An-Najah National University

Faculty of Graduate Studies

Life Cycle Costing Analysis of Polyethylene and Polycarbonate Greenhouses in the West Bank

By

Dyana Azzam Nassif

Supervisors

Dr. Abdel Fattah R. Hasan

Dr. Monther B. Dweikat

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This Thesis was defended successfully on 8/9/2021 and approved by:

Defense Committee Members	**Signature**
– **Dr. Abdel Fattah R. Hasan/ Supervisor**	**…..……..…………**
– **Dr. Monther B. Dweikat / Co- Supervisor**	**……..…………….**
– **Dr. Yahya Istaitih / External Examiner**	**….………………..**
– **Dr. Riyad Abedel Karim / Internal Examiner**	**…..………………..**

Dedication

To my father's soul who loved me unconditionally

To my mother who always supports me

To my husband Ameed who believes in me

To my beloved sons Marwan and Aser, so you always pursue your dreams

To my brothers Salim, Wasim, and my sister Selena

To my nephews and nieces

To all of my family and friends who gave me the courage to continue in times of desperation

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Thanks to my husband and my kids for being my happy place.

Thanks to my brothers and sister for always being there for me.

Last but not least, my forever gratitude is to my parents, who empowered me with their love and support.

الإقرار

أنا الموقعة أدناه، مقدمة الرسالة التي تحمل العنوان:

Life Cycle Costing Analysis of Polyethylene and Polycarbonate Greenhouses in the West Bank

أقر بأنّ ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأنّ هذه الرسالة كاملة أو أي جزء منها، لم يُقدم من قبل للحصول على أي لقب أو بحث لدى أي مؤسسة بحثية أخرى.

Declaration

The work provided in this thesis unless otherwise referenced is the researcher own work and has not been submitted elsewhere for any other degree or qualification.

Student's Name:	**ديانا عزام ناصيف**	**اسم الطالب:**
Signature:		**التوقيع:**
Date:	**8/9/2021**	**التاريخ:**

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List of Abbreviations

GDP	**Gross Domestic Product**
UNCTAD	United Nations Conference on Trade and Development
PARC	Palestinian Agricultural Relief Committee
PADRRIF	Palestinian Disaster Risk Reduction and Insurance Fund
FAO	Food and Agriculture Organization
NPV	Net Present Value
NIS	New Israeli Shekel
LDPE	Low-density polyethylene
LCC	Life Cycle Costing
ISO	The International Organization for Standardization
MOA	Palestinian Ministry of Agriculture
SAP	Structural Analysis Program
ASCE	American Society of Civil Engineers

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Abstract

The Palestinian greenhouse agriculture is suffering from the weather conditions in the winter season, leaving the farmers with many losses in the greenhouse sructure and the inside plants.

The farming industry in Palestine uses polyethylene as a covering material for greenhouse space buildings. The harsh weather conditions in winter cause rupture of the polyethylene sheets and lead to tremendous losses. Many countries nowadays use polycarbonate sheets to cover the greenhouse, for its many useful properties, mainly toughness against harsh weather conditions and long-life duration. However, switching from polyethylene to polycarbonate might be an expensive plan.

This research suggests eight polycarbonate greenhouse structural designs suitable to be used in the West Bank, and those eight designs are checked using SAP2000 computer software under the different load combinations of four Palestinian agricultural zones. The Palestinian MoA divided the West Bank into four agricultural zones, An-Nassareya, Tammoun, Qabatia, and Hebron on one of their projects, and those four zones are used by this research.

For every zone, only one design that has the lowest initial construction cost is adopted.

This study also performs life cycle cost analysis of the certified Palestinian polyethylene greenhouse, and life cycle cost analysis of the adopted polycarbonate greenhouse along their life period, twenty years. Eventually, the net present value for both types of greenhouses is found and compared.

It’s been found that switching from polyethylene sheeting to polycarbonate sheeting is indeed an expensive procedure, and it will add to the cost of the farmers almost 25% more in An-Nassareya, Tammoun, and Qabatia zones, and it will also add to the cost of the farmers almost 40% more in Hebron zone.

Chapter One

Introduction

Chapter One

Introduction

Overview

The agricultural sector in Palestine is an essential part of the economic activities contributing to the Palestinian GDP. The contribution of the Palestinian agricultural activities to the GDP has been falling steadily since the 1990s ((UNCTAD), 2001; (PARC), 2005; (PADRRIF), 2017)).

Protected agriculture or controlled farming is becoming more reliable and practical. The greenhouse is considered a sophisticated secure environment, is spreading widely globally, especially in Europe (Nadal et al., 2017). The Mediterranean region is increasingly competing in growing greenhouses plants (FAO, 2013).

Palestinian agriculture also is relying on greenhouses. In 2017, the number of greenhouses in the west Bank reached 10,316 greenhouses (PADRRIF, 2017).

1.1. Research Problem

Agriculture in Palestine is suffering from many losses due to different causes. The tremendous losses which farmers are facing are driving investors away from investing in the agricultural sector. Some of the agricultural sector obstacles are trade restrictions across border points, labor forces switching from agriculture towards working in the occupied lands, restrictions to access natural sources, agriculture financing difficulties, and weakness of agricultural services (Hussain Abugamea, 2008).

Another reason is the heavy losses in the Palestinian economy due to greenhouse damages caused by extreme weather conditions in winter, having a significant share of the agricultural losses. Records show about NIS 56,000,000 loss in the greenhouses agriculture sector in 2012-2015, only because of weather conditions (PADRRIF, 2017). Table (1) shows the damaged greenhouses spaces, the percent of damaged crops in damaged greenhouses, and the economic losses these damages are causing ((PADRRIF), 2017).

Figures (1) and (2) show the number of damaged greenhouses in 2015, and Figures (3) and (4) show the financial losses in 2015.

Table 1: Palestinian greenhouses losses from 2012-2015 (PADRRIF, 2017)

City	Damaged spaces (dunum)	percent of damaged crops in damaged greenhouses (%)	Greenhouse's losses in (NIS)
Tubas	6,483	81	20,000,000
Jenin	7,556	61.3	17,000,000
Hebron	2,651	70	6,000,000
Tulkarem	1,578	67	5,000,000
Jericho	562	99	3,000,000
Qalqelia	2,733	80	3,000,000
Nablus	9,948	89	2,000,000
Ramallah	89	99	1,000,000
Betlehem	120	75	500,000
Salfit	28.5	39.5	140,000

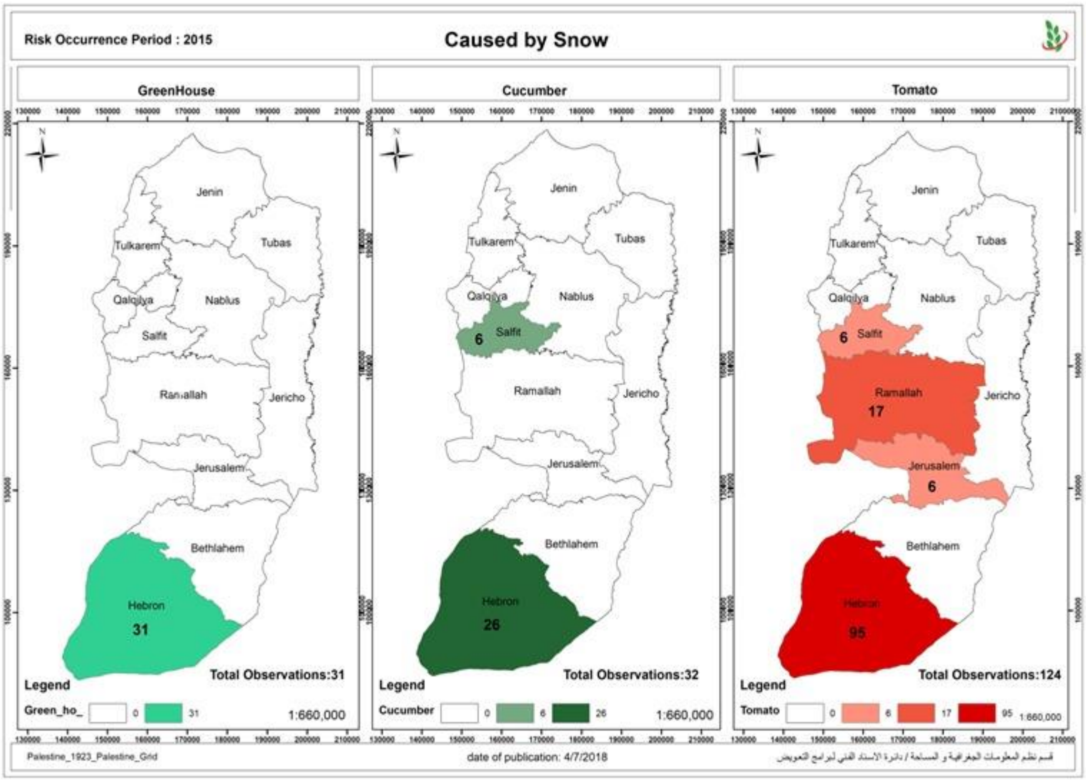

Figure 1 The number of damaged greenhouses in 2015 due to snow load (PADRRIF, 2017).

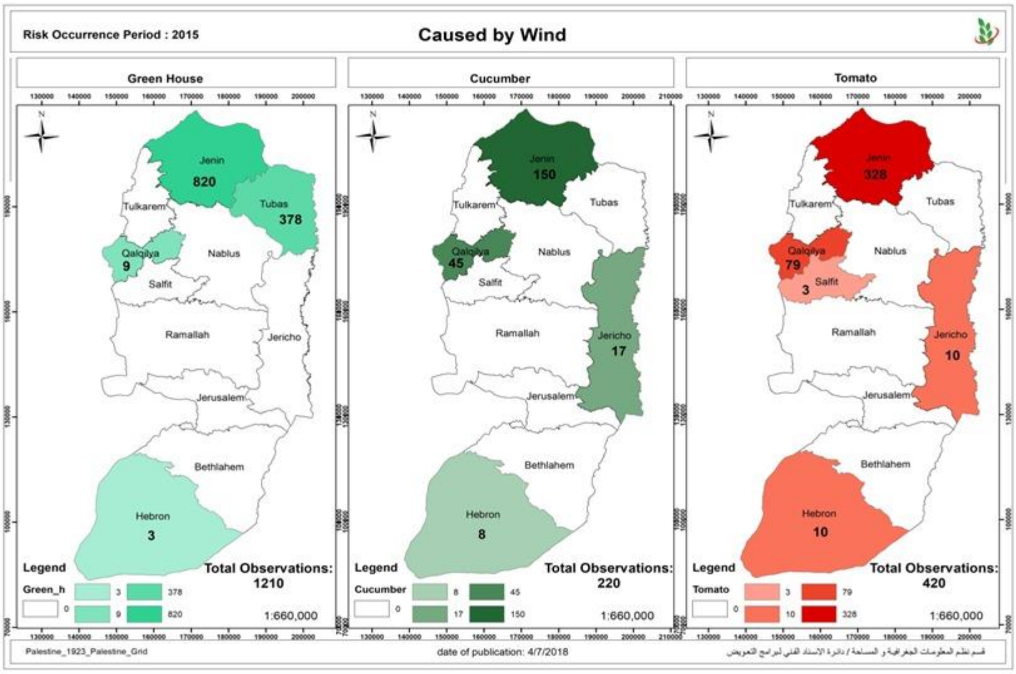

Figure 2 The number of damaged greenhouses in 2015 due to the wind load (PADRRIF, 2017).

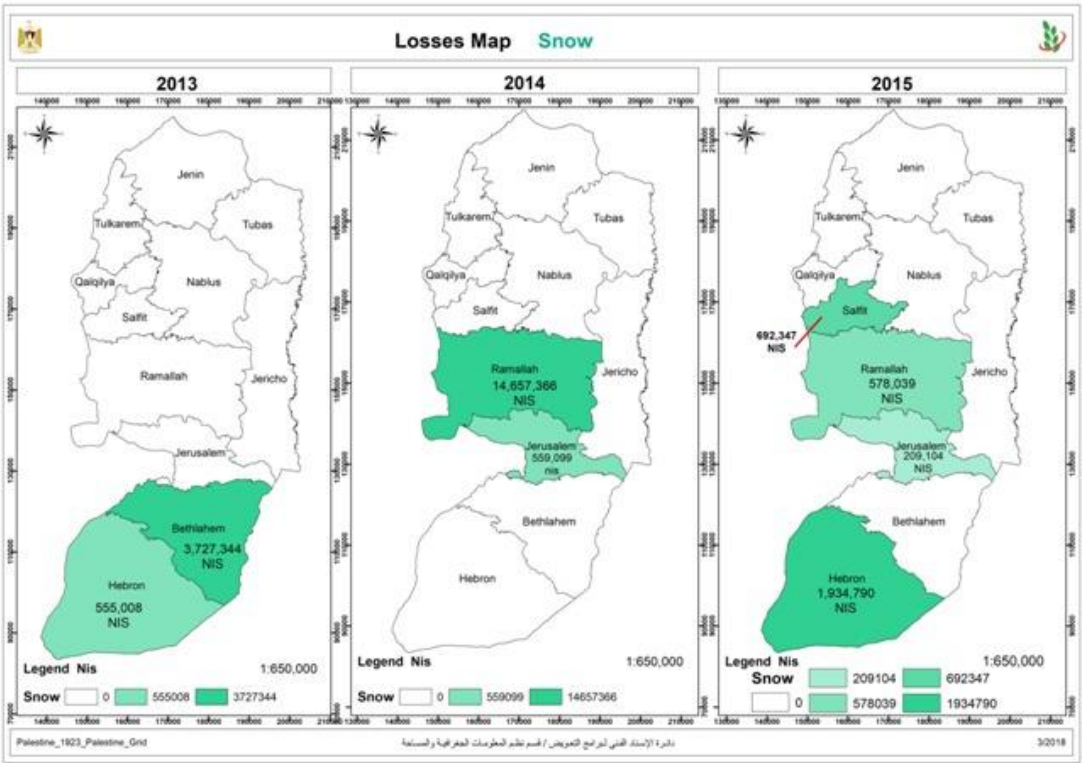

Figure 3 Financial losses in greenhouses due to snow load (PADRRIF, 2017).

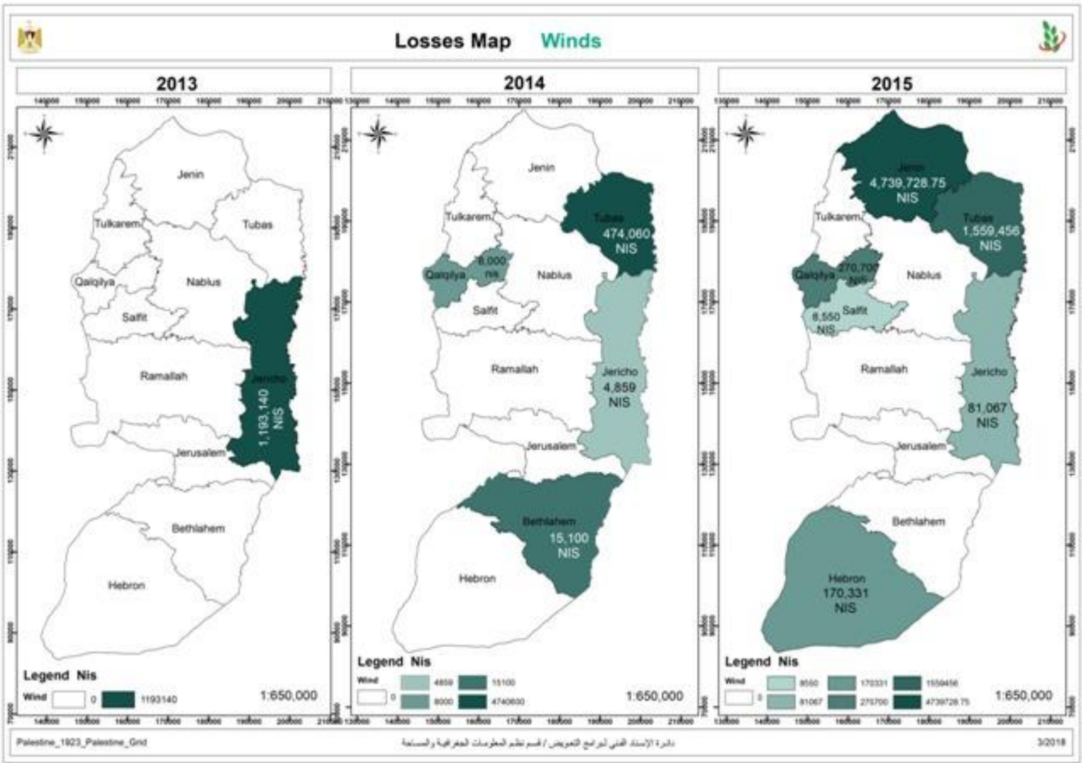

Figure 4 Financial losses in greenhouses due to the wind load (PADRRIF, 2017).

The PADRRIF reports show many greenhouse damages happening due to the rupture of polyethylene sheeting during the winter season. Many countries nowadays use polycarbonate as a covering material because of its many advantages such as high solar transmittance (Nadal *et al.*, 2017).

This research will study the idea of replacing the polyethylene cover of greenhouses with polycarbonate sheets, and the conclusion will be drawn depending on a life cycle costing analysis between polyethylene greenhouses and polycarbonate greenhouses.

1.2. Research Questions.

This research will answer the following questions:

- What is the appropriate design of a greenhouse covered with polycarbonate sheeting?
- Which is more economically viable, a polyethylene greenhouse or a polycarbonate greenhouse?

1.3. Research Objectives

The objectives of this research are,

- Provide an appropriate design guideline for building polycarbonate greenhouses.
- Perform a life cycle costing analysis on polyethylene and polycarbonate greenhouses.

1.4. Research Structure

This research is divided into five chapters, as shown in Figure (5):

- The first chapter introduces the research's main issue, the purpose of this research, the objectives, and the questions the study will answer.

- The second chapter presents a literature review to provide the relevant information about greenhouses in literature, polycarbonate polyethylene, and life cycle costing.
- The third chapter discusses the methodology followed to reach the research's objectives and answer its questions.
- The fourth chapter is data collection and data analysis and following the methodology presented in the third chapter.
- The fifth chapter is the conclusion of the study and recommendations for future studies.

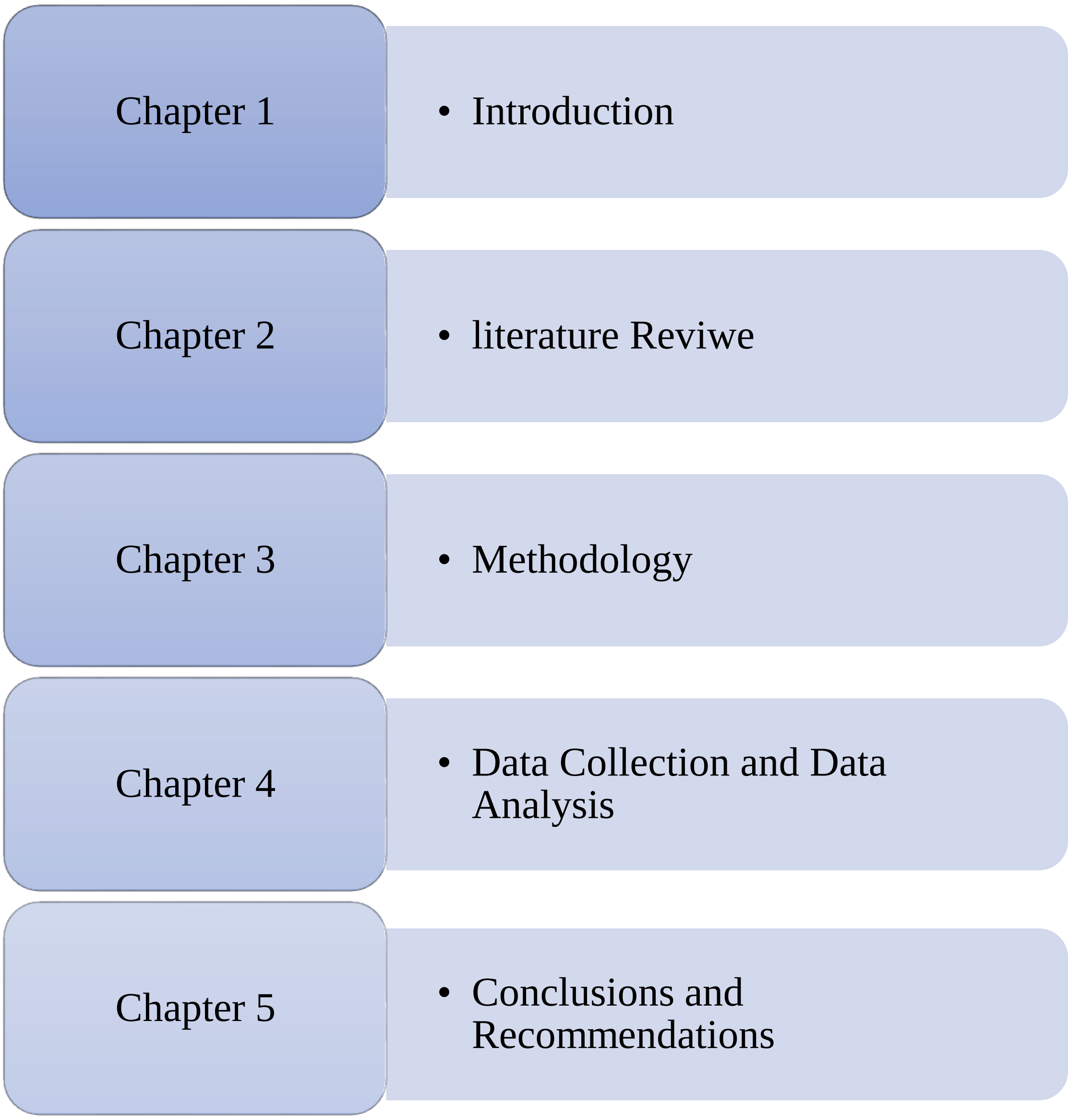

Figure 5 Research structure

Chapter Two

Literature Review

2. Literature Review

2.1. Agricultural Business

The agricultural sector is an essential part of any nation's economy. Johnston and Mellor (1961) argued that agriculture represents 40%-60% of the national income in underdeveloped countries, and 50%-80% of the nation's labor force is engaged in agricultural businesses. Other researchers, Meijerink and Roza (2007); and Carletto, Jolliffe, and Banerjee (2015), also emphasized the role of agriculture in national growth and poverty reduction.

In Palestine, the agricultural sector is considered one of the most important sectors contributing to the Palestinian economy. Figure (6) shows that this sector contributed 37% to the total domestic production in the mid-70s. However, in 1994 its contribution fell to 13.3 %, and then by the year 2009, it reached 5.5% (Palestinian Central Bureau of Statistics, 2013).

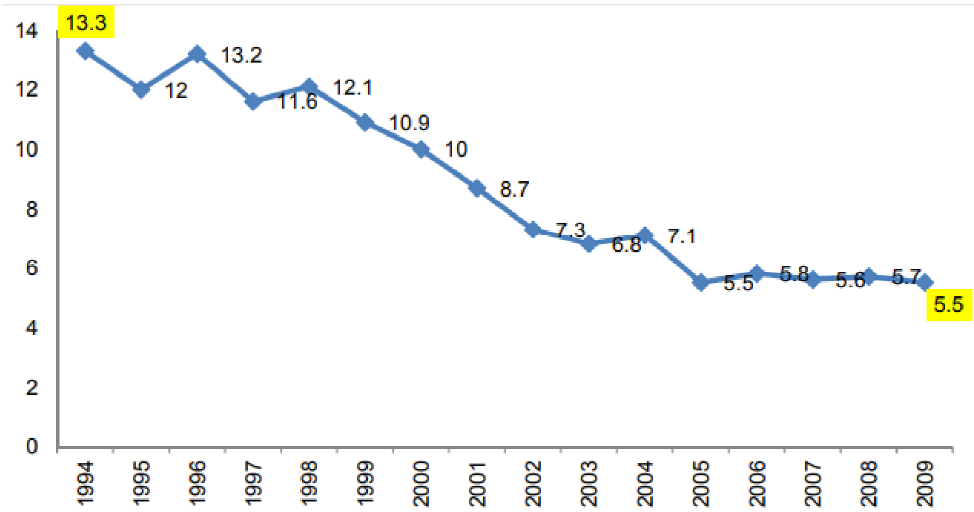

Figure 6 The contribution of the agricultural sector to the Palestinian economy 1994-2009 source: Palestinian Central Bureau of Statistics, 2010

2.2. Agricultural Cultivation Systems

Agriculture and farming have been developing over the years. New systems and new technologies are taking place to improve the quality and the yielding quantities of cultivation. Cultivation methods vary, from open fields to protected cultivation.

FAO (2013) claimed that protected cultivation is expanding in the Mediterranean region and divided protected cultivation into four types:

- Plastic mulch: covering the plants with a polyethylene sheeting to control the weeds and increase soil temperature.
- Floating mulch: covering the top of the crop with polyethylene sheets or non-woven fabric to protect the crops from frosting, hail, and insects.
- Low tunnels: temporary covering the crops, with the automated mounting of hoops and plastic (mainly polyethylene), at the early stage of the plant life cycle, to speed up the plant's growth. In some countries, low tunnels cover the crops through all of their life cycles.
- Greenhouses: growing crops inside buildings and structures covered with plastic or glass. Greenhouses help increase luminosity in the cold seasons and provide a cool atmosphere during the hot seasons.

2.3. Agricultural Greenhouses

An essential part of the protected cultivation systems is the greenhouse. A greenhouse is a structure where plants grow in a protected area and are provided with the appropriate conditions for their survival to produce high-quality plants around the year (Critten and Bailey, 2002; FAO, 2013; Gundu and Mithun, 2018; Taki *et al.*, 2018). or as Lodovica Gullino, Albajes, and van Lenteren (1999) simplified, a place for growing out-of-season crops.

2.3.1. Greenhouse Location

A greenhouse site allocation is the first step in initiating a greenhouse. Nelson (1991), in his book “Greenhouse operation and management,” determined three factors for choosing greenhouse site location: production cost, production yield quality, and cost of transportation to markets. The price and quality of production rely mainly on the climate of the selected area, and different plants need different climate conditions. It's best to choose a greenhouse with suitable plant climate conditions to minimize the costs of cooling or heating the greenhouse and avoid the high prices of a high-tech greenhouse. However, Castilla and Hernandez (2007) suggested a greenhouse strategy to grow the same plant in two or more complementary harvesting locations. With different greenhouse technological levels, it allows an entire year supply of the plant.

To select a site for the greenhouse, Castilla (2013) specified several factors:

- Site Topography: places to build greenhouses must be flat or inclined with a slope that reaches a maximum of 0.5% along the central axis (must not be more than 1-2%). In places with steep areas, it is better to separate greenhouses into several units.
- Site Microclimate: places covered with high buildings or mountains must be avoided since greenhouses need to be well illuminated. Areas with frequent night fog must be avoided as well.
- Harsh weather conditions: for example, wind and rain, greenhouses in places with high wind speed or cold wind should be protected with windbreakers. The same thing applies to areas expecting snow. These places should be protected from snow by choosing locations away from trees or other obstacles that snow could accumulate around.
- Irrigation: water availability is essential for greenhouse crops.
- Labor: labor availability should be taken into account when choosing a location for the greenhouse.

- Drainage: drainage of rain in the winter.
- Soil characteristics: soil suitability for plants to be cultivated.
- Pollution: like air pollution coming from factories, dust may accumulate in the greenhouse and limit the sun's illuminance from reaching inside.
- Space availability: for future expansion, storage, and offices, etc.
- Infrastructure: consideration of the availability of proper communication, transportation, and energy.

2.3.2. Greenhouse Climate Conditions

As mentioned earlier, a suitable greenhouse location helps lower the costs required for cooling or heating. Greenhouse inside temperatures is often very high relative to the outside temperature during the day. Meanwhile, at night the temperature difference between the inside and the outside is slightly different (2-4 °C) (FAO, 2013). FAO (2013) also suggested strategies for cooling or heating the greenhouse; using technology to raise or lower temperatures is a way to do so. Another method that may be more economically viable is using natural ventilation to renew the inside air and lower temperature or using isolation to avoid low temperature.

In Palestine, there are several topographical features, along with climate diversity, occurring because of the geographical location of Palestine (Ighbareyeh and Cano, 2014). The climate diversity encouraged many Palestinians to engage in the agricultural sector.

Farmers in Palestine rely heavily on greenhouse usage. Figure (7) shows the number of greenhouses and their distribution in the West Bank in 2017. The figure shows that Tulkarem, Jenin, Qalqilya, and Jericho have many greenhouses.

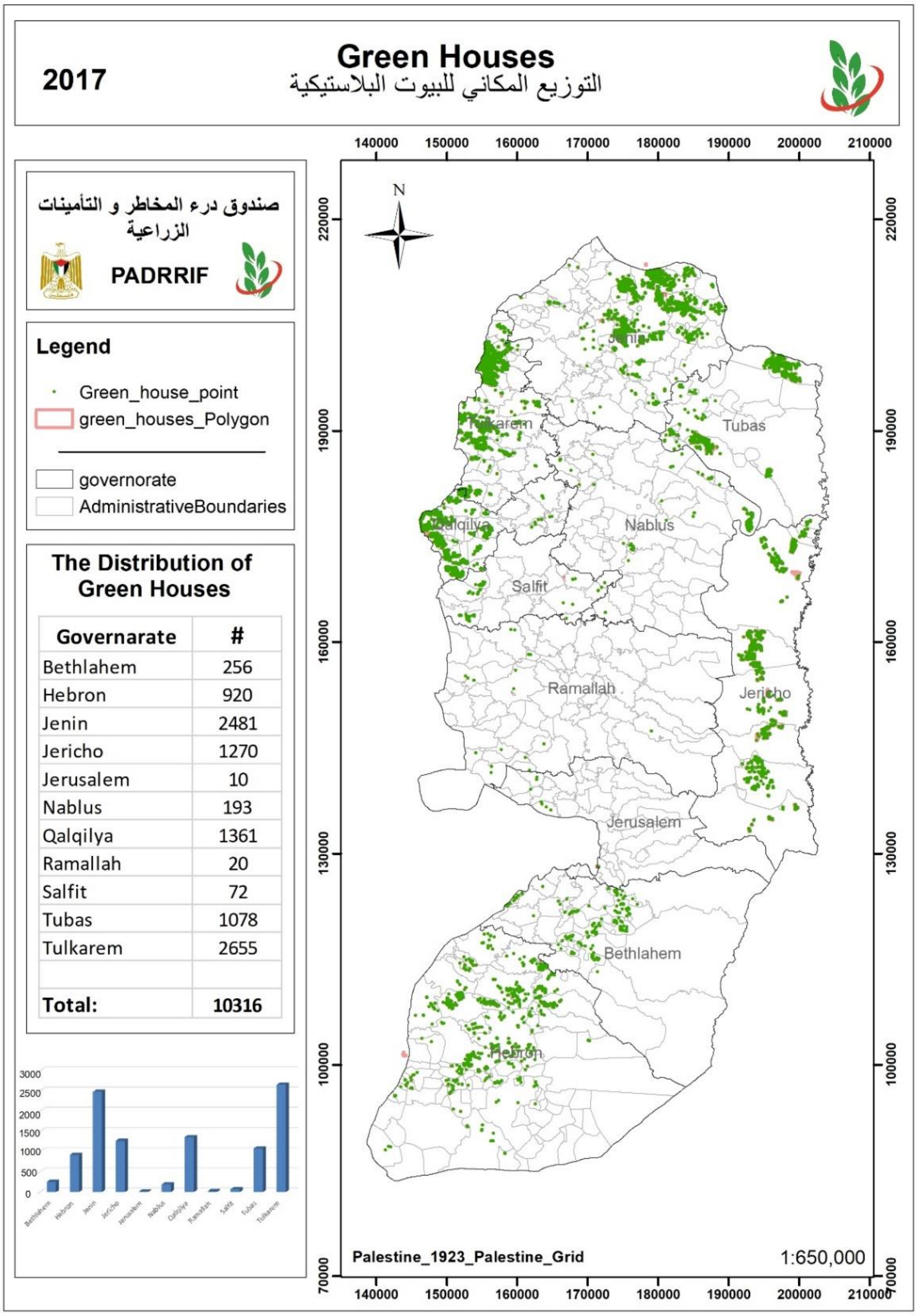

Figure 7 Distribution of agricultural greenhouses over the West Bank in 2017. Source: (PADRRIF, 2017)

2.3.3. Greenhouse design

To build a greenhouse, one must decide what type of greenhouse he wants. Greenhouses differ from small to significant structures and can be temporary or permanent. Usually, the typical greenhouse is made of steel truss, concrete footings to support the truss columns, and covering material, usually plastic or glass.

An article by Castilla and Hernandez (2005) defined two types of used greenhouses according to the greenhouse technology level:

1. High-tech greenhouses:
   - In Northern cold countries, high technological greenhouses are used to warm and increase the transmittance of light inside the greenhouse.
   - Glass is the covering material used in this type.
   - This type achieves maximum production yield.
   - It has high costs.
2. Moderate to low technology greenhouse:
   - In the southern countries of Europe and Mediterranean regions with small investments, low or moderate technology is used; sometimes, no technology is used, just natural ventilation.
   - Plastic films are the covering material used in this type.
   - This type achieves a lower production yield than the high-tech greenhouse.
   - Lower costs.
   -

2.3.4. Greenhouse covering materials

Agricultural greenhouses are usually covered with two types of materials glass or plastic. The covering of the greenhouse must be strong, consistent, and safe. Not only that, but the covering material properties play a significant role in the plant growing process since its responsible for two crucial parameters, light illuminance into the greenhouse and heat absorbed from the surrounding area of the greenhouse (Giacomelli and Roberts, 1993; Fadel *et al.*, 2016). Taki et al. (2013) assured that the greenhouse covering material is the main responsible for the greenhouse production yield since the covering material is responsible for the energy inputs inside the greenhouse.

2.3.5. Greenhouse Roof slope

Light illuminance into the greenhouse differs according to the covering material used. However, FAO (2013) pointed out that the roof slope also plays a significant role in catching the sunlight, especially in Winter. They also mentioned that computer simulations show that light transmittance during winter can be raised 10% if the roof slope increases from 11° to 45°. A compromise can be made between the slope and the light transmittance, and the construction costs, the roof slope of greenhouses can range from 25°–30° (FAO, 2013).

2.4. Polyethylene as a greenhouse covering material

The different plastic types are considered an important and widely used covering material of agricultural greenhouses worldwide (Giacomelli and Roberts, 1993). One particular plastic-type that is more commonly used than others, especially in the Mediterranean region, is low-density polyethylene (LDPE) (Papadakis *et al.*, 2000)(Babaghayou *et al.*, 2018). It is commonly used in greenhouses because of its properties; polyethylene films are cheap, available, easily handled, and make a suitable greenhouse covering material.

Plastic sheets of greenhouses are usually replaced frequently; FAO in 2013 published that in the 1950s, plastic films used to be changed almost every nine months, but in later years, plastic sheets last for nearly 45 months. However, Babaghayou *et al.* in 2018 proved that LDPE exposed to natural weathering lasts about 8-21 months. The additives in the plastic film and the effect of the weather in the selected geographical location are the direct reason for the weathering of the plastic film (Cepla, 2006).

An experiment was conducted by Fadel et al. (2016) to measure light and heat transmittance of different types of greenhouse covering materials; Polyethylene was one of the tested materials. The description and the transmittance results of the tested polyethylene film are given in Table (2).

Table 2 Light transmittance measured for polyethylene films. Source:(Fadel *et al.*, 2016)

material	Description	Transmittance (%)
A single layer of polyethylene	A single layer of UV treated polyethylene sheet	77.3
Double layers of polyethylene	Double layer of UV treated polyethylene sheet	70.72
Polyethylene with Agril net	A single layer of polyethylene sample covered with an Agril sheet	73.9

The results in Table (2) are similar to what P.Picuno and C.Sica (2004) found, a single virgin sheet of 80µm polyethylene has a transmittance of 80%. Meanwhile, a recycled sheet would have 70%.

The thermal conductivity or the k-value of a material explains the thermal losses for this material. Table (3) shows the thermal conductivity of polyethylene at 23°C:

Table 3 Thermal conductivity of polyethylene at 23°C

Material	Low-density polyethylene	High-density polyethylene
Thermal conductivity (W/m.K)	0.33	0.45-0.52

2.5. Polycarbonate as a greenhouse covering material

The different types of plastic materials are competing and proving their efficiencies when used as greenhouses covering materials. One particular plastic material trending in the greenhouse industry is polycarbonate. Bendler, Donald G LeGrand (2000), mentioned in their book “The Handbook of polycarbonate science and technology” some of the properties of the polycarbonate: "inherent toughness, transparency, broad temperature resistance, good electrical properties, a high index of fraction, ease of color-ability and compounding, and general structural properties suitable for engineering and durable goods applications." These properties make polycarbonate a suitable covering candidate for agricultural greenhouses.

Earlier, an experiment by Fadel *et al.* (2016) was mentioned to measure different materials' light and heat transmittance. In their experiment, the polycarbonate light transmittance was also calculated; the description and the transmittance results of the tested polycarbonate film are shown in Table (4).

Table 4 Light transmittance measured for polyethylene films. Source:(Fadel et al., 2016)

material	Description	Transmittance (%)
Plain polycarbonate	6mm polycarbonate board	86.84
Polycarbonate with a Polyethylene sheet	6mm polycarbonate board covered with a polyethylene sheet	68.98
Polycarbonate with Agril net	6 mm polycarbonate board covered with an Agril sheet	72.67

The results in Table (4) show that light transmittance values of plain polycarbonate exceed those of polyethylene or plain polycarbonate covered with polyethylene.

As for thermal conductivity, Table (5) shows the thermal conductivity of polycarbonate at 23°C:

Table 5 Thermal conductivity of polycarbonate at 23°C

Material	**polycarbonate**
Thermal conductivity (W/m.K)	0.19 - 0.22

As given in "The Handbook of polycarbonate science and technology," Polycarbonate has good insulation properties (Bendler, Donald G LeGrand, 2000). Papadakis *et al.* in (2000) argued that using a double layer of polycarbonate or corrugated polycarbonate in a single layer improves insolation. However, using double layers of flat polycarbonate for increasing the insulation results in transmitting about 10% less light than a single glass layer (Sonneveld and Arnhem, 2016).

Fadel et al. in (2016) proved that light and heat transmittance in both polycarbonate and polyethylene is close, which does not significantly affect the yield of the plant inside the greenhouse.

However, converting to polycarbonate from polyethylene may cause additional expenses to the establishment phase of the greenhouse. This thesis will discuss the life cycle costing of both types of greenhouses, polyethylene greenhouses and polycarbonate greenhouses.

2.6. Life Cycle Costing (LCC)

Making investment decisions should always take into account all expenses of the decision. Judging on the initial cost only may lead to tremendous losses. Decision-makers use life Cycle Costing (LCC) to study all the costs associated with the cradle to the grave investment.

2.6.1. LCC Definition

LCC is defined by (ISO 15686-5, 2017) as “a valuable technique used for predicting and assessing the cost performance of constructed assets.” Dhillon in 2010 and Eltamaly and Mohamed in 2018 referred to LCC as the sum of all costs relevant to an investment or system during all of its lifetime. LCC costs include the initial purchasing cost, operational costs over the investment lifetime, maintenance costs, delivery or transportation of raw material costs, installation costs, taxes, inflation rates, disposal costs (Brown, 1979).

Ness et al. in 2007 argued that LCC is used for assessing products rather than projects. Meanwhile, Fuller in 2016 stated: “LCC is beneficial when project alternatives that fulfill the same performance requirements, but differ concerning initial costs and operating costs.”

According to (Fuller 2016) and (Cabeza et al., 2014), LCC evaluates the cost of owning a project.

2.6.2. LCC Analysis

LCC analysis requires all costs of a system to be identified. A ten-step analysis criterion was proposed by Greene and Shaw (1990). Although the criterion contains ten steps, green and Shaw agreed that the analyst could use some or all steps in sequence or simultaneously. Figure (8) shows Green and Shaw’s proposed LCC analysis.

1. Specify the reason after conducting LCC analysis.
2. Define and scope the system/support system.
3. Choose LCC models (methodology).
4. Collect all needed data (Input data).
5. Check sanity of inputs and outputs.
6. if necessary, use Risk assessment and Sensitivety analysis.
7. formulate results from LCC.
8. document the results.
9. Present the LCC analysis.
10. Update the analysis.

Figure 8 LCC analysis steps *(Greene and Shaw, 1990)*.

A simpler and clearer method was proposed by Jiran *et al.* in 2014. This method is shown in Figure (9)

1. Specify cost elements* and cost structure.*
2. Establish techniques of cost estimation.
3. Specify the aggregate formulation of LCC.
4. perform LCC

Figure 9 LCC analysis steps *(Jiran* et al., *2014)*

*The cost element is the entire cost of the system all along its time period.

*The cost structure is categorizing the system into parts to specify costs related to every category.

2.6.3. Cost Estimation Techniques.

To find the total costs of alternative buildings during their life cycles. For each building, costs occurring yearly must be identified along the life span of the building then discounted and summed to present value.

The four main categories of costs classified by Kubba (2010) are:

1. Initial cost includes design, acquisition, raw materials, labor, and construction costs (ISO 15686-5, 2017; Kubba, 2010; Fuller, 2016).

2. Operating cost includes all costs needed for running the building, energy, electricity, drainage, water costs (ISO 15686-5,2017; Kubba, 2010; Fuller, 2016). There might be costs that are hard to predict early at the designing stage; these costs can be estimated using computer programs (Fuller, 2016).

3. Maintenance cost includes replacing and repairing (ISO 15686-5,2017; Kubba, 2010; Fuller, 2016).

4. End of life cost includes demolition of parts of the building and recycling the reusable parts costs (ISO 15686-5,2017; Kubba, 2010; Fuller, 2016).

According to Niazi *et al.* (2016) and Taylor *et al.* (2010), cost estimation techniques are either qualitative (comparing the similarities of a new system with an old manufactured version of it) or quantitative, which requires a detailed cost analysis of a system.

Kolarik (1980) and Gupta (1983) divided cost estimation models into three general models conceptual, analytical, and heuristic.

- Zhang and Fuh (1998) categorized cost estimation into:
  - Detailed breakdown cost estimation.
  - Simplified breakdown cost estimation.
  - Group Technology (GT) based cost estimation.
  - Cost estimation based on cost function or cost increase functions.
  - Activity-based cost estimation (ABC).

2.6.4. Methodology of LCC

A methodology for conducting LCC was proposed by Jiran *et al.* (2014). This methodology is shown in Table (6).

Table 6 A proposed LCC methodology (Jiran *et al.*, 2014)

Stage	Proposed steps	Detail description
1	1. Collect relevant data. 2. Define the objective of the proposed LCC analysis. 3. Identify all activities (primary and secondary). 4. Mapping resources.	All data related to product manufacturing is listed and gathered based on the category to build a cost structure.
2	5. Assemble cost and data to be used in the analysis. 6. Select cost estimation.	The selection of a suitable cost estimation technique can be referred to Niazi *et al.* (2016).
3	7. Develop cost calculation for each cost structure and LCC by using cost estimating techniques.	To calculate LCC, the ABC method will be used due to a limited number of historical data.
4	8. Develop a cost estimation model (GUI) 9. Validation process	GUI is built to help the end-user to use this method for assessing LCC quickly and accurately.

While performing a life cycle costing analysis and implementing its methodology, it must be noticed that alternatives sometimes do not have the same length of life span. Also, the time value of money must be taken into account since yearly costs occurring at different periods. (ISO 15686-5, 2017) illustrated important parameters to include in life cycle costing analysis. Those parameters are:

- The analysis period is the length of the building's life cycle (ISO 15686-5, 2017). ISO 15686-5 (2017) recommended limiting the studying period to 100 years since afterward years do not affect the calculations significantly. A study suggested using a period of 10 to 12 years in the private sector and 25-30 years in public sectors (Heralova, 2017).
- The service life of the building starts after completing the building, and once it's occupied, and it lasts as long as the building is in use or service (Fuller, 2016).
- Discount rate or time value of money. It is the change of the money value in time (Blank and Tarquin, 2012). When having multiple alternatives with different life cycles, it is important to discount the costs occurring yearly to a specific point in time using the discount rate (Fuller, 2016; Dwaikat and Ali, 2018).
- Inflation/deflation rate. It is the increment or decrement of prices. ISO 15686-5 (2017) suggests using inflation/deflation rates only when nominal costs are used, but it should not be used when using the real costs rate of inflation/deflation.

2.6.5. Net Present Value (NPV)

Since the money changes over time, it is crucial when comparing alternatives to discount the costs occurring during the building's life to a specific point in time. Net Present Value is the sum of all the expenditures on an asset to a present monetary value taking into account the time value of money (ISO 15686-5, 2017).

ISO 15686-5 (2017) provided an equation to calculate the net present value, NPV, as shown in equation (2.1).

$$\text{NPV}= \sum_{n-1}^{P} \frac{Cn}{(1+d)^n} \qquad \text{.... 2.1}$$

Where:

- *C*: is the cost in year n;
- *d*: is the expected real discount rate per annum;
- *n*: is the number of years between the base date and the occurrence of the cost;
- *p*: is the period of analysis.

ISO 15686-5 (2017) implied that the time value of money can be reflected through the discount rate, which is a factor used to convert the costs occurring at different times to a specific time. In the NPV calculation, the discount rate is used to convert the future costs to their present value.

A real discount rate is used when real costs are used, without considering the inflation/deflation rate in calculations. Since, Inflation rates are used only with nominal costs, not real costs (ISO 15686-5, 2017).

In this research real costs are used with a real discount rate. Hence, the inflation/deflation rate will not be considered in life cycle costing calculations in chapter four.

Chapter Three
Methodology

3. Methodology

3.1. Introduction

To achieve the objectives and the desired outcome of this research, it is necessary to specify the research methods to be followed and discuss them. This section discusses the methods or tools used to reach the final desired outcome to form the research methodology plan.

Among the different types of research, this research followed the analytical and the exploratory methodology. It analyzes the current greenhouse in Palestine and explores the ability to use a different covering material (the polycarbonate).

A convergent mixed-method approach was adopted in this research. Both quantitative and qualitative data were collected and analyzed to form a conclusion.

3.2. Research Approach

"Research approaches are the plans and the procedures for research that span the steps from broad assumptions to detailed methods of data collection, analysis, and interpretation" (Creswell, 2014)

This research approach is divided into two phases. Phase one represents polycarbonate greenhouse design, while phase two represents life cycle costing (LCC).

The following steps describe the approach followed by this research:

3.2.1. Phase One: Polycarbonate Greenhouse Design

1. Data collection, data were collected from several sources:

    - Literature review. Available literature and publications about the greenhouses structure, covering materials, polyethylene and polycarbonate, greenhouses in the WestBank, and the weather conditions affecting the WestBank were gathered.
    - The Palestinian Ministry of Agriculture. Reports and data about the regulated Palestinian greenhouse were collected from the Palestinian Ministry of Agriculture. Greenhouses in Palestine are divided into four groups representing four climate conditions (four Palestinian areas) affecting the WestBank. Each climate (or area) has its own conditions. Four load conditions were used to represent the suitable conditions for the greenhouses in each climate. The data collected about the greenhouse groups included the structure of the greenhouses, the properties of the covering material and the steel skeleton, the footing type, and the loads used to construct each group.
    - Interviews: Construction companies were reached and interviewed to form a clear view of the structure of the greenhouse. Agricultural engineers were interviewed to make sure that the constructed greenhouse resulting from this research will be useful and fulfill the needs of the plants.

- Observation through field visits: Several Palestinian greenhouses were visited to take notes about the structure of the greenhouse, including the covering material (polyethylene). A polycarbonate greenhouse constructed by the National Agricultural Research Center in Jenin was also visited and observed.

2. A suggestion of polycarbonate greenhouse structure for the polycarbonate greenhouse. Once all needed data were collected, eight polycarbonate greenhouses designs were suggested using the Palestinian regulated greenhouses as a reference and considering the literature suggestions.
3. Analyzing and checking the suggested polycarbonate greenhouse. The eight designs were checked structurally using the computer software SAP2000 version 22.2.0. Each suggested design of the eight designs was checked in the SAP computer software four times using four different load conditions representing the Palestinian weather conditions.
4. Reporting results. This research proposed four polycarbonate designs representing four Palestinian climate conditions.

3.2.2. Phase Two: Life Cycle Costing (LCC)

1. Data collection, data were collected from several sources:
    - Literature review. Available literature and publications about life cycle costing concepts and analysis were reviewed.

- The Palestinian Ministry of Agriculture. Reports and data about the costs of the regulated Palestinian greenhouse materials were collected from the Palestinian Ministry of Agriculture.
- Interviews. Construction companies, polymer fabrication companies, steel companies, and farmers were reached and interviewed to form a clear view of the costs of the greenhouse structure and covering materials (polyethylene and polycarbonate).

2. Calculation of life cycle costing for polyethylene greenhouse. The life cycle costing of the existing polyethylene was calculated using the suggested procedure by ISO 15686-5 (2017).
3. Calculation of Life cycle costing for polycarbonate greenhouse. The Life cycle costing of the suggested and analyzed polycarbonate greenhouse was calculated using the recommended procedure by ISO 15686-5 (2017).
4. Final conclusion. A comparison between polyethylene greenhouse and polycarbonate greenhouse was made based on the life cycle costing results. Afterward, final conclusions and future recommendations were proposed.

3.2.3. **Life Cycle Procedure**.

ISO 15686-5 (2017) suggests the following LCC procedure, which is adopted in this research.

1. Define the scope of costs included in the analysis. The expenses needed along the functional life of the greenhouse building are listed. Figure (10) shows the costs required for the analysis suggested by (ISO 15686-5, 2017):

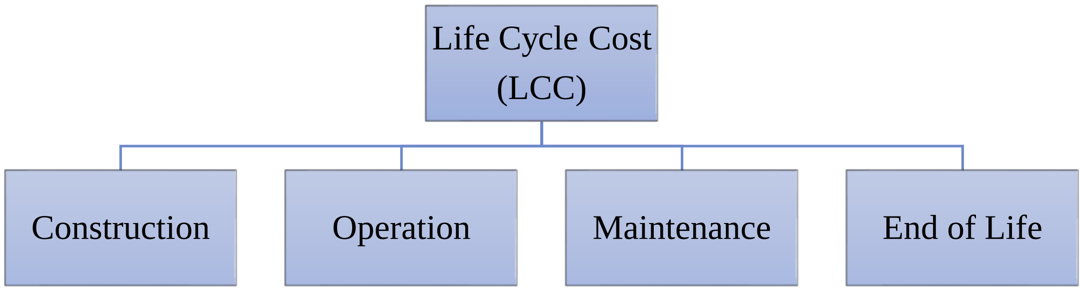

Figure 10 Costs that should be included in LCC analysis (ISO 15686-5, 2017)

- The construction cost of a greenhouse includes:
  - Steel.
  - Plastic coverage cost, including needed fixation accessories.
  - Excavation.
  - Piles.
  - Irrigation system.
  - Labor and equipment.
- Operation cost includes:
  - Electricity.
  - Irrigation water.

- ❖ Maintenance cost
    - ▪ Plastic coverage replacement.
    - ▪ Minor damages or accidents.
    - ▪ Insect net replacement
    - ▪ Irrigation pipes replacement.
- ❖ End of Life cost
    - ▪ Demolish the greenhouse.
    - ▪ Reusing undamaged parts.
    - ▪ Recycling the steel or the plastic cover.

2. Once all costs occurring along the polyethylene and polycarbonate greenhouses life cycle are identified, the costs will be discounted using the discount rate “d” to their present value to find the NPV for both types of greenhouses, following equation (2.1).
3. The final judgment between the polyethylene and polycarbonate covering material will be drawn based on the NPV values.

3.3. Methodology Chart

The following chart in Figure (11) represents the steps of the methodology:

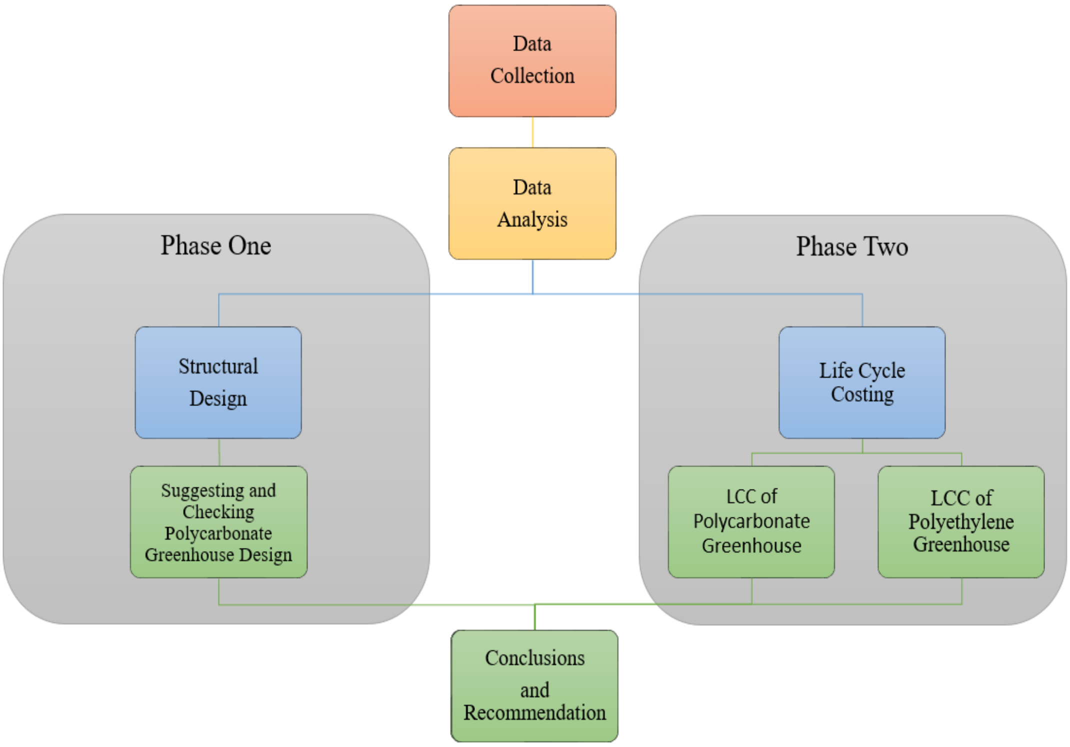

Figure 11 Research methodology hierarchy

Chapter Four
Data Collection & Data Analysis

4. Data Collection and Data Analysis

Many models and structures of greenhouses are used worldwide. Some are considered more successful than others for particular weather or a specific situation, but no one can argue about an ideal best greenhouse (Aldrich and Bartok, 1992).

In this chapter, the certified Palestinian greenhouse structure will be modified and restructured to suit the polycarbonate as a covering material instead of the commonly used plastic film.

4.1. The polyethylene Palestinian greenhouse

To build a SAP model for the polycarbonate greenhouse, The Palestinian certified greenhouse properties are collected from the Palestinian Ministry of Agriculture:

The Palestinian greenhouse has a parallel rectangle steel structure, with a steel skeleton barrel on top to support the covering material. The Palestinian greenhouse design is categorized into four models representing four zones: Qabatia model, Tammoun model, An-Nassareya model, and Hebron model (Palestinian ministry of agriculture, 2018).

Each model represents the weather conditions affecting the surrounding area of the zone. As Table (7) shows, the models differ in dimensions, Hight, steel tmember size, and loads.

The loads used to design each of the four models are clarified in Table (8).

As for the steel skeleton of the polyethylene Palestinian greenhouses, galvanized steel pipes are used. The section of each part is illustrated in Table (9), and the details of the polyethylene greenhouses are shown in Figures (12- to 15).

Table 7 The Palestinian certified greenhouse models' information (Palestinian ministry of agriculture, 2018)

	Dimensions (m)	Truss hight (m)	columns' steel thickness (mm)	load			
				dead	live	wind	snow
Qabatia	32.95* 29.4	1.73	3.4	✓	✓	✓	
Tammoun	45*22.05	1.48	3.4	✓	✓	✓	
An-Nassareya	33*29.4	1.48	3.4	✓	✓	✓	
Hebron	33.05*29.4	1.48	4	✓	✓	✓	✓

Table 8 The loads used to build the certified Palestinian greenhouses (Palestinian ministry of agriculture, 2018)

Load	Model			
	Qabatia	Tammoun	An-Nassareya	Hebron
Dead (KN/m)	self-weight*	self-weight	self-weight	self-weight
Live (KN/m)	0.30	0.30	0.30	0.30
Wind (KN/m)	0.67	0.67	0.67	0.67
Snow (KN/m)	0	0	0	1.00

Table 9 The steel sections of each part in the polyethylene Palestinian greenhouse *(Palestinian ministry of agriculture, 2018)*

Frame section	Model							
	Qabatia		Tammoun		An- Nassareya		Hebron	
	D(in)	T(mm)	D(in)	T(mm)	D(in)	T(mm)	D(in)	T(mm)
Column	3	3	3	3	3	3	3	3
Arch	1.5	2	1.5	2	1.5	2	2	2
Strut	1	2	1	2	1	2	1	2
Truss	1	2	-	-	-	-	-	-
Purlin	1.5	2	1.5	2	1.5	2	2	2
bracing	-	-	1.5	2	1.5	2	1.5	2

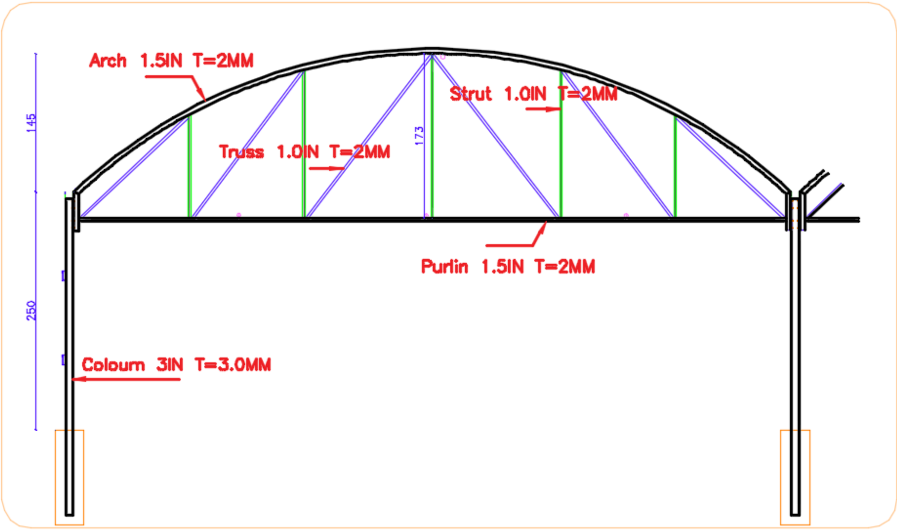

Figure 12 Qabatia's Polyethylene greenhouse (Palestinian ministry of agriculture, 2018)

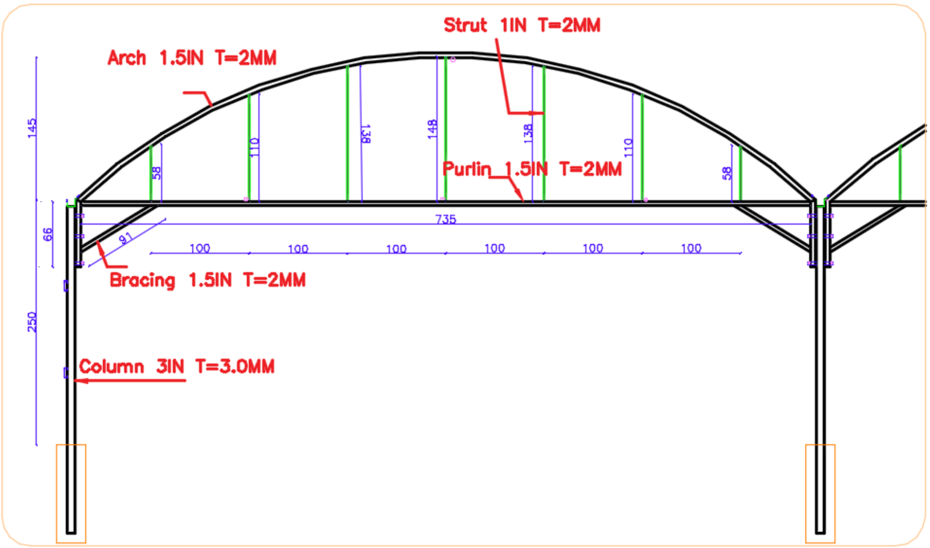

Figure 13 Tammoun's Polyethylene greenhouse (Palestinian ministry of agriculture, 2018)

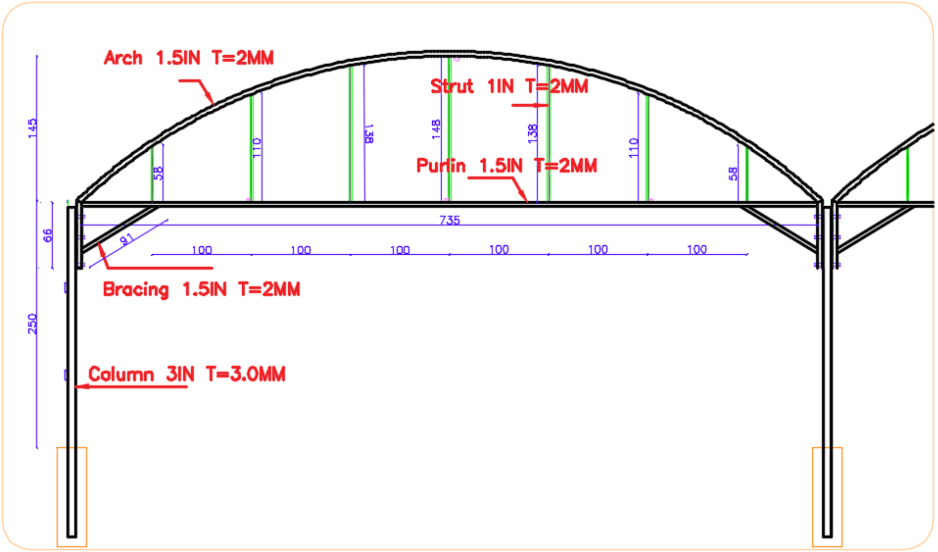

Figure 14 An-Nassareya's Polyethylene greenhouse (Palestinian ministry of agriculture, 2018)

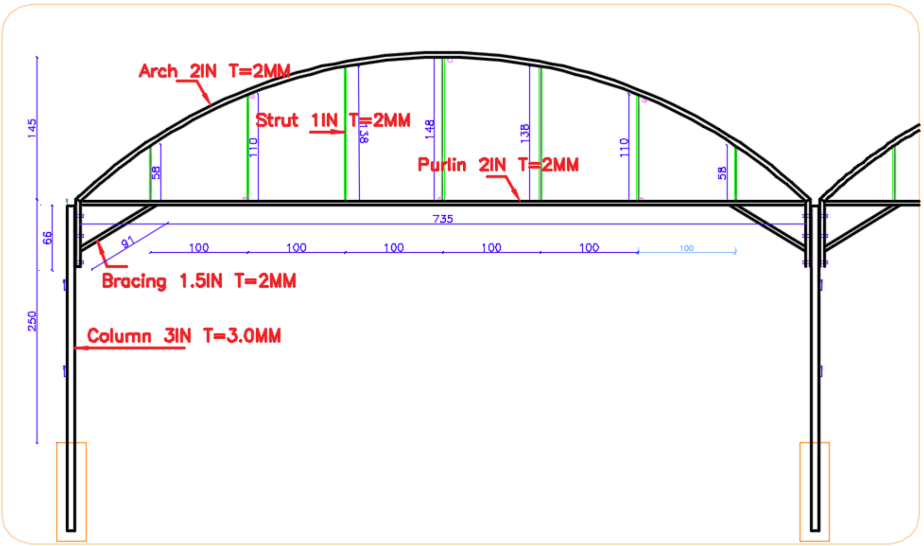

Figure 15 Hebron's Polyethylene greenhouse (Palestinian ministry of agriculture, 2018)

4.2. Polycarbonate greenhouse design (Phase one)

4.2.1. The Suggested Polycarbonate Greenhouse Design

Polycarbonate sheets are different in physical properties from polyethylene sheeting material; hence, the current greenhouse structure should be modified to fit the polycarbonate properties.

The previous models are restructured to fit the polycarbonate greenhouse. To do so, the curved skeleton is replaced with a pyramid skeleton since polycarbonate is a rigid plastic material, and it is easier to support it in its usual shape than to bend it to fit the curve. As for the roof's slope, Teitel and Baeza in 2012 argued that in the Mediterranean region, the ideal inclination of the roof range between 25º-30º. However, the greenhouse European code EN 13031-1 fixed the roof slope from 20º-26º (PrEN13031-1, 1997). J.G.Vieira Neto and J.Soriano in 2017 also used the European code and fixed the roof slope from 20º-26º to evaluate the effect of the various shapes of pitched roof greenhouses on the stress distribution in rural areas in Brazil. J.G.Vieira Neto and J.Soriano's article showed that increasing the slope from 20º-26º, decreased the maximum stress in the roof by about 20%. From here, two groups of slopes are adopted and tested to model the polycarbonate greenhouse: group A: 22º, group B: 26º.

Based on the Palestinian greenhouse, four sets of dimensions are adopted, Span length 7m, span length of 8 m, gutter height 2.5m, and gutter height 3m.

According to the angles and the dimensions adopted, eight models of polycarbonate greenhouses are analyzed and checked under the various loading conditions adopted each Palestinian model (zone). Table (10) shows the dimensions and angles of the eight adopted models.

Table 10 Dimensions and angles of the adopted models to be tested

groups	model	Span length (m)	Gutter height (m)	Ridge height (m)
Group A (22^o)	A1.	7	2.5	0.35
	A2.	7	3	0.35
	A3.	8	2.5	0.41
	A4.	8	3	0.40
Group B (26^o)	B1.	7	2.5	0.43
	B2.	7	3	0.42
	B3.	8	2.5	0.49
	B4.	8	3	0.49

After studying the information about the polyethylene Palestinian greenhouses, some modifications were made based on literature suggestions to fit the polycarbonate. Eight new designs were suggested to be analyzed and checked.

The loads used to analyze and check the suggested polycarbonate greenhouse designs are shown in Table (11),

Table 11 The loads used to test the suggested polycarbonate greenhouse designs

Load		Model			
		Qabatia	**Tammoun**	**An-Nassareya**	**Hebron**
Dead (KN/m)		self-weight*	self-weight	self-weight	self-weight
Live (KN/m)		0.30	0.30	0.30	0.30
Wind (KN/m)	**windward**	0.70	0.70	0.70	0.70
	leeward	0.50	0.50	0.50	0.50
	Side-wall	0.64	0.64	0.64	0.64
	Roof	0.77	0.77	0.77	0.77
Snow (KN/m)		0.2	0.11	0	1.5

*self-weight = weight of the building (implicitly computed) + weight of polycarbonate.

Fabrizio, in 2012, conducted an experiment to study the effect of using hollow polycarbonate to minimize the energy needed in a greenhouse and found out that using polycarbonate with two layers and a gab between them would maximize thermal insulation and light transmittance. Hence, two layers of hollow polycarbonate will be used in this study.

A polycarbonate technical guide of a polycarbonate Company called gelem2000 has been reviewed (Gelem2000, 2021) to study the technical specifications of the used polycarbonate.

In An-Nassareya, Tammoun, and Qabatia, the wind load=0.77 KN/m2 was the key to deciding the type of polycarbonate used in those areas. However, in Hebron, the gravity load (snow load + dead load) governs the type of polycarbonate.

However, in both cases, the outcome was the same, 8mm thickness polycarbonate with a width of 600 mm.

According to the technical guide in Figure (16), polycarbonate with 8mm thickness and 600mm width will be used in all cases. The technical specifications of the used polycarbonate are shown in Table (12),

Thick./Width	Direction	750Pa	1000Pa	1250Pa	1500Pa	1750Pa	2000Pa
8/600	Uplift load	1.1	1	0.85	0.7	0.6	0.5
	Gravity load	1.4	1.3	1.2	1.1	1	0.9
10/600	Uplift load	1.3	1.15	0.95	0.85	0.8	0.7
	Gravity load	1.5	1.4	1.3	1.2	1.1	1
16/600	Uplift load	1.4	1.25	1.1	1	0.9	0.8
	Gravity load	1.65	1.6	1.55	1.5	1.45	1.4
16/1000	Uplift load	0.9	0.6				
	Gravity load	1.5	1.4	1.35	1.3	1.25	1.2
20/1000	Uplift load	1.2	0.8	0.6			
	Gravity load	1.6	1.5	1.45	1.4	1.35	1.3

Figure 16 Span length between purlins for multi polycarbonate thicknesses and widths (Gelem2000, 2021)

Table 12 Technical specifications of the used polycarbonate (Gelem2000, 2021).

Technical specification	Value
Thickness	8 mm
Width	600 mm
Area weight	0.015 KN/m^2
U-factor	3.3 $W/m^2.C$
Light transmittance	80 % (clear polycarbonate)

Wind Load Calculations:

According to the American Society of Civil Engineers, ASCE-7 (2016), the wind load is calculated using the procedure in Table (13),

Table 13 Wind load calculation procedure (ASCE-7, 2016).

Step no.	Procedure
1	Determine the risk category of the building
2	Determine the basic wind speed, V, for the applicable risk category
3	Determine wind load parameters: • Wind directionality factor, K_d

	• Exposure category • Topographic factor, K_{zt} • Gust Effect Factor, G • Enclosure classification • Internal pressure coefficient, GC_{pi}
4	Determine velocity pressure exposure coefficient, K_z or K_h
5	Determine velocity pressure q_z or q_h
6	Determine external pressure coefficient, C_p or C_N
7	Calculate wind pressure, p, on each building surface

The values in the above-required steps are given in Table (14).

Table 14 Wind load calculations

Step	*Parameter*	*Notes*
1	Risk category of the building: 1	The building represents a low risk to human life in the event of failure
2	The basic wind speed, V=155 km/hr	The Jordanian national building Code (2006) usually uses V=120 km/hr in our area. However, the ASCE 7-16 code is being used in this thesis. Therefore, the wind speed is adjusted to be V=155 km/hr.
3	The wind load parameters:	
	• Wind directionality factor, K_d= 0.85	Trussed tower (triangular)
	• Exposure category: C	Open terrain with scattered obstructions having heights generally less than 9.1 m
	• Topographic factor, K_{zt}=1	Flat terrain
	• Gust Effect Factor, G= 0.85	rigid building
	• Enclosure classification	Enclosed building
	• Internal pressure coefficient, GCpi= 0.18	Enclosed building with exposure category C
4	Velocity pressure exposure coefficient, K_z=K_h= 0.85	• K_h is the constant which calculations depends on the mean height of the building • K_z is not constant and changes with the building height; it starts from the bottom of the building. • The building height (0-4.6) m
5	Wind velocity pressure q_z or q_h =818.9 N/m^2	$qz = 0.613\ K_z\ K_{zt}\ K_d\ V^2$, where: • q_z = velocity pressure calculated at height z, (N/m^2) • q_h = velocity pressure calculated at mean roof height h, (N/m^2)

		• K_d = wind directionality factor • K_z = velocity pressure exposure coefficient • K_{zt} = topographic factor • V = basic wind speed, in m/s
6	External pressure coefficient, C_p on external surfaces* windward= 0.8 leeward= -0.5 sidewalls= -0.7 roof= -0.9	Depends on the rooftop angle. Angels of the suggested polycarbonate greenhouse are 22^o and 26^o
7	wind pressure, p windward= 704.34 N/m^2 leeward= 495.5 N/m^2 sidewalls= 643.7 N/m^2 roof= 774 N/m^2	Wind pressure is calculated on each external surface

*The external surfaces 1: windward, 2: leeward, 3: sidewalls, 4: roof, which the wind affects are shown in Figure (17)

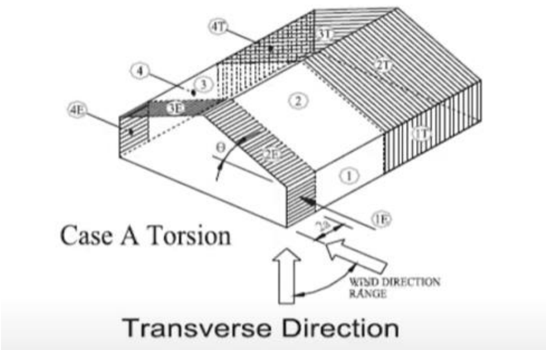

Figure 17 The affected external walls by wind (ASCE7-10, 2013)

Snow Load Calculations:

According to the Jordanian national building Code (2006), the snow load on the roof can be estimated using the following equation:

$$S_d = S_o * \mu_i$$

Where:

- S_d = Snow load or the snow density on the roof (kN/m^2).

- S_o = Site accumulated snow load in the building area (kN/m^2), given in Table (15).
- μ_i = building shape coefficient**.**

Table 15 Site snow load according to building height. (Jordanian national building Code, 2006)

Snow load (S_o) kN/m^2	Height of structure above sea level (h) in meters
0	250 > h
(h-250)/800	500 > h > 250
(h-400)/320	1500 > h > 500

In this study, four regions represent the West Bank in Palestine, Qabatia, An-Nassareya, Tammoun, and Hebron.

As stated by The Palestinian Ministry of Local Government, the altitudes of those four regions are shown in Table (16),

Table 16 Altitudes of the four regions representing the West Bank (The Palestinian Ministry of Local Government, 2020)

Region	Altitude above sea level (h) in meters
An-Nassareya	-45
Tammoun	365
Qabatia	450
Hebron	995

- An-Nassareya region is below 250m,

  S_o=0

- Tammoun is 365 m above sea level,

  $S_o = \frac{h-250}{800} = \frac{365-250}{800} = 0.14$ kN/m^2

- Qabatia is 450 m above sea level

  $S_o = \frac{h-250}{800} = \frac{450-250}{800} = 0.25$ kN/m^2

- Hebron is 995 m above sea level,

$S_o = \frac{h-400}{320} = \frac{995-400}{320} = 1.9$ kN/m^2

As for building shape coefficient (μi), the suggested polycarbonate greenhouse shape has an inclined roof (tilted roof). For tilted roofs with 0<α<30, μi= 0.8.

The results of Implementing the snow equation Sd = So * μi for all four regions are shown in Table (17)

Table 17 Snow load for the regions representing the West Bank in Palestine

region	S_o (KN/m^2)	μ_i	S_d (kN/m^2)
Qabatia	0.25	0.8	0.201
An-Nassareya	0	0.8	0
Tammoun	0.14	0.8	0.11
Hebron	1.9	0.8	1.52

4.2.2. Computer Model

the suggested eight polycarbonate models were analyzed and designed using the computer program SAP 2000 under different load combinations in each area. To help minimize the cost and unify the steel of the greenhouse sections, the steel members of the greenhouse in each SAP model were divided into five groups representing five sections in the greenhouse, inner columns, outer columns at the surrounding sides of the greenhouse, purlins, top members of the truss, and bottom members of the truss. Figure (18) illustrates the five sections of the greenhouse.

The steel section used in the greenhouses models is galvanized tube steel.

The design results are reported in Tables (18- to 21). The tables show the steel section length of the member, the Section width of the member, the section area which is summed for all section members to be used later in cost calculations, the length of the member, and the number of members in each group.

These results represent the appropriate design for the polycarbonate greenhouse in the West Bank. Later in this chapter, the cost of those designs will be checked to choose only one single design for each zone.

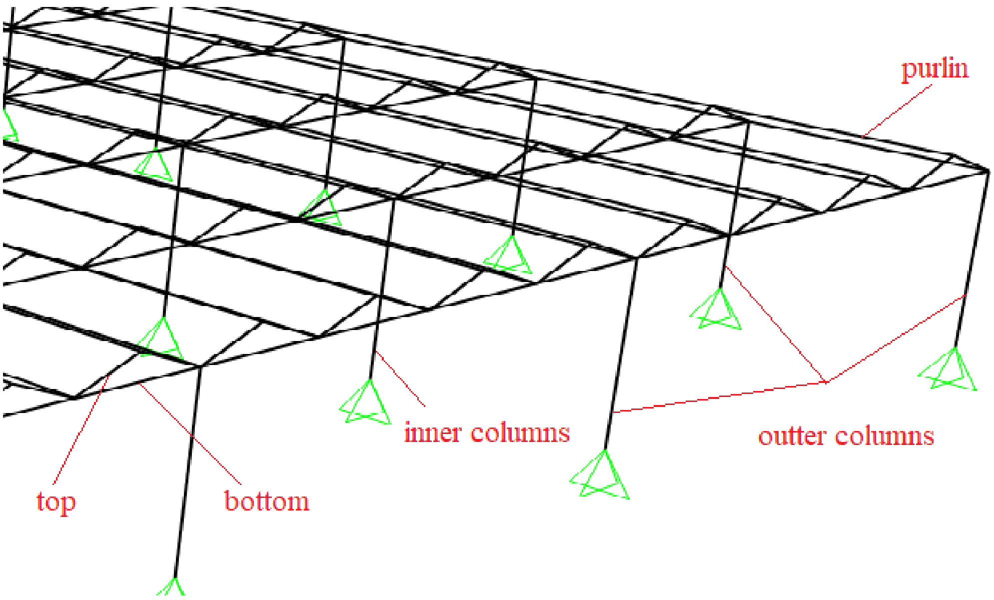

Figure 18 Steel parts of a polycarbonate greenhouse

Table 18 Design results of steel skeleton of polycarbonate greenhouse in An-Nassareya

model	Group	Section Length (mm)	Section Width (mm)	Section Thickness (mm)	Section Area (mm^2)	Length of member (m)	Number Of members
A1	Inner columns	90	90	2.65	925.91	2.5	27
	Outer columns	120	80	3.25	1257.75	2.5	23
	Purlin	100	40	2	544	27	33
	Top	120	120	3.25	1517.75	0.94	320

	Bottom	120	60	3.25	1127.75	7	40
		sum			5373.16		
A2	Inner columns	80	80	2.9	894.36	3	27
	Outer columns	120	120	3.25	1517.75	3	23
	purlin	60	40	2	384	27	33
	top	120	120	4	1856	0.94	320
	bottom	120	60	2.9	1010.36	7	40
		sum			5662.47		
A3	Inner columns	100	100	2.9	1126.36	2.5	27
	Outer columns	120	80	6	2256	2.5	23
	purlin	100	40	2	544	27	33
	top	120	120	3.65	1698.71	1.08	320
	bottom	120	60	2.9	1010.36	8	40
		sum			6635.43		
A4	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	5	2300	3	23
	purlin	100	40	2	544	27	33
	top	120	120	3.25	1517.75	1.08	320
	bottom	120	80	2.65	1031.91	8	40
		Sum			6520.02		
B1	Inner columns	90	90	2.65	925.91	2.5	27
	Outer columns	120	80	3.25	1257.75	2.5	23
	purlin	60	40	2	384	27	33
	top	120	120	4	1856	0.94	320
	bottom	100	6	2.9	581.16	7	40
		sum			5004.82		
B2	Inner columns	100	100	2.65	1031.91	3	27
	Outer columns	120	120	4	1856	3	23
	purlin	100	40	2	544	27	33
	top	120	80	3.25	1257.75	0.94	320
	bottom	120	60	3.25	1127.75	7	40
		sum			5817.41		
B3	Inner columns	90	90	2.9	1010.36	2.5	27
	Outer columns	120	120	4	1856	2.5	23
	purlin	60	60	2	464	27	33

	top	120	120	5	2300	1.08	320
	bottom	120	80	2.65	1031.91	8	40
	sum				6662.27		
B4	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	2.9	1358.36	3	23
	purlin	60	60	2	464	27	33
	top	120	120	4	1856	1.08	320
	bottom	120	60	2.65	925.91	8	40
	sum				5730.63		

Table 19 Design results of steel skeleton of polycarbonate greenhouse in Tammoun.

model	Group	Section Length (mm)	Section Width (mm)	Section Thickness (mm)	Section Area (mm^2)	Length of member (m)	Number Of members
A1	Inner columns	90	90	2.65	925.91	2.5	27
	Outer columns	120	120	2.9	1358.36	2.5	23
	purlin	60	40	2	384	27	33
	top	120	80	6	2256	0.94	320
	bottom	100	50	2.65	766.91	7	40
	sum				5691.18		
A2	Inner columns	80	80	2.65	819.91	3	27
	Outer columns	120	120	3.25	1517.75	3	23
	purlin	60	40	2	384	27	33
	top	120	120	5	2300	0.94	320
	bottom	90	90	2.65	925.91	7	40
	sum				5947.57		
A3	Inner columns	100	100	2.9	1126.36	2.5	27
	Outer columns	120	120	3.25	1517.75	2.5	23
	purlin	60	60	2	464	27	33
	top	120	120	6	2736	1.08	320
	bottom	100	50	2.2	640.64	8	40
	sum				6484.75		
A4	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	4	1856	3	23
	purlin	60	60	2	464	27	33

	top	120	120	6	2736	1.08	320
	bottom	100	60	2.9	894.36	8	40
	Sum				7076.72		
B1	Inner columns	80	80	2.9	894.36	2.5	27
	Outer columns	120	80	2.65	1031.91	2.5	23
	purlin	60	40	2	384	27	33
	top	120	80	6	2256	0.94	320
	bottom	100	40	2	544	7	40
	sum				5110.27		
B2	Inner columns	120	80	2.65	1031.91	3	27
	Outer columns	120	120	2.9	1358.36	3	23
	purlin	60	40	2.2	420.64	27	33
	top	120	80	6	2256	0.94	320
	bottom	100	50	2.2	640.64	7	40
	sum				5707.55		
B3	Inner columns	90	90	2.9	1010.36	2.5	27
	Outer columns	160	80	4	1856	2.5	23
	purlin	60	60	2	464	27	33
	top	120	120	6	2736	1.08	320
	bottom	120	60	2.9	1010.36	8	40
	sum				7076.72		
B4	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	3.25	1517.75	3	23
	purlin	60	60	2	464	27	33
	top	120	120	5	2300	1.08	320
	bottom	100	50	2.2	640.64	8	40
	sum				6048.75		

Table 20 Design results of steel skeleton of polycarbonate greenhouse in Qabatia.

model	**Group**	**Section Length (mm)**	**Section Width (mm)**	**Section Thickness (mm)**	**Section Area (mm^2)**	**Length of member (m)**	**Number Of members**
A1	Inner columns	90	90	2.9	1010.36	2.5	27
	Outer columns	120	120	2.9	1358.36	2.5	23
	purlin	60	60	2	464	27	33

	top	120	80	6	2256	0.94	320
	bottom	120	80	2.65	1031.91	7	40
	sum				6120.63		
A2	Inner columns	80	80	2.9	894.36	3	27
	Outer columns	120	120	3.25	1517.75	3	23
	purlin	60	40	2.2	420.64	27	33
	top	120	120	6	2736	0.94	320
	bottom	90	90	2.65	925.91	7	40
	sum				6494.66		
A3	Inner columns	100	100	2.9	1126.36	2.5	27
	Outer columns	120	120	3.25	1517.75	2.5	23
	purlin	60	60	2	464	27	33
	top	120	80	6	2256	1.08	320
	bottom	100	60	2.9	894.36	8	40
	sum				6258.47		
A4	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	4	1856	3	23
	purlin	60	60	2	464	27	33
	top	120	120	6	2736	1.08	320
	bottom	120	60	3.25	1127.75	8	40
	sum				7310.11		
B1	Inner columns	80	80	2.9	894.36	2.5	27
	Outer columns	120	80	2.65	1031.91	2.5	23
	purlin	60	40	2	384	27	33
	top	120	80	6	2256	0.94	320
	bottom	100	50	2.2	640.64	7	40
	sum				5206.91		
B2	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	3.25	1517.75	3	23
	purlin	60	60	2.2	508.64	27	33
	top	120	120	4	1856	0.94	320
	bottom	120	60	2.9	1010.36	7	40
	sum				6019.11		
B3	Inner columns	120	80	3.25	1257.75	2.5	27

	Outer columns	160	80	4	1856	2.5	23
	purlin	100	40	2	544	27	33
	top	160	80	4	1856	1.08	320
	bottom	160	80	2.9	1358.36	8	40
	sum				6872.11		
B4	Inner columns	100	100	2.9	1126.36	3	27
	Outer columns	120	120	3.25	1517.75	3	23
	purlin	60	60	2	464	27	33
	top	120	120	5	2300	1.08	320
	bottom	100	60	2.9	894.36	8	40
	sum				6302.47		

Table 21 Design results of steel skeleton of polycarbonate greenhouse in Hebron.

model	Group	Section Length (mm)	Section Width (mm)	Section Thickness (mm)	Section Area (mm^2)	Length of member (m)	Number Of members
A1	Inner columns	120	120	2.9	1358.36	2.5	27
	Outer columns	160	80	6	2736	2.5	23
	purlin	90	90	2.9	1010.36	27	33
	top	200	100	6.3	3621.24	0.94	320
	bottom	150	150	5	2900	7	40
	sum				11625.96		
A2	Inner columns	100	100	3.25	1257.75	3	27
	Outer columns	150	150	5	2900	3	23
	purlin	100	50	2.65	766.91	27	33
	top	200	100	8	4544	0.94	320
	bottom	150	150	6	3456	7	40
	sum				12924.66		
A3	Inner columns	160	80	3.25	1517.75	2.5	27
	Outer columns	160	80	6	2736	2.5	23
	purlin	100	50	2.65	766.91	27	33
	top	200	100	6	3456	1.08	320
	bottom	150	150	5	2900	8	40
	sum				11376.66		
A4	Inner columns	120	120	3.25	1517.75	3	27

	Outer columns	150	100	6	2856	3	23
	purlin	100	50	2.65	766.91	27	33
	top	200	100	8	4544	1.08	320
	bottom	150	150	5	2900	8	40
		Sum			12584.66		
B1	Inner columns	160	80	2.9	1358.36	2.5	27
	Outer columns	160	80	6	2736	2.5	23
	purlin	90	90	2.65	925.91	27	33
	top	200	100	6	3456	0.94	320
	bottom	150	150	5	2900	7	40
		Sum			11376.27		
B2	Inner columns	120	120	3.25	1358.36	3	27
	Outer columns	150	150	5	2736	3	23
	purlin	90	90	2.65	925.91	27	33
	top	200	100	8	3456	0.94	320
	bottom	150	150	6	2900	7	40
		Sum			11376.27		
B3	Inner columns	150	150	4	2336	2.5	27
	Outer columns	200	100	6	3456	2.5	23
	purlin	120	60	2.65	925.91	27	33
	top	100	100	10	3600	1.08	320
	bottom	200	100	6	3456	8	40
		Sum			13773.9		
B4	Inner columns	100	100	2.25	879.75	3	27
	Outer columns	150	150	4	2336	3	23
	purlin	100	50	2.65	766.91	27	33
	top	100	100	10	3600	1.08	320
	bottom	160	80	6	2736	8	40
		Sum			10318.66		

4.2.3. Summary of Polycarbonate Greenhouse Design (Phase One)

The polyethylene greenhouse certified by the Palestinian Ministry of Agriculture was studied in the research. Eight models of polycarbonate greenhouse suitable to use in Palestine were suggested as shown in Table (10). The eight models represent two groups of roof angles 22º and 26º, two different span lengths 7 m and 8 m, and two gutter heights 2.5 m and 3 m. The eight models were analyzed under the four climate zones represent the West Bank areas: Tammoun, Qabatia, An-Nasareya, and Hebron using SAP software.

The result of this step was a well-designed 32 models of polycarbonate greenhouses, eight for each Palestinian zone as shown in Tables (18- to 21).

4.3. Life Cycle Costing (Phase two)

The main objective of this thesis is to compare the life cycle cost of a polyethylene greenhouse and the life cycle cost of a polycarbonate greenhouse. In this section life cycle cost for both types of greenhouses is calculated and compared.

4.3.1. Polyethylene Greenhouse Life Cycle Costing

4.3.2.1 The construction cost of a polyethylene greenhouse

construction cost or initial cost is the sum of all of the costs needed to build the building (Fuller, 2016).

As mentioned before, there are four different polyethylene greenhouses in Palestine, representing the four zones. Those four greenhouses' costs will be analyzed in this section.

It should be noted that the steel skeleton is different among the four polyethylene greenhouses, and all other parts are similar in the four zones.

Based on the design of the polyethylene greenhouse taken from the Palestinian Ministry of agriculture, the life cycle cost of the polyethylene greenhouse is calculated.

- **Steel**

The galvanized steel pipes are used in the certified polyethylene greenhouses. The price of galvanized steel pipes in the Palestinian market is NIS 5.5 per kilogram.

According to the Palestinian ministry of agriculture, the cost of a polyethylene greenhouse steel in An-Nassareya, Tammoun, Qabatia, and Hebron, that is made from galvanized pipes are as follows in Tables (22- to 25):

Table 22 Steel prices of one donum polyethylene greenhouse in An-Nassareya.

Part	Diameter (cm)	Thickness (mm)	Length (m)	Number	Price (NIS)
Columns	3.0	3.4	2.5	55	4922
Sub columns	3.0	3.4	1.0	63	2255
Top member	1.5	2.0	8.3	48	4194
Bot members	1.5	2.0	7.4	48	3714
Ver. member	1.0	2.0	7.7	48	2594
Roof brace	1.5	2.0	9.0	12	1137
Wind brace	2.0	2.0	3.6	8	404
Long.top	1.5	2.0	33.0	4	1390
Long.bot	1.5	2.0	33.0	12	4169
Wall col	1.5	2.0	2.5	8	211
Gutter	--	3.0	33.0	5	8168
		sum			33157

Table 23 Steel prices of one donum polyethylene greenhouse in Tammoun.

Part	Diameter (cm)	Thickness (mm)	Length (m)	Number	Price (NIS)
Columns	3.4	3.4	2.5	55	5578
Sub columns	3.4	3.4	1.00	63	2556
Top member	1.5	2.0	8.30	48	4194
Bot members	1.5	2.0	7.35	48	3714
Ver. member	1.0	2.0	7.70	48	2594
Roof brace	2.0	2.0	9.00	12	1516
Wind brace	1.5	2.0	3.60	8	303
Long.top	1.5	2.0	45.00	3	1421
Long.bot	1.5	2.0	45.00	9	4264
Wall col	1.50	2.00	2.50	8.00	210.5558
Gutter	--	3.00	33.00	5.00	8167.5
		sum			34518.49

Table 24 Steel prices of one donum polyethylene greenhouse in Qabatia.

Part	Diameter (cm)	Thickness (mm)	Length (m)	Number	Price (NIS)
Columns	3.0	3.4	2.5	55	4922
Sub columns	3.0	3.4	1.0	63	2255
Top member	1.5	2.0	8.3	48	4194
Bot members	1.5	2.0	7.3	48	3714
Ver. member	1.5	3.0	7.7	48	5837
Roof brace	1.5	2.0	12.0	12	1516
Wind brace	2.0	2.0	3.6	8	404
Long.top	1.5	2.0	33.0	1	347
Long.bot	1.5	2.0	33.0	4	1390
Wall col	1.5	2.0	2.5	12	316
Gutter	--	3.0	33.0	5	8168
		sum			33063

Table 25 Steel prices of one donum polyethylene greenhouse in Hebron.

Part	Diameter (cm)	Thickness (mm)	Length (m)	Number	Price (NIS)
Columns	4.0	3.0	2.5	55	5790
Sub columns	4.0	3.0	1.0	63	2653
Top member	2.0	2.0	8.3	48	5592
Bot members	1.5	2.0	7.4	48	3714
Ver. member	1.5	2.0	7.7	48	3891

Roof brace	1.5	2.0	9.0	12	1137
Wind brace	2.0	2.0	3.6	8	404
Long.top	2.0	2.0	33.0	12	5559
Long.bot	1.5	2.0	33.0	12	4169
Wall col	1.5	2.0	2.5	8	211
Gutter	--	2.5	33.0	5	6806
		sum			39927

In addition to the steel prices, there are other expenses needed to build the greenhouse steel structure. These expenses are mentioned in Table (26),

Table 26 Additional expenses for building the steel structure

Item	Cost (NIS)
Formation of steel	4,000
Metal tiles	1,000
Screws	800
Sum	5,800

- **Polyethylene coverage cost**

According to the Palestinian ministry of agriculture, the polyethylene coverage cost of the Palestinian greenhouse is shown in Table (27),

Table 27 Cost of one donum greenhouse polyethylene coverage

Polyethylene part	Price (NIS)
polyethylene for roof coverage (UVA) (150 µm)	3,520
polyethylene for sides coverage (IR) (120 µm)	1,235
Steel net	1,280
Aluminum clips	3,000
Sum	9,648

- Other expenses

Other expenses, including land preparation, footings, irrigation system, and labor, are shown in Table (28)

Table 28 Other expenses needed to build a polyethylene greenhouse

Part	Cost (NIS)
Excavation and land preparation	800
Footing and concrete	1,920
Irrigation system	1,500
Labor	4,000
Sum	8,220

4.3.2.2 Operation cost

The running cost of a greenhouse in the West Bank is 20,000 NIS/year, as provided by the Palestinian Ministry of Agriculture (PADRRIF, 2017). The running costs include electricity, irrigation, labor, seeds and plants, and fertilizers.

4.3.2.3 Maintenance cost

Since there is no clear data on polyethylene greenhouse maintenance cost, several farmers, greenhouses owners, and greenhouse builders in the West Bank were interviewed to get a clear idea of the maintenance expenses of greenhouses in the West Bank.

Almost all of the interviewees gave a close approximate number to the maintenance cost they spent yearly on fixing minor damages, which may include gutter fixations, screws, and fixation parts, among other damages. The interviewees and the Palestinian Ministry of Agriculture agreed on the necessity to replace the polyethylene cover every two years and the insect net every four years for the best results. Meanwhile, the primary pipes providing the water to the irrigation system can last the entire life period of the greenhouse. Only the secondary pipes used in dripped irrigation will be maintained every three years as recommended by the manufacturing companies of irrigation pipes. The water drip system costs 700 NIS; this means every three years, 700 NIS is spent on maintaining the irrigation system.

However, the certified Palestinian greenhouse is the greenhouse under study and not the greenhouses built randomly. Therefore, the structure of the greenhouse must be able to withstand the weather conditions in winter. Hence, it is assumed that the structure does not have a yearly maintenance cost and will last the entire life cycle of the greenhouse (which is already the same as the steel's life cycle). In this thesis, the life cycle of a greenhouse is considered 20 years as recommended by the steel companies in the area.

The maintenance expenses and the maintaining period of the polyethylene greenhouse are shown in Table (29)

Table 29 Maintenance expenses of the polyethylene greenhouse

Part to maintain	Cost (NIS)	Maintaining period (years)
Yearly maintenance of minor damages	2,000	1
polyethylene for roof coverage (UVA) (150 μm)	3,520	2
polyethylene for sides coverage (IR) (120 μm)	1,235	2
Insect net	1,280	4
Water dripping system	700	3

4.3.2.4 End of Life cost

The steel companies, the farmers, and the Palestinian Ministry of Agriculture, agreed that the average time span of a Palestinian greenhouse equals 20 years. Usually, some parts can be demolished once a system reaches the end-of-life point, and others can be reused.

After digging in the greenhouse industry, it is found that no parts of the greenhouse should be reused in new greenhouses but must be demolished or sold for recycling purposes.

In the polyethylene greenhouse, only steel can be sold. Meanwhile, all of the other parts: the polyethylene cover and the irrigation system, will be demolished. Some people sell the irrigation pipes, but most farmers treat them as waste since there are not many people who buy used irrigation pipes. Even when they are available, the revenues coming from the used irrigation pipes are considered trivial.

As mentioned above, the steel can be sold at the end of the greenhouse life for recycling purposes and sometimes for reusing purposes. Some people working in the used steel industry were consulted and illustrated that they are willing to pay a third of the original steel price in most cases.

Table (30) shows approximate values for the steel revenues at the end of the greenhouse life in the four zones.

Table 30 The salvage value of one donum of polyethylene greenhouse life.

City	Original steel price (NIS)	Salvage value (NIS)
An-Nassareya	33,157	11,050
Tammoun	34,518	11,510
Qabatia	33,062	11,020
Hebron	39,926	13,310

4.3.2.5 Net present value (NPV) of polyethylene greenhouse

To find the NPV value, the discount or interest rate must be identified. For that reason, Palestine Monetary Authority provided the mean interest rate (d) of 6.88% for the year 2020 (PMA, 2020), and this value is used in equation (2.1) to find the NPV.

$$\text{NPV} = \sum_{n-1}^{P} \frac{Cn}{(1+d)^n} \qquad \text{.... 2.1}$$

Based on equation 2.1, the following Tables (31- through 34) show the polyethylene greenhouse annual costs along its time span, 20 years, and the equivalent annual present value in the four zones. At the end of each table, all present values are summed to find the net present value for each zone.

These tables list the costs of the cost cycle assessment of a polyethylene greenhouse year by year, the initial costs, the operational costs, the maintenance costs, and the end of life cost (the salvage value). The calculation interval started at the end of year zero and ended at the end of year 19 since the life span of a greenhouse is twenty years.

The net present value is then calculated using equation 2.1, by dividing the sum of the costs at the end of each year by $(1 + d)^n$. d is the interest rate of 6.88%, and n is the year in which the costs are occurring. It must be noted that calculating the NPV for the year (n-1), requires dividing the sum of the costs by $(1 + d)^n$ and not $(1 + d)^{n-1}$ as shown in the equation.

Table 31 Complete NPV calculations for An-Nassareya polyethylene greenhouse

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)				end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	Insect net	irrigation system		
0	56,825	-	-	-	-	-	-	53,167
1	-	20,000	2,000	-	-	-	-	19,259
2	-	20,000	2,000	4,755	-	-	-	21,914
3	-	20,000	2,000	-	-	700	-	17,396
4	-	20,000	2,000	4,755	1,280	-	-	20,101
5	-	20,000	2,000	-	-	-	-	14,759
6	-	20,000	2,000	4,755	-	700	-	17,232
7	-	20,000	2,000	-	-	-	-	12,920
8	-	20,000	2,000	4,755	1,280	-	-	15,404
9	-	20,000	2,000	-	-	700	-	11,670
10	-	20,000	2,000	4,755	-	-	-	12,869
11	-	20,000	2,000	-	-	-	-	9,901
12	-	20,000	2,000	4,755	1,280	700	-	12,099
13	-	20,000	2,000	-	-	-	-	8,667
14	-	20,000	2,000	4,755	-	-	-	9,862
15	-	20,000	2,000	-	-	700	-	7,829
16	-	20,000	2,000	4,755	1,280	-	-	9,046
17	-	20,000	2,000	-	-	-	-	6,642
18	-	20,000	2,000	4,755	-	700	-	7,755
19	-	20,000	2,000	-	-	-	-11,050	2,894
				sum				291,384

Table 32 Complete NPV calculations for Tammoun polyethylene greenhouse

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)				end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	Insect net	irrigation system		
0	58,186	-	-	-	-	-	-	54,441
1	-	20,000	2,000	-	-	-	-	19,259
2	-	20,000	2,000	4,755	-	-	-	21,914
3	-	20,000	2,000	-	-	700	-	17,396
4	-	20,000	2,000	4,755	1,280	-	-	20,101
5	-	20,000	2,000	-	-	-	-	14,759
6	-	20,000	2,000	4,755	-	700	-	17,232
7	-	20,000	2,000	-	-	-	-	12,920
8	-	20,000	2,000	4,755	1,280	-	-	15,404
9	-	20,000	2,000	-	-	700	-	11,670
10	-	20,000	2,000	4,755	-	-	-	12,869
11	-	20,000	2,000	-	-	-	-	9,901
12	-	20,000	2,000	4,755	1,280	700	-	12,099
13	-	20,000	2,000	-	-	-	-	8,667
14	-	20,000	2,000	4,755	-	-	-	9,862
15	-	20,000	2,000	-	-	700	-	7,829
16	-	20,000	2,000	4,755	1,280	-	-	9,046
17	-	20,000	2,000	-	-	-	-	6,642
18	-	20,000	2,000	4,755	-	700	-	7,755
19	-	20,000	2,000	-	-	-	-11,510	2,772
sum								292,536

Table 33 Complete NPV calculations for Qabatia polyethylene greenhouse

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)				end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	Insect net	irrigation system		
0	56,731	-	-	-	-	-	-	53,079
1	-	20,000	2,000	-	-	-	-	19,259
2	-	20,000	2,000	4,755	-	-	-	21,914
3	-	20,000	2,000	-	-	700	-	17,396
4	-	20,000	2,000	4,755	1,280	-	-	20,101
5	-	20,000	2,000	-	-	-	-	14,759
6	-	20,000	2,000	4,755	-	700	-	17,232
7	-	20,000	2,000	-	-	-	-	12,920
8	-	20,000	2,000	4,755	1,280	-	-	15,404
9	-	20,000	2,000	-	-	700	-	11,670
10	-	20,000	2,000	4,755	-	-	-	12,869
11	-	20,000	2,000	-	-	-	-	9,901
12	-	20,000	2,000	4,755	1,280	700	-	12,099
13	-	20,000	2,000	-	-	-	-	8,667
14	-	20,000	2,000	4,755	-	-	-	9,862
15	-	20,000	2,000	-	-	700	-	7,829
16	-	20,000	2,000	4,755	1,280	-	-	9,046
17	-	20,000	2,000	-	-	-	-	6,642
18	-	20,000	2,000	4,755	-	700	-	7,755
19	-	20,000	2,000	-	-	-	-11,020	2,902
sum								291,304

Table 34 Complete NPV calculations for Hebron polyethylene greenhouse

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)				end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	Insect net	irrigation system		
0	63,595	-	-	-	-	-	0	59,501
1	-	20,000	2,000	-	-	-	0	19,259
2	-	20,000	2,000	4,755	-	-	0	21,914
3	-	20,000	2,000	-	-	700	0	17,396
4	-	20,000	2,000	4,755	1,280	-	0	20,101
5	-	20,000	2,000	-	-	-	0	14,759
6	-	20,000	2,000	4,755	-	700	0	17,232
7	-	20,000	2,000	-	-	-	0	12,920
8	-	20,000	2,000	4,755	1,280	-	0	15,404
9	-	20,000	2,000	-	-	700	0	11,670
10	-	20,000	2,000	4,755	-	-	0	12,869
11	-	20,000	2,000	-	-	-	0	9,901
12	-	20,000	2,000	4,755	1,280	700	0	12,099
13	-	20,000	2,000	-	-	-	0	8,667
14	-	20,000	2,000	4,755	-	-	0	9,862
15	-	20,000	2,000	-	-	700	0	7,829
16	-	20,000	2,000	4,755	1,280	-	0	9,046
17	-	20,000	2,000	-	-	-	0	6,642
18	-	20,000	2,000	4,755	-	700	0	7,755
19	-	20,000	2,000	-	-	-	-13,310	2,297
sum								297,121

4.3.3 Polycarbonate Greenhouse Life Cycle Costing

In this section, the polycarbonate greenhouse designed in this thesis will be analyzed using life cycle costing.

4.3.3.1 The construction cost of a polycarbonate greenhouse

Construction costs needed to build a greenhouse are as follows:

- **steel price**

After calculating the steel needed for every polycarbonate greenhouse design, the steel price for every suggested design will be calculated.

As mentioned earlier, 1 kg per m^2 of galvanized steel costs 5.5 NIS. According to this, the steel prices of all the suggested and designed polycarbonate greenhouses models A1, A2, A3, A4, B1, B2, B3, B4 were calculated.

Tables (35- through 38) show the corresponding steel prices per m^2 and the total steel price of one donum of every model.

Table 35 Steel prices of An-Nassareya models

Model	Steel price/m^2 (NIS)	Total Steel price (NIS)
A1	79.5	60,085
A2	78	58,732
A3	80	69,108
A4	79	68,613
B1	69.5	52,485
B2	78	60,373
B3	87	75,239
B4	77.5	67,082

Table 36 Steel prices of Tammoun models

Model	Steel price/m^2 (NIS)	Total Steel price (NIS)
A1	78.5	59,405
A2	83.5	63,216
A3	86	74,566
A4	93	80,489
B1	75	56,743
B2	81	61,496
B3	94.5	81,687
B4	81.5	70,425

Table 37 Steel prices of Qabatia models

Model	Steel price/m^2 (NIS)	Total Steel price (NIS)
A1	87	65931
A2	93	70548
A3	82	70910
A4	97	83713
B1	76.5	57911
B2	86	64850
B3	89	76677
B4	85.5	73930

Table 38 Steel prices of Hebron models

Model	Steel price/m^2 (NIS)	Total Steel price (NIS)
A1	174	131689
A2	190	143315
A3	153	132335
A4	175	151168
B1	169	127727
B2	200.5	151595
B3	179	154441
B4	153	132530

- **Polycarbonate prices**

After the steel prices are computed, it is necessary to calculate the prices of the polycarbonate covering material.

According to Gelem 2000, one m^2 of 8 mm polycarbonate costs NIS 130, including all fixation accessories.

The greenhouse areas that the polycarbonate material covers are shown in Table (39), Table (39) also demonstrates the total polycarbonate price of the corresponding model,

Table 39 Polycarbonate prices for one donum of the greenhouse models

Model	The total area of polycarbonate (m^2)	Price of polycarbonate (NIS)
A1.	515.5	67,028
A2.	573.5	74,568
A3.	569	73,996
A4.	631	82,056
B1.	523	67,964
B2.	581	75,504
B3.	579	75,244
B4.	641	83,304

The models' total price for every region is shown in Tables (40- through 43). The lowest model price is highlighted in red.

Table 40 Total prices of An-Nassareya models

Model	Total Steel price (NIS)	Price of polycarbonate (NIS)	The total price of greenhouse (NIS)
A1	60085	67,028	127,113
A2	58732	74,568	133,300
A3	69108	73,996	143,104
A4	68613	82,056	150,669
B2	60373	75,504	135,877
B3	75239	75,244	150,483
B4	67082	83,304	150,386

Table 41 Total prices of Tammoun models

Model	Total Steel price (NIS)	Price of polycarbonate (NIS)	The total price of greenhouse (NIS)
A1	59405	67,028	126,433
A2	63216	74,568	137,784
A3	74566	73,996	148,562
A4	80489	82,056	162,545
B2	61496	75,504	137,000
B3	81687	75,244	156,931
B4	70425	83,304	153,729

Table 42 Total prices of Qabatia models

Model	Total Steel price (NIS)	Price of polycarbonate (NIS)	The total price of greenhouse (NIS)
A1	65932	67,028	132,959
A2	70548	74,568	145,116
A3	70910	73,996	144,906
A4	83713	82,056	165,769
B2	64850	75,504	140,354
B3	76677	75,244	151,921
B4	73929	83,304	157,233

Table 43 Total prices of Hebron models

Model	Total Steel price (NIS)	Price of polycarbonate (NIS)	The total price of greenhouse (NIS)
A1	131689	67,028	198,717
A2	143315	74,568	217,883
A3	132335	73,996	206,331
A4	151168	82,056	233,224
B2	151595	75,504	227,099
B3	154441	75,244	229,685
B4	132530	83,304	215,834

Based on the computations of the greenhouses alternatives prices, it is found that model B1 has the lowest price in all of the areas. Therefore, it will be considered the representative greenhouse model for the polycarbonate cover greenhouse.

- **Other expenses**

Other expenses, including land preparation, footings, irrigation system, and labor, are shown in Table (44). Those costs are taken exactly like the polyethylene greenhouse since they are extras and can be used without changing.

Table 44 Other expenses needed to build a polycarbonate greenhouse

Part	Cost
Excavation and land preparation	800
Footing and concrete	1920
Irrigation system	1500
Labor	4000
Sum	8220

4.3.3.2 Operation cost

The running cost of a polycarbonate greenhouse in the West Bank is the same as a polyethylene greenhouse.

The running cost of a greenhouse in the West Bank 20,000 NIS/year as provided by the Palestinian Ministry of Agriculture (PADRRIF, 2017).

The running costs of a polycarbonate greenhouse also include electricity, irrigation, labor, seeds and plants, and fertilizers.

4.3.3.3 Maintenance cost

In the West Bank, polycarbonate is not used as a covering material for the greenhouses. Therefore, the polycarbonate company Gelem 2000 was contacted to learn about the maintenance cost of polycarbonate.

According to Gelem 2000, the polycarbonate lasts for ten years without any change in its properties. Hence, the polycarbonate must be changed every ten years.

The rest of the greenhouse will maintain parts the same way as the polyethylene greenhouse.

Table (45) shows the maintenance cost and the maintaining period of a polycarbonate greenhouse,

Table 45 Maintenance expenses of the polycarbonate greenhouse

Part to maintain	Cost (NIS)	Maintaining perio (years)
Yearly maintenance of minor damages	2,000	1
Polycarbonate (B1 model)	67,964	10
Irrigation system	700	3

4.3.3.4 End of Life cost

The Palestinian market has been searched to find out if polycarbonate can be reused or recycled. Unfortunately, the polymers market in the West Bank does not reuse or recycle the polycarbonate since it is mainly used in buildings for open spaces covering, and the polycarbonate is replaced only when it is damaged for some reason, then the replaced part is demolished.

From here, the same as in the polyethylene greenhouse, the steel is the only recyclable part in a greenhouse after the end of its life.

The following Table (46) shows the steel revenues in the four zones once a polycarbonate greenhouse’s life ends.

Table 46 The salvage value of one donum of the polycarbonate greenhouse.

city	Original steel price (NIS)	Salvage value (NIS)
An-Nassareya	52,485	17,495
Tammoun	56,743	18,915
Qabatia	57,911	19,304
Hebron	127,727	42,576

4.3.3.5 Net present value of polycarbonate greenhouse

The following Tables (47- to 50) show the polycarbonate greenhouse annual costs with the equivalent present value along its time span in the four zones. At the end of each table, the summation of all present values is the net present value for that zone.

These tables list the costs of the cost cycle assessment of a polycarbonate greenhouse year by year, the initial costs, the operational costs, the maintenance costs, and the end of life cost (the salvage value). The calculation interval started at the end of year zero and ended at the end of year 19 since the life span of a greenhouse is twenty years.

The net present value is then calculated using equation 2.1, by dividing the sum of the costs at the end of each year by $(1 + d)^n$. d is the interest rate of 6.88%, and n is the year in which the costs are occurring. It must be noted that calculating the NPV for the year (n-1), requires dividing the sum of the costs by $(1 + d)^n$ and not $(1 + d)^{n-1}$ as shown in the equation.

Table 47 Complete NPV calculations for An-Nassareya polycarbonate greenhouse.

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)			end of life (NIS)	NPV (NIS)
			minor damages	**Plastic cover**	**irrigation system**		
0	128,669	-	-	-	-	-	120,386
1	-	20,000	2,000	-	-	-	19,259
2	-	20,000	2,000	-	-	-	18,019
3	-	20,000	2,000	-	700	-	17,396
4	-	20,000	2,000	-	-	-	15,774
5	-	20,000	2,000	-	-	-	14,759
6	-	20,000	2,000	-	700	-	14,248
7	-	20,000	2,000	-	-	-	12,920
8	-	20,000	2,000	-	-	-	12,088
9	-	20,000	2,000	-	700	-	11,670
10	-	20,000	2,000	67,964	-	-	43,272
11	-	20,000	2,000	-	-	-	9,901
12	-	20,000	2,000	-	700	-	9,558
13	-	20,000	2,000	-	-	-	8,667
14	-	20,000	2,000	-	-	-	8,109
15	-	20,000	2,000	-	700	-	7,829
16	-	20,000	2,000	-	-	-	7,099
17	-	20,000	2,000	-	-	-	6,642
18	-	20,000	2,000	-	700	-	6,412
19	-	20,000	2,000	-	-	-17,495	1,191
			sum				365,197

Table 48 Complete NPV calculations for Tammoun polycarbonate greenhouse.

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)			end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	irrigation system		
0	132,927	-	-	-	-	-	124,370
1	-	20,000	2,000	-	-	-	19,259
2	-	20,000	2,000	-	-	-	18,019
3	-	20,000	2,000	-	700	-	17,396
4	-	20,000	2,000	-	-	-	15,774
5	-	20,000	2,000	-	-	-	14,759
6	-	20,000	2,000	-	700	-	14,248
7	-	20,000	2,000	-	-	-	12,920
8	-	20,000	2,000	-	-	-	12,088
9	-	20,000	2,000	-	700	-	11,670
10	-	20,000	2,000	67,964	-	-	43,272
11	-	20,000	2,000	-	-	-	9,901
12	-	20,000	2,000	-	700	-	9,558
13	-	20,000	2,000	-	-	-	8,667
14	-	20,000	2,000	-	-	-	8,109
15	-	20,000	2,000	-	700	-	7,829
16	-	20,000	2,000	-	-	-	7,099
17	-	20,000	2,000	-	-	-	6,642
18	-	20,000	2,000	-	700	-	6,412
19	-	20,000	2,000	-	-	-18,914	816
			sum				368,806

Table 49 Complete NPV calculations for Qabatia polycarbonate greenhouse.

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)			end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	irrigation system		
0	134,095	-	-	-	-	-	125,463
1	-	20,000	2,000	-	-	-	19,259
2	-	20,000	2,000	-	-	-	18,019
3	-	20,000	2,000	-	700	-	17,396
4	-	20,000	2,000	-	-	-	15,774
5	-	20,000	2,000	-	-	-	14,759
6	-	20,000	2,000	-	700	-	14,248
7	-	20,000	2,000	-	-	-	12,920
8	-	20,000	2,000	-	-	-	12,088
9	-	20,000	2,000	-	700	-	11,670
10	-	20,000	2,000	67,964	-	-	43,272
11	-	20,000	2,000	-	-	-	9,901
12	-	20,000	2,000	-	700	-	9,558
13	-	20,000	2,000	-	-	-	8,667
14	-	20,000	2,000	-	-	-	8,109
15	-	20,000	2,000	-	700	-	7,829
16	-	20,000	2,000	-	-	-	7,099
17	-	20,000	2,000	-	-	-	6,642
18	-	20,000	2,000	-	700	-	6,412
19	-	20,000	2,000	-	-	-19,304	713
			sum				369,795

Table 50 Complete NPV calculations for Hebron polycarbonate greenhouse.

year	initial cost (NIS)	Operation cost (NIS)	Maintenance cost (NIS)			end of life (NIS)	NPV (NIS)
			minor damages	Plastic cover	irrigation system		
0	203,911	-	-	-	-	-	190,785
1	-	20,000	2,000	-	-	-	19,259
2	-	20,000	2,000	-	-	-	18,019
3	-	20,000	2,000	-	700	-	17,396
4	-	20,000	2,000	-	-	-	15,774
5	-	20,000	2,000	-	-	-	14,759
6	-	20,000	2,000	-	700	-	14,248
7	-	20,000	2,000	-	-	-	12,920
8	-	20,000	2,000	-	-	-	12,088
9	-	20,000	2,000	-	700	-	11,670
10	-	20,000	2,000	67,964	-	-	43,272
11	-	20,000	2,000	-	-	-	9,901
12	-	20,000	2,000	-	700	-	9,558
13	-	20,000	2,000	-	-	-	8,667
14	-	20,000	2,000	-	-	-	8,109
15	-	20,000	2,000	-	700	-	7,829
16	-	20,000	2,000	-	-	-	7,099
17	-	20,000	2,000	-	-	-	6,642
18	-	20,000	2,000	-	700	-	6,412
19	-	20,000	2,000	-	-	-42,576	-5,438
sum							428,967

4.3.4 Summary of Life Cycle Costing (Phase Two)

The life cycle costing phase was divided into two parts: the life cycle costing of a polyethylene greenhouse and the life cycle costing of a polycarbonate greenhouse.

- In the first part, the life cycle costing of a polyethylene greenhouse was performed in stages:

Stage one: the initial cost of polyethylene was found, which includes: the costs of steel for every zone of the four zones in Tables (22-to 25), additional expenses needed for building the steel structure in Table (26), costs of polyethylene cover shown Tables (27), and other expenses like land preparation and labor mentioned in Table (28).

Stage two: operational cost of the Palestinian greenhouse was suggested by the Palestinian Ministry of Agriculture, 20,000 NIS/year, and the life period of the greenhouse is recommended to be 20 years in this research.

Stage three: maintenance cost of a polyethylene greenhouse will include the covering replacement every two years, the insect net replaced every four years, the dripping pipes replacement every three years, and minor damages and replacement happen yearly. The maintenance costs of a polyethylene greenhouse shown in Table (29).

Stage four: end of life cost of a polyethylene greenhouse. It was found that all parts of the polyethylene greenhouse will be demolished except for the steel structure, which can be sold for a third of its original price. In Table (30), the revenues from the steel are mentioned for every zone.

At the end of the life cycle costing stages, all costs in addition to the revenues from steel at the end-of-life stage were discounted to their present value and summed together to give the net present value of a polyethylene greenhouse for each zone. NPV calculations are illustrated in Tables (31 – to 34), a table for every zone.

- Part two, the polycarbonate greenhouse life cycle costing, was also divided into stages like polyethylene greenhouse life cycle costing.

  Stage one: the initial cost of polycarbonate greenhouse was found, which includes the costs of steel shown in Tables (35- to 38) and costs of polycarbonate in shown Table (39). The lowest polycarbonate greenhouse cost was the cost of the B1 greenhouse. B1 had the lowest cost in all the Palestinian zones, as shown in Tables (40- to 43). Afterward, the additional expenses were illustrated in Table (44).

  Stage two: the operational cost of the polycarbonate greenhouse was considered to have the exact cost as the polyethylene greenhouse, 20,000 NIS/year.

  Stage three: maintenance cost, the polycarbonate company recommended changing the polycarbonate cover every ten years, so in a greenhouse life cycle of 20 years, the polycarbonate cover will be changed only once. However, the other expenses, including minor damages and dripping pipes, were taken the same. Table (45) shows the maintenance cost of a polycarbonate greenhouse.

  Stage four: the end-of-life cost of a polycarbonate greenhouse was found. The steel is the only usable part once the polycarbonate greenhouse life's ends. Table (46) shows the steel revenues from selling the steel of the polycarbonate greenhouse.

After all the life cycle costs stages were found, the net present value of a polycarbonate greenhouse for every zone was found in Tables (47- to 50).

The following table compares the NPV of a polyethylene greenhouse and the NPV of a polycarbonate greenhouse in every zone.

As the table shows, the NPV of polycarbonate greenhouse is almost NIS 75,000 more than the polyethylene greenhouse during their life cycles in An-Nassareya, Tammoun, and Qabatia zones. Moreover, the NPV of polycarbonate greenhouse is almost NIS 130,000 more in Hebron zone.

Table 51 The NPV of polyethylene and polycarbonate greenhouses

Zone	NPV of polyethylene greenhouse (NIS)	NPV of polycarbonate greenhouse (NIS)
An-Nassareya	291,384	365,197
Tammoun	292,536	368,806
Qabatia	291,304	369,795
Hebron	297,121	428,967

Chapter Five
Conclusions and Recommendations

5. Conclusions and Recommendations

This chapter focuses on the crucial conclusions of the data analysis and highlights the objectives of the research.

It also shows the limitations the study faced while collecting and analyzing data.

In the end, some future recommendations are presented for researchers who are interested in this field.

5.1 Research conclusions

based on this research calculations and findings, the following conclusions were drawn:

- Based on the greenhouse European code EN 13031-1 recommendation of designing greenhouse roof with a slope ranging from 20^o-26^o (PrEN13031-1, 1997), two angles were suggested for the polycarbonate greenhouse design and checked in this thesis, 22^o and 26^o. It was found that increasing the angle slope of the roof angle to 26^o will optimize the steel of the greenhouse structure to a minimum, which in turn will minimize the costs needed to build the greenhouse.
- Based on the typical structure dimensions of the Palestinian greenhouse, the most economical design dimensions of a polycarbonate greenhouse is the design that has a span of 7m, gutter height of 2.5 m, and a roof slope of 26^o. It is also suitable to be used in all of the four Palestinian zones.

- The NPV of polycarbonate greenhouse to be built over one donum area is almost NIS 75,000 more than the polyethylene greenhouse during their life cycles in An-Nassareya, Tammoun, and Qabatia zones. Moreover, the NPV of polycarbonate greenhouse is almost NIS 130,000 more in Hebron zone.
- Based on the economic calculations, the West Bank in Palestine is not ready yet to replace polyethylene with polycarbonate as a covering material for the agricultural greenhouses.

5.2 Research limitations

This research was affected by some factors that may influence the final results, some of those factors:

1. Not enough available data on the performance of the certified polyethylene greenhouse since the MoA has approved it for two years only, and farmers haven’t widely used it.
2. The unavailability of exact data on the damages and maintenance of the polyethylene greenhouse in the West Bank.
3. Not using polycarbonate as a greenhouse cover in the West Bank, Consequently, the absence of any related data about polycarbonate greenhouse performance in Palestine.

5.3 Future recommendations

Based on the research results, the following recommendations are presented to develop the greenhouse industry in Palestine:

Recommendations for:

- Farmers:
  - Although the polyethylene cover of greehhouses was concluded as more economic than polycarbonate, the polycarbonate might be feasible if we consider the requirements for specific light waves or a specific growing atmosphere.
- MoA
  - The ministry needs to provide clear policies for selecting greenhouses types/covers to provide more alternatives for farmers.
  - MoA needs to build its capacity regarding the extension services for different types of greenhouses.
- Researchers
  - Researchers are advised to research in recycled polymers for a material similar to the polycarbonate properties to be used as a covering material for greenhouses. This, in turn, can lower the costs of the covering material and improve strengthening qualities.
  - A polycarbonate greenhouse design without a steel frame will require a simpler footing design and eventually lower the costs of building a greenhouse covered with polycarbonate.
  - To study the environmental impacts (gains and losses) due to the use of different greenhouses covers. Life cycle assessment might be conducted for this regard under Palestinian conditions.

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جامعة النجاح الوطنية
كلية الدراسات العليا

تقييم تكلفة حياة الدفيئات البلاستيكية المصنوعة من البولايثيلين والبوليكاربونيت في مناطق الضفة الغربية

إعداد
ديانا عزام ناصيف

إشراف
د. عبد الفتاح حسن
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قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في الادارة الهندسية بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس، فلسطين
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الملخص

القطاع الزراعي في فلسطين يعاني من أحوال الطقس الصعبة خلال فصل الشتاء، مما يتسبب في خسائر كثيره للمزارع الفلسطيني في المبنى الانشائي للبيت البلاستيكي والنباتات الموجودة بداخله.

يستخدم القطاع الزراعي في فلسطين مادة البولي إيثيلين كمادة تغطية لمباني البيوت البلاستيكية، لكن الظروف الجوية القاسية في الشتاء تتسبب في تمزق البولي إيثيلين وتؤدي إلى خسائر فادحة. العديد من البلدان في الوقت الحاضر تستخدم صفائح البولي كاربونيت لتغطية البيوت البلاستيكية، لما تتمتع به من العديد من الخصائص المفيدة، وخاصة المتانة والقوة ضد الظروف الجوية القاسية وطول مدة حياتها مقارنة مع البولي إيثيلين. على الرغم من ذلك، قد يكون التحول من البولي إيثيلين إلى البولي كاربونيت مكلف من ناحية اقتصادية.

يقترح هذا البحث ثمانية تصاميم انشائية لبيت بلاستيكي مغطى بمادة البولي كاربونيت، ومناسبة للاستخدام في الضفة الغربية. في هذا البحث يتم فحص التصاميم الإنشائية الثمانية باستخدام برنامج كمبيوتر SAP2000 تحت تأثير مجموعات الأحمال المختلفة لأربع مناطق زراعية فلسطينية. حيث قسمت وزارة الزراعة الفلسطينية في أحد مشاريعهم الضفة الغربية إلى أربعة مناطق زراعية هي: النصارية، وطمون، وقباطية، والخليل.

تم اختيار تصميم واحد فقط من التصميمات الانشائية الثمانية لكل منطقة، حسب تكلفة الإنشاء الأولية، فقد تم اختيار البيت الزراعي الأقل تكلفة لكل منطقة.

يقوم هذا البحث أيضًا بتحليل تكلفة دورة حياة البيت البلاستيكي الفلسطيني المغطى بالبولي إيثيلين والمعتمد من وزارة الزراعة الفلسطينية، كما ويقوم بتحليل تكلفة دورة الحياة للبيت البلاستيكي المغطى بصفائح البولي كاربونيت طوال فترة حياتهما، عشرين عامًا. في النهاية، تم حساب صافي القيمة الحلية لكلا النوعين من البيوت البلاستيكية الزراعية ومقارنتها.

لقد وجد أن التحول من البولي إيثيلين إلى ألواح البولي كاربونيت هو بالفعل إجراء مكلف، وسيضيف إلى تكاليف بناء البيت البلاستيكي في مناطق النصارية وطمون وقباطية حوالي 25%، كما أنه سيزيد من تكاليف البيوت الزراعية في الخليل بمقدار 40%.