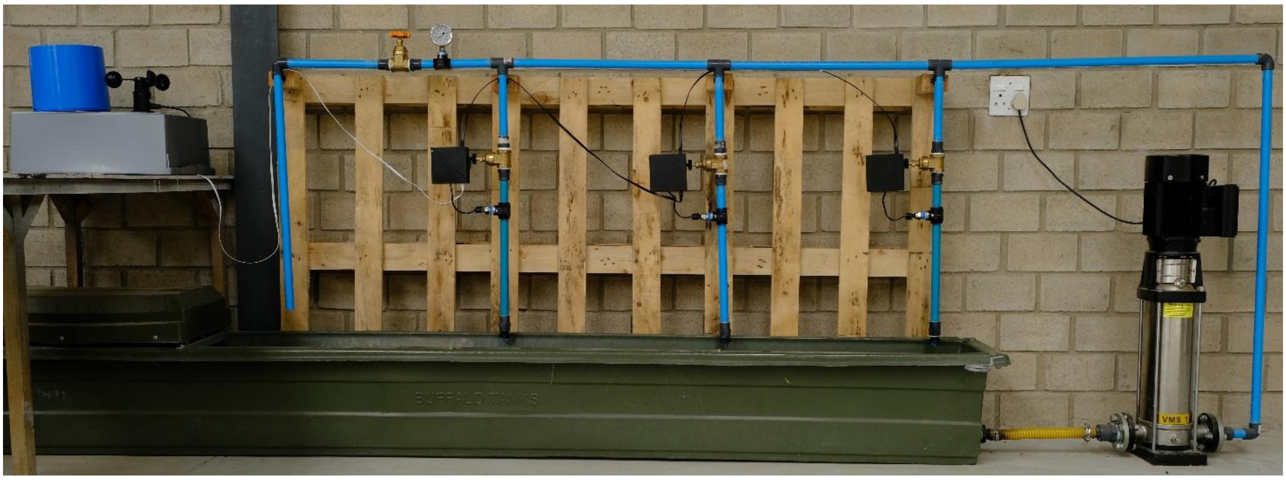


Figure 57: Testing Facility

4.6.2.2. Measuring Devices

The mobile App and the Web Server Page is used to read the values of all the conditions of the test. The state of the system is observed under different conditions.

4.6.2.3. Experimental Procedure

Using the mobile App set the setpoints to the values as seen in Table 11.

Table 11: Experiment 2 Setpoint Values

	Setpoint	
	Min Value	**Max Value**
Rain	-	-
Temperature	7°C	25°C

	Setpoint	
	Min Value	**Max Value**
Wind	-	20 km/h
Flow	-	-
Moisture	100	3000

Test 1: Moisture

Step 1: Ensure the temperature sensor value is between the min and max setpoint value and the wind sensor value is smaller than the max wind setpoint value.

Step 2: Take the moisture sensor out of the water and observe the state of the system. (Expected state: ON)

Step 3: Submerge the moisture sensor in the water until the moisture sensor value is between the min and max moisture value. Observe the state of the system. (Expected state: ON)

Step 4: Submerge the moisture sensor in the water until the moisture sensor value is greater than the max moisture value. Observe the state of the system. (Expected state: OFF)

Test 2: Wind

Step 1: Ensure the moisture sensor value is between the min and max value and ensure the temperature sensor value is between the min and max setpoint value.

Step 2: Blow wind over the wind sensor until the wind sensor value is greater than the wind setpoint value. Observe the state of the system. (Expected state: OFF)

Step 3: Turn off the wind supply and allow the wind sensor value to be smaller than the wind setpoint value. Observe the state of the system. (Expected state: ON)

Test 3: Temperature

Step 1: Ensure the moisture sensor value is between the min and max value.

Step 2: Ensure the wind sensor value is smaller than the max wind setpoint value.

Step 3: Observe the state of the system while the temperature is between the min and max temperature setpoint value. (Expected state: ON)

Step 4: Blow cold air over the temperature sensor until the temperature value is smaller than the min temperature setpoint value. Observe the state of the system. (Expected state: OFF)

Step 5: Blow hot air over the temperature sensor until the temperature value is greater than the max temperature setpoint value. Observe the state of the system. (Expected state: OFF)

Test 4: Rain

The following test is to confirm that the rain meter is accurately measuring the rainfall.

Step 1: Toggle the rain meter and observe the value on the mobile App.

Step 2: Repeat Step 1 ten times.

4.6.2.4. Experimental Results

The results of Experiment 2 are displayed in Table 12.

Table 12: Experiment 2 Results

Test 1	**Moisture**	**State**	
		Expected	**Actual**
	Moisture < min	On	On
	Min < Moisture < Max	On	On
	Moisture > Max	Off	Off
Test 2	**Wind**	**State**	
		Expected	**Actual**
	Wind > Max	Off	Off
	Wind < Max	On	On
Test 3	**Temperature**	**State**	
		Expected	**Actual**
	Min < Temperature < Max	On	On
	Temperature > Max	Off	Off
	Temperature < Min	Off	Off

Test 4	Rain toggle	Reading on App	
		Expected	Actual
	0	0 mm	0 mm
	1	0.2 mm	0.2 mm
	2	0.4 mm	0.4 mm
	3	0.6 mm	0.6 mm
	4	0.8 mm	0.8 mm
	5	0.10 mm	0.10 mm
	6	0.12 mm	0.12 mm
	7	0.14 mm	0.14 mm
	8	0.16 mm	0.16 mm
	9	0.18 mm	0.18 mm
	10	0.20 mm	0.20 mm

4.6.2.5. Discussion of Results

As seen from the results in Table 12 all the actual tested outcome is the same as the expected outcome. Thus, it can be confirmed that the system can accurately perform according to the system requirements. This also confirms that there is correct communication between the mobile App, the Web Server, and the Primary System.

4.6.3. Experiment 3: Secondary System

Experiment 3 is the testing of the communication of the Secondary System. The Secondary System is tested by simulating the change in pressure with a potentiometer.

4.6.3.1. Experimental Setup

The experimental setup can be seen in Figure 58.

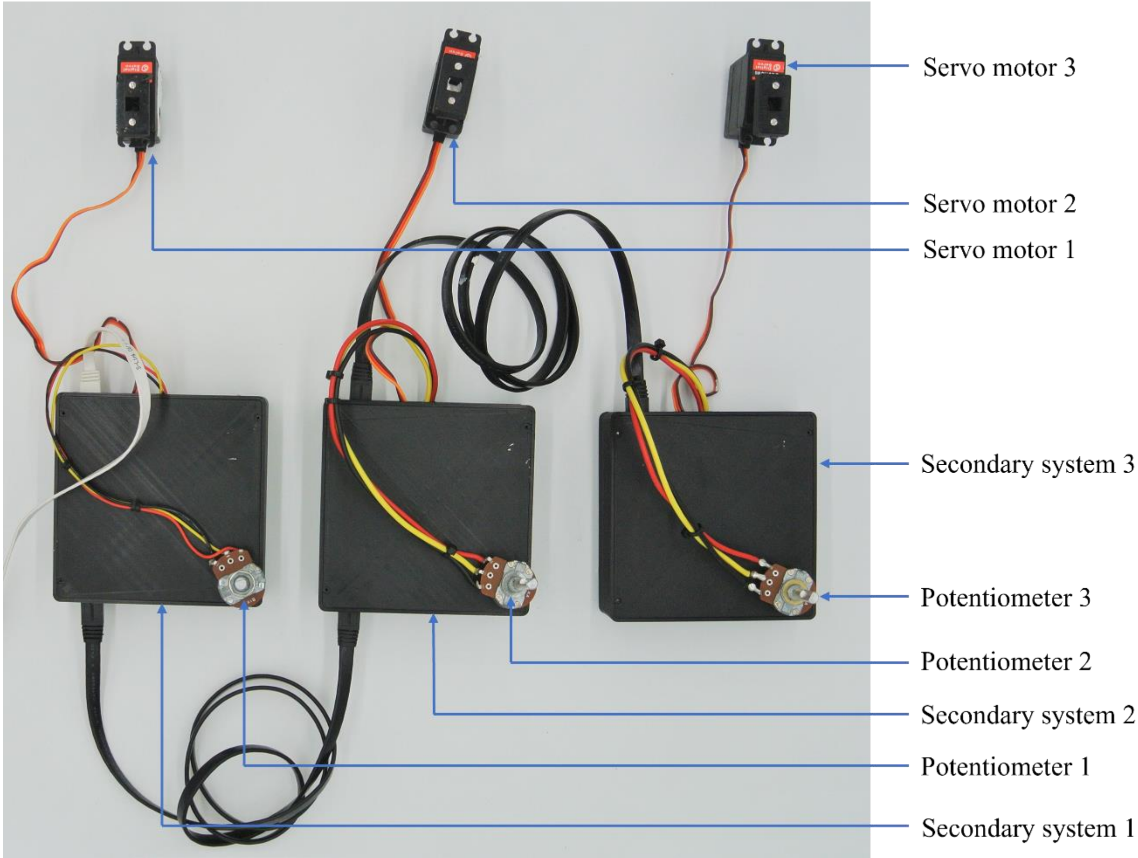


Figure 58: Experimental setup for Experiment 3

4.6.3.2. Measuring Devices

The pressure signal was simulated using a potentiometer and the result read with the mobile App and Web Server Page. The state of the system was observed.

4.6.3.3. Experimental Procedure

The following procedure is performed to execute Experiment 3:

Step 1: Set the pressure setpoint to 5 kPa using the mobile App.

Step 2: Turn the potentiometer that the simulated pressure is smaller than the setpoint value of 5kPa.

Step 3: Observe if the system is activated.

Step 4: Turn the potentiometer that the simulated pressure is greater than the setpoint value of 5kPa.

Step 5: Observe if the system is activated.

Step 6: Turn the potentiometer so that the simulated pressure is equal to the setpoint value.

Step 7: Observe if the system has stopped.

Step 8: Set the pressure setpoint value to 7.5 kPa using the mobile App.

Step 9: Repeat step 2 – step 7 with the setpoint value now equal to 7.5 kPa.

4.6.3.4. Experimental Results

There is an upper and lower error allowance of 0.5 kPa. Thus, if the reading of the actual pressure has a variance of 0.5 kPa away from the setpoint value the pressure condition is satisfied. In other words, if the setpoint is set to be 5 kPa and the actual pressure is any value between 4.5–5.5 kPa the condition will be satisfied. The results of Experiment 3 are displayed in Table 13 and Table 14.

Table 13: Results of Experiment 3 with Pressure Setpoint at 5 kPa

Sensor	Setpoint	Test 1		Test 2		Test 3	
		Reading on App (kPa)	State	Reading on App (kPa)	State	Reading on App (kPa)	State
Node 1	5 kPa	4.51	Off	3.83	On	7.11	On
Node 2	5 kPa	4.67	Off	2.39	On	8.39	On
Node 3	5 kPa	4.63	Off	3.17	On	9.06	On

Table 14: Results of Experiment 3 at 7.5 kPa

Sensor	Setpoint	Test 1		Test 2		Test 3	
		Reading on App (kPa)	State	Reading on App (kPa)	State	Reading on App (kPa)	State
Node 1	7.5 kPa	7.11	Off	6.36	On	8.08	On
Node 2	7.5 kPa	7.65	Off	5.33	On	9.79	On
Node 3	7.5 kPa	7.41	Off	4.68	On	8.68	On

4.6.3.5. Discussion of Results

From the results as seen in Table 13 and Table 14, it can be concluded that the Secondary System is working according to the system requirements and that there is correct communication between the mobile App and the Secondary System.

4.7. Cost Analysis

A cost analysis is done to compare the costs of the Powasave concept with Conventional pivot irrigation systems. This is done by summarising the capital and operating cost of both the Powasave and Conventional Systems and a model is built to calculate when a return on investment is expected based on assumed input variables. The currency unit ₵ is used to define all cost values. This is done so that all costs are independent of a specific currency. In this study the ₵ is equivalent to the current South African Rand (ZAR) and ¢ is equivalent to the ZAR cent value. A cost analysis model is developed and conditions under worst-case, average, and best-case scenarios are investigated. The developed cost analysis model is then applied by investigating three different case studies.

4.7.1. Capital Cost

Capital cost (Capex) is the up front, once off cost of purchasing all the equipment. For the Conventional System this will include the sprayers, pressure regulators and the high-pressure pump required to pressurise the water to the desired pressure. For the Powasave System the capital cost includes the sprayers, the Primary System, network of Secondary Systems and the low-pressure pump required to pressurise the water to the desired pressure. The cost breakdown of each system can be seen in Appendix C.

According to Irrigation Express (2021) the average total capital cost of the Conventional System, which is a Nelson pressure regulator and Nelson sprayer, is ₵510. The cost breakdown of the Powasave System can be seen in Appendix C. The total cost of the Primary System is approximately ₵2450. It is assumed that there is an average of 80 sprayer heads on an average size Pivot of 262 m. Thus, the Primary System cost per spray unit equates to approximately ₵30. The total cost price of the Powasave System, which includes the cost of the Primary System per spray unit, the Secondary System and the Powasave sprayer is approximately ₵550.

The cost of the pump is not investigated in this study, and it is assumed to be the same for both systems. In reality the cost of the low-pressure pump for the Powasave System will typically be cheaper than the high-pressure pump required for Conventional Systems.

It is further assumed that the same pivot structure is used for both the Conventional pivot irrigation system and the Powasave System. Thus, the cost in both scenarios will be the same.

4.7.2. Operating Cost

Operating costs (Opex) are the continuous costs of operating the equipment. For both the Conventional and Powasave System the operating cost includes the Pumping power cost and Cost of Water. An excel model was developed to calculate the pumping cost saving of the Powasave when compared to Conventional Systems. The model calculates the pumping cost saving based on different input variables for both the Powasave and Conventional System. The pumping cost saving **per hour** is defined by Equation (43) where $C_{Powasave}$ and $C_{Conventional}$ is the respective pumping cost of the Powasave and Conventional System as defined by Equation (8).

$$Pump\ Cost\ Saving = C_{Powasave} - C_{Conventional} \tag{43}$$

Equation (8) is substituted into Equation (43) and Equation (44) is obtained.

$$Pump\ Cost\ Saving = (\frac{\rho gQHc}{\eta_p \eta_m})_{Powasave} - (\frac{\rho gQHc}{\eta_p \eta_m})_{Conventional} \tag{44}$$

Since $\rho_{Powasave} = \rho_{Conventional}$ and g is gravitational acceleration, Equation (44) becomes,

$$Pump\ Cost\ Saving = \rho g[\left(\frac{QHc}{\eta_p \eta_m}\right)_{Powasave} - \left(\frac{QHc}{\eta_p \eta_m}\right)_{Conventional}] \tag{45}$$

It is further assumed that the cost (c), motor efficiency (η_m) and pumping efficiency (η_p) is the same for both the Powasave and Conventional System. Thus, Equation (45) can be further reduced to

$$Pump\ Cost\ Saving = \frac{\rho gc}{\eta_p \eta_m}[(QH)_{Powasave} - (QH)_{Conventional}] \tag{46}$$

Thus, the pumping cost saving is dependent on the Flow Rate (Q) and Pressure Head (H) of the Powasave and Conventional System that is defined Equation (47).

$$H = H_g + h_{sprayer} + h_L \tag{47}$$

H_g is the geodetic pressure defined by Equation (3), $h_{sprayer}$ is the pressure head requirement of the sprayer, and h_L is the head loss in the pipeline defined by Equation (48).

$$h_L = \sum_{i}^{n} \frac{f_i L_i}{d_i} \frac{1}{2g} v_{wi}^2 \tag{48}$$

This model can be used with many different input variables. It is assumed that the same irrigation system is used for the Powasave and Conventional scenarios thus H_g and h_L is the same for both systems. It is further assumed that the cost of electricity, pump efficiency and motor efficiency are also the same for both the Powasave and Conventional System. Table 15 contains the values of all the constant input variables.

Table 15: Pump Cost Calculations Constant Values

Constants	Symbol	Value	Units
Pressure Head Requirement: Powasave sprayer	$h_{Powasave}$	0.5	m
Pressure Head Requirement: Conventional Sprayer	$h_{Conventional}$	10	m
Line Loss	h_L	4.67	m
Powasave Flow Rate	Q	24.6	L/min
Slope Range	θ	0-15	°
Water Saving Percentage	WS%	5-50	%
Darcy Friction Factor	f_i	0.015	m
Gravitational Acceleration	g	9.81	m/s
Span Length	L_1	60.5	m
Pipe Diameter	d_1	0.165	m
Span Length	L_2	60.5	m
Pipe Diameter	d_2	0.165	m
Span Length	L_3	60.5	m
Pipe Diameter	d_3	0.127	m
m Span Length	L_4	60.5	m
Pipe Diameter	d_4	0.127	m
Span Length	L_5	20	m
Pipe Diameter	d_5	0.101	m
Water Velocity	v_{wi}	1.8	m/s

By Substituting the inputs of Table 15 into Equation (48) and Equation (3) the Geodetic Pressure and Line Loss is calculated at a field slope range of 0-15° and is found in Table 25 in Appendix F.

The **water saving percentage** (WS%) is the percentage of water saved if the Powasave System is used instead of the Conventional System under the same environmental conditions. An analysis is done at a field slope ranging from 0-15° and a WS% of 0%, 15%, 30% and 50%. The operating pressure of the Powasave sprayer is 5 kPa which is equivalent to 0.5 m head and the operating pressure of the Conventional sprayer is 100 kPa which is equivalent to 10 m head and the cost of electricity 180 ¢/kWh.

From Equation (46) with the inputs of Table 15 and Table 25 the values displayed in Figure 59 is acquired. Figure 59 is multiple graphs where the pumping cost saving can be obtained at a respective field slope and WS%. Table 26 in Appendix F contains the exact values of Figure 59.

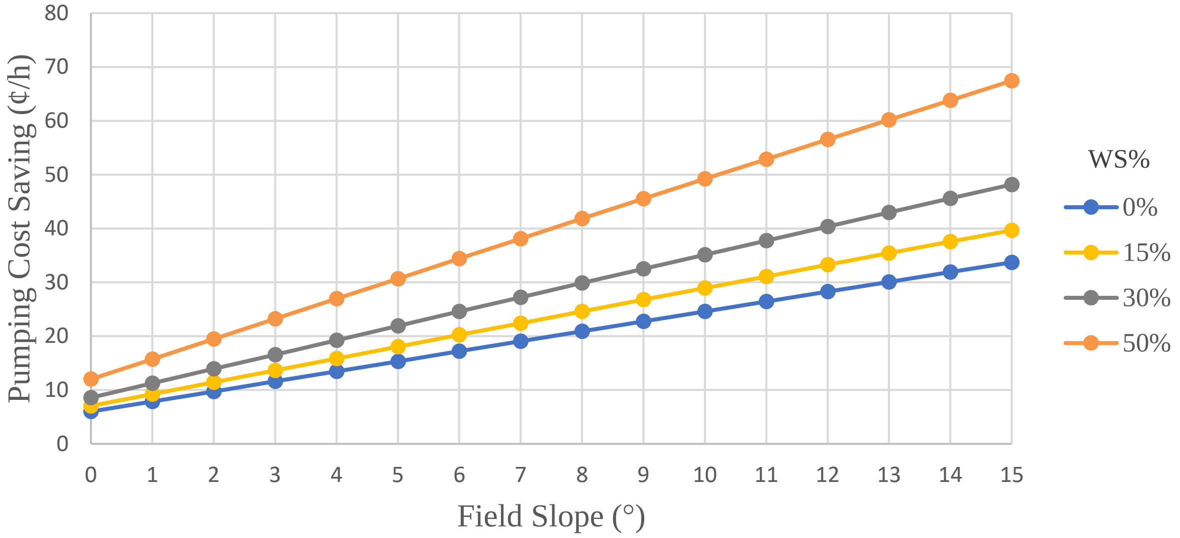


Figure 59: Pumping Cost Saving Graph with $c = 180$ ¢/kWh

From Figure 59 it is evident that the slope of the field being irrigated and the WS% has the largest effect on the pumping cost saving. When comparing the Powasave System with Conventional irrigation systems the smaller the slope of the field the smaller the pumping cost resulting in a smaller pumping cost saving. Also, the higher the WS% the less water is being pressurised resulting in a larger pumping cost saving.

From Figure 59 it is seen that for the worst-case scenario where the field slope is 0° and the WS% is 0%, the Pumping cost saving is approximately 7 ¢/kWh. The best-case scenario where the field slope is 15° and WS% is 50%, the Pumping cost saving is approximately 67 ¢/kWh.

The same analysis is done with $c = 500$ ¢/kWh and the results can be seen in Figure 60. It is further discovered that the pumping cost saving increases as the cost of electricity increases. At $c = 500$ ¢/kWh the pump cost saving range is 16.67 – 187.33 ¢/kWh. Table 27 in Appendix F contains the exact values of Figure 60.

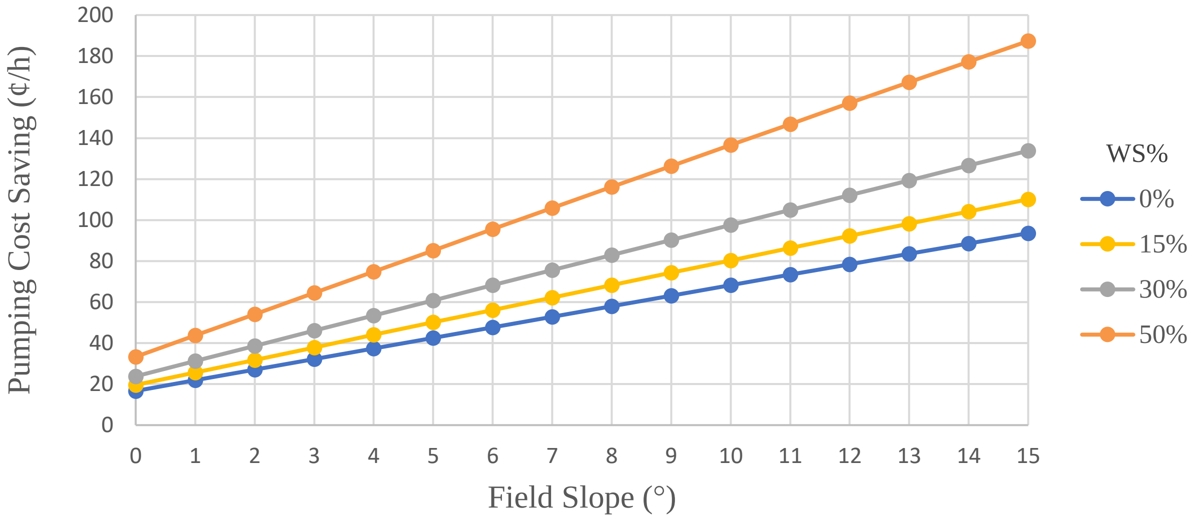


Figure 60: Pumping Cost Saving Graph with $c = 500$ ¢/kWh

Thus, comparing the Powasave sprayer at a required pressure head of 5 kPa with a Conventional irrigation sprayer that has a required pressure head of 100 kPa, the pump cost saving percentage can range between 7-187 ¢/kWh depending on the WS%, the slope of the field being irrigated and the cost of electricity. It can be concluded that this system has the potential to considerably reduce the pumping cost of pivot irrigation systems, especially if the slope of the field being irrigated is large.

4.7.3. Return on Investment

To understand the financial feasibility of the Powasave System the total cost of the Powasave System is compared to the total cost of Conventional Systems by calculating the return on investment. Although the capital cost of the Powasave System is more than the capital cost of the Conventional Systems, the operating cost of the Powasave System is less than the operating cost of the Conventional Systems. Thus, over time the Powasave System will be the most economical option. The payback period (PBP) is the point in time where the cost saved during operation is equal to the extra expense of the Powasave System.

The $Opex$ is equal to the pumping cost (C) and can be calculated with Equation (49), obtained by substituting $H = H_g + h_{sprayer} + h_L$ into Equation (7).

$$Opex = C = \frac{\rho g Q(H_g + h_{sprayer} + h_L)c\Delta t}{\eta_p \eta_m} \tag{49}$$

Once the $Opex$ is calculated for both the Powasave and Conventional System and the $Capex$ is as seen in Table 16, the PBP is calculated with Equation (50).

$$PBP = \frac{Capex_{Powasave} - Capex_{Conventional}}{Opex_{Powasave} - Opex_{Conventional}} \tag{50}$$

The assumptions that are made to calculate the $Opex$ and PBP is summarised in Table 16. There is a markup percentage of 30% in the cost price of the product. Thus, with a cost price of ₵550 and a markup of 30%, the $Capex$ of the Powasave per spray unit is ₵715.

Table 16: BEP Calculation Assumptions

Constants	Symbol	Value	Units
Motor efficiency	η_m	70	%
Pump efficiency	η_p	70	%
Powasave Cost Price	$Cost\ Price$	₵550	ZAR
Powasave System markup	$Markup$	30	%
Powasave Capital Cost	$Capex_{Powasave}$	₵715	ZAR
Conventional Capital Cost	$Capex_{Conventional}$	₵510	ZAR
Average hours of irrigation per day	-	8	Hours
Average number of days of irrigation per year	-	120	Days

The PBP is calculated over a range of cost of electricity of 150-850 ¢/kWh. Three different crops: Corn, Wheat and Lucerne are investigated. The average irrigation time per year is calculated based on the water requirement of the different crops as seen in Table 24 in Appendix F, with a conservative assumption of WS% = 0 and a field slope, θ = 0°. The results can be seen in Figure 61.

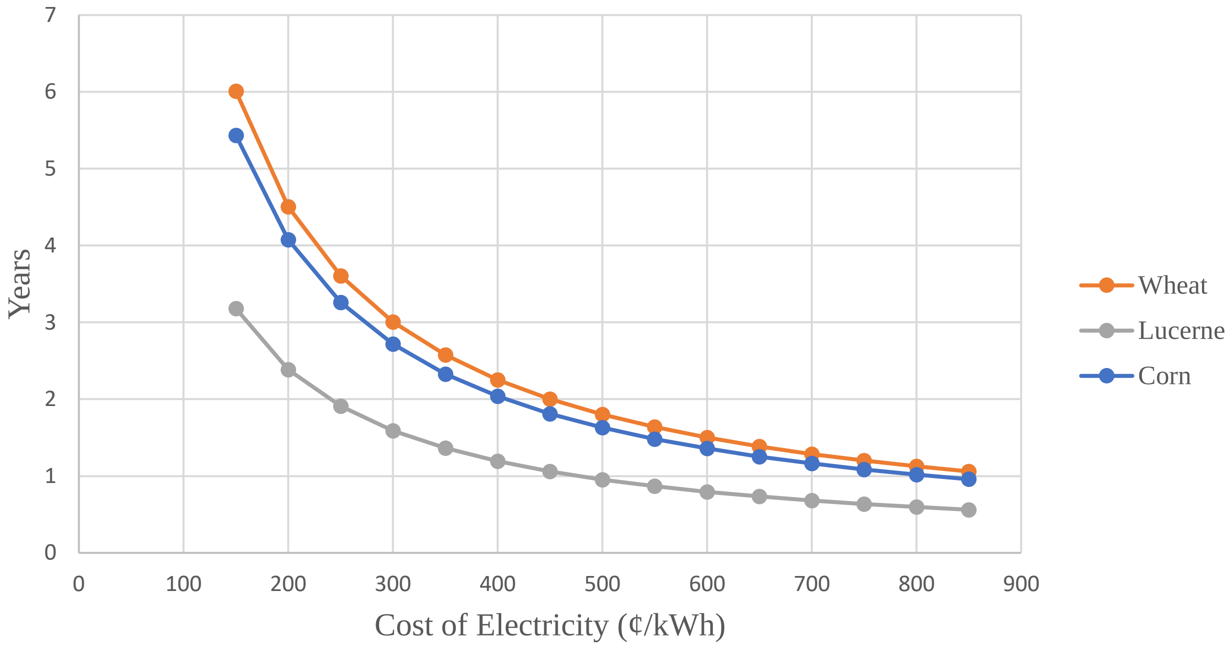


Figure 61: Crop Specific PBP with WS% = 0% and θ = 0°

The worst-case PBP scenario of 150 ¢/kWh is considered. From Figure 61 it is evident that lucerne has the best PBP of approximately 3 years. Corn has the second best PBP of approximately 5 and a half years and wheat has a PBP of approximately 6 years.

The average PBP of the three crops at different WS% of 0%, 15%, 30% and 50% is also calculated and the results can be seen in Figure 62.

From Figure 62 it is evident that the PBP decreases as the WS% increases. For the worst-case scenario of 150 ¢/kWh with a WS% = 0, the average PBP is approximately 4 and a half years and the PBP at a WS% = 15% is approximately 3 and a half years. This is only for the worst-case scenario, in reality the PBP is expected to be even lower since the cost of electricity and the WS% is expected to be higher.

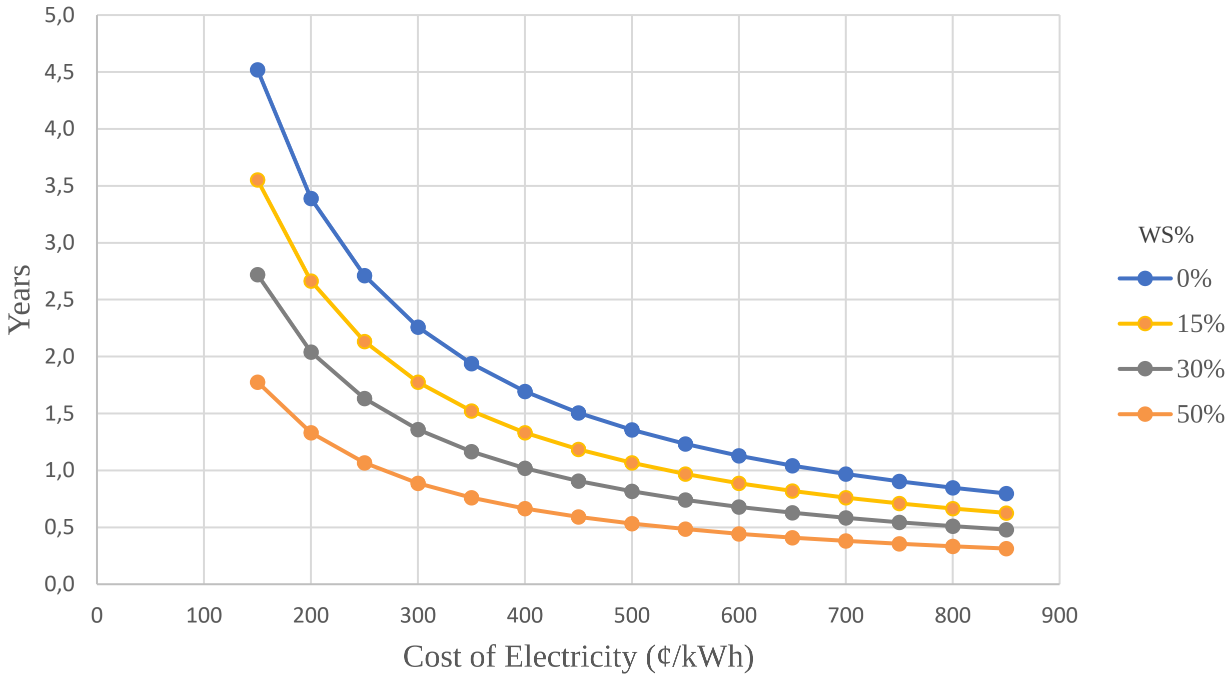


Figure 62: Average PBP over different WS%

4.7.4. Cost of Electricity in the Rural and Farming Category Areas

According to the Energy Price Report (2018) the annual average Eskom prices for the customer category of Rural or Farming in cents per kilowatt hour from 2009 to 2018 is as seen in Table 28 in Appendix F, based on the data the Graph in Figure 63 is populated. In Figure 63, the actual graph is the increase in cost of electricity from 2009 to 2018. The estimated graph is the predicted increase in cost of electricity based on the increase of cost of electricity of the actual graph.

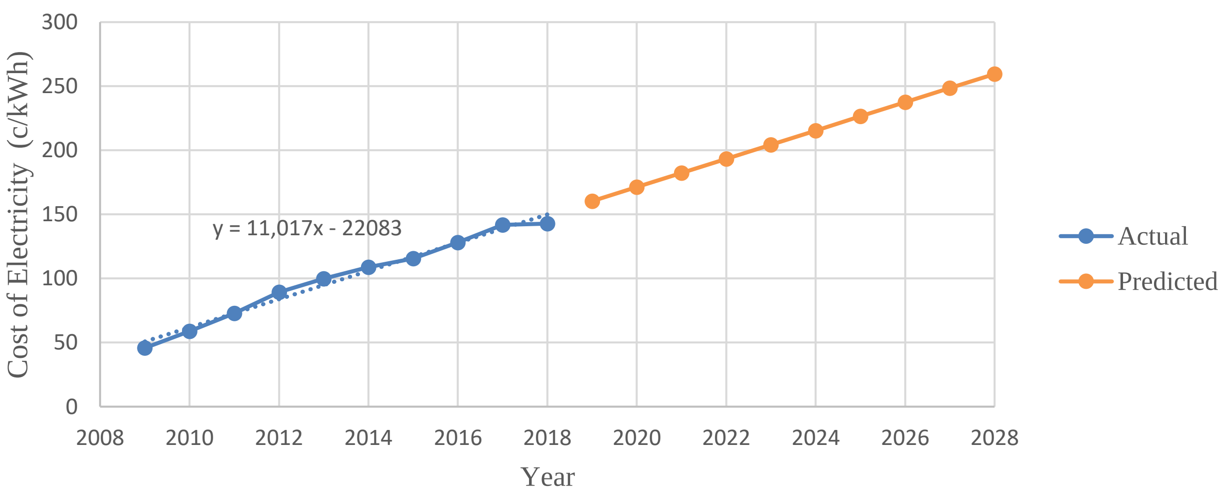


Figure 63: Cost of Electricity in Rural/Farming Areas (Energy Price Report, 2018)

It is a reasonable assumption that the cost of electricity will increase over time. Thus, it can be concluded that the PBP will reduce even more at the years pass by.

4.7.5. Case Studies

Three case studies are investigated to determine what the estimated PBP will be in the three different scenarios. The location and crop type of the three different scenarios are stated and the average cost of electricity for each scenario is obtained. In all three scenarios the worst-case scenario of a WS% = 0 is assumed to obtain the most conservative PBP. The cases are also investigated at a WS% = 15%.

Case 1

Farm location: near Priska, Northern Cape, South Africa

Average cost of electricity: 180 ¢/kWh

Crop type: Corn and Wheat

WS% = 0%

For Corn, according to the PBP model the estimated PBP will be 4 and a half years. For Wheat, according to the PBP model the estimated PBP will be 5 years.

WS% = 15%

For Corn, according to the PBP model the estimated PBP will be 3 and a half years. For Wheat, according to the PBP model the estimated PBP will be 4 years.

Case 2

Farm location: near Matatiele, Eastern Cape, South Africa

Average cost of electricity: 230 ¢/kWh

Crop type: Corn

WS% = 0%

According to the PBP model the estimated PBP will be 3 and a half years.

WS% = 15%

According to the PBP model the estimated PBP will be just under 3 years.

Case 3

Farm location: near, Luckhof, Free State, South Africa

Average cost of electricity: 150 ¢/kWh

Crop type: Corn and Wheat

WS% = 0%

For Corn, according to the PBP model the estimated PBP will be 5 and a half years. For Wheat, according to the PBP model the estimated PBP will be 6 years.

WS% = 15%

For Corn, according to the PBP model the estimated PBP will be just over 4 years. For Wheat, according to the PBP model the estimated PBP will be just over 4 and a half years.

4.7.6. Other Costs

The **cost of water** is also a major cost contributing factor. The PBP, in Section 4.7.3, is calculated under the worst-case scenario with a WS% = 0. It is expected that if the Powasave is used the water consumption will be reduced, increasing the WS%, and thus reducing the overall water cost. The water cost will be reduced by the same percentage as the WS%. It can further be expected that all costs involved with building dams and infrastructure to transporting and storing water will potentially be decreased. The exact amount of total cost saving due to water saving is still unknown, but it is expected to be a significant amount and thus decreasing the PBP even more.

In Section 4.7.5 the case studies are investigated with WS% = 0 and WS% = 15%. In the scenario where the WS% = 15% the water cost saving is excluded. Once the WS% is greater than zero the cost of water will also decrease since less water is being used. Thus, the overall costs will decrease also resulting in a decreased PBP.

Since irrigation can now take place with an increased water efficiency, cheaper arid areas can be considered as potential crop farming areas. Thus, the **cost of irrigation land** could potentially decrease making the overall cost of crop farming less.

Another cost factor that must be considered is the **increase in profit** due to an increase in crop yield. The increased crop yield is not yet known since the system has not yet been tested over time in the field, but the prediction is that the crop yield will increase equating to an increase in profit.

The **cost of time and labour** of manually switching pivots on and off and inspecting systems to detect breakdowns is also reduced. This also has the potential to reduce downtime and costs involved with breakdowns and downtime since, a faulty pivot will be detected much earlier. Thus, reducing the potential damage it can cause to the equipment and the crops.

If the same pump is used for both the Conventional and for the Powasave System, the pump will be on for a shorter amount of time resulting in less pumping costs and less wear and tear. Alternatively, a smaller pump with less capital and operational costs can be used to pressurise the water to the low-pressure requirement of the Powasave System.

4.7.7. Discussion

Since the Powasave System is designed to only operate during optimal conditions, it is expected that the water losses will be considerably reduced. The soil moisture is constantly measured ensuring that over or under irrigation does not occur. This result in an optimisation of water consumption. Also, it ensures that the crops are not under irrigated and suffer due to insufficient irrigation. This reduces the costs involved with a reduced crop yield. With the water flow meter incorporated into the Powasave System, the user can track water usages and compare it to the water usage of previously used irrigation systems provided that the previous water usage is known. Currently, the exact amount of water being saved is difficult to predict since it is dependent on so many factors like rainfall, ambient temperatures, and wind conditions in the area.

One Primary System can be used on multiple pivot irrigation systems provided that the irrigation systems are situated in a relatively close proximity such that the weather conditions will be the same for all. In the case of using one Primary System for multiple pivot irrigation systems, each pivot will still require its own Moisture and Flow sensor but will be able to share the Wind, Rain and Temperature sensors. This will reduce the overall Capital Cost of the Powasave System.

Investigation can be done around using one Secondary System on more than one Powasave sprayer. This could be using one Secondary System on two or three Sprayers, reducing the overall cost by half or two thirds. Another investigation that can be done is to use one Secondary System for all the sprayers that have the same field topography. If this is correctly implemented, it will also reduce the Capital Cost of the Powasave System.

To conclude, it is very difficult to predict the exact costs since it is dependent on so many external factors, like the water availability, pumping costs, environmental conditions, and field topography. Further the possibility of implementing IoT technologies in pivot irrigation systems is a huge benefit for the agricultural sector since many conditions can be monitored and irrigation can be adjusted accordingly to ensure an optimal water and power usage for an optimal crop yield. The system can also be switched on and off with a mobile App reducing the time spent on manually switching pivot irrigation systems on and off or checking if the system is still in operation, resulting in the farming lifestyle to be even more enjoyable.

4.8. Chapter Summary

In this Chapter the design requirements and design specifications of the product are defined. The detailed design of the product is described, and the product is developed according to design specifications. Once the product is developed it is tested to determine if the design specifications are achieved. The developed product is tested by conducting three experiments. After the three experiments are conducted it can be concluded that developed product adheres to all the design requirements and specifications. Lastly a cost analysis is performed, the payback period of the product is analysed, and three case studies are investigated. This concludes that the research objectives of Chapter 4 are achieved, and the research questions are answered.

Chapter 5

Enterprise Life Cycle

"The heart and soul of a company is creativity and innovation"

- Robert Iger

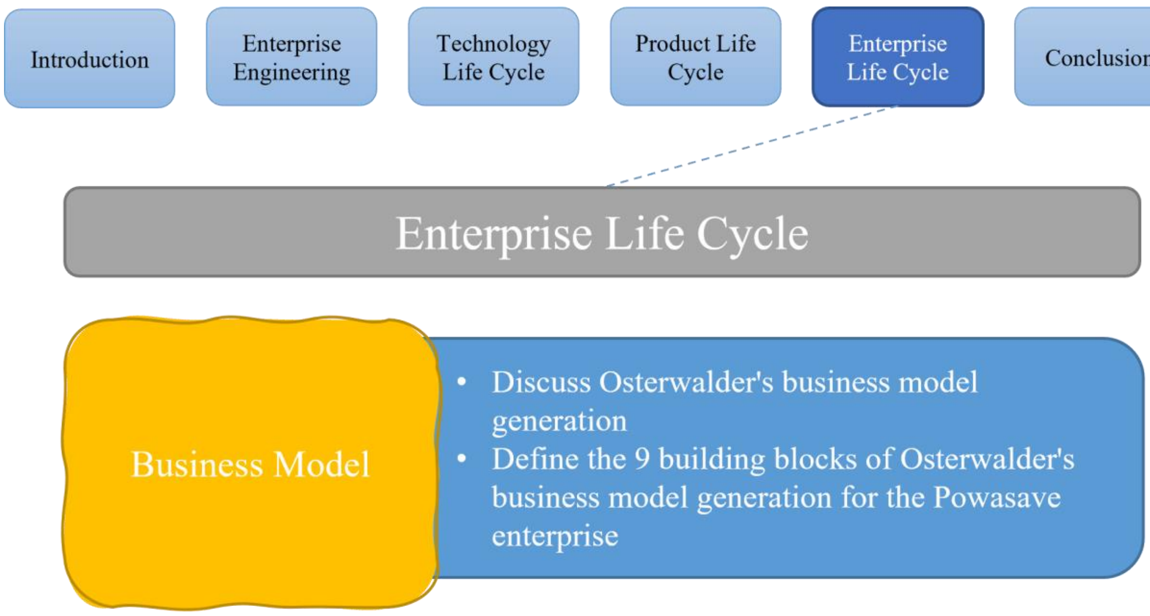


Figure 64: Navigation Structure of Chapter 5

The research objectives and research questions addressed in Chapter 5 are summarised in Table 17.

Table 17: Chapter 5 Objectives

Primary Objective	**Research Objectives**	**Research Questions**	**Document Structure**
Propose the Enterprise	Design an Enterprise by generating a business model that can commercialise the developed product.	How can innovative irrigation systems be commercialised?	Section 5.2

5.1. Introduction

The success of a product or service is dependent on the success of the enterprise that develops, manages, and sells the product or service. Thus, it is of utmost importance to develop an enterprise that can effectively commercialise the developed product. This is done by developing the Enterprise life Cycle for an Enterprise that will develop and sell the Powasave product.

The enterprise is at the end of the concept phase of the Enterprise Life Cycle as seen in Figure 65. The identification and concept phase of the Enterprise Life Cycle is completed, and the next phase is to develop a preliminary design of the enterprise. The preliminary design is developed by generating a business model for the Enterprise that will commercialise the Powasave product. Since the Enterprise is in the design phase the implementation, operation and decommission phases are not part of the scope of this study and is thus not discussed.

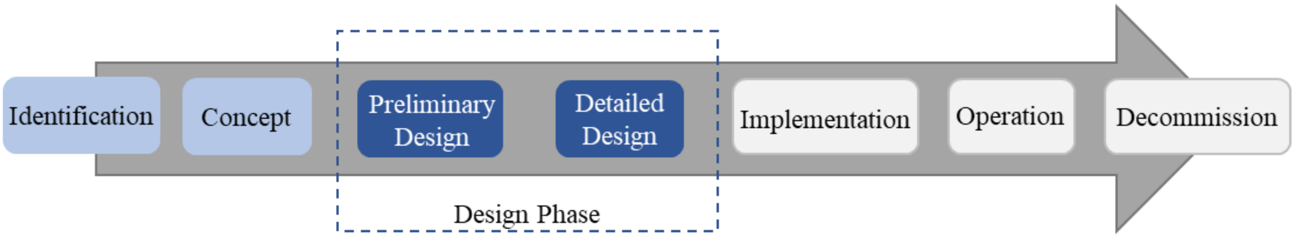


Figure 65: Enterprise Life Cycle Progress

A business model is the operational strategies that an enterprise follows to be successful. Many different approaches can be used to generate a business model. In this study Osterwalder (2010) is used to develop a business model for the Enterprise that will commercialise the developed Powasave product. The business model can be summed up in a one-page canvas and the interactions between the different sections of the business model are visually displayed. Osterwalder developed the business generation model as part of his PhD research and the model is used by many organisations around the globe due to the simplicity and ability to visually represent an organisations infrastructure. By defining the 9 building blocks of the business model the organisation is set to make a profit by delivering a value to customers.

The 9 building blocks of Osterwalder (2010) are customer segments, value proposition, channels, customer relationships, revenue streams, key resources, key activities, key partnerships, and cost structure. The relationship and interaction of the 9 building blocks can be seen in Figure 66.

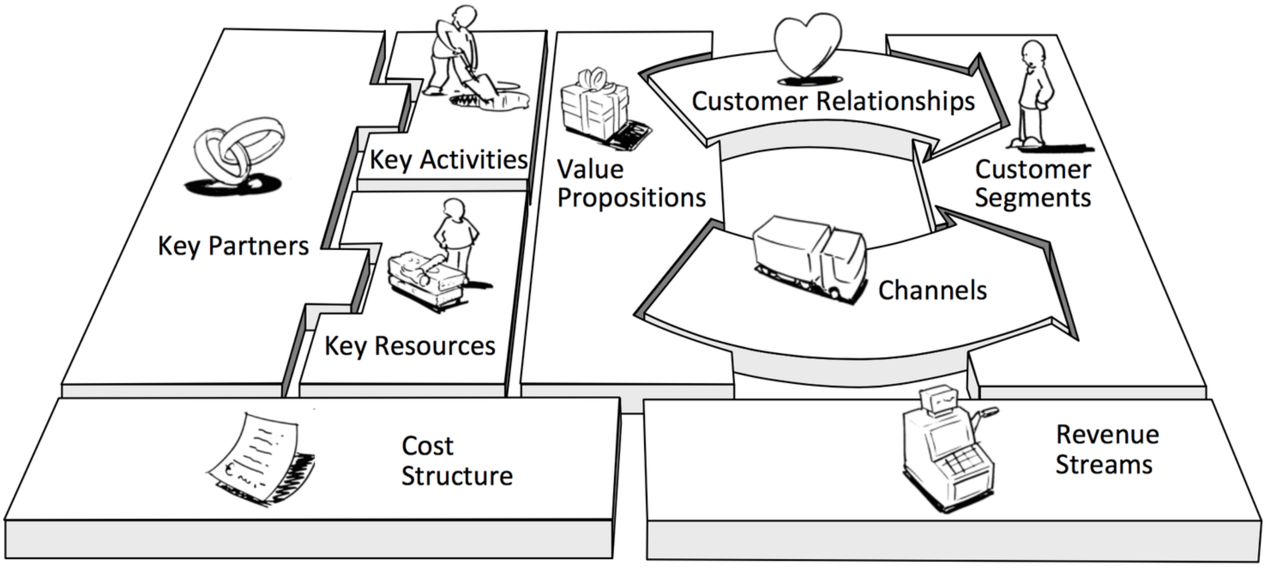


Figure 66: Buiding Blocks of a Business Model Osterwalder (2010)

The key partnerships are the network of suppliers and partners that an enterprise requires to be operational and successful. The key activities are the actions that an enterprise must execute to enable the enterprise to function. The key resources are the resources that are most important to enable the enterprise to function. The relationship between the key partners, key activities and key resources are usually dependant on one another. In many enterprises key resources and key activities are obtained by establishing partnerships with key suppliers or outsourcing key activities to other enterprises that are experts in that specific field.

The customer segment is the type of customer that is targeted. The value proposition is the value of the product or service that an enterprise delivers to customers. Customer relationship is the type of relationship an enterprise has with its customers and the channels are how an enterprise communicates and delivers the value proposition to customers.

The cost structure entails all the costs involved with operating an enterprise and it represents the cash outflow. The revenue streams are how an enterprise creates revenue from the customer and it represents the cash inflow. The profit is the difference between the inflow revenue streams and outflow of the costs. To make a profit, an enterprise must ensure that the revenue is greater than the costs.

5.2. Business Model

A suggested preliminary business model is developed in this section. The Enterprise is a joint venture between Powasave and a well-established irrigation system manufacturing company. A joint venture is a business partnership that is made up of two or more parties that have different resources to bring to the table. It is an agreement where both parties are responsible for profits, losses and other costs, and the venture is independent and an entity of its own (Hargrave, 2021).

The main reason for a joint venture is the access to existing customers. It is much easier to partner with a company that is already established and trusted than to try and convince and gain new customers. According to Nasir (2017) it is much easier and cheaper to increase customer retention than to try and gain new customers. Nasir (2017) further states that customers trust product or service provides that they have already used and tend to continuously return to the same product or service provider. According to Farris et al. (2010) there is a probability of 60-70% of retaining an existing customer and the probability of gaining a new customer is only 5-20%. Newell-Legner (2008) states that the cost of acquiring a new customer compared to retaining an existing customer is six to seven times more.

The **competitive advantage** of the Powasave product over conventional systems is that overall water and power costs are considerably reduced, and the user gains the possibility of remotely controlling irrigation systems with IoT technology.

The Business Model Canvas of the enterprise can be seen in Appendix G. An overview of the business model is as follows. Firstly, parts and raw materials are sourced. The sources parts and materials are used to produce the Powasave product. This includes all hardware and firmware as seen in Appendix C. The production process requires labour and there are running costs involved. After the hardware and firmware is manufactured the software is installed onto the circuit boards of the product.

The marketing team promotes the product through existing customer relationships and online platforms. Once a sale is made an installation team goes and installs the product on site and the mobile App is downloaded on the desired mobile device of the buyer. The team trains the buyer on how to operate the product. Support is provided to customers that require assistance and notifications are sent via the mobile App on new software updates or new features of the product.

Next the business model is discussed in more detail and is categorised according to the 9 building blocks of Osterwalder (2010).

5.2.1. Customer Segments

The customer is a very important aspect of any enterprise. Without a customer there is no one to sell the product to and hence no revenue. The customer segment is the type of customer that is targeted. The target customer of Powasave is farmers that wish to reduce the water losses and power consumption of pivot irrigation systems and ultimately increase crop yield and profits. It also targets farmers that wish to have remote control over pivot irrigation systems and be able to check conditions via a mobile device.

5.2.2. Value Propositions

An enterprise must deliver value to its customers. The value proposition is the value of the product or service that an enterprise delivers to customers. The value proposition of the Powasave is a product that reduces water losses and power consumption of pivot irrigation systems. It further empowers farmers to have remote control over pivot irrigation systems with the help of IoT technology. This leads to the potential increase in crop yield and increase in profitability of crop farming.

The value proposition factors of Powasave are ***Newness***, ***Cost Reduction***, ***Performance***, ***Risk Reduction***, and ***Convenience***. The **Newness** is that this is a new product for the agricultural sector empowering farmers to control pivot irrigation systems from a mobile App. The **Cost Reduction** factor is that the operating costs involved with pivot irrigation systems will reduce. The Capital Expenditure (Capex) value might be slightly more, but the operating expenditure (Opex) will decrease considerably as seen in the Cost analysis of the product in Section 4.7. Thus, making the Powasave cheaper than conventional systems over time. The **Performance** of pivot irrigation systems are increased and there is a potential increase in the **Performance** of crop yield. **Risk** of wasting water and power is reduced. Further the **Risk** of under or over irrigation is also reduced, and thus minimising the risk of reduced crop yield. The **Convenience** of the Powasave is being able to control pivot irrigation systems and see live environmental conditions on a mobile App. All these factors contribute to the value proposition of the business.

5.2.3. Channels

The channels are how an enterprise communicates and delivers the value proposition to customers. The channels of Powasave are the existing customer relationships of the partnering irrigation company. Other channels that Powasave will use is a website and the mobile App that is installed on the user's device.

These channels are used to create ***awareness*** of the new product by promoting it under existing customers and potential new customers and the value of the product is communicated. This is done via established communication channels like email and telephone calls.

The purchasing of products can be done via electronic fund transfer (EFT) or card payments. Once the product is purchased the product is delivered to the customer by the installation team that installs the product on site. After sales support is also provided to customers who need assistance by a support team. Support is done via telephone calls, the mobile App, and in person assistance.

5.2.4. Customer Relationships

Customer relationship is the type of relationship an enterprise has with its customers. There is already a relationship established with customers through the customer channels of the partnering irrigation company, and the new joint venture will build those established relationships.

For the installation stage, ***personal assistance*** will be provided to customers who require help with installation and training. As the product grows, online or in app ***self-service*** training platforms will be made available to improve the efficiency of training customers.

With regards to the software of the product, ***automated services*** will be developed to notify customers of software updates and when new features are available.

5.2.5. Revenue Streams

The revenue streams are how an enterprise creates revenue from the customer. The Powasave consists of two parts, the hardware and firmware, and the software. The hardware and firmware are a once off ***asset sale*** and the software is provided on a ***subscription based*** model. This will be a monthly or annual subscription that the customer pays for access and use of the software. An ***economies of scale*** is also included in the cost structure depending on how large the demand of the customer is. For example, if the farmer has 1 or 20 pivot irrigation systems the cost of the product will vary.

5.2.6. Key Resources

The key resources are the resources that are most important to enable the enterprise to function. The design of the Powasave sprayer is patented and thus the one of the key resources is the intellectual property of the design and patent of the Powasave sprayer. Another key resource is the firmware design and the software of the mobile App and Webserver enabling the user to control the irrigation system from a remote location. The existing customer relationships that the partnering company brings to the table is also a key resource. The fact that there already is an existing customer database makes the marketing and sales much easier. Customers tend to trust product and service providers that they have already used. According to Nasir (2017) it is easier and cheaper to retain an existing customer than to try and acquire a new customer.

Physical resources like materials, manufacturing machinery and facilities are also required to manufacture the product. A ***Financial*** resource is required to initially fund the development and launch of the Product. This initial financial resource will come from investors or venture capitalists that take an interest in the product. Once the product is on the market, company profits will be reinvested in the company to further innovate and expand the product.

5.2.7. Key Activities

The key activities are the actions that an enterprise must execute to enable the enterprise to function. The key activities are the **development** and **production** of the Powasave product. The ongoing **maintenance** and development of the software of the mobile App and Webserver. **Marketing**, **sales**, **installation**, and **support** are also key activities required to make the enterprise successful.

These key activities can be categorised under production, problem solving and organisational categories. The ***production*** activity includes the development, manufacturing and delivering of the product that is of high quality and adheres to the product requirements. The ***problem-solving*** activity is that the product solves the problem of power and water losses of pivot irrigation systems. The marketing, sales, installation, and support activities all fall under ***organisational*** activities of the enterprise.

5.2.8. Key Partnerships

The key partnerships are the network of suppliers and partners that an enterprise requires to be operational and successful. A ***joint venture*** with an already established irrigation company is proposed. The motivation for a joint venture is to ***reduce the risk of uncertainty***. By partnering with a company, that already has an established relationship with customers, reduces the risk of not acquiring customers to buy the developed product. The ***acquisition of particular resources and activities*** is also made possible with a partnership. Access to the design of pivot irrigation systems and a sales force are huge resources gained through the partnership.

Other key partnerships are the partnerships with suppliers to obtain raw materials and parts. To reduce the cost of raw materials and parts, bulk orders are made from all suppliers. To publish the mobile App a partnership with the App store and Play store is also required.

5.2.9. Cost Structure

The cost structure entails all the costs involved with operating an enterprise. The costs involved with the operation of the enterprise include the cost of the raw materials and parts, the running costs of production, labour costs, marketing costs, and call out and installation costs.

The company will predominantly have a ***cost-driven*** structure but still strive to deliver a high-quality product that provides good value to the customer. The cost-driven structure is an enterprise that focuses on keeping the expensed down. This is done by purchasing raw materials and parts in bulk and acquiring the cheapest suppliers that still meet the quality requirement of the product.

Production and manufacturing processes will be optimised to have the lowest possible cost. Over time as the product becomes more popular the installation and support processed will also be streamlined and made as cost effective as possible.

5.3. Chapter Summary

In this Chapter a Business Model is generated illustrating the proposed business model for the enterprise that will commercialise the developed Powasave Product. The research objective of designing an Enterprise by generating a business model that can commercialise the developed product is achieved, and the research question of Chapter 5 is answered. A summary of the populated Business Model Canvas can be seen in Table 18.

Table 18: Summary of Business Model Canvas

<table>
<tr>
<td rowspan="2"><u>Key Partners</u>
• Joint Venture
• Suppliers
• App Store
• Google Play Store</td>
<td><u>Key Activities</u>
• Production
• Software maintenance/ development
• Marketing & sales
• Product installation & support</td>
<td rowspan="2"><u>Value Proposition</u>
• Reduce water and power losses
• IoT technology for pivot irrigation systems
• Increase in crop yield</td>
<td><u>Customer Relationship</u>
• Personal assistance
• Self service
• Automated services</td>
<td rowspan="2"><u>Customer Segments</u>
• Farmers that wish to reduce water and power losses of pivot irrigation systems
• Farmers that wish to use IoT technology with pivot irrigation systems</td>
</tr>
<tr>
<td><u>Key Resources</u>
• Powasave intellectual property
• Software
• Firmware design
• Customer database</td>
<td><u>Channels</u>
• Email
• Telephone
• Website
• Mobile App
• In person assistance
• Delivery and service vehicles</td>
</tr>
<tr>
<td colspan="3"><u>Cost Structure</u>
Cost driven structure, costs involved are cost of the:
• Raw materials
• Running costs of production
• Labour
• Marketing cost
• Call out and installation</td>
<td colspan="2"><u>Revenue Streams</u>
• Asset sale (hardware & firmware)
• Subscription fee (software)</td>
</tr>
</table>

Chapter 6

Conclusions and Recommendations

"Limitations live only in our minds. But if we use our imaginations, our possibilities become limitless."

- Jamie Paolinetti

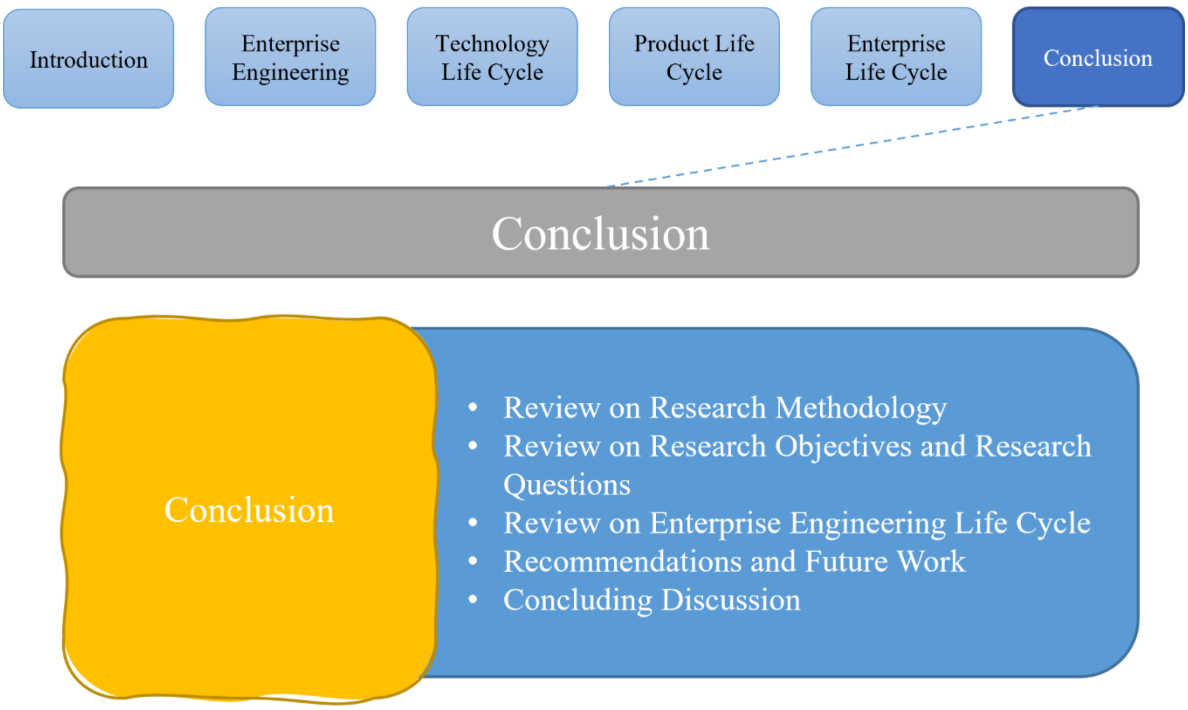


Figure 67: Navigation Structure of Chapter 6

6.1. Research Methodology Review

In this study a design research approach is performed by executing the three steps of design-based research namely:

- Analysis and exploration
- Design and construct
- Evaluation and reflection

Analysis and exploration is done in Chapters 2, 3 and 4. In Chapter 2 enterprise engineering is analysed and explored by conducting a literature review. In Chapter 3 Irrigation and IoT technologies are analysed and explored by also conducting a literature review on a variety of topics that fall under irrigation and IoT technology. In Chapter 4 the design requirements are formulated.

Design and construction is done in Chapter 4 and Chapter 5. In Chapter 4 a solution (product) is designed and constructed and in Chapter 5 a preliminary design for an enterprise that can commercialise the solution is developed.

Evaluation and refection is done in Chapter 4 and Chapter 6. In Chapter 4 the developed product is tested and evaluated, and a cost analysis is performed. In Chapter 6 reflection is done on the research and the developed product. Recommendations and future work is also discussed.

6.1.1. Research Objectives and Research Questions Review

All the **research questions** are answered and the **research objectives** for this study are met:

Firstly, the Enterprise Engineering Life Cycles are understood. Next the context of the Technology Life Cycle is understood. The maturity of current technologies used in pivot irrigation systems are analysed and discussed. This includes the movement of pivot irrigation systems, water consumption and irrigation scheduling, soil moisture and power consumption. Further the maturity of some IoT technologies are analysed and discussed. This includes mobile App technology, JSON string communication, the ESP 32 Module, and the RS 485 Transceiver.

A product, the Powasave System, is developed that reduces the power and water consumption of pivot irrigation systems with the help of IoT technology. The design is based on design requirements obtained from the user need to reduce water and power consumption. The product is tested by executing three experiments and it is found that the product adheres to the design requirements and specifications. A cost analysis is performed to determine the cost of the developed product and is compared to Conventional Systems that are already on the market. The pumping power and payback period is also analysed, compared, and discussed. Lastly, a business model is developed for an Enterprise to commercialise the developed product.

6.1.2. Enterprise Engineering Life Cycles Review

The following conclusions can be made with regards to the **Enterprise Engineering Life Cycles**:

Technology Life Cycle

The developed product is still in the innovator's technology enthusiasts category and perhaps moving toward the early adopters, visionaries category of Figure 5. As for the Technology Life Cycle of Figure 6, the technology firstly moved through the Identification phase when the problem was identified that a lot of water and power losses occur when irrigating with Pivot irrigating systems. Secondly, it moved through the Solution Architecture phase when a solution to the identified problem was obtained. This was done by defining the product requirements and specifications as to how water losses and power consumption in pivot irrigation systems can be reduced. Thirdly, it moved through the Development phase when the solution to this identified problem was developed. The next phase would be to enter the implementation phase but that is outside the scope of this study.

Product Life Cycle

The Product Life Cycle is similar to the Technology Life Cycle. From Chapter 4 it is evident that the concept, definition and design phase of the Product Life Cycle as seen in Figure 7 is completed. The next phase that the product will enter is the Industrialisation phase but that is outside the scope of this study.

The product is also in the first iteration. Once it passes through to the Industrialisation and Production phases new development will be identified and the product will enter a second iteration.

Some new development or design improvements that have already been identified are, to source an improved soil moisture sensor that can measure the soil moisture at deeper soil levels. Improve the electronic board and 3D printed housings since the ones used in this study are only prototypes. Improve the look and feel of the mobile App.

As for the product maturity life cycle of Figure 8, the product is still before the introduction phase since the product has not yet entered the market.

Enterprise Life Cycle

The enterprise has passed through the Identification, Concept and Preliminary Design phase of the Enterprise Life Cycle seen in Figure 9. The preliminary design was developed in Chapter 5 by generating a business model.

Considering how rapid technology is advancing in current times, sectors can no longer afford not to include IoT technologies to improve business strategies.

6.2. Limitations, Recommendations, and Future Work

There are still some limitations to this study that will have to be addressed in future work. These issues were not investigated since it fell outside of the scope of this study. These are important aspect to make the Powasave concept viable in the field.

A recommendation for future work is to investigate an improved solution for the soil moisture sensor. The most appropriate location to place the soil moisture sensor to represent the soil moisture of the whole field will also have to be investigated. Another recommendation is to obtain crop specific data on water requirements and include it as a setting on the mobile App so that the App will pre calculate the minimum and maximum soil moisture requirement based on the crop type. Further study will also be required to establish exactly how the Powasave system will link to current pivot OME controls.

The power source

The power source is discussed in Section 4.4.1. The Powasave system will use the same power supply as the pivot irrigation system since there is already power on the system to power the pump and drive unit. Should the need arise a solar panel and battery pack to power the primary and secondary system of the Powasave can be investigated.

Filtration

Any hole size for the Powasave sprayer is possible depending on the water quality and filtration. Filtration is always going to be part of any pivot irrigation system. The water quality will be dependent on how well the performance of the irrigation system is. Thus, in future it will be very important to ensure that proper filtration is in place on pivots that irrigate using the Powasave sprayer.

Soil Compaction

According to Budler (2017), the Powasave sprayer can be designed to emit a droplet size that will best suit the irrigation need to minimise soil compaction and soil crusting. A suggestion for future study could also be to investigate the effects of the Powasave systems droplet size affect tillage and no-till agricultural methods and which crops are most suitable for irrigation with the Powasave sprayer.

Stability of the Powasave sprayers once mounted on the Pivot

A very important aspect to make the Powasave concept viable is to ensure that the Powasave sprayers are stable once mounted on the pivot structure. This unfortunately fell outside the scope of this study but will have to be investigated to ensure the success of the Powasave system once it is being tested in the field.

6.3. Concluding Discussion

In this study an innovative solution, the Powasave System, is developed that considerably reduces the power and water consumption of pivot irrigation systems. This is achieved by irrigating with a much larger droplet diameter, resulting in the droplets to be heavier resulting in reduced evaporation and wind drift losses. To produce the larger droplets, the Powasave System irrigates at much lower operating pressures than Conventional Systems. This results in a reduction in pumping power requirement and thus a reduction in operating costs.

The pumping power cost can be considerably reduced with the Powasave concept when compared to the Conventional pivot irrigation systems, depending on the slope of the field, the crop being irrigated, the WS%, and the cost of electricity.

Even though the initial capital costs of the Powasave are more than Conventional irrigation systems the operating costs are less making it the cheaper solution over time. The average payback period is found to be between 1-2 years, depending on the type of crop being irrigated and the cost of electricity. In the worst-case scenario the payback period is approximately 4 and a half years.

A further value, and arguably the biggest value adding factor of this study, is the ability to incorporate IoT technology with pivot irrigation systems. The Powasave System can be controlled with a mobile

App and irrigation scheduling is based on environmental conditions to ensure an optimal water usage for an optimal crop yield.

A soil moisture sensor is used to avoid over or under irrigation, ensuring that the crop is irrigated with the exact amount of required water. Each crop has a soil moisture requirement to grow. The soil moisture can be controlled with the Powasave concept ensuring an optimal crop growth and crop yield. The wind speed is also considered to avoid wind drift losses as much as possible. This is done by not irrigating at high wind speeds without letting the crop suffer from under irrigation.

This study has the potential of reducing the overall cost of farming with crops and increasing the crop yield. Not only is the pumping power and water consumption reduced but a reduction in agricultural land cost and water storage facilities can also potentially be reduced. Thus, enabling crop farming in arid areas that was previously not suitable due to low water availability.

This technology can be widely used in the agricultural sector, not just on pivot irrigation systems, but also on many different sections of the agricultural sector, like temperature or moisture control of green houses. It can also be implemented in many other sectors like home automation, supply chains etc. Any sector that requires specific conditions to be monitored remotely over a mobile App will benefit from this research.

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Appendix A: Web Server Screen Shot

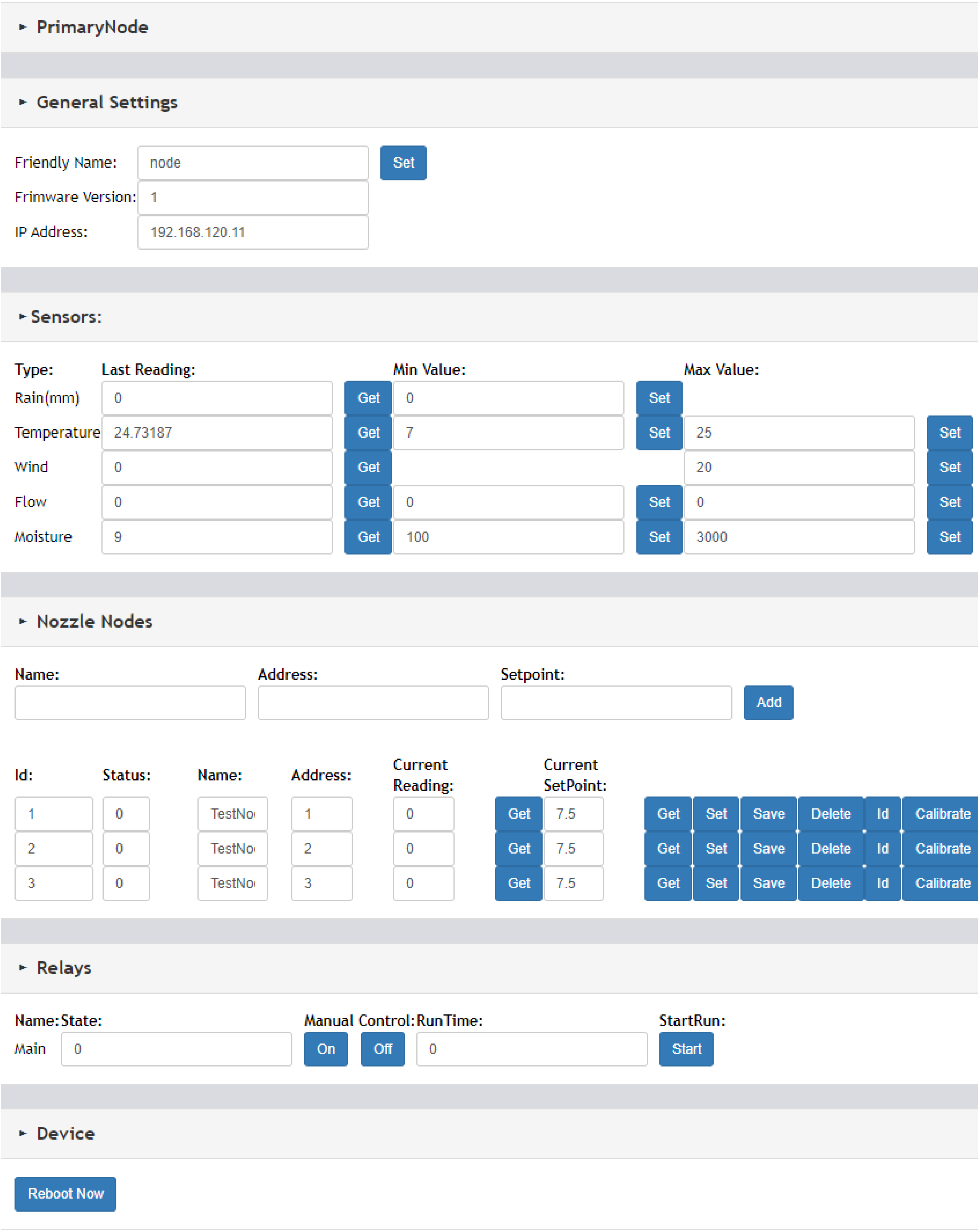


Figure 68: Web Server Screen Shot

Appendix B: Data structure of the JSON string


```
{
  "data": {
    "setting": {
      "friendlyName": "SmartNode01",
      "FirmwareVersion": 1,
      "IPAddress": ""
    },
    "sensors": {
      "rain": {
        "reading": 0.0,
        "cutOffValue": 0.0,
        "cutoffDuration": 0,
        "minValue": 0,
        "maxValue": 0
      },
      "temp": {
        "reading": 0.0,
        "cutOffValue": 0.0,
        "cutoffDuration": 0,
        "minValue": 0,
        "maxValue": 0
      },
      "wind": {
        "reading": 0.0,
        "cutOffValue": 0.0,
        "cutoffDuration": 0,
        "minValue": 0,
        "maxValue": 0
      },
      "flow": {
        "reading": 0.0,
        "cutOffValue": 0.0,
        "cutoffDuration": 0,
```

```
  "minValue": 0,
  "maxValue": 0
},
"moisture": {
  "reading": 0.0,
  "cutOffValue": 0.0,
  "cutoffDuration": 0,
  "minValue": 0,
  "maxValue": 0
},
"nodes": {
  "numberOfNodes": 3,
  "linkedNodes": [
    {
      "id": "Span01N01",
      "address": 1,
      "setPoint": 0,
      "reading": 0
    },
    {
      "id": "Span01N02",
      "address": 2,
      "setPoint": 0,
      "reading": 0
    },
    {
      "id": "Span01N03",
      "address": 3,
      "setPoint": 0,
      "reading": 0
    }
  ]
},
"relay": {
  "state": 0,
```

"onFor": 0
}
}
}
}

Appendix C: Parts List and Cost

Table 19: Primary System Electronic Parts

Symbol	Part	Value	Cost	
			Local	**Bulk**
B1	Logic Level Converter	LOGIC_LEVEL_CONVERTER	ℂ 47,92	ℂ 1,45
C1	Capacitor	0.1uF	ℂ 3,00	ℂ 3,00
C2	Capacitor	10uF	ℂ 1,00	ℂ 1,00
C3	Capacitor	0.1uF	ℂ 3,00	ℂ 3,00
C4	Capacitor	1uF	ℂ 0,50	ℂ 0,50
C5	Capacitor	0.1uF	ℂ 3,00	ℂ 3,00
IC1	Voltage Regulator	LD117AV33	ℂ 5,50	ℂ 5,50
J1	Ethernet Jack	RJ45	ℂ 28,52	ℂ 2,18
J2	3 Pin Screw Terminal	Relay	ℂ 7,20	ℂ 7,20
J3	3 Pin Screw Terminal	Moisture	ℂ 7,20	ℂ 7,20
J4	3 Pin Screw Terminal	Temp	ℂ 7,20	ℂ 7,20
J5	3 Pin Screw Terminal	Wind	ℂ 7,20	ℂ 7,20
J6	2 Pin Screw Terminal	Rain Fall	ℂ 6,00	ℂ 6,00
J7	2 Pin Screw Terminal	Water Flow	ℂ 6,00	ℂ 6,00
R1	Resistor	330	ℂ 0,01	ℂ 0,01
R2	Resistor	1k	ℂ 0,03	ℂ 0,03
R3	Resistor	10k	ℂ 0,05	ℂ 0,05
R4	Resistor	15k	ℂ 0,08	ℂ 0,08
R5	Resistor	4.7k	ℂ 0,04	ℂ 0,04
SV1	6 Pin Pitch Connector Head	Debug	ℂ 0,50	ℂ 0,50
U$1	ESP 32	ESP32DEVKITV1	ℂ 129,00	ℂ 49,16
U$2	Voltage Regulator	LM350	ℂ 10,20	ℂ 10,20
U$3	Power Jack	2.1MMJACKTHM	ℂ 28,00	ℂ 1,45
U$4	RS 485 Transceiver	MAX485DIL	ℂ 93,00	ℂ 29,00
U$5	Tactile Switch	TACTILE-SWITCH-PTH	ℂ 2,25	ℂ 2,25
	Board	Electronic board	ℂ 50,00	ℂ 38,00
Total			**ℂ 446,40**	**ℂ 191,19**

Table 20: Primary System Sensors and Housing Cost

Part	Cost
Wind Sensor	ℂ 430,00
Flow Sensor	ℂ 550,00
Rain Sensor	ℂ 500,00
Moisture Sensor	ℂ 750,00
Temperature Sensor	ℂ 2,00
Housing	ℂ 30,00
Total	**ℂ 2 262,00**

Table 21: Secondary System Electronic Parts

Symbol	Part	Value	Cost	
			Local	Bulk
C1	Capacitor	1000µF	₵ 8,50	₵ 0,49
C2	Capacitor	1000µF	₵ 8,50	₵ 0,49
C3	Capacitor	10µF	₵ 1,00	₵ 1,00
C4	Capacitor	0.1uF	₵ 3,00	₵ 3,00
C5	Capacitor	22pF	₵ 1,99	₵ 1,99
C6	Capacitor	22pF	₵ 1,99	₵ 1,99
C7	Capacitor	0.1uF	₵ 3,00	₵ 3,00
C8	Capacitor	0.1uF	₵ 3,00	₵ 3,00
C9	Capacitor	0.1uF	₵ 3,00	₵ 3,00
C10	Capacitor	1µF	₵ 0,50	₵ 0,50
C11	Capacitor	0.1µF	₵ 3,00	₵ 3,00
DEBUG	6 Pin Pitch Connector Head	FTDI	₵ 0,50	₵ 0,50
J1	Ethernet Jack	RJ45	₵ 28,52	₵ 2,18
J2	Ethernet Jack	RJ45	₵ 28,52	₵ 2,18
J3	3 Pin Screw Terminal	PRESSURE	₵ 7,20	₵ 1,45
PWR	LED	GRN	₵ 5,00	₵ 1,45
Q1	Crystal Oscillator	16Mhz	₵ 4,95	₵ 0,73
R1	Resistor	2.2	₵ 0,40	₵ 0,40
R2	Resistor	10k	₵ 0,05	₵ 0,05
R3	Resistor	220	₵ 0,03	₵ 0,03
R4	Resistor	1k	₵ 0,03	₵ 0,03
R5	Resistor	330	₵ 0,01	₵ 0,01
R6	Resistor	220	₵ 0,03	₵ 0,03
RESET	Tactile Switch	MOMENTARY-SWITCH-SPST-PTH-6.0MM	₵ 2,25	₵ 0,58
RN2	Resistor	10k	₵ 0,05	₵ 0,05
SERVO	3 Pin Pitch Connector Head	PWM	₵ 0,50	₵ 0,50
STATUS	LED	GRN	₵ 5,00	₵ 1,45
SW1	DIP Switch	ADR	₵ 11,80	₵ 0,29
U$1	RS 485 Transceiver	MAX485DIL	₵ 93,00	₵ 29,00
U$2	Voltage Regulator	LM350	₵ 10,20	₵ 10,20
U1	ATMEGA328P Microcontroller	328P	₵ 37,40	₵ 25,67
	Board	Electronic board (estimate)	₵ 50,00	₵ 38,00
Total			**₵ 322,92**	**₵ 136,23**

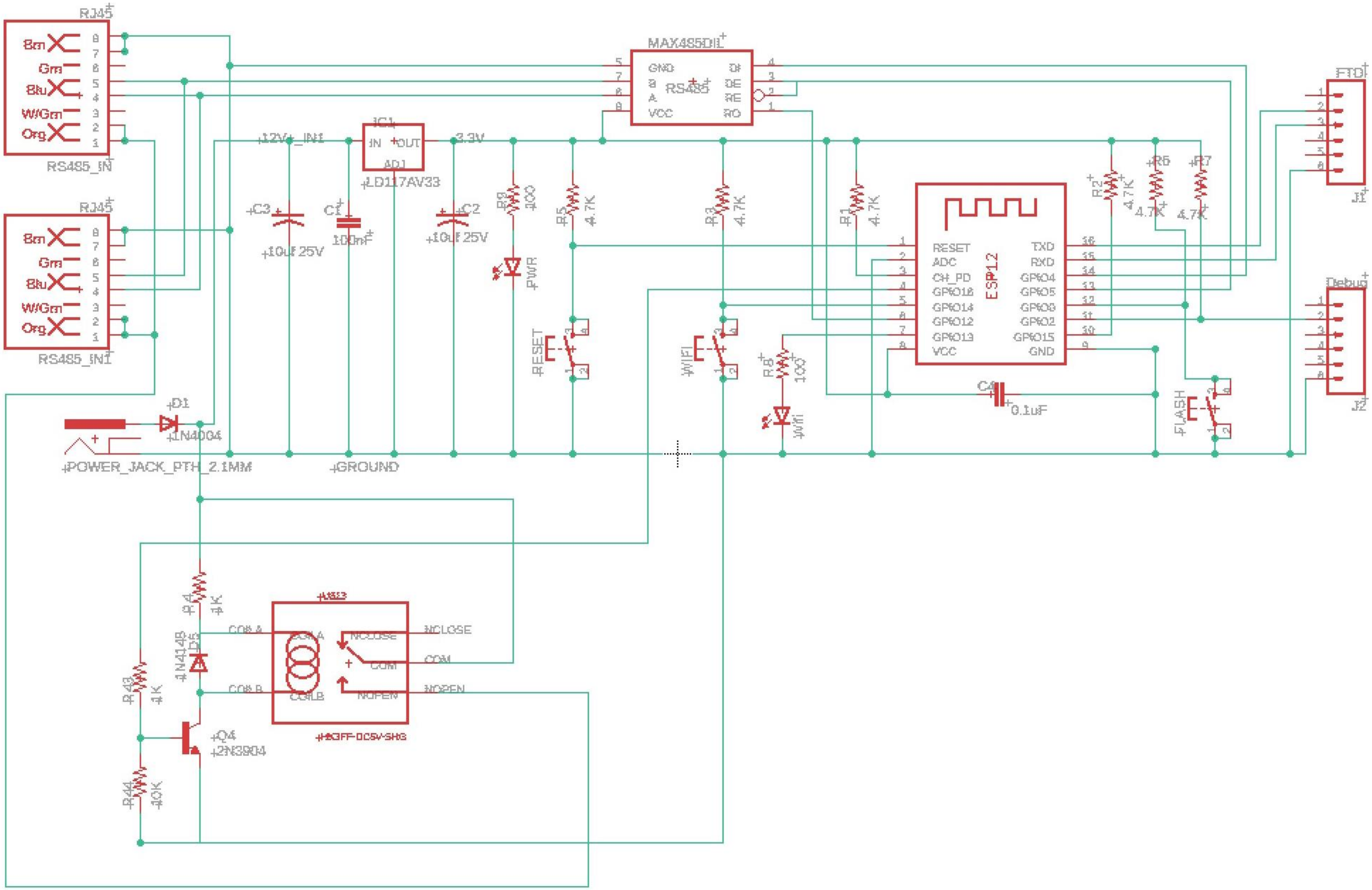
Table 22: Parts List of Pressure Regulator and Powasave Sprayer

Part	**Cost**	
	Local	**Bulk**
Gate valve	₵ 121,96	₵ 72,50
Pressure Sensor	₵ 114,50	₵ 115,86
Servo Motor	₵ 194,35	₵ 38,43
Housing	₵ 50,00	₵ 25,00
Powasave Sprayer	₵ 80,00	₵ 80,00
Total	₵ **560,81**	₵ **331,79**

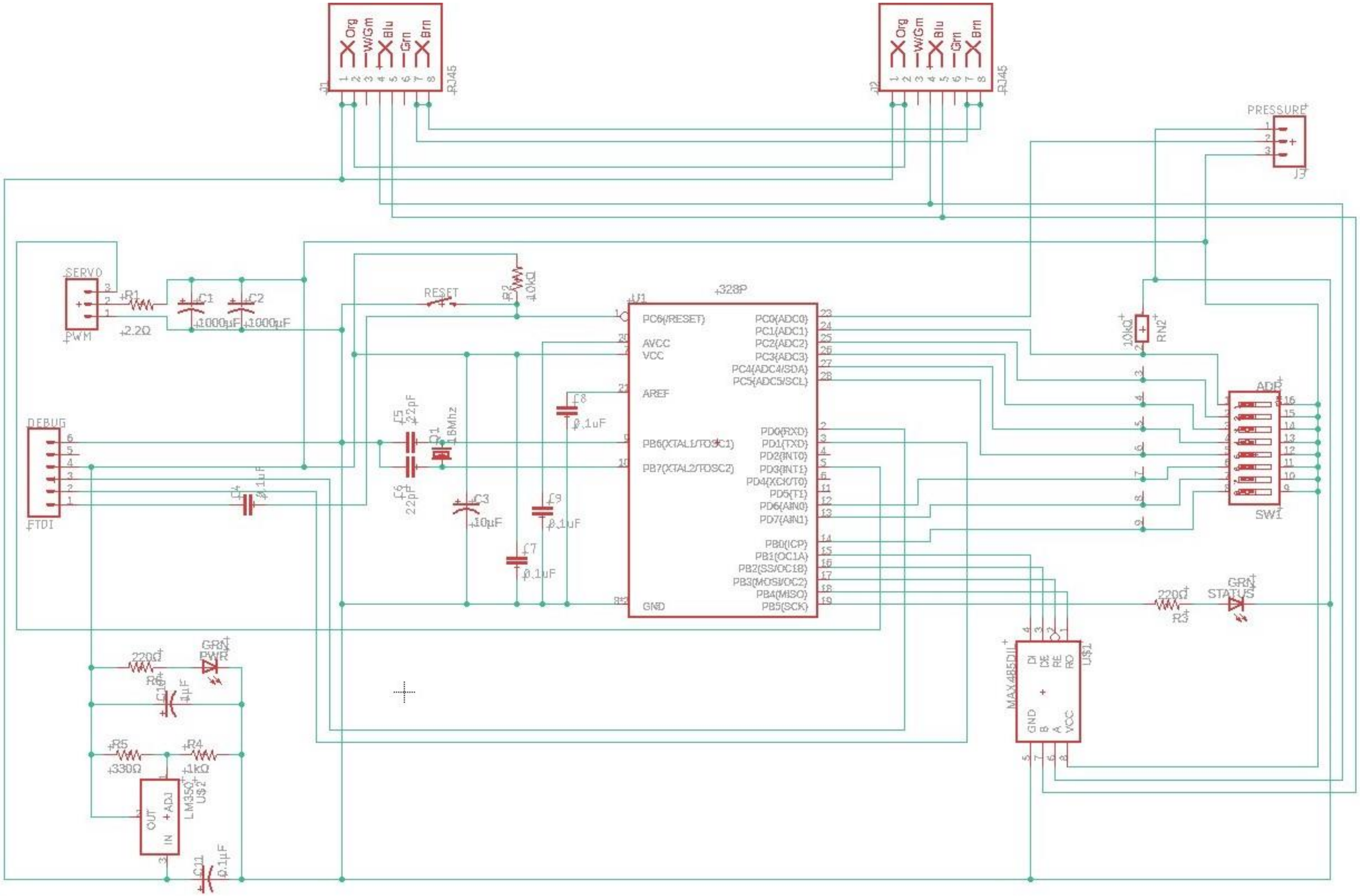
Table 23: Other Costs

Primary System per sprayer	₵ 30,66
Approximate labour cost of production per unit	₵ 50,00
Total	₵ **80,66**

Appendix D.1: Schematics of Primary Circuit Board



Appendix D.2: Schematics of Secondary Circuit Board



Appendix E: CAD Drawings

Note that the following CAD drawings are not formal drawings. Since the parts are 3D printed formal drawings are not required. These drawings are only to obtain the general size of the parts.

Figure 69 is the drawing of the Primary System housing and Figure 70 is the drawing of the Secondary System housing. Figure 71 is the drawing of the primary and Secondary System housing lid. The parts are designed that the primary and secondary housings use the same lid design making production cheaper and assembly easier. Figure 72 is the drawing of the servo motor housing and Figure 73 is the drawing of the servo motor housing lid.

Appendix E.1: Primary System Housing

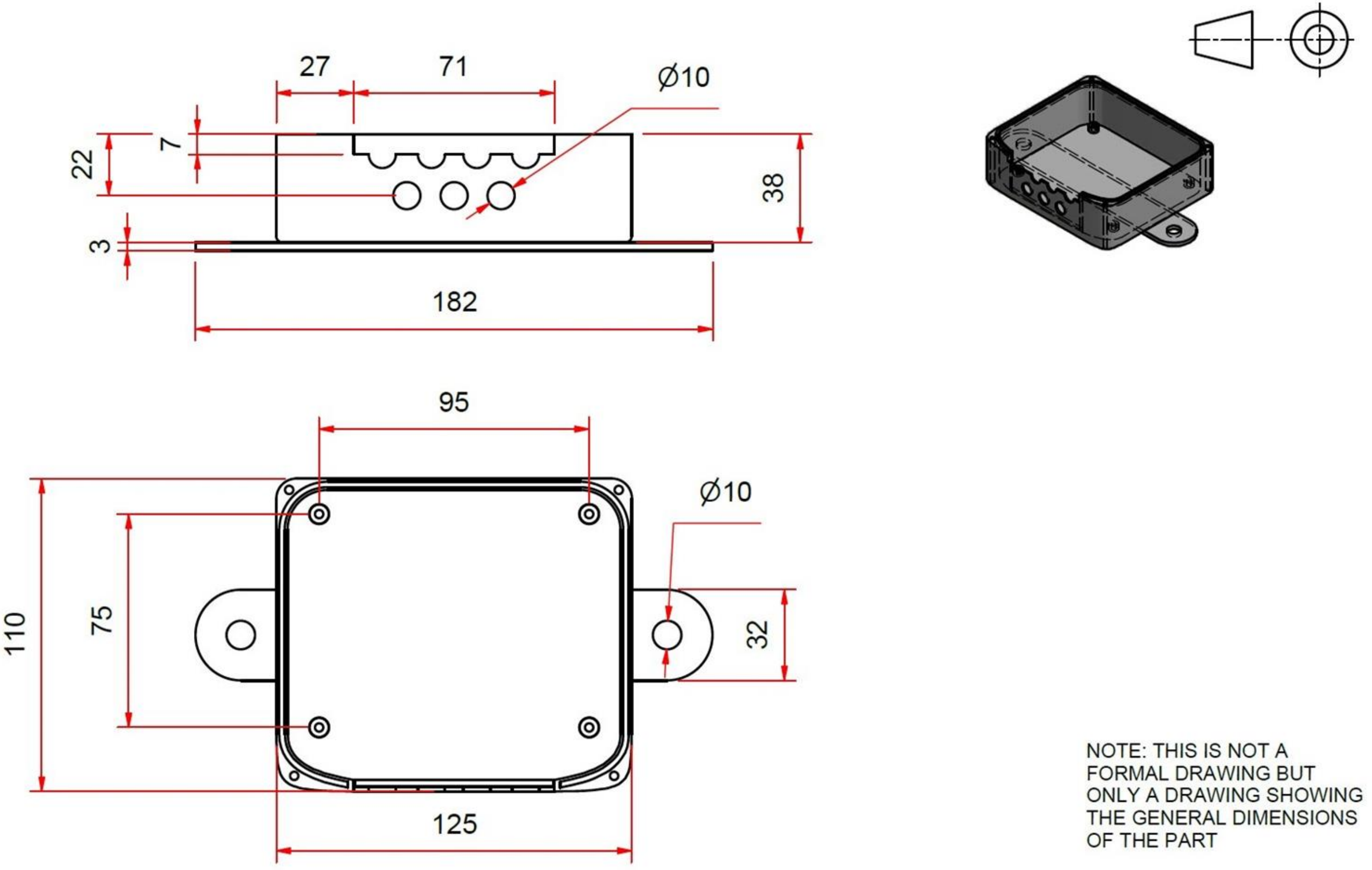


Figure 69: Drawing of Primary System Housing

Appendix E.2: Secondary System Housing

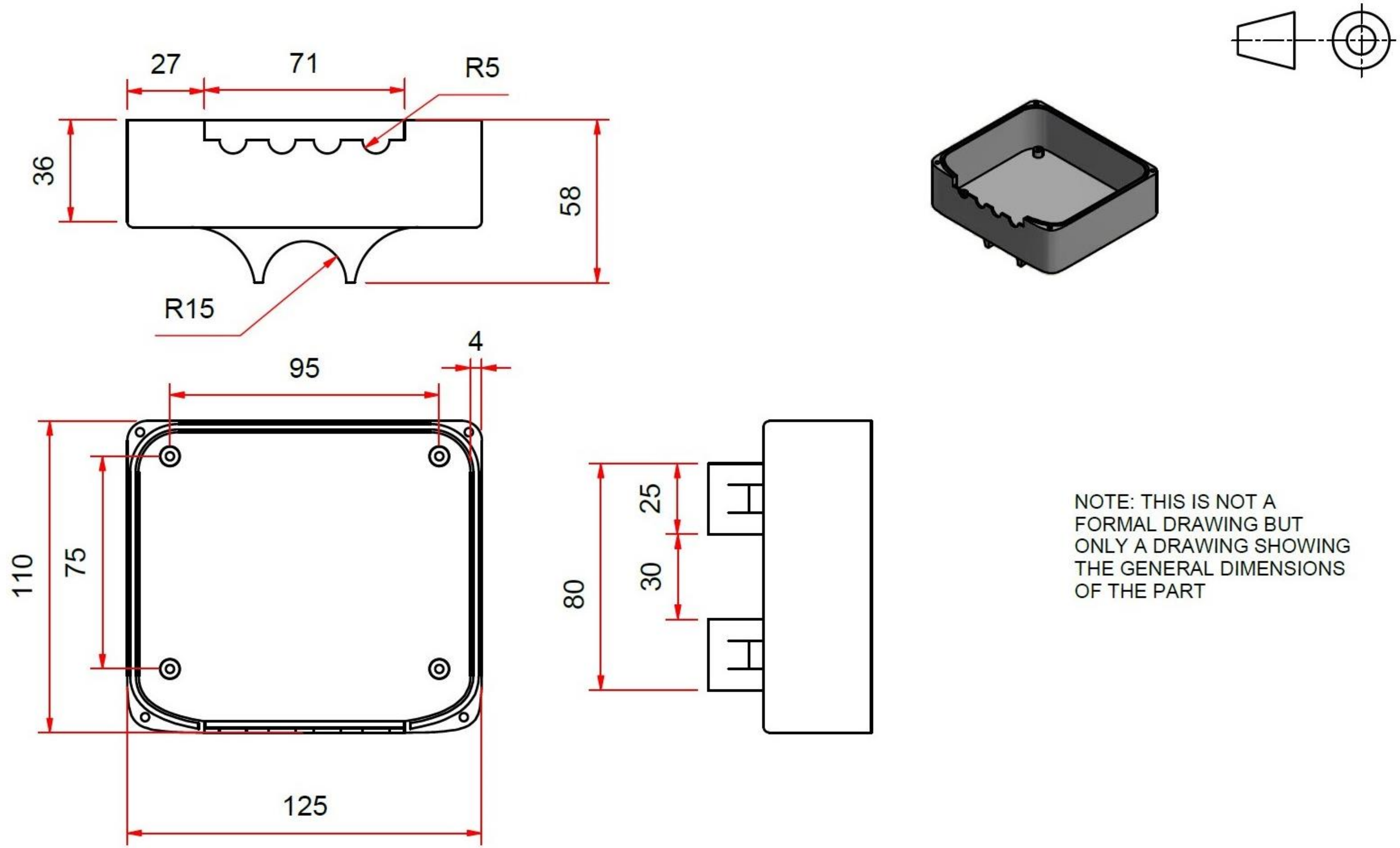


Figure 70: Drawing of Secondary System Housing

Appendix E.3: Primary and Secondary System Housing Lid

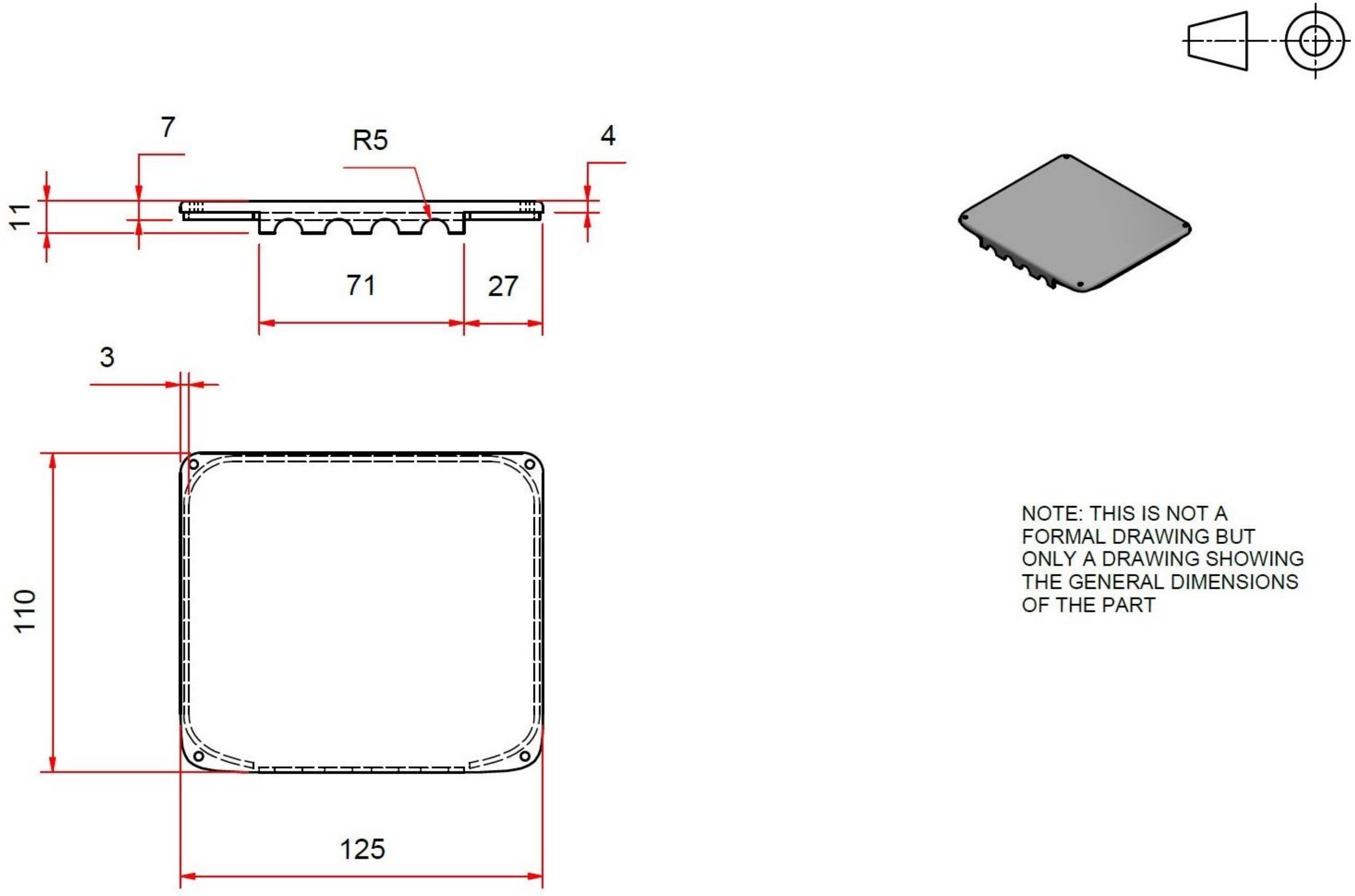


Figure 71: Drawing of Primary and Secondary System Housing Lid

Appendix E.4: Servo Motor Housing

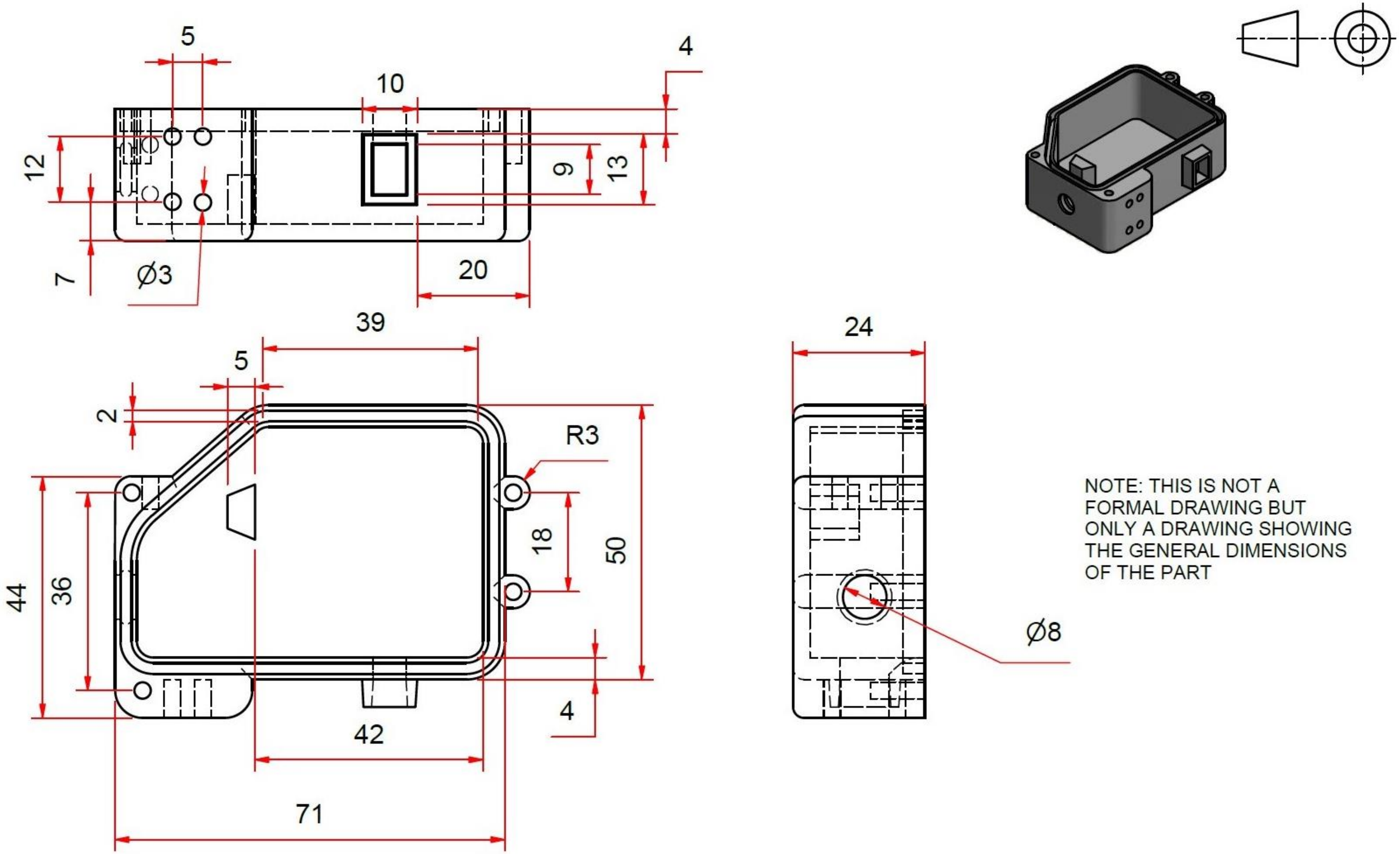


Figure 72: Drawing of Servo Motor Housing

Appendix E.5: Servo Motor Housing Lid

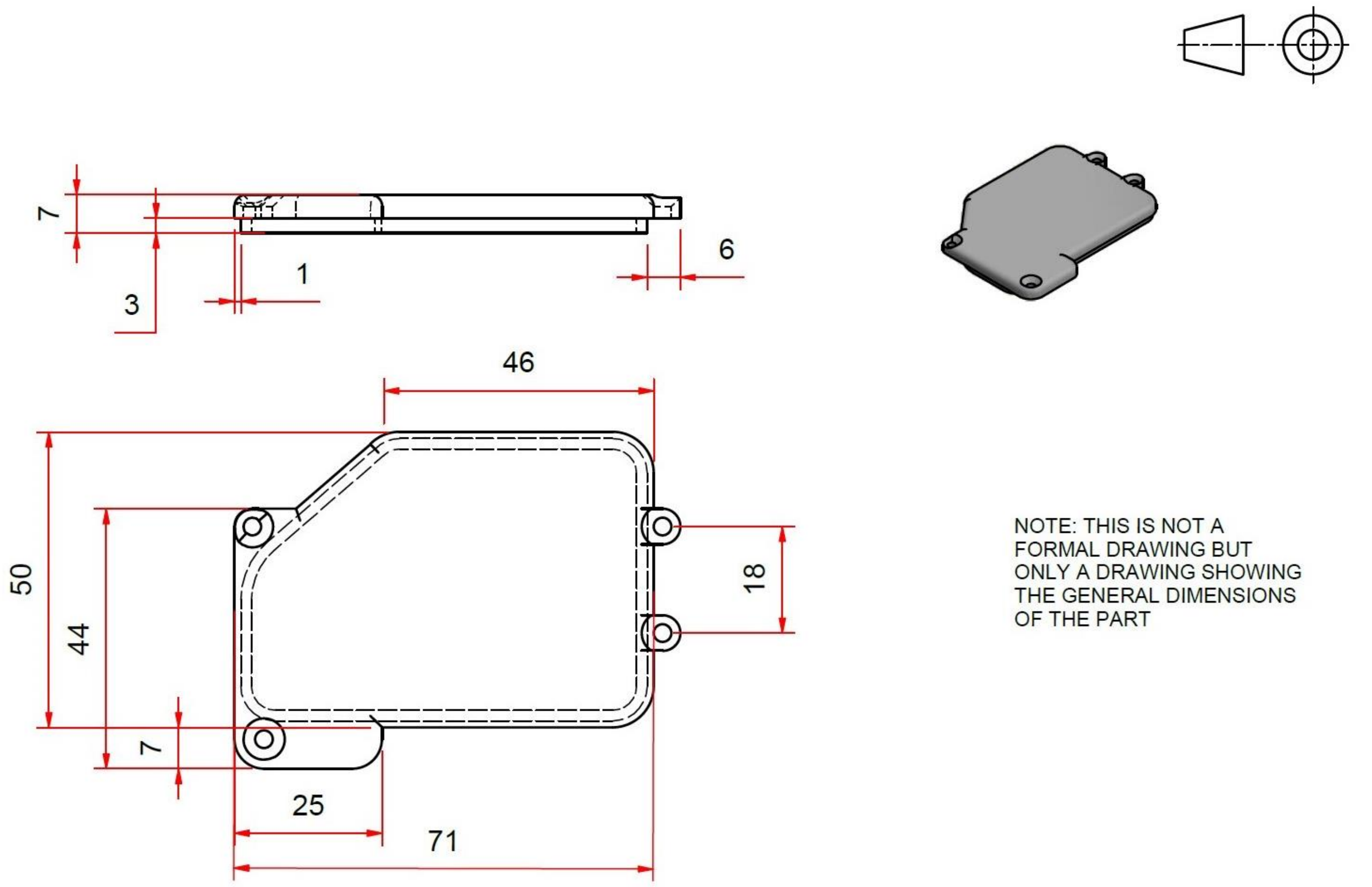


Figure 73: Drawing of Servo Motor Housing Lid

Appendix F: Cost Analysis Tables

Table 24: Crop Water Usage and Irrigation Time

Crop	Water Requirement	Water Requirement	Water for Tillage	Total Water Requirement	Total Volume*	Total Irrigation Time	Total Days
Unit	**(mm)**	**(m^3/ha)**	**(mm)**	**(mm)**	**(m^3)**	**(s)**	**(8h a day)**
Corn	618	6180	20	638	137516	4192558	146
Wheat	557	5570	20	577	124368	3791702	132
Lucerne	1090	10900	0	1090	234941	7162834	249
Average							**175**

* Based on a 262 m Pivot with an average of 80 sprayers with an average flow rate of 24,6 L/min per sprayer and irrigating 8 hours a day.

Table 25: Geodetic Pressure Head in System over Slope Range of 0-15°

Slope (°)	H_g (m)
0	0
1	4,5702
2	9,1390
3	13,7051
4	18,2669
5	22,8233
6	27,3726
7	31,9137
8	36,4450
9	40,9652
10	45,4730
11	49,9669
12	54,4457
13	58,9078
14	63,3520
15	67,7770

Table 26: Pumping Cost Saving per Slope and WS% at $c = 180$ ¢/kWh

Slope (°)	**Water Saving Percentage (WS%)**			
	0%	**15%**	**30%**	**50%**
0	5,9995	7,0586	8,5716	12,0010
1	7,8677	9,2568	11,2412	15,7393
2	9,7353	11,4543	13,9101	19,4764
3	11,6018	13,6505	16,5773	23,2113
4	13,4666	15,8447	19,2421	26,9428
5	15,3291	18,0363	21,9036	30,6697
6	17,1888	20,2244	24,5611	34,3909
7	19,0451	22,4086	27,2137	38,1053
8	20,8974	24,5881	29,8607	41,8118
9	22,7451	26,7623	32,5011	45,5091
10	24,5878	28,9305	35,1343	49,1963
11	26,4248	31,0920	37,7594	52,8722
12	28,2556	33,2462	40,3757	56,5357
13	30,0797	35,3925	42,9822	60,1856
14	31,8964	37,5301	45,5783	63,8208
15	33,7052	39,6584	48,1631	67,4402

Table 27: Pumping Cost Saving per Slope and WS% at $c = 500/\text{kWh}$

Slope (°)	**Water Saving Percentage (WS%)**			
	0%	**15%**	**30%**	**50%**
0	16,6652	19,6071	23,8099	33,3362
1	21,8546	25,7133	31,2256	43,7203
2	27,0425	31,8176	38,6391	54,1012
3	32,2272	37,9181	46,0480	64,4758
4	37,4072	44,0131	53,4502	74,8410
5	42,5808	50,1007	60,8434	85,1935
6	47,7466	56,1790	68,2253	95,5302
7	52,9029	62,2462	75,5937	105,8480
8	58,0482	68,3004	82,9463	116,1438
9	63,1809	74,3398	90,2809	126,4143
10	68,2995	80,3625	97,5954	136,6565
11	73,4023	86,3667	104,8873	146,8673
12	78,4879	92,3506	112,1546	157,0435
13	83,5546	98,3124	119,3950	167,1821
14	88,6010	104,2503	126,6063	177,2800
15	93,6256	110,1623	133,7863	187,3340

Table 28: Cost of Electricity in Rural/Farming Areas (Energy Price Report, 2018)

Year	**Cost (¢/kWh)**
2009	45,78
2010	58,96
2011	72,72
2012	89,22
2013	99,75
2014	108,75
2015	115,66
2016	128,19
2017	141,7
2018	142,78

Appendix G: Business Model Canvas

<table>
<tr>
<td rowspan="2"><u>Key Partners</u>
A Joint venture between Powasave and another well-established pivot irrigation manufacturing company is proposed.

The motivation for a partnership is reduction of risk and uncertainty, and the acquisition of resources and activities.

Other partners:
Suppliers of parts and raw materials,
App store, and
Google Play store.</td>
<td><u>Key Activities</u>
The key activities are development and Production of the Powasave product

Maintain the software of the mobile App and Web server of the Powasave product

Other key activities are marketing, sales, installation, and support.</td>
<td rowspan="2" colspan="2"><u>Value Propositions</u>
The value of the product is the ability to control irrigation systems with IoT technology and remotely check on conditions.
Reduction of overall water and power costs.
Potential increase in crop yield.
Increase of profitability of crop farming.</td>
<td><u>Customer Relationships</u>
Personal assistance available for installation and online or in app self-service training platforms with Automated services to notify customers of software updates and new features.</td>
<td rowspan="2"><u>Customer Segments</u>
Powasave targets farmers that wish to reduce the overall water and power costs involved with pivot irrigation systems.

Also, farmers that wish to have remote control over pivot irrigation systems and be able to check conditions via a mobile device.</td>
</tr>
<tr>
<td><u>Key Resources</u>
The intellectual property of the design of the Powasave sprayer.
Software of the mobile App and Webserver, firmware design and existing customer relationships</td>
<td><u>Channels</u>
Existing customer channels are used to create awareness of the new product via email and telephone calls.

Sales are facilitated via EFT or card payments.

The mobile App and website are other communication channel where new features will be communicated.

After sales support will be done via telephone calls, the mobile App and in person assistance.</td>
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<td colspan="3"><u>Cost Structure</u>
The company will have a cost-driven structure but still strive to deliver a high-quality product that provides good value to the customer. The costs involved are: cost of the raw materials, running costs of production, labour cost, marketing cost, and call out and installation costs</td>
<td colspan="3"><u>Revenue Streams</u>
Asset sales of the hardware and firmware
Subscription fee of the mobile App (Software)</td>
</tr>
</table>