REGENERATIVE DESIGN GUIDELINE TO OPTIMIZE A GREENHOUSE INTO AN ECO-INDUSTRIAL PARK BASED ON ECOSYSTEM SERVICES

By

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ABSTRACT

To feed our growing population, innovative solutions for increasing productivity, while lowering energy requirements for food production and provision will be required. The main objective of this study was to develop a sustainable design guideline based on ecosystems services and the concept of regenerative design, which can guide the optimization of the existing energy or low-carbon energy resources to increase the efficiency of the greenhouse integrated into an eco-industrial park (or EIP). To pursue this aim, ecosystem services have been studied to develop an understanding of the interplay between internal elements of various ecosystem and the services each provide. The term ecosystem service had been used to refer to both natural ecosystem services and those services from within human-made ecosystem(EIP and Urban) that are considered to be potentially analogous if using the lens of industrial ecology that views sustainable industrial systems as those attempting to mimic natural systems and processes. To examine the design guideline and its practical capability, the guideline was applied to an actual case of the Port Hawkesbury Micro-Eco Industrial Park (MEIP). The results revealed the applicability of the guideline for facilitating sustainable design with an emphasis on increased efficiency of the greenhouse and reduced overall energy consumption.

Keywords: Design Guideline, Regenerative design, EIP, Greenhouse, Ecosystem Services

LIST OF ABBREVIATIONS USED

EIP	Eco-Industrial Park
MEIP	Micro Eco-Industrial Park
PH	Port Hawkesbury
PHP	Port Hawkesbury Paper factory
PH MEIP	Port Hawkesbury Micro Eco-Industrial Park
GH	Greenhouse

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CHAPTER ONE: INTRODUCTION

1.1. Statement of The Problem

The global population is growing; to feed this growing population we will need to produce more food and ensure its accessibility, at a time when available resources scarcity is increasing. Researchers suggest that people in cold climates could encounter a greater challenge ensuring food security as compared to those populations in warmer or at least more temperature climates (Shannon & Montha, 2015). Taken together with the issue of needing to dramatically reduce GHG emission from all sectors – including food production and related transportation of food globally (versus local production) – innovative solutions for increasing productivity, while lowering energy requirements for food production and provision will be required.

Outdoor farming in cold climate areas is subjected to various environmental challenges such as harsh weather and exposure to wide variety of uncontrolled conditions can cause reduction in annual yield. This situation ofttimes necessitates people in cold climate areas to import food which can result in an elevated carbon footprint per unit product (Albright, 2013). To address these efficiency issues within food production systems, one option is to apply a lens of eco-efficiency, realized through the application of industrial symbiosis. This concept supports the integration of food systems into broader network to optimize the existing resource use and reduce the collective impact. As noted by Gancone et al. (2017) eco-efficiency in agriculture means increasing the efficiency of food production system, while reducing its negative impacts on the environment (Dace & Blumberga, 2016; Timma, Zoss, & Blumberga, 2016) which can be possible through considering required requirements with desperate, and seek other sectors (i.e. EIPs) available resources to make symbiotic relationships to fulfill these requirements.

1.2. Increasing Energy Consumption and Environmental Degradation

Cold climate communities face a variety of challenges such as higher consumption of energy, water and materials in order to maintain or access basic amenities, such as food, shelter, heat and transportation (Wei et al., 2016; Zentner et al., 2011). Increasing resource costs and scarcity (Mussard, 2017), higher food prices during winter (Shannon & Motha, 2015), and food security challenges are all linked to the necessity of extensive transportation needed to provide food from productive areas far removed from Canada's rural communities (Kortright & Wakefield, 2011; Shannon & Motha, 2015). If such populations are to be able to access fresh food during the off-seasons, low intensity, high productivity approaches to sustainable food production will be needed (Enenkel et al., 2015; Opitz, Berges, Piorr, & Krikser, 2016). Scholars noted that food distribution and its potential negative impact linked to GHG emissions and other environmental issues have led some to investigate more sustainable practices that also benefit food security issues (Beske et al., 2014; Gupta & Gangopadhyay, 2013; Sharma, 2016). The increasing cost of energy, the desire to preserve the quality of water and soil, and the growing concern about greenhouse gas emissions are three main reasons for interest in high output food production systems in terms of both quality and quantity (Cohen & Garrett, 2010; Hoeppner et al., 2006; Pahl-Wostl, 2017; Pimentel et al., 2005; Smith et al., 2004).

The link between technological development and negative environmental impacts have led researchers to increase their focus on improving resource efficiency of technical systems (Drouant et al., 2014; Enenkel et al., 2015; Lang & Barling, 2012). In the case of agricultural systems, the efficient consumption of resources, requires creative technological development (Bochtis et al., 2012; Chel & Kaushik 2011; Nelson et al., 2016). Creative crop systems may provide producers with opportunities to decrease their fossil fuel consumption and increase the energy efficiency of their operations (Coxworth et al., 1996; Dalgaard et al., 2001; Lang & Barling, 2012; Opitz et al., 2016). This, in turn, can reduce GHG emissions and improve the long-term environmental sustainability of agricultural industries (Gregory et al., 2005; Gupta & Gangopadhyay, 2013; Lang & Barling, 2012; Neitzert et al., 1999; Pahl-Wostl, 2017; Pimentel et al., 2005).

Agricultural has three primary impacts on natural systems: a) biodiversity is threatened with land clearing (Dirzo & Raven, 2003; Ford Denison & McGuire, 2015;Muller et al., 2017; Musitelli et al., 2016) ; b) carbon sequestration is reduced as a consequence of land clearing (Buratti et al., 2017; Burney et al., 2010; Liu, Zhang, & Bae, 2017); and c) land fertility/productivity can be reduced due to the land being overworked and over fertilized (Besthorn, 2013; Gupta & Gangopadhyay, 2013; Muller et al., 2017; Zhang et al., 2017b). Additionally, fertilizers can contaminate fresh water, which threatens aquatic life (Zhang et al., 2017b). In contrast, intensive indoor farming may provide an opportunity for farmlands to regrow hardwood forests, which can decrease the environmental degradation and preserve nature (Pinstrup-Andersen, 2017).

In addition, indirect greenhouse gas (GHG) emissions and land-cover change are issues as well (Liu, Ahang, & Bae, 2017). Both increase the global GHG emissions by 19-29% annually (Gancone et al., 2017), but can be reduced by replacing nonrenewable fuel sources and artificial fertilizers with renewable sources and natural fertilizers (de Azevedo et al., 2017; Liu, Ahang, & Bae, 2017; Salvador, Corazzin, Piasentier, & Bovolenta, 2016). Sustainable food system designers implement cyclic loops in their consumption systems, which use the resources from nature and then return them (Cole et al., 2011). In terms of energy a variety of renewable energies can be used for agricultural purposes such as: biomass, solar, wind, and hydro power (Ali, Dash, & Pradhan, 2012) (Awani et al., 2015; Bibbiani et al., 2017; Nadal et al., 2017; Salah et al., 2017; Taki et al., 2016), or integrate the agriculture production into disperate industries and make symbiotic relationships to improve eco-efficiency [read resource efficiency] at the system level.

1.3. Industrial Ecology

Considering the fact that human impact on the environment needs to be reduced, and that lessons on how to do that can be learned from natural ecosystems, can be address by Industrial ecology. Indeed, in natural ecosystems the use of energy and materials are optimized while wastes and pollution need to be minimized. (Marianne Boix,2014); industrial ecologists views these natural ecosystems as potentially analogous for the sustainable operations of industrial systems. Industrial Ecology is a system which deals with other systems, such as the environment, nature, and human societies (Graedel & Allenby, 2010). Eco-industrial parks are a form of Industrial Ecosystems that are designed to imitate natural ecosystems, described as a community of industries which are located close together and can exchange materials, energy, and information, together and improve eco-efficiency at the system level (Lowe, 2001). Eco industrial designers can reduce both the waste and pollution; this can reduce GHG intensity of the system as a whole and increase material and energy efficiency (Chen, Xi, Geng, & Fujita, 2011). For instance, paper production is an energy intensive industry, but supplying energy in the form of waste heat to other adjacent industries can dramatically reduce the negative GHG contribution of the system (Korhonen, 2001).

2. Background

2.1. Alternatives: Indoor Farming

Greenhouses are essential parts of modern agriculture in order to provide people with a variety of foods throughout the year (Besthorn, 2013; Pinstrup-Andersen, 2017). Researchers have struggled to generate and implement new methods for agriculture that are more resource efficient and locally focused with a view to improve current conditions linked to increased prices and regional food insecurity issues (Despommier, 2013; Song, Tan, & Tan, 2018). In 1930, Gericke and his colleagues, who work at University of California used a liquid containing essential nutrients instead of soil as an alternative method for farming (Gericke, 2010). This novel idea which eventually became known as hydroponics was taken up by others in indoor farming settings in the following decades. Since 1999, vertical farming has been the subject of debate among researchers; however, it has only been since 2013 that we can find any working examples of vertical farming: South Korea, Japan, Singapore, Chicago, and Vancouver (Despommier, 2013; Pinstrup-Andersen, 2017). While vertical farming is a novel strategy that is thought to be in closer harmony with natural systems, considerable research is still needed to establish it as part of the suite of solutions to the issues now presented by existing agricultural systems (Pinstrup-Andersen, 2017).

2.2. Indoor Farming as Part of Integrated Industrial Networks

Industries provide valuable resources to society, as well as economic development through employment and their role within material supply-chains. However, such operations also contribute to many local and global environmental challenges. A reasonably new approach to maximizing industries' benefits is a concept referred to as Industrial Symbiosis (IS). Industrial symbiosis represents the relationship between disparate industries in which material, energy or by-product are exchanged to achieve a collective benefit greater than the total sum of the individual benefits (Afshari, Farel, & Peng, 2018; Afshari, Jaber, & Searcy, 2018; Branson, 2016; Chertow, 2007; Felicio al., 2016).

Eco-industrial park (EIP) are community of enterprises located sufficiently close together in order to exchange materials, energy, and information (Valenzuela-Venegas, Salgado, & Díaz-Alvarado, 2016; Raabe et al., 2017). The intent of this collaboration is to improve overall environmental and socioeconomic performance by developing a complex network of flows among the community (Afshari, Farel, & Peng, 2018; Yu, Dijkema, De Jong, & Shi, 2015). Some of these flows could support for agricultural production; indoor farming - for example – could be considered as a part of an EIP, and provide society with additional job opportunities, products and localized economic benefits. However, it also has some requirements, such as material and energy sources (Andrews & Pearce, 2011). By creating integrated industrial network that include such systems, one can mitigate the impact of industries on the environment and maximize energy and material efficiency (Kim et al., 2018).

2.3. Food Production in Rural Nova Scotia

The advantages of indoor farming can outweigh its disadvantages in several ways; for example, one can control the conditions of the crops, provide for the specific requirements, maximize yield and grow various vegetables and fruits in a common area (Despommier, 2010; Pinstrup-Andersen, 2017). Another advantage is that crops can be considerably less affected by severe weather events (Despommier, 2013). However, in colder climates greenhouses have typically relied heavily on fossil-based heating systems if they are to function year-round (Baas & Korevaar, 2010; Graamans, Baeza, Dobbelsteen, Tsafaras, & Stanghellini, 2018 ; Sethi, Sumathy, Lee, & Pal, 2013) which is both expensive and a contributing factor to global warming (Ahamed, Guo, & Tanino, 2018; Theurl et al., 2014). To improve the economic viability of such operations and reduce any negative impacts, one needs to reduce such dependence while simultaneously ensuring the dramatic improvements in the productivity normally associated with greenhouse operations.

3. Research Objectives and Research Questions

3.1. Research Objectives

Creating a sustainable design guideline based on ecosystems services and best practice - which can optimize existing energy resources or low-carbon energy resources to increase the efficiency of greenhouse integration into an EIP - is the objective of this study. Port Hawkesbury Paper (PHP) factory located in Port Hawkesbury, Cape Breton Island, is the test subject used to pilot the utility of the guideline.

3.2. Research Questions

The major research question is as follows:

- How can a regenerative design guideline help to optimize the productivity of a greenhouse integrated into EIP, while minimizing the need for external (to the EIP) input of resources?

The sub-questions focus on understanding:

- What are the greenhouse requirements?
- What are available ecosystems services to support a greenhouse?
- What are services that greenhouse provides for ecosystems?

4. Methods of Data Collection and Analysis

4.1. Data Collection and Data Processing

The method of this research has several steps as follow.

- ***Literature review:***

It has three main parts and will be expanded upon in the literature review: Part one provides an overview of greenhouse requirements that reflect the actual needs of the greenhouse operations and were used to create a list of requirements to be considered in the process of design. Part two investigates the methods, strategies and thereby the potential application of biomimicry to the project. The concept of biomimicry has been used to guide the development of a nature-based strategy for greenhouse integration into an ecosystem. Part three explores the definitions of ecosystem services and analyze the relationship amongst them.

- ***Case studies:***

In addition to the literature review described above, data related to five existing urban/innovative greenhouses/food production systems were assessed to add additional insight to potential key design features and consideration.

- ***Guideline Design:***

The regenerative method provides the conceptual framework for the development of the design guideline. It is underpinned by the basic greenhouse requirements, and available ecosystem services to fulfill the greenhouse requirements.

- ***Pilot (Beta) test:***

Port Hawkesbury Paper's EIP was selected to pilot test the design guideline; the purpose to evaluate data needs and the comprehensiveness of the resulting design recommendations.

4.2. Conceptual Framework for Design

The framework used for designing the system is broadly considered sustainable design. Sustainable design can generate new ideas and reduce negative environmental impacts (Perez et al., 2014) as poor system design has been linked with environmental crises across the globe (Ahmed & Rashid, 2009; Molla, Abareshi & Cooper, 2014; Shu-Ysng et al., 2004). Eco-design – one aspect of sustainable design - can help ddress this problem. The main feature of eco-design, as it is linked to sustainable production systems, is the reduction in energy, materials, water consumption and waste generation (Deutz, McGuire, & Neighbour, 2013; Donnelly, Beckett-Furnell, Traeger, Okrasinski, & Holman, 2006; Knight & Jenkins, 2009). Incorporating such factors when developing more resource efficient food production systems can reduce the emissions and impacts associated with food production and distribution that service cold climate regions. They can also consider implementing technological tools to improve the performance of systems through eco-design methods (Benitez-Amado & Walczuch, 2012; Deutz McGuire, & Neighbour, 2013; Rivard, Raymond, & Verreault, 2006; Tyl, Lizarralde, & Allais, 2015).

Such sustainable food production systems can have long-term positive effects on both global and local scales (Chopin, Blazy, Guinde, Wery, & Dore, 2017). Designing new local agriculture systems can result in particular crop composition which provides various ecosystem services (Benoît et al., 2012; Castellazzi et al., 2010; Schaller et al., 2012). Another aspect of a sustainable food production system is its positive economic effects such decreasing the price by minimizing transportation costs that are exposed to potential carbon tax and provide accessible food for local people. This research considers various aspects of designing a new local sustainable food production system for cold climate areas in Canada. In addition to eco-design, sustainable design has several other approaches such as green design, biomimicry, cradle to cradle etc. Designers have utilized different strategies and techniques to achieve their design aims (Pauw, Karana, Kandachar, & Poppelaars, 2014).

Although, scholars have discussed Eco-design about 35 years, it has only really been considered as a design method since 1990-1995 (Kazulis, Muizniece, & Blumberga, 2017; Stevels, 2001; Van Hemel & Cramer 2002). In 1898 Ebenezer Howard wrote about "garden cities" in which houses surrounded by gardens made a healthy atmosphere for the citizens (Shu-Ysng et al., 2004). At the beginning of twentieth century, Frank Lloyd Wright generated a new idea as "organic architecture". Wright employed minimal and naturalistic features in his architectural design (Shu-Ysng et al., 2004). Since the 1960s, designers have adopted historical ideas with technology to create a novel design approach. (Shu-Ysng et al., 2004; Kazulis et al., 2017). In the 1970s, John Todd invented of "living machines" which were an alternative treatment for municipal sewage that attempted to explore natural mechanisms to alleviate the pollution (Du Plessis & Brandon, 2015; Shu-Ysng et al., 2004; Zari, 2006).

Before the term biomimicry gained prominence, eco-design was seen as a method of design which manages industrial and environmental issues in a sustainable way (Fuller, 1975; Olkowski, 1979; Todd & Todd 1994; Scott 1999). Eco-design is a product development process that takes into account the complete life cycle of a product and considers environmental aspects at all stages of the process striving for products, which make the lowest possible environmental impact throughout the product's life cycle (Donnelly et al., 2006; Kazulis et al., 2017). Shu-Ysng, et al. (2004) stated that one of the features of eco-design is using ancient methods design. The technique of cultivating various plants in a complex rotation is an example of ancient methods, which has been used by numerous ancient cultures and has provided a sustainable and predictable agroecosystem design (Shu-Ysng, et al., 2004). By considering all the above-mentioned documents, it is suggested that integrating the concepts of eco-design to the design and construction will benefit the sustainability of the food production system. There are also common concepts regarding the use of local materials or a livelihood system in the construction of buildings in eco-design method design (Shu-Ysng, et al., 2004).

As Jensen mentioned (1998) eco-design mainly focuses on three main fields: raw material consumption, energy efficiency, and waste management (Kazulis et al., 2017; Zhu, Zhou, Cui, & Liu, 2010). In the past, eco-design was primarily employed for choosing the material to be used for products. Now, it draws the attention of researchers to the production process, life cycle of products, (Berzina et al., 2010; Deutz et al., 2013 Martín Gómez, Aguayo González, & Marcos Bárcena, 2018; Ramani et al., 2010) and corporative systems and services (Braungart, McDonough, & Bollinger, 2007; M'hamdi et al., 2017; Ociepa-Kubicka & Pachura, 2017; Repele, Udrene, & Bazbauers, 2017). Based on eco-design's principles, one can design products and processes that are environmentally benign (Blumberga et al., 2016; Cherifi et al., 2015; Ghisellini et al.,2016; Zhu et al., 2010). The intention is to apply the eco-design method to the material and energy flows of food production systems to create more sustainable systems (Dong et al., 2016; Sacirovic, Ketin, & Vignjevic, 2018).

5. Outline of The Thesis

Chapter 2 presents a more in-depth review of some of the key concepts discussed earlier and other applicable literature. It begins with greenhouse requirements, the concept of regenerative design, and then the nature of natural, eco-industrial parks, and urban ecosystem services. Chapter 3 describes a number of case studies which provided insight to the various considerations for key design features and consideration. The design guideline is presented in Chapter 4 and then more fully examined in Chapter 5 through a cases study where it is applied to Port Hawkesbury Paper. Chapter 6 offers final thoughts on some of the remaining knowledge gaps, pertinent aspects of project implementation and further research.

CHAPTER TWO: LITERATURE REVIEW

Introduction

Chapter Two reflects that literature reviewed to build the knowledge foundation contributing to developing the design guideline. It has three main parts: Part one provides an overview of greenhouse requirements that reflect the actual needs of the greenhouse operations and were used to create a list of requirements to be considered in the process of design. Part two investigates the methods, strategies and thereby the potential application of biomimicry to the project. The concept of biomimicry has been used to guide the development of a nature-based strategy for greenhouse integration into an ecosystem. Part three explores the definitions of ecosystem services and analyze the relationship amongst them through the lens of industrial ecology, which views industrial ecosystems as analogous to [oftimes immature] natural ecosystems. Ecosystem services have been studied to develop an understanding about the interplay between internal elements of various ecosystem services, as well as between different ecosystem services, seeking inspiration to support applying the IE lens to greenhouse development and operations – particularly those integrated into a broader industrial ecosystem such as an eco-industrial park. This information provides the basis for the design considerations presented in Chapter Four.

Part I: Greenhouse Requirements

I.1. Site Selection

Proper site selection is the most important step to ensure the success of the greenhouse; almost all greenhouse's requirements are connected to the site selection (Baudoin et al., 2013; Chen et al., 2018; Kittas et al, 2013; Kumar, Tiwari, & Madan, 2009). In nature, natural food production is linked to the availability of appropriate, specific ecosystem services. In this instance, scholars recommend choosing a site that permit all operations to be on the same level with minimal elevation difference between work areas to permit easy movement of personnel and materials, as well as reduce the cost of operation (Ponce, Molina, Cepeda, Lugo, & MacCleery, 2014). Additionally, building the greenhouse on one level provides the opportunity of expanding the greenhouse in the future. The site should be well-drained site as almost all greenhouses need a draining system both on the roof and on-site greenhouses (Ponce et al., 2014; Sanjuan-Delmás et al., 2018; Tiwari, 2003). Considering wind direction and seek topography that offers a natural windbreak (like a hill) (Kim, Lee, & Kwon, 2017). If it is not feasible, a stand of trees on the north side can replicate this feature (Nelson, 2003).

I.2. Climate Conditions

The climate conditions of the site are key factors for the successful operation of a greenhouse (Graamans et al., 2018; Taki et al., 2017). They can not only affect greenhouse resource requirements (e.g. HVAC system requirements and construction materials) but can determine crop choice, greenhouse structure, and building features (Briassoulis, Dougka, Dimakogianni, & Vayas, 2016; Ha et al., 2017; Lee, 2017).

I.3. Windbreak and Shading

As noted, it is important to have a windbreak on the north and northwest side in the form of tree stands or from natural topography (Ponce et al., 2014). However, any windbreak should not overshadow the facilities: such features should be set back about 2.5 times their height. Considering the fact that the wind pressure on greenhouses built on coastal land is higher than that in other sites - due to the high coastal wind velocity and atmospheric turbulence (Kim et al., 2017) - it is also recommended for windy and snowy climates to build greenhouse about one tree-length away from any such vegetation to keep drifts back from the greenhouse. Natural windbreaks not only can affect the temperature around the greenhouse but also provide the greenhouse with a milder micro-climate. In case of having natural ventilation, it is recommended to consider room for future expansion (Tiwari, 2003).

I.4. Orientation and Natural Light

Two important criteria for greenhouse orientation are sunlight level (Çakir & Şahin, 2015; Taki, Rohani, & Rahmati-joneidabad, 2017) and wind direction (Benni, Tassinari, Bonora, Barbaresi, & Torreggiani, 2016; Kim et al., 2017; Kumar et al., 2009; Santolini et al., 2018). Sunlight level should be adequate and uniform. The orientation of the greenhouse depends on the latitude and could also be different depending on shape (Chen et al., 2018; He et al., 2018; Taki et al., 2017). For example, a single-sided greenhouses in areas above 40-degrees N latitude (Northern hemisphere) is best built with the ridge running east to west; below 40-degrees N, the ridge of the greenhouse should be oriented from north to south (Sethi, 2009). For multi-span greenhouses, they should be oriented from north to south to avoid the shadow in the greenhouses (Sethi, 2009).

I.5. Shape and Orientation

As noted, the shape of the greenhouse will influence both orientation and site selection. Different greenhouse shapes are available and can be chosen based on climatic condition of the site (Figure 2.1) (Table 2.1). The table below demonstrates different greenhouse structure design and their advantages and disadvantages.

Structure Type	Advantage	Disadvantage
Arch Roof ,Quonset	High light transmission, High thermal inertia, High wind and snow load resistance, Low construction complexity	Low ventilation efficiency in absence of roof vent system
Standard Peak, Even Span	Low construction complexity, Easy side ventilation, suitable for any kind of flexible and rigid materials, Easy to drain rainwater	Roof ventilation problem, Less in closed space that arch roof, Greater shading, Needs more internal supports
Uneven Span, Single Span	Low cost, High wind load resistance, Poor ventilation, High light transmission, Work well on slope sites	Less in closed space than arch roof, Greater shading,

Table 2.1: Advantages and disadvantages of different greenhouse forms [Adapted from (Ghasemi, Ajabshirchi, & Faramar 2016; Ponce et al., 2014; Sethi, 2009; Taki et al., 2017)]

The greenhouse orientation and solar transmission are connected together (Ghasemi et al., 2016; Lee, 2017; Sethi, 2009). According to several studies East-West orientation is generally best for most latitudes (Ghasemi et al., 2016; Sethi, 2009; Taki, Rohani, & Rahmati-Joneidabad, 2017). An uneven-span shaped greenhouse receives the most solar orientation (Ghasemi et al., 2016; Sethi, 2009; Taki, Rohani, & Rahmati-

Joneidabad, 2017). The reason for selecting this orientation is that East-West orientation receives greater total radiation in winter (maximizing heat) and less in summer (minimizing cooling requirements) in all latitudes excluding near the equator (Sethi, 2009).

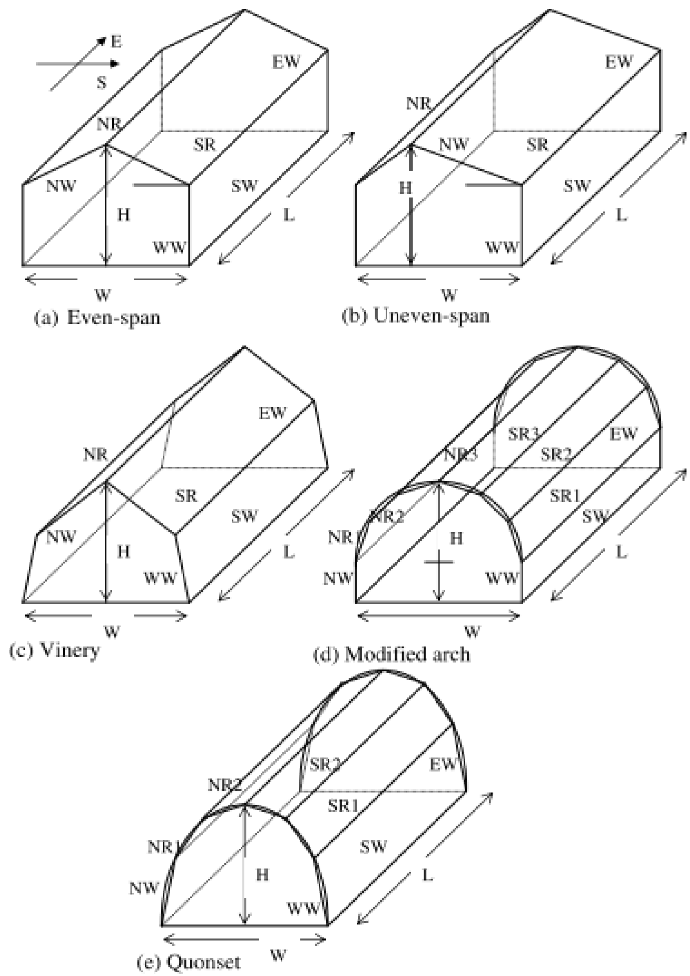

Figure 2.1: Greenhouses shape in East to West orientation (Sethi, 2009)

Based on Sethi's (2009) research, an uneven span is the best form of greenhouse in terms of solar radiation for all latitudes (Figure 2.1); however, the shape effect increases in lower latitudes (Figure 2.2).

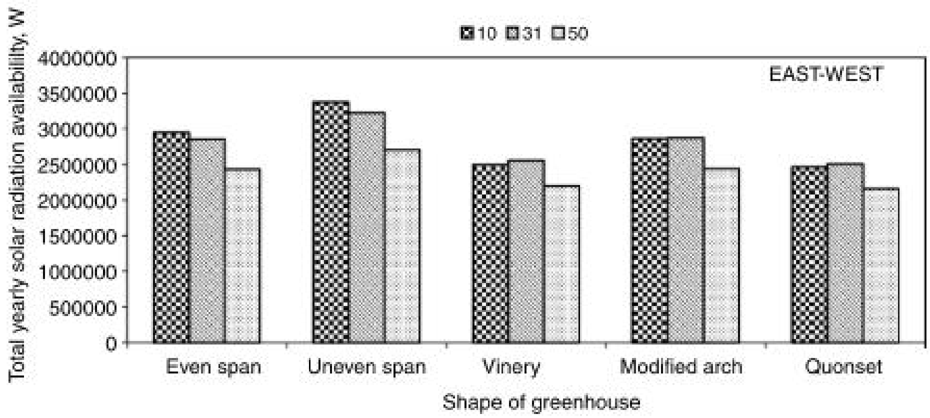

Figure 2.2: Greenhouses shapes and their solar radiation at different latitudes in East to West orientation, source (Sethi, 2009)

Also, as the latitude increases, the difference between summer and winter the solar radiation of the greenhouse also increases (Figure 2.3).

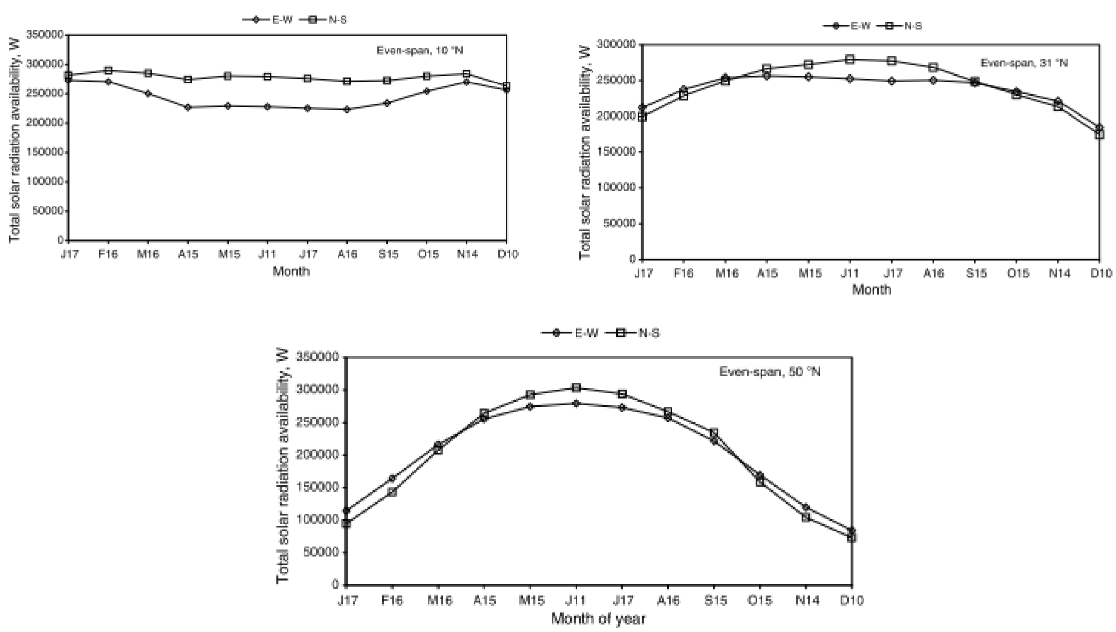

Figure 2.3: Total solar radiation of even-span greenhouse in E-W and N-S orientation at 10, 31 and 50 latitude, source (Sethi, 2009)

At 10 degrees latitude, for example, the solar radiaton decreases in the summer and increases in the winter. However, the solar radiation in 50 latitude increases in the summer and deacreases in the winter. The solar radiation of the greenhouse in summer time at 50 latitude is almost same as the 10 latitude during winter time (Figure 2.3).

Therefore, if we have a greenhouse which operates with waste heat in the winter and renewable electricity for lighting in higher latitudes, it might more efficient compared with greenhouses in lower latitudes in terms of solar radiation.

In another study Ghasemi et al. (2016) compared the solar radiation of different shapes of greenhouses (Figure 2.4) and concluded that single span greenhouses can gain more solar radiation in total (Figure 2.5).

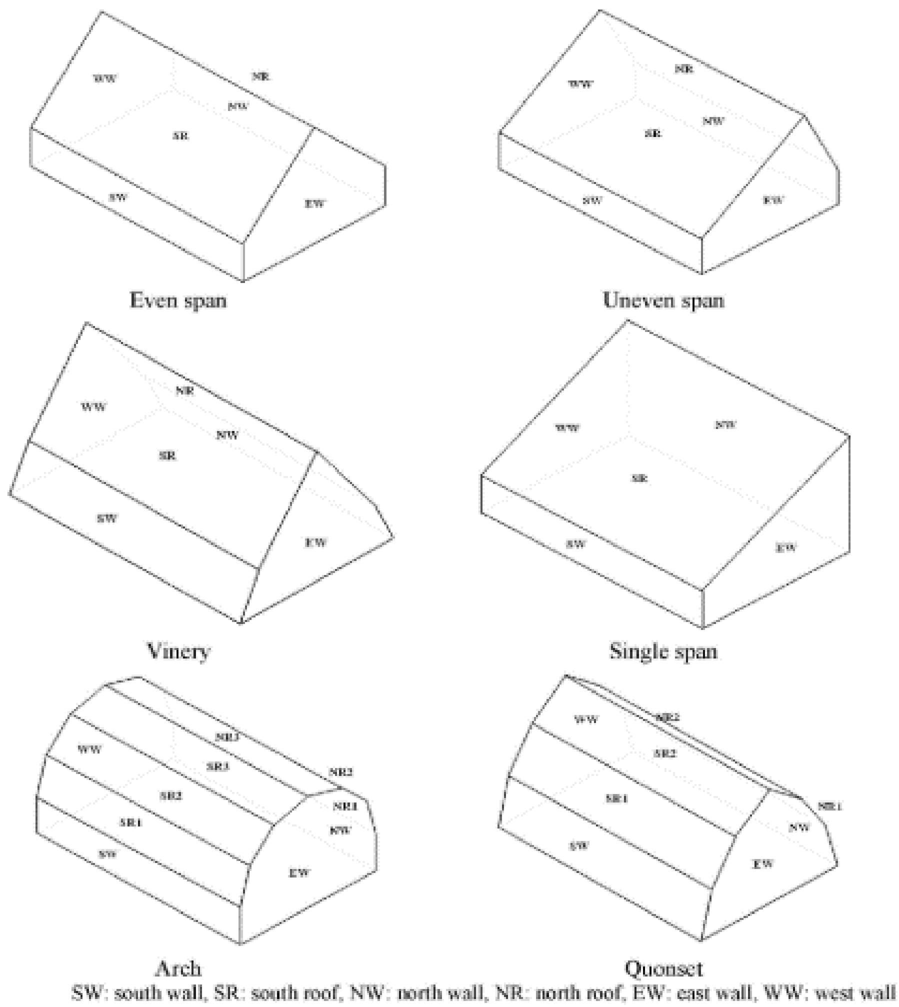

Figure 2.4: Greenhouses shapes, source (Ghasemi et al., 2016)

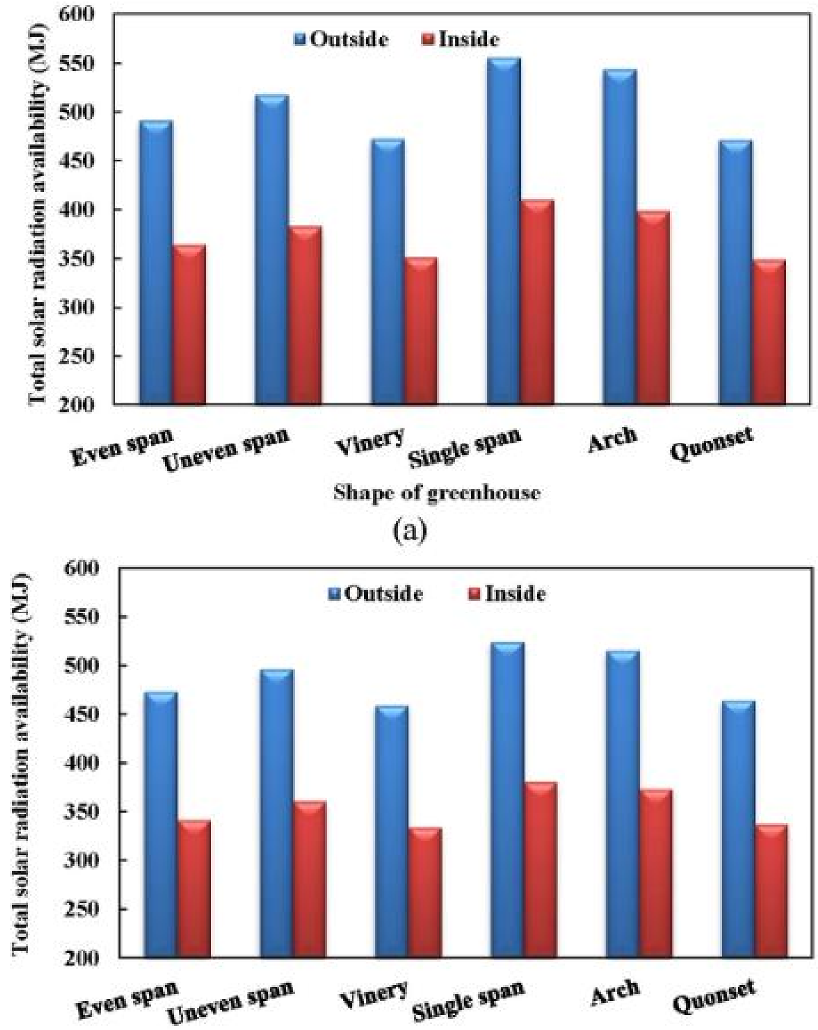

Figure 2.5: Total solar radiation for different shaped greenhouse in East-West (a) and North-South (b) orientation, source (Ghasemi et al., 2016)

Previous research reveals that the best orientation for the greenhouse in terms of solar radiation will depend on the latitude of the site and the shape of the structure (Ghasemi et al., 2016; Sethi, 2009; Taki et al., 2017). The North-South orientation recieves more solar raditation which increses the tempreature of the greenhuse in the summer, while the East-West orientation has less difrenece between summer and winter. Furthermore, the best greenhouse shape in terms of solar radiation in 50 latitude is uneven span (Sethi, 2009) and in 38 latitude, single span (Ghasemi et al., 2016) in terms of solar radiation (Figure 2.5).

I.6. Energy Sources

A reliable energy supply is vital for greenhouse operation, cooling, heating, and lighting (Tiwari, 2003; Lee, 2017; Chu, Lan, Tasi, Wu, & Yang, 2017;Taki, Rohani, & Rahmati-Joneidabad, 2017; Omrani, Garcia-Hansen, Capra, & Drogemuller, 2017; Salah, Hassan, Fath, Elhelw, & Elsherbiny, 2017). The power requirement for a greenhouse will vary based on size, material, structure and location; for example a 500 m^2 size draws a load of (on average) 15 kW in a typical temperate climate, while a greenhouse between 8000 to 12000 m^2 size can require a supply of at least 145 kW in the same climatic conditions (Ponce, Molina, Cepeda, Lugo, & MacCleery, 2014). The research clearly reveals that renewable energies and energy saving methods, such as using heat pump, can significantly decrease the greenhouse energy consumption (Cuce, Harjunowibowo, & Mert, 2016; Vadiee & Martin, 2012; Salah et al., 2017; Joudi & Farhan, 2014).

I.7. Cooling System

Typical natural ventilation for the greenhouse consists of two side vents and a zenith and two exhausted fans (Ponce et al.,2014). Natural ventilation not only can influence the microclimate inside the greenhouse. but also can decrease the ventilation energy costs (Daish et al., 2016; He et al., 2018; Montero et al., 2009; Omrani et al., 2017; Santolini et al., 2018; Von Zabeltitz, 2011; Zhai et al.,2016). There are two kinds of natural ventilation: wind-driven ventilation and buoyancy-driven ventilation (Boulard, Haxaire, Lamrani, Roy, & Jaffrin, 1999; Montero et al., 2009; Santolini et al., 2018) both of which are depend on external conditions, such as wind speed, direction, temperature (Bournet and Boulard, 2010; Etheridge, 2011; Santolini et al., 2018); and internal conditions, such as the configuration of the greenhouse and the size of the openings. The greenhouse's length and any internal infrastructure that limits internal air movement will have a direct relationship with the efficiency of the natural ventilation (Chu & Chiang, 2013). If the length of the greenhouse becomes larger than five to six times the height, the effects of natural ventilation will decrease (Chu & Chiang, 2014; Chu et al., 2017). To increase the natural ventilation effect and control the wind, the greenhouse should be constructed with the shorter wall exposed to the side with the winter prevailing wind (Chu et al., 2017). Another important consideration is the typical weather conditions linked to the prevailing wind, such as cold winter winds from the north-east, or warm moist summer winds from the southwest, or dry winds from the west, etc.

I.8. Heating system

There are numerous types of greenhouse heating systems based on the availability of the resources in the site. For example, in some locations with high solar radiation, heat can be stored (large tanks or aquifer storage) and then using heat pump exchange during cold weather (Abdel-Ghany, 2011; Joudi & Farhan, 2014; Ooteghem, 2010; Salah et al., 2017; Sethi, Sumathy, Lee, & Pal, 2013; Vadiee & Martin, 2012); there is the possibility of decreasing fuel consumption by 23% using this type of heat capture. The desired temperature of the greenhouse depending on the insulation, outdoor temperature, and crop types can be different. The most common heating system for a greenhouse is hot water (ten Caat, 2017; Mussard, 2017; Sethi et al., 2013). For example one foot of 2" in. iron pipe with hot water at 180°F (82 °C) can provide 0.0469 kWh or 154 W/m energy, so a greenhouse that requires 469 kWh needs 1000 linear feet of 2" hot-water pipe at 180°F (82 °C) (Nelson, 2003).

I.9. Water Source (Irrigation, Heating, Cooling)

Access to water is an essential requirement of a greenhouse. The quantity and quality of available water is a crucial resource to consider before establishing a greenhouse in a site (Nelson, 2003; Nikolaou, Neocleous, Katsoulas, & Kittas, 2019; Salah et al., 2017). Water is used in a greenhouse for different purposes, such as irrigation, heating, and cooling systems (Salah et al., 2017). Well water for irrigation in a greenhouse should not contain any chemical pollution, such as fluoride found in domestic water or organism disease found in pond, and lake water (De La Cueva Bueno, Gillerman, Gehr, & Oron, 2017). Irrigation methods can differ according to number of different plant species that are grown in the greenhouse, the container sizes, field and soil characteristics, crop requirement, and climate conditions (Nikolaou et al., 2019). The method of irrigation systems can be chosen based on three factors; climate monitoring, soil or substance monitoring, and crop monitoring (Nikolaou et al., 2019). Soilless production of plants which has been called hydroponic since 1937, has become the most common crop grow system for the greenhouses recently (Al-Chalabi, 2015; Graamans, 2015). The advantages of this systems are as follows: 70-90% less water consume (Ponce et al., 2014)), maximum crop yield, crop production in absence of suitable soil, minimal use of land, and efficient use of fertilizers (Graamans, 2015; Muller et al., 2017; teen Caat, 2017).

I.10. Carbon Dioxide (Co_2) Source

Carbon dioxide is one of the most important resources for a greenhouse and can accelerate plants, growth and increase quality (Fang et al., 2017; Graamans, van den Dobbelsteen, Meinen, & Stanghellini, 2017; Nadal, Llorach-Massana, et al., 2017b). CO_2 level in the atmosphere air is about 410 ppm in 2019 (CO_2-Earth, 2019). In a greenhouse, due to its enclosed nature , the amount of CO2 varies during the day; carbon dioxide increases at night time, and then starts to decreases between 12 pm and 9pm to less than natural atmosphere's CO_2 as the plants' metabolize the CO2 (Sanjuan-Delmás et al., 2018; Tiwari, 2003). To guarantee the growth of plants in a greenhouse, it is recommended to enrich the greenhouse with CO_2, the amount depending on the type of crop could be different (Graamans, 2015; Graamans et al., 2018; ten Caat, 2017; Teitel, Atias, & Barak, 2010).

I.11. Accessibility

The site of a greenhouse should have access to shipping route, road or airport (Baudoin et al., 2013; Nelson, 2003). The accessibility of the greenhouse to these transportation routes is important for transporting resources, people to the greenhouse, and allowing market access to the greenhouse's product (Ponce et al., 2014; ten Caat, 2017). To facilitate the accessibility of the greenhouse it should either connected through connection hubs or built next to an appropriate market site (La Rosa, Barbarossa, Privitera, & Martinico, 2014); access to the greenhouse must be direct, safe and be a good location for the transport of the products (Nadal, Alamús, et al., 2017a).

I.12. Construction and Materials Availability

A greenhouse building requires material for its frame, as well as covering the structure. The service life of greenhouse is about 25 years as a semi- permanent structure (Ponce et al., 2014). The frame can be made from wood, metal, and plastic material

(Ponce et al., 2014); to cover the greenhouse, glass and different types of plastic films can be used. The greenhouse structure should not only support loads and stresses of its own weight, wind, and snow but also should transmit the maximum light to the greenhouse. The covering material and the structure has a direct relationship with the light transmittance and as a consequence with crop growth (Alboustani, 2017). The structure material should be able to sustain under different types of loads such as snow, wind, permanent and repair installation loads. The advantages and disadvantages of common materials for a greenhouse structure are noted below (Table 2.2).

Material	Advantage	Disadvantage
Galvanized Steel	High resistance, High shock resistance, Flexible	High cost, Heated by solar radiation
Wood (Pine and Maple)	Natural insulation, Environmentally friendly, Low cost	Need repair, Low shock resistance, Need chemical treatment, Thick structure
Aluminum	Flexible, Lightweight, Strong, Easy drilling	High cost, Certain material can be match for cladding
Low Carbon steel (AISI 1010)	Low cost, Short production process, High durability	Malleable, Less shock resistance, High cost
High-strength low alloy Steel (HSLA 340)	Strong, Thin structure,	Low climate resistance, Low flexibility, Low durability, High cost
Material	Advantage	Disadvantage
Galvanized Steel	High resistance, High shock resistance, Flexible	High cost, Heated by solar radiation
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Aluminum	Flexible, Lightweight, Strong, Easy drilling	High cost, Certain material can be match for cladding
Low Carbon steel (AISI 1010)	Low cost, Short production process, High durability	Malleable, Less shock resistance, High cost
High-strength low alloy Steel (HSLA 340)	Strong, Thin structure,	Low climate resistance, Low flexibility, Low durability, High cost

Table 2.2: Advantages and disadvantages of greenhouse structure materials [Adapted from Ponce et al. (2014)]

The characteristics of cladding or covering material has a direct impact with the quality of transmitted light into the greenhouse. The cladding material should have the characteristics, such as durability, strengths, light transmission, and safety (Ponce et al., 2014). The advantages and disadvantages of common materials for greenhouse cladding are noted in Table 2.3.

Material	Advantage	Disadvantage
ETFE (ethylene-tetra-fluorine-ethylene)	Low weight, UV resistance, Easy to repair, Flexible, High light transmission, Recyclable, Self-cleaning, High durability	High cost, High light transmission increase internal heat, High tech material
Glass	UV resistance, High light transmission, Nonflammable, Tensile strength, Long lifetime	High cost, High weight, Low shock resistance,
Polyethylene (PE)	Low weight, Low cost, High light transmission,	Short lifetime, Degradable, low heat and UV resistance, Low fire resistance
Polycarbonate (PC)	High light transmission, fire resistance, Medium durability	High cost, High weight, Low UV resistance
Fiberglass Reinforced Panels (FRPs)	High resistance, Low weight, Long lifetime, High durability, High light transmission	Rigid plastic, Low fire resistance, High cost

Table 2.3: Advantages and disadvantages of greenhouse cladder materials adapted from (Alboustani, 2017; Cremers & Marx, 2016; Ponce et al., 2014; Srisuwan & Srisuwan, 2016)

To select a greenhouse material the climate type of the site, the shape of the greenhouse, and the economic aspects of the project should be considered. Using the proper type of material to build the structure of the greenhouse is important for the resiliency and efficiency of the greenhouse (Alboustani, 2017; Briassoulis et al., 2016; Lee, 2017).

Part II: Biomimicry

II.1. History and Terminology

History reveals that since the beginning, human beings have been inspired by nature in their designs (Chen,Klotz, and Ross, 2016; Grigorian, 2014). Greek philosophers since about 500 B.C have used natural organisms as models (Radwan & Osama, 2016); in 1482, Leonardo Da Vinci was inspired by nature and invented the flying machine (Radwan & Osama, 2016). Jack E. Steele, in 1958, proposed the term Bionics and represented it as the science of natural systems. In 1997, Janine Benyus proposed nature as a source of inspiration for designers, and coined the term biomimicry (Benyus, 1998; Radwan & Osama, 2016; Shu-Ysng, et al., 2004) as an ideal sustainable solution for human problems (Fecheyr-Lippens & Bhiwapurkar, 2017; López, Rubio, Martín, & Ben Croxford, 2017).

Design methods which use nature as a source of inspiration, study the patterns that occur in nature are a paradigm for sustainability (Bansode, Hiremath, Kolgiri, & Deshmukh, 2016; De Pauw et al., 2010; Pauw et al., 2014; Sabry Aziz & El Sherif, 2016). The main aim of biomimicry is to learn from and use efficient sustainable strategies that exist in nature (Alboustani, 2017; Antony et al., 2017; Huang, Hwang, & Radermacher, 2017; Pauw et al., 2014). Benyus (1998) mentioned that designers are required to conduct data analysis about forms, systems, and processes of biological creatures in order to design a sustainable system (Badarnah, 2017; Chen,Klotz, and Ross, 2016; Pauw et al., 2014; Kennedy & Marting, 2016; Steadman, 2008).

II.2. Approaches

Designers can use two approaches to apply biomimicry in their system-design: looking to biology to solve the problems (top-down approach), and biology influencing design (bottom-top approach) (Ahmar, 2011; Aziz & El Sherif, 2016; Badarnah & Kadri, 2015; Gamage & Hyde, 2012; Knippers & Speck, 2012; Maglic, 2014). The top-down approach (problem-based approach) is looking for solutions in nature for human problems (Aziz & El Sherif, 2016; Maglic, 2014; Radwan & Osama, 2016; Xing, Jones, & Donnison, 2017) which depend on recognition of goals and design limitations (Mazzoleni, 2013); however, the bottom-top approach (solution-based approach) is the implementation of nature's strategies into human designs (Ahmar, 2011; Aziz & El Sherif, 2016; Knippers & Speck, 2012). For instance, the scientists have used the idea of self-cleaning surfaces in their building design, since they noted that that dust particles cannot adhere to the surface of a lotus flower (bottom top approach) (Badarnah & Kadri, 2015; Zari, 2007). Having a deep understanding of the biological evolution of animals and plants can help designers to extract nature's strategies and adaptation methods (Kellert, 2016). In this regard, the bio-inspiration method is suitable for integrated design processes (Zuazua-Ros, Martín-Gómez, Ramos, & Gómez-Acebo, 2017).

In the development of a sustainable food production system, we are defining the problems, so the problem-based approach is used to develop the system design. Although, the idea of using nature as a source of inspiration seems simple, the process of "Bio-Inspired Design" is complicated and broad (Baldussu & Cascini, 2015; Drack, Limpinsel, Bruyn, Nebelsick, & Betz, 2017; Zari, 2016). The desire to thrive on this planet leads us to try methods that are sustainable and use resources efficiently and effectively (Antony et al., 2017; Cui et al., 2016; Zuazua-Ros et al., 2017). However, due to complexity of human needs and fast growing nature of technology emulating nature' s strategies is a challenge for bio-inspired designers (Baldussu & Cascini, 2015; Blok & Gremmen, 2016; Ford Denison & McGuire, 2015; Helms, Vattam, & Goel, 2009; Iñigo & Albareda, 2016). Some scholars noted that there is a potential need for considering systems' level of biomimicry in sustainable design (Montana-Hoyos, 2008 ; Stojanovic, 2017); to do this end we can employ biomimicry method in aspects of sustainable food systems (Stojanovic, 2017), such as material selection, energy systems, lighting systems, water use, etc.

II.3. Mimicking Ecosystems

According to Benyus (1997), biomimicry has three levels of implementation: form, process or behavior, and ecosystem (relationships). Designers mimic ecosystems in terms of form, process and relationships, because ecosystems are a source of innovation and creativity for designers (Ahmar, 2011; Garcia-Holguera, Clark, Sprecher, & Gaskin, 2016 Zari, 2006; Zari, 2016; Zari, 2018). In order to mimic ecosystems, designers require a deep understanding of ecosystems and the interrelationships in these systems

(Despeisse, Ball, & Evans, 2013; Zari, 2006, 2015b). To make the challenge clear, mimicking the form and structure of an organism is possible by simply copying the form of the organism. However, mimicking an ecosystem's relationships or process needs a much more thoughtful approach (Stojanovic, 2017; Tsujimoto, Kajikawa, Tomita, & Matsumoto, 2018). Designers must investigate several aspects, such as the form, material, construction (how it is made), process (how it works), function (how to do) of the ecosystem (Zari, 2018; Zari, 2006), as well as any synergist effects given that ecosystems are complex and causal relationships are not always straightforward (Pedersen Zari, 2015). These aspects overlap in some respect, for example material selection and construction design cannot be separated and must be addressed together; nature integrates structure and materials when addressing need (Cohen, Reich, & Greenberg, 2014).

Designers can mimic ecosystems in two ways: mimicking process and mimicking function (Zari, 2015a). Function is the results of ecosystems processes; the advantage of ecosystem implementation into design considerations is that it improves the function and process of buildings/systems rather than just the form or material ((López, Rubio, Martín, & Ben Croxford, 2017b ; Reap, Guild, & Bras, 2005). The Eastgate building in Harare, Zimbabwe is an example of ecosystem-level implementation to improve the function of building's ventilation system (Garcia-Holguera, Clark, Sprecher, & Gaskin, 2016). Designers mimic the function of a termite mound ventilation system into building and create a natural ventilation. The bionic implementation in Eastgate building improves the natural ventilation efficiency of the building. As a result, Eastgate's ventilation system consumes 35% less total energy than the average energy use by nearby buildings in Harare (Doan, 2012).

Ecosystems use efficient adaptation strategies to respond to disturbances such as those resulting from climate change or invasive species (Palomo, 2017; Garcia-Holguera et al., 2016). Eco-designers can imitate ecosystems' adaptation strategies and create efficient systems (Zari, 2015a) with high adaptation capacity to climate changes (Mitsch,1996) and minimize ecosystem degradation (Matlock & Morgan, 2011.). The analysis of processes and functions of the ecosystem where a building is located; designers can design responsive buildings, which use the environments' services and increase its efficiency while decreasing environmental stress on the building and by the building (reduced emissions for example) (Fecheyr-Lippens & Bhiwapurkar, 2017; Garcia-Holguera et al., 2016). For example, Council House 2 is a sustainable building located in Melbourne, Australia. The western façade of the building is covered by timber shutters that are responsive to the sun's motion and control sunlight. Designers used double-glazing windows for this side to reduce heat loss of the building and provides the building with maximum natural light. Additionally, natural ecosystems are dynamic systems which can understand changes, reacting and responding to local organisms needs (Stojanovic, 2017; Zari, 2015a). If we consider a greenhouse as an ecosystem, and plants as local organisms, the greenhouse's building and its systems should provide for the organisms' needs. This same analogy applies to the greenhouse as the organism and the surrounding landscape and infrastructures as the ecosystem.

II.4. Mimicking Ecosystems' Relationships

Ecosystem-level application can provide designers with well-adapted organism relationship patterns which are developed over a long time and continuous change (Drouant, Rondeau, Georges, & Lepage, 2014; Garcia-Holguera et al., 2016; Gruner & Power, 2017) Organisms in ecosystems use different approaches and strategies to adapt themselves to the ecosystem's condition (Lurie-Luke, 2014; Radwan & Osama, 2016; Zari, 2006; Zari, 2012a) As noted, a biological system is a highly responsive and multi-functional system (Gamage & Hyde, 2012; López et al., 2017b; Mang & Haggard, 2016; Pawlyn, 2011). It alters itself or its surroundings in different ways (Mang & Haggard, 2016). For instance, plants and trees alter their structure or strategies to adapt to the environment; leaves roll up in windy weather to reduce wind-loading on the tree, or to minimize transpiration when it is too hot/dry. In other situations, organism alter the ecosystem and their habitat. To mimic an ecosystem, designers should pay close attention to the ecosystem's relationships and structure, investigating the ecosystem application that is applicable to their design or required solution (El-zeiny, 2012; Zari, 2015a). Researchers assert that learning from nature is different from learning about nature; eco-inspired designers understand how nature solves the problem, and not simply mimic the nature's strategies without understanding the rationale (Despeisse et al., 2013; Drouant et al., 2014; Jucevičius & Grumadaitė, 2014; Zari, 2018). For instance, architects have used the design of the ventilation system within a termite mound to the inspire the design of large buildings with incredibly efficient passive heating and cooling. However, recently scholars found out that the relationship between ground temperature and the ventilation system also has a significant influence on the system function, something which had not been considered before.

Additionally, ecosystems are self-repairing and self-organizing, responding to changes, repairing aspects that are less than optimal, and creating new connections as needed (Zari, 2018). Therefore, researchers must also apply a cyclic element within the design method. Cyclic design is a method used to understand system feedback to a design and then continuously update or "redesign" the systems (Cole et al., 2011; Holtzapple & Reece, 2005). This method is useful for the design of human-made systems and can provide designers with an adaptive approach to various aspects of their system design (Cherifi et al., 2015).

II.5. Regenerative Design

Regenerative design is the creation of an opportunity to reuse resources and materials based on redesigning usage cycles by considering their natural life cycle (Hoxie, Berkebile, & Todd, 2012; Mang & Reed, 2018; Mang, Reed, Mang, & Reed, 2012; Skilbeck, 2015). Zari (2018) defines regenerative design as a method to address ecosystem degradation and "restore the capacity of ecosystems to function at optimal health for the mutual benefit of both human and non-human life". Ungard (2018) builds on this notion and integrates the need for purpose and the developmental capacity as two main conditions for a regenerative model or design. Regenerative design is based on the understanding of ecosystem services with the intent of improving ecosystem's health, rather than simply striving to interact with it in a benign manner (Cole, 2012; Hoxie et al., 2012; Mang & Reed, 2018; Skilbeck, 2015). Human activities accelerate the natural changes that occur within any ecosystem, damaging both form and function. Scholars point out that regenerative design must strive to deliver the function that society seeks while improving the health of ecosystems (Conte & Monno, 2016; Thomson & Newman, 2018; Zari, 2018).

Early adopters of this concept suggested the first step to using a regenerative method in design is to create/develop a map of on-site resource and process relationships (Gou & Xie, 2017; Lyle,1996; Morbiducci & Vite, 2017; Svec, Berkebile, & Todd, 2012). To do so, human management must be aware of the ecosystem's performance (Melby & Cathcart, 2002; Plaut, Dunbar, Wackerman, & Hodgin, 2012), understand what influences its function, develop the built environment according to these parameters, and thereby improve the health conditions of the whole ecosystem (Conte & Monno, 2016; Mang & Reed, 2018; Thomson & Newman, 2018; Zari, 2012a). Humans should consider nature as a model and a context (Gibbons, Cloutier, Coseo, & Barakat, 2018; Lyle,1996). For instance, the landscape changed in an ecosystem over a long time in which energy and material cycles developed within an ecosystem (Gibbons et al., 2018; Lyle,1996); designers can emulate nature's landscape functioning and ecosystem development to develop their living environment. For example, building infrastructure and human-made changes to the topography of an area can make changes to the impact of winds on those areas.

The main characteristics of ecosystems include resourcefulness and the opportunities for symbiotic relationships (Conte & Monno, 2016; Morbiducci & Vite, 2017; Zari, 2018) that consider human, biotic and abiotic components and their relationships to the whole. In fact, regenerative design explores the potentials and character of the ecosystem proposes and practices design approaches according to their unique conditions (Mang & Reed, 2018). Regenerative design method should not contribute to resource depletion (in fact it should do the opposite), eliminate needless technologies that are exploitative, and restore the environment (Mang & Haggard, 2016; Mang & Reed, 2018). Figure 2.6 shows the range of the different sustainability approaches and emphasize the need to shift from degenerating to regenerating systems (Craft, Ding, Prasad, Partridge, 2017). The left side of the graph are unsustainable design methods, in contrast the right side of the graph are sustainable methods either which contribute to improve the health of ecosystem or do not degrade ecosystem, such as green design, regenerative, and restorative (Craft et al., 2017).

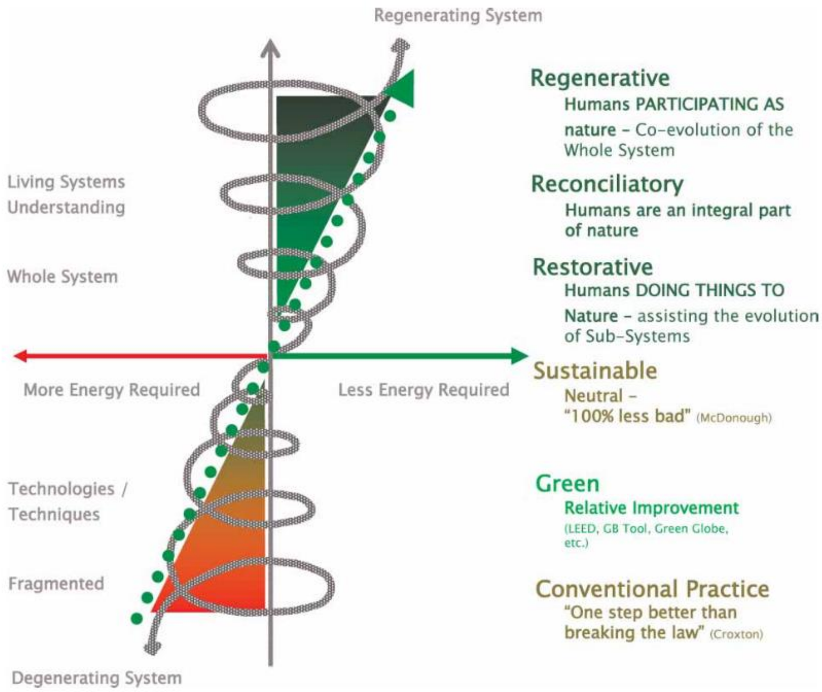


Figure 2.6: Trajectory of Environmentally Responsible Design, source(Reed, 2007)

II.6. Climate Change Effect

Adapting to the impacts of climate change requires that designers try to anticipate potential [likely] impacts based on good scientific evidence applicable to their region (Carter et al., 2015; Cortekar, Bender, Brune, & Groth, 2016; Craft, Ding, Prasad, Partridge, 2017; IPCC, 2014; Olusegun & Clinton, 2017). Climate change impacts , such as increasing temperature or more extreme fluctuations, intense weather events, rising sea levels (Palomo, 2017), and changing wind patterns and intensity, can have direct and indirect impacts on the built environment and (IPCC, 2014; Olusegun & Clinton, 2017; Zari, 2010) resiliency of the ecosystem (Dhakal & Kattel, 2019; Steeves & Filgueira, 2019). For example, changing weather patterns can affect the structure, fabric, and façade parts of the building (Zari, 2018), but also the operational efficiency and effectiveness of existing structures and systems (Corfee-Morlot et al., 2009). The severity of these impacts will [obviously] differ regionally, as well as the actual siting of the structure. To reduce these impacts going forward, the location, form, and the structure of the building should be chosen carefully, with due consideration to the predicted impacts in that area

(Loonen, Trčka, Cóstola, & Hensen, 2013; Morbiducci & Vite, 2017; Thalfeldt, Pikas, Kurnitski, & Voll, 2013; Zari, 2010). In addition, sustainable design building can also mitigate the influence of the built environment on the climate, thereby influencing a virtuous cycle of adaptation influencing mitigation (Figure 2.7) (McPhearson, Andersson, Elmqvist, & Frantzeskaki, 2015; Olusegun & Clinton, 2017).

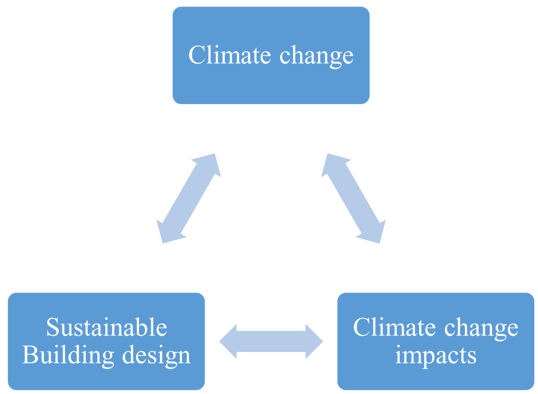


Figure 2.7: Relationship among climate change, sustainable building design, and climate change impact

II.7. Bio-Climate Passive Design

Bio-climate passive design are design strategies that specifically focus on minimizing energy consumption of the building and decreasing external negative environmental effects on its structure and function (Dobbelsteen, 2008; Lee, 2017; Morbiducci & Vite, 2017; Thalfeldt et al., 2013). For example, increasing the R-value for insulation in the walls of the sides of the building exposed to prevailing winter winds, while having solar walls or extensive window coverage on the south facing sides the building, are strategies that can be used for cold climate buildings (Ragheb, El-Shimy, & Ragheb, 2016; Sadineni, Madala, & Boehm, 2011; Thalfeldt et al., 2013).

With passive design strategies, designers can minimize challenging impacts and optimize building efficiency (López et al., 2017b). Bio- envelopes are one of these passive methods that can reduce energy consumption of buildings (Erdim & Manioglu, 2014; Fiorito et al., 2016; López et al., 2017b; Muntinga, 2013; Oral & Yilmaz, 2003; Zhai et al., 2016) as well as reduce environmental stress on the building (Al-Obaidi, Azzam Ismail, Hussein, & Abdul Rahman, 2017; Herring & Roy, 2007; Yuan et al., 2017). The Gherkin Tower, located in London, UK is an example of implementing form of bio-climate passive design. The envelope has canals that let the wind circulates in its canals and ventilates the building. This design not only decreases the load of wind on the building structure, but also provides a natural ventilation for the building (Meijenfeldt, 2014; Pawlyn, 2016). Another bio-climate passive design is Bird's Nest stadium in Benji, China, in an earthquake prone area that is also exposed to strong winds. The stadium has two independent structures, a concrete seating bowl and an outer steel frame around it. Outer steel frame provides sunlight filtration and reduces the dead load supported by the roof. As a result, the stadium can withstand earthquakes without much damage and its special structure provides it with wind protection. By using this method designers were not only able to reduce the cost of the project, but most importantly, they were able to increase durability and recyclability of this building and increase its adaptability to the climate (Antony et al., 2017; Pawlyn, 2016; Yuan et al., 2017).

Part III: Natural Ecosystems

An ecosystem consists of living (biotic), non-living (abiotic) components, as well as the relationships between the various components or processes (Bohan, Pocock, & Woodward, 2016; Lyle,1996; Lyons, Brigham, Traut, & Schwartz, 2005). These natural processes and functions are termed as ecosystem services (Bohan et al., 2016; J. Li & Zhou, 2016). Delivery of these services reflect the existing processes and cycles within the system (Costanza et al., 2017). Ecosystem composition, structure, and processes – and therefore the services provided - will vary across different ecosystems (Fu, Wang, Su, & Forsius, 2013). Furthermore, an ecosystem's composition depends on the nature of the biotic and abiotic components, and existing material and energy flows, which will therefor influence the type of ecosystem processes and available (Fu et al., 2013; Wallace, 2007). For example, soil needs biotic recycling to keep essential nutrients and circulate them through the metabolism of detritus (biomass) (Jiang, Liu, & Zhang, 2017; Muller et al., 2017; Ulanowicz, 1989). Coral reefs are examples of efficient natural systems that retain, use, and recycle resources (Crossman, Burkhard, et al., 2013; Maglic, 2014). Wetlands and lakes are essential parts of natural systems to regulate temperature and water levels throughout different times of the year (Harasarn & Chancharat, 2016; Janse et al., 2019; Shelton David et al., 2001).

III.1. Natural Ecosystem Services

All life-support functions are delivered by natural ecosystems as ecosystem services (Bohan et al., 2016; Lyle,1996; Small, Munday, & Durance, 2017). Ecosystem services play a vital role for human wellbeing (Fu et al., 2013; Grêt-Regamey, Weibel, Kienast, Rabe, & Zulian, 2015; Harrison et al., 2014; Schröter et al., 2014) as many have no technological substitute. However, due to the different definitions of ecosystem boundaries in the different sciences (Wernecke, Schwanewedel & Harms, 2018), and the notion that ecosystem services are interlinked (Mancinelli & Mulder, 2015), it is difficult to define ecosystem boundaries and isolate ecosystem services. Structure, process, function, and the temporal nature of service provisioning of the ecosystem services can contribute to understanding the potential services in an ecosystem.

This lack of understanding has led to increased ecosystem destruction and resource depletion (de Groot et al., 2012; Silvertown, 2015); for example according to the Millennium Ecosystem Assessment (2005) report, 60% of global ecosystem services have been degraded or managed unsustainably (La Notte et al., 2017). While steps have been taken, this trend has not been dramatically altered, which interjects increased fragility into the complex systems that ensure the provision of these services (Elmqvist et al, 2013). Ecosystems provide four types of services: provisioning (e.g. food), regulating (e.g. water quality regulation and pollination), cultural (e.g. recreation) and supporting (e.g. nutrient cycling)(Weitzman, 2019) (Table 2.4).

III.1.1. Supporting Services

Basic services that ease the delivery of other services are called supporting services, such as primary production, water cycling, and nutrition cycling (Costanza et al., 2017; Harrison and Hester, 2010; Elmqvist et al,.2013; Mancinelli & Mulder, 2015; Zari, 2010). Table 4 lists the supporting services (Zari, 2012) that are fundamental for other ecosystem services and increase by biodiversity (Bohan et al., 2016; Durance et al., 2016; Harrison et al., 2014; Rossi, 2011). Most of these are provided through primary production and can be affected by climate change, pollution, landscape alteration and biodiversity loss (Harrison and Hester, 2010; Mancinelli & Mulder, 2015; MEA, 2005; Shi, Liu, Shi, Li, & Li, 2017) (Table 2.4).

III.1.2. Provisioning Services

Provisioning services are those benefits obtained through the supply of food and other resources, such as fiber and raw biotic materials needed for the production of a myriad of natural -resource based goods (Calderón-Contreras & Quiroz-Rosas, 2017; Chatterton, Graves, Audsley, Morris, & Williams, 2015; Harrison and Hester, 2010; Jackson et al., 2017; Kandziora, Burkhard, & Müller, 2013; Russo, Escobedo, Cirella, & Zerbe, 2017) (Table 2.4).

III.1.3. Regulating Services

Regulation services are those elements which influence and [ideally] maintain ecosystem processes, such as climate, disease and pest regulation, protection from hazards, and environmental quality regulation (Chatterton et al., 2015; Elmqvist et al., 2015a; Harasarn & Chancharat, 2016; Harrison and Hester, 2010; Jackson et al., 2017; Posner, Verutes, Koh, Denu, & Ricketts, 2016; Shi et al., 2017; Zari 2012)(Table 2.4).

III.1.4. Cultural Services

Cultural services are non-material services of the ecosystem (Beinborn, Quinn, & Kopin, 2011; Chatterton et al., 2015; Hall, 2018; Small et al., 2017). Harrison and Hester (2010) categorize cultural services into two main groups: ‘’Spiritual, aesthetics, inspirational and sense of place; and recreational, ecotourism, cultural heritage and educational’’. Although it is not easy to apply the economic value to these services, they can increase the value of provisioning services (Harrison and Hester, 2010; Zari, 2012) through increasing circular economy in the ecosystem by tourism (Harasarn & Chancharat, 2016; Lanfranchi and Giannetto, 2014; Ruijs, Wossink, Kortelainen, Alkemade, & Schulp, 2013; Russo et al., 2017). Another example of cultural services benefit for ecosystems is increasing floral and faunal of a landscapes and as a result the biodiversity of the ecosystem will increase (Hall, 2018; La Rosa et al., 2014) (Table 2.4).

1. Provisioning Services	2. Regulating services (human time scale)	3. Supporting services (long time scale)	4. Cultural services
Food: Human (land/fresh water/marine) Forage	Pollination and seed dispersal	*Soil*: Formation Retention Renewal of fertility Quality control	Artistic inspiration
Biochemicals: Medicines Other	*Biological control*: Pest regulation Invasive species resistance Disease regulation	*Fixation of solar energy*: Primary production/plant growth (above ground, below ground, marine, fresh water)	Education and knowledge
Raw materials: Timber Fibre Stone Minerals	*Climate regulation*: Greenhouse gas (GHG) regulation Ultraviolet light (UV) protection Moderation of temperature	*Nutrient cycling*: Regulation of biogeochemical cycles Retention of nutrients	Aesthetic value
Fuel: Biomass Mineral Other	*Prevention of disturbance and the moderation of extremes*: Wind/wave force modification Mitigation of flood/drought Erosion control	*Habitat provision*: Refuguim Nursery function	Cultural diversity and history
Fresh water: Consumption Irrigation Industrial processes	*Decomposition*: Waste removal	*Species maintenance*: Biodiversity Natural selection Self-organization	Recreation and tourism
Ornamental resources	*Purification*: Water/air/soil		Spiritual and religious inspiration
Genetic information			Creation of a sense of place
			Relaxation and psychological well-being

Table 2.4: Ecosystem Services, source (Zari, 2012)

III.1.5. Ecosystem Services and Built Environment

Despite the fact that ecosystems provide both direct and indirect benefits, not all the services in the ecosystem can be easily be applied in the built environment (Du Plessis, 2012; Pedersen Zari, 2018; Zari, 2012b, 2015b). Services, such as pollination, carbon sequestration, and the regulation of species diversity are considered exclusive to natural systems (Lin, Wu, Yang, Wang, & Wu, 2018; Truchy, Angeler, Sponseller, Johnson, & McKie, 2015). However, modern human-based structures should attempt to integrate some of the services and be designed to adapt to other services that perhaps are not currently useful for the structure's operations (Benne & Mang, 2015; Morbiducci & Vite, 2017; Thomson & Newman, 2018). For example, one can explore how to integrate urban design/structures into existing ecosystems, making use of existing resources, minimizing the impact on the local environmental, and native ecosystem services (Gou & Xie, 2017; Pedersen Zari, 2018). A hierarchy of ecosystem services can be used when looking to the potential applicable ecosystem services and investigating the overall impacts that can support designers to categorize ecosystem services (Conte & Monno, 2016) (Figure 2.8). In other words, future environments are built based on current available ecosystem services and provides new services for the ecosystem, as a result the new integration makes changes/increases the ecosystem service (Figure 2.8).

III.1.6. Ecosystems Within the Built Environment

Ecosystems within the built environment can still be considered living systems, with infrastructure also acting in the role of an 'organism'(Conte & Monno, 2016; Craft et al., 2017). Living buildings are structures that have been designed to interact and/or react to their surroundings, rather than simply acting as passive recipients of external influences (Al-Obaidi et al., 2017; Badarnah, 2012; Badarnah, 2017; Boer et al., 2011; Dewidar et al., 2013; Loonen et al., 2013; Loonen et al., 2010; López et al., 2017b; Wong, Li, & Wang, 2005). An important point about nature is that time in nature is defined by seasons (Todd & Todd, 1993,). If designers want to design living buildings, they should look at time from nature's perspective (Craft et al., 2017; Reed, 2007). In other words, considering different seasons with different sources of energy and materials make possibilities for designers to design interactive buildings which are efficient in terms of energy and water consumption (Badarnah & Knaack, 2007; Barozzi, Lienhard, Zanelli, & Monticelli, 2016; Dewidar et al., 2013; Pan & Jeng, 2010; Pesenti et al., 2015; Ramzy & Fayed, 2011; Schleicher et al., 2015; Wang, Beltrán, & Kim, 2012). In this instance, we have different ecosystem services in different seasons. Therefore, to design an eco-product/system, designers should look at the ecosystems and consider the whole ecosystem in the design (Craft et al., 2017; Mang & Reed, 2015; Mitsch,1996).

PART IV: Urban Ecosystems

Different habitats provide different kinds of services. For example, forests purify air and can influence weather patterns; cities create “heat islands” and [can] positively influence the well-being of its population through enhanced provision of services (Gómez-Baggethun & Barton, 2013). Urban ecosystems can be categorized as life-supporting ecosystems (Barthel & Isendahl, 2013; De Valck et al., 2019) in which human life conditions are [of times] improved (McPhearson et al., 2015).

If researchers consider humans, their food crops, and livestock as parts of this life-supporting ecosystem (Pocock et al., 2016), these elements can also contribute to the services that humans provide to a broader ecosystem. In such cases, humans would be a part of the ecosystems and the urban area built based on available ecosystem services not only in harmony with nature (Crossman, Bryan, Groot, Lin, & Minang, 2013) but also provides services (De Valck et al., 2019; Maes, Jones, Toledano, & Milligan, 2019) (Table 2.5). Land use management and understanding ecosystem processes have a great impact on supply and the use of ecosystem services in this way. Understanding the natural ecosystem landscape elements, such as green spaces (parks, urban forests, gardens and yards) and blue spaces (streams, lakes, ponds, lakes), their roles on natural ecosystems and urban areas, can contribute to sustainable city development (Cortinovis & Geneletti, 2018; Elmqvist et al., 2015b).

IV.1. Urban Metabolism

Urbanization is increasing on a global scale, result in creating both opportunities and challenges to build a sustainable environment (Li & Kwan, 2018; McPhearson, Haase, Kabisch, & Gren, 2016). Modeling energy and materials flows (inputs, consumption, and outputs) in an urban is known as city’s ‘metabolism’ (Conke & Ferreira, 2015; Dijst et al., 2018). As Broto, Allen, & Rapoport (2012) noted, to understand *urban metabolism*, it is important to understand six main themes: (1) the city is an ecosystem, (2) the material and energy flows within the city, (3) the internal economic–material relationships, (4) the economic drivers of rural–urban relationships, (5) the reality of urban inequality, and (6) the city needs to be re-imagined through new socioecological relationships In this respect, an urban ecosystem has cycles, processes, and structures same as a natural ecosysetem/ rganism (Kissinger & Stossel, 2019; Li & Kwan, 2018). These cycles and proceses can improve by emulating natur's methods and increase the efficiency of urban metabolism (Dijst et al., 2018; Thomson & Newman, 2018).

Rosado, Kalmykova & Patrício (2017) defined eight characteristics for urban metabolisms: needs; accumulation; support; dependency; efficiency; diversity of processes; self-sufficiency; and pressure on the environment. *Needs* are linked to the necessity of different material flow and consumption patterns, and it depends on the city, the region it is located, and the local industrial economy (Li & Kwan, 2018; Ohnishi, Dong, Geng, Fujii, & Fujita, 2017; Ravalde & Keirstead, 2017; Rosado et al., 2017). *Accumulation* refers to the amount of available material in urban areas through a lens of cradle to grave lifecycle of products (Rosado et al., 2017). The variety of processes are high in urban areas which increases the resiliency and complexity of the ecosystem (Chrysoulakis et al., 2013; Meerow, Newell, & Stults, 2016); urban areas can also *support* regional or national systems depending on their size and throughput (Meerow et al., 2016; Rosado et al., 2017) By increasing the *dependency* of an urban area on global resources, the vulnerability of the system also will increase (Cui, Wang, & Feng, 2019; Larondelle & Haase, 2013; Tammi, Mustajärvi, & Rasinmäki, 2017). However, the self-sufficiency of a city improves with dependency on local and inner city materials (Grewal & Grewal, 2012; Rosado et al., 2017) and decreases its *pressure on the environment* (Kissinger & Stossel, 2019; Zhang, & Yang, 2010; Rosales Carreón & Worrell, 2018).

The pressure of an urban area on the environment is the most important aspect of urban metabolism (Cortinovis & Geneletti, 2018; Huang, Cui, Yarime, Hashimoto, & Managi, 2015; Kissinger & Stossel, 2019; Li et al., 2010); this has two components: negative outputs – such as waste, emissions, and pollution; and resource depletion linked to excessive material and energy consumption (Céspedes Restrepo & Morales-Pinzón, 2018; Rosado et al., 2017). Emission reduction strategies, and more cyclic material/energy flows can increase the efficiency of urban metabolism and reduce negative effects on adjacent ecosystems.

Increased efficiency in the urban metabolism will ideally reflect a reduced resource requirement per capita. This efficiency can be influenced through the application of circular economy strategies such as closing material loops through by-product valorization and the development of industrial synergies to decrease waste while delivering services (Broto, Allen, & Rapoport, 2012; Conke & Ferreira, 2015; Davis, Polit, & Lamour, 2016; Ness & Xing, 2017). Sustainably managing human-made ecosystems can lead to increasing the ecosystem services (Durance et al., 2016; Ernstson, 2013) and the efficiency of their metabolism (Blečić et al., 2014; Thomson & Newman, 2018).

Waste management is one of key elements of urban ecosystems by which urban metabolism can increase and lead to a more sustainable city (Céspedes Restrepo & Morales-Pinzón, 2018; Thomson & Newman, 2018). Waste management can make profit for the community by converting waste to energy, or through diverting it to value-adding processes (e.g. recycling, upcycling, symbiosis…); providing career opportunities while decreasing the cities' negative impacts on the natural environment (Davis et al., 2016). Additionally, waste management improving the sustainability of the material and energy flows in the city (Cui, Wqang & Feng, 2019; García-Guaita, González-García, Villanueva-Rey, Moreira, & Feijoo, 2018).

IV.2. Urban Farming

Food as a fundamental human need should be considered as an essential part of urban ecosystem (Badami & Ramankutty, 2015; Barthel & Isendahl, 2013). Urban farming not only can fulfill human food needs (Grewal & Grewal, 2012; Ramankutty et al., 2018), but it can also increase the resiliency of the city (Barthel & Isendahl, 2013; La Rosa et al., 2014; Pearson, 2013) and improve food security and productivity of land use in urban areas (Badami & Ramankutty, 2015; Ramankutty et al., 2018). With rapid urban development, food security might be a major challenge for urban areas (Andersson Djurfeldt, 2015; Lang & Barling, 2012; Melkonyan, Krumme, Gruchmann, & De La Torre, 2017; Sharma, 2016). About 80 percent of the world's population is expected to live in urban areas by 2050 (Besthorn, 2013; Gupta & Gangopadhyay, 2013; Rayfuse & Weisfelt, 2012). Linked to rapid urban development, there are an estimated 800 million people involved with urban farming in the future (Cohen & Garrett, 2010; Ramankutty et al., 2018; Sharma, 2016).

Urban farming is faced with different challenges, such as land, energy, water scarcity, climate change, and growing population most of which have negative effects on the food security of urban areas (Enenkel et al., 2015; Nelson et al., 2016; Sanjuan-Delmás et al., 2018; Tilman et al., 2001; Zhang & Vesselinov, 2017). In urban areas food goes through different steps including: production, processing, distribution, consumption and waste disposal or recycling (Gupta & Gangopadhyay, 2013; Opitz, Berges, Piorr, & Krikser, 2016). Sustainable management of these steps can ensure food security in urban areas (Ackerman et al., 2014; Gupta & Gangopadhyay, 2013; Melkonyan et al., 2017). Considering various recovery types, such as recycling, reusing material, and close loops of energy can contribute to the waste management and increase food security in urban areas (Ackerman et al., 2014; Alexander et al., 2017; Rosado et al., 2017).

IV.3. Biodiversity in Urban Ecosystem

Biodiversity can be incresed in urban areas by increasing the amount of green space as well as planting different types of plant speicies, both native and non-native (Clergeau, Mennechez, & Savard, 2000; Goddard, Dougill, & Benton, 2010; Kowarik, 2011; Paker, Yom-Tov, Alon-Mozes, & Barnea, 2014; Vergnes, Viol, & Clergeau, 2012). Due to the heat island effect, soil tempreture tends to be higher than natural areas in rural settings (Zhou et al., 2017). If one continues using industrial ecology as the lens to view such phenomena, this could be considered as an ecosystem service for cold climate urban areas to increase the green space in cities and moderate the tempreture (Goddard et al., 2010; Vergnes et al., 2012). In order to increse the metabolism of the future cities, designers should consider past urban best practices (Barthel & Isendahl, 2013) as well as understand links among biodiversity, ecosystem processes, and services (Durance et al., 2016; Jansson, 2013) (Tatble 2.5) to make sustainable cities (Rosado et al., 2017; Thomson & Newman, 2018). Biodiversity in an ecosystem can increase supporting, provisioning and regulating services. Thereforeto achieve more sustainable cities, mapping natural available ecosystem services (Jansson, 2013) as well as human made ecosystem services, and to make a corelation among these services can decreases urban areas' pressure on natural ecosystems and imptove the quality life of people in an urban area.

Urban services			
Supporting	**Provisioning**	**Regulating**	**Cultural**
Water cycling	Providing Food by urban farming (Gómez-Baggethun & Barton, 2013)	Urban temperature regulation	Educational
Energy cycling	Providing Material and resources	Waste treatment	Aesthetic
Career opportunity	Generating Renewable energy	Water Flow regulation (Gómez-Baggethun & Barton, 2013)	Truism attraction
Circular economy	Delivering food and resources	Air purification	
Information circularity	Adapt native species to new environment (Kowarik, 2011)	Protection from natural hazard such as strong winds	Making a link between nature and EIP
Material cycling	Improve Health conditions	Runoff mitigation (Gómez-Baggethun & Barton, 2013)	
	Security		
	Increasing biodiversity of natural ecosystem in terms of plants and pollinators		
	Sewage as a source of energy		

Table 2.5: Urban Ecosystem Services

Part V: Industrial Ecosystems

One form of Industrial ecosystem is an Eco-Industrial parks (EIP), which can be described as a community of industries which are located close together and can exchange materials, energy, and information, together to improve eco-efficiency at the system level (Liu, Côté, & Zhang, 2015; Lowe, 2001). Researchers pointed out that an EIP can be viewed and optimized from different ways (Zhu & Cote, 2004) through optimization of energy linkages and reuse, the water and wastewater network, or the exchanges of materials (raw material, by-products or wastes) (Afshari, Farel, & Peng, 2018; Liu, Adams, Cote, Geng, & Li, 2018; Yan, Zhang, Yen, & Fath, 2015). The final aim is to optimize all these components and reduce the burden of industries on environment (Boix, Montastruc, Azzaro-pantel, & Domenech, 2015; Chae, Kim, Yoon, & Park, 2010; Felicio et al., 2016).

Furthermore, three dimensions of sustainability can obtained benefit through an EIP: economic, environmental, and social (Boix, Montastruc, Azzaro-Pantel, & Domenech, 2015; Cote & Cohen-Rosenthal, 1998; B. Huang et al., 2019; Valenzuela-Venegas et al., 2018; Valenzuela-Venegas et al., 2016). These dimensions are related to profitability and resiliency, environmental impact reduction (Côté & Liu, 2016; Liu et al., 2018) and factors related to local community of near the park (Afshari et al., 2018; B. Huang et al., 2019; Nair, Soon, & Karimi, 2017; Valenzuela-Venegas et al., 2016). There are complex material and energy flow exchanges among industries; however, such exchanges can reduce the total consumption on virgin materials and energy sources, resulting in less CO_2 and other pollutants emissions (Boix et al., 2015; Chae et al., 2010; Kuznetsova, Zio, & Farel, 2016; B. Zhang, Du, & Wang, 2018).

V.1. Biological Ecology vs. Industrial Ecology

Biological ecology (BE) can provide industrial ecology with useful tools for resource utilization, recycling and relationships (Drack eta al., 2017; Geng & Côté, 2002; Gruner & Power, 2017; Zhang et al., 2015). To design a sustainable cycle, designers should consider several aspects, such as designing a closed loop which is shorter and reduces material and energy loss (Graedel & Allenby, 2010; Hartley, Momsen, Maskiewicz, & D'Avanzo, 2012; Hoffmeyer, Kull, & Sharov, 2017; Liu et al., 2018). By designing short cycles, designers can also decrease the risk of breaking the cycle by missing a loop over time.

An important point about Industrial ecosystems (IE) is that such systems use much more varied types of materials compared to BE (Deutz & Ioppolo, 2015). Industrial operations use different types of materials, such as metal, plastic, and organic materials which makes it difficult to exchange the materials among industries (Boix et al., 2015;

Deutz & Ioppolo, 2015; Yun Zhang et al., 2017). However, in a BE, organisms are using and exchanging one type of material (organic nutrients) with each other (Graedel & Allenby, 2010; Hartley et al., 2012). In terms of energy consumption, BE consume renewable energy (sun), and are self-sustaining (Deutz & Ioppolo, 2015; Drouant et al., 2014; Hartley et al., 2012; Mitsch,1996), while IE mostly depend on nonrenewable energies (fossil fuels) (Deutz & Ioppolo, 2015; Graedel & Allenby, 2010; Zhang, Romagnoli, Zhou, & Kraft, 2017a; Yan Zhang et al., 2015). Eco-designers should mimic natural ecosystems in terms of energy efficiency, reduce industrial ecosystems' dependency on fossil fuels, and substitute them with renewable energies (Liu et al., 2018; Mitsch,1996).

V.2. EIP Ecosystem Services

Consumerism behavior toward nature and its ecosystem services separates humans far from nature (Robertson, 2012); yet human life relies on earth's life-supporting system (Raymond et al., 2013). Industrial ecosystems are another type of ecosystems which depend on natural ecosystems services and are developed with the intention of emulating natural ecosystems (Shi et al., 2017; Youzhi Zhang, Lu, Wing-Yan, & Feng, 2018); from this perspective we have suggested that such industrial ecosystems can offer their own ecosystem services (to be discussed further in Chapter 4).

Using ecosystem services of EIPs' can reduce pressure on natural ecosystems and also fulfill human needs. An ideal relationship between natural ecosystem services and humans is a closed loop in which humans use ecosystem services as long as they can be used sustainably (Raymond et al., 2013). Food production is a provisioning service within natural ecosystems, but it can also be an ecosystem services of an EIP if the materials and energy required to produce food come (at least in part) from within the EIP. Although in most cases the aim of industrial development is economic benefits, it has a great impact in the ecology of the landscape, natural environment, and ecosystem services. The EIP services will be categorized in chapter 4.

V.3. Heat Exchange

The term "waste heat" refers to heat that is a by-product of an industrial operation, or which is rejected from a power generation station (Earley, 2015; Nair et al., 2017). However, in industrial sector huge energy is consumed, only small portions of the waste heat from industrial processes have been utilized by another industry through industrial symbiosis networks in industrial park (Kim et al., 2018; Zhang et al., 2016). Reusing waste heat in an EIP can significantly increase the total energy efficiency of the whole park, (Zhang et al., 2016), while reducing its greenhouse gas emission (Jung, Dodbiba, Chae, & Fujita, 2013; Yun Zhang et al., 2017). Greenhouses are a logical choice for utilizing the available exergy provided by industrial operations for a number of industry-specific reasons (Andrews & Pearce, 2011). Greenhouses require heat at a relatively low temperature to maintain ambient conditions (Baas & Korevaar, 2010; Graamans et al., 2018; Sethi et al., 2013).

The largest barrier to greenhouse operations in cold climate areas is the heating prices, which can account for 15%-35% of a greenhouse operation (Ahamed, Guo, & Tanino, 2018); heat exchange can offset a large amount of energy each year and address this problem (Kim et al., 2018; Liew et al., 2013). Truly Green is an example of a greenhouse operation using a waste heat of nearby power plant to reduce the heat cost of the greenhouse in cold climate area (to be discussed further in Chapter 3). Many other organizations worldwide utilize energy exchanges in the form of steam and combustion products from industries. In the Netherlands, combined heat and power plants have been also used for many years to provide space heating to local greenhouse farmers (Korhonen, 2000; Spekkink, 2013; Vadiee & Martin, 2012).

V.4. The Relationship Among the Ecosystems Services

Modeling and mapping ecosystem services as a tool can assist designers to understand the interactions between ecosystem functions and correlations among the services (Boumans, Roman, Altman, & Kaufman, 2015; Crossman, Burkhard, et al., 2013; Drakou et al., 2015; Grêt-Regamey et al., 2015; Jackson et al., 2017; Maes et al., 2019; Posner et al., 2016; Volk, 2013, 2015; Wolff, Schulp, & Verburg, 2015). Figure 2.8 presents a graphical representation of the varied and complex relationship among the ecosystems and their services. Most of the services are provided by natural ecosystems and used directly or transferred to other forms to be used in human-made ecosystems. Provisioning and supporting are dominant types of services. The cycles and processes of provisioning services are known as supporting services. The services that the greenhouse (GH) at the center of the figure provides for all the ecosystems are written in white font. The greenhouse is mostly dependent on industrial ecosystem services as its host ecosystem.

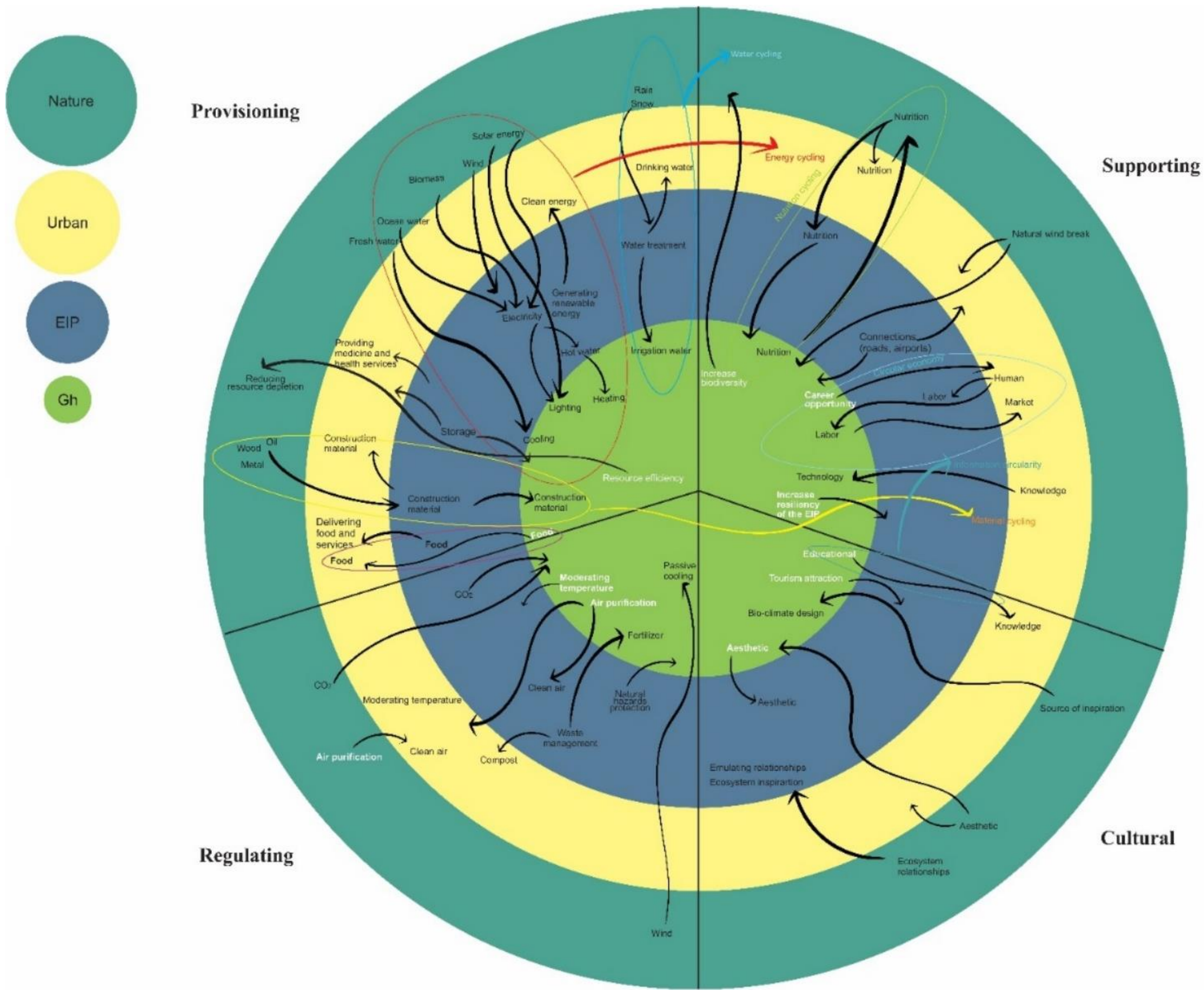


Figure 2.8: The relationships and exchanges between the various *ecosystem services* and the greenhouse

CHAPTER THREE: THE CASE STUDIES

Introduction

In addition to the previous literature review, data related to five existing industrial and urban/innovative greenhouses/food production systems were assessed to add additional insight to potential key design features and consideration. Design factors, environmental considerations, as well as (where applicable) the resulting operational conditions will be discussed. Three of the cases are located in the Netherlands and two in Canada.

1. The New Farm

The New Farm is located on top of a former Philips factory, a 1200 m2 structure in The Hague, the capital of South Holland province. The floor below The New Farm greenhouse has been made suitable for a 250 m2 fish farm. Taken together it forms an efficient symbiotic system (also referred to as aquaponics) for fish and vegetable production in an urban area. This operation demonstrates how combining different functional units can have a smaller environmental footprint than if each function separately. In this case, the combination of a greenhouse producing vegetables and a land-based fish farm. This integrated approach to food production saves up to 90% of the water needed compared to a greenhouse operating independently.

1.2. Technical Design Challenges

The New Farm is a hydroponic greenhouse with a single layer production which limits its production scale. The lights are installed on the ceiling far from the production layer (Photo 3.1) and are not the more efficient LED bulbs – so the system consumes more electricity than necessary. The height of the greenhouse is more than necessary, increasing the volume of air that needs to be heated and/or cooled; it also exposes the greenhouse to the wind. The heating pipes are installed on the side walls of the building (Photo 3.2) and heat is lost through the transmission to the outside, while they could be installed underground. There is no evidence that local environmental/weather conditions were considered in the design (orientation to the sun, prevailing wind, etc.…) (Impact City, 2016).

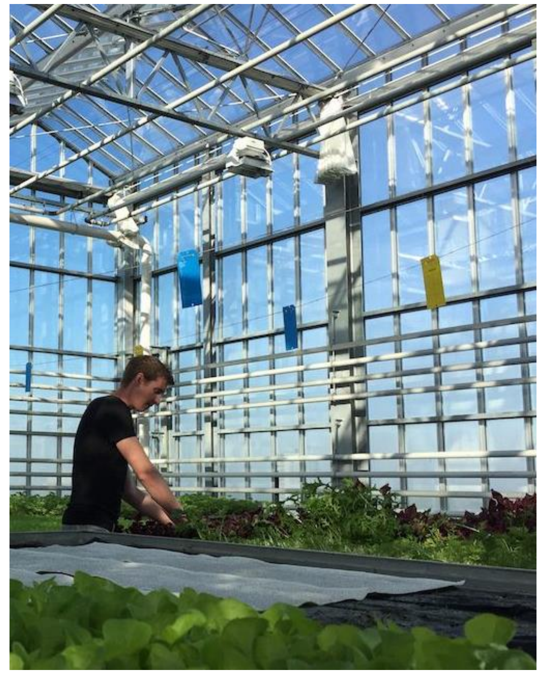


Photo 3.1: The New Farm, Outside view, source (A Dutch Experience, 2019)

Photo 3.2: The New Farm, Inside view, source (Zegwaard,2016)

Figure 3.1 shows the location of this greenhouse in of the center of the city, where the city has some of the highest densities of greenhouse operations in the Netherlands. The crops coming from these areas have lower price compared to an urban greenhouse crops. The New Farm is a stand-alone greenhouse with high operational costs, growing lower-value products, such as lettuce; such factors negatively influence the competitiveness of the project if agriculture crops with lower pricing are being produced in the farming arounds adjacent the city.

Figure 3.1: Map of the New Farm location and greenhouse centers in the Netherlands, source (Google Map, 2018)

2. QO Amsterdam Hotel Greenhouse

The QO Amsterdam Hotel greenhouse is located on the roof of the QO hotel (Photo 3.3) in Amsterdam, Netherlands. It is a hydroponic greenhouse with LED lights and several production layers. Photos 3.3 and 3.4 show how it is integrated to the building, and how it looks in the summer.

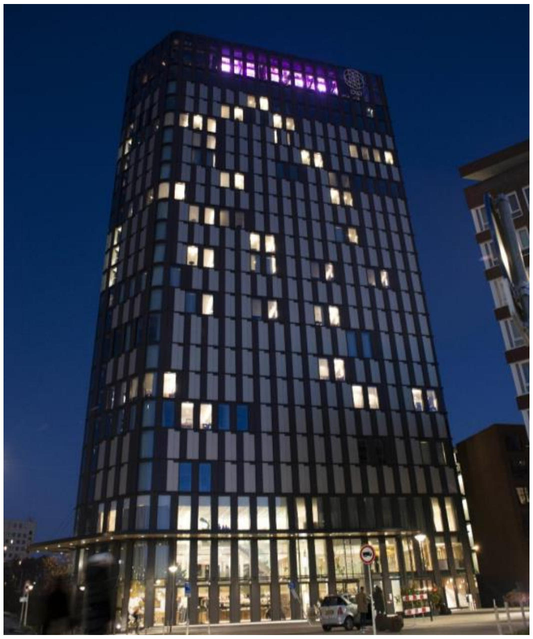


Photo 3.3: QO Hotel, greenhouse outside summer, source (Bink, 2018)

Photo 3.4: Greenhouse inside view, view, source (QO-Amsterdam, 2019)

2.1. Technical Design Challenges

There are several technical challenges with the design of this greenhouse. The lighting, heating, cooling pipes, and the thick structure of the building block sunlight and thereby increase the electricity demand for greenhouse lighting (Photo 3.5). The greenhouse integration into the building was not considered until after the building was designed, so the structure and the form of the greenhouse were established after the building was designed, thereby developed to meet the needs of the building, not the optimal design of the greenhouse and its operating systems.

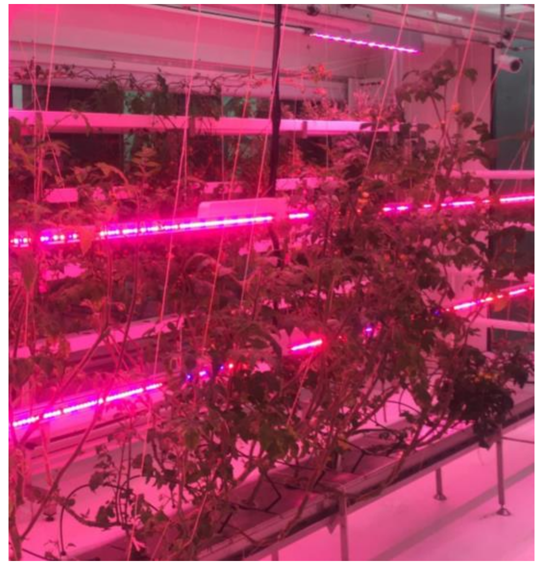


Photo 3.5: Heating and cooling pipes, production, taken by (Bashirivand, 2018)

Photo 3.6: Lightings are close to layer, taken by (Bashirivand, 2018)

Another issue is that the position of the LED lights are such that when the plants grow to a certain size, the foliage block the lights (Photo 3.6). In addition, the greenhouse can only be operated as a seasonal greenhouse (Photo 3.4); the hot water in the heating system reaches the greenhouse at 40 degrees and it is not enough to warm enough to heat the greenhouse. To exacerbate the situation, the building orientation (and therefore the greenhouse) is exposed to prevailing winter winds. Potential solutions could be to install heat pumps to increase the temperature of heating system water for the greenhouse or make use of the waste heat produced by restaurants' ovens on the 21st floor.

In the summer the greenhouse has cooling and ventilation problems. The greenhouse cannot use the passive cooling system as a typical greenhouse in the summer, because this greenhouse does not have the features of a standard greenhouse, such as a sloping roof that is more efficient at facilitating air flow.

If the greenhouse had been explicitly designed as a vertical farm it would not have the heating problems. Vertical farming or plant factories are completely closed vegetable production without any windows and do not lose heat through transmission. This ad hoc design does not serve to deliver efficient operations in any manner. Additionally, this greenhouse has a marketing value for QO hotel, so operational expenses can be considered as marketing expenditures for the hotel rather than reducing expenditures on food within hotel operations.

3. The Floating Cow Farm

The Floating Farm cow farm is a standalone farm located in a peri-urban area of Rotterdam, Netherlands. This case study is a food production system and it considered to examine its potential as an integrated ecosystem approach. It is located in an industrial setting, but the surrounding ecosystem is projected to transition to an urban setting over the next 10 to 15 years.

The farm is constructed with a concrete base, has two levels (each $600m^2$) and is located in the middle of Merwehaven Harbor (Photo 3.7). The first floor is dedicated to the milk production an animal husbandry; the second-floor houses for 32 cows (Photo 3.8). The farm initially focused on milk production but intends to expand into yogurt and cheese production.

Photo 3.7: The Floating Cow Farm 2019, taken by (Bashirivand, 2018)

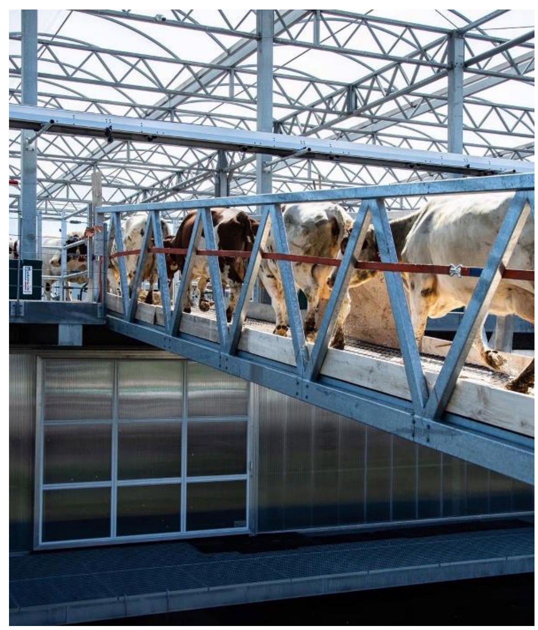


Photo 3.8: The farm launched on May taken by (Dario Kleimee, 2019)

3.1. Technical Design Challenges

The farm's building design did not integrate considerations of local environmental and climatic conditions. For example, the building is exposed to the prevailing wind and was constructed with a limited R-value (predominantly glass and steel), thus exposing the operations to considerable heat loss (and related energy expenditures) during winter. To decrease the heat loss of the farm, the north side of the building should be insulated as it will have limited impact on the solar radiation entering the facility.

Currently, the farm is located near industries (peri-urban area); however, the project managers didn't consider any symbiotic relationships with nearby industries which would reduce the project's costs significantly. In the near future (10-15 years), the industrial lands near the farm will be lost for residential areas, and farms will be located in urban areas. Therefore, the health risks of the community and environmental concerns will increase at that time. These conditions can change social perceptions about the future of the project and threaten the success of the farm.

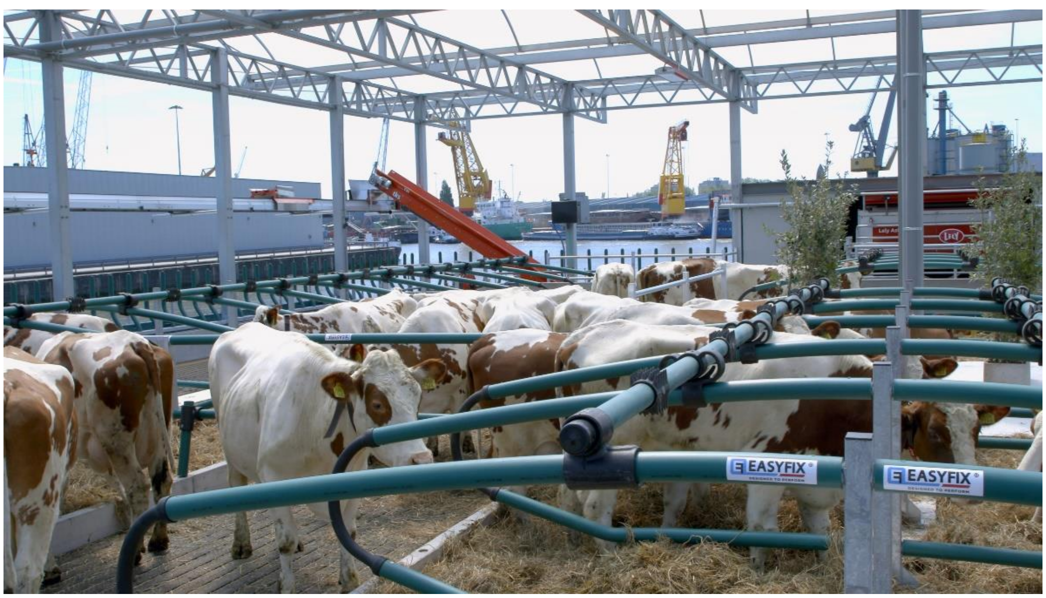


Photo 3.9: Inside view, The Floating Cow Farm, taken by (Dario Kleimee, 2019)

In terms of cow feed, neither the feed produced by the farm is sufficient, nor the way that they are producing the feed efficient. They plan to use LED lights on the ground floor to produce duckweed, while the first floor can be used to grow feed by using natural light and reduce both the energy consumption for lighting and heating. Having the duckweed production on the south side of the building on the first floor can also increase the building's ability to retain heat.

The project managers intend to use city food waste to feed the cows; however due unanticipated complexities and the high cost of the plan, instead the feed is transported from rural areas. In addition, the calves after a few weeks of delivery will be sent to the rural farm thereby incurring more transportation costs. These costs will affect the price of the final product, as well as adding air pollution, and traffic to the local area. Water will also be used for several purposes, including cleaning the milking system, and the floor of the production section, as well as the cows' floor. Therefore, the water consumption of this farm will be much higher than typical cow farms outside of cities.

In terms of social license, the separation of calves from their mothers is increasing running contrary to the social expectations of the community about animal welfare in dairy sector. In particular, this could have a negative effect on the farm if they become a lightning rod for animal welfare activists. There are also some concerns about methane production of the cows at the site which can increase social resistance to adding cow farms to cities. Unfortunately, while the Floating Farm is a novel idea and can address various problems related to the dairy sector in urban areas, such as food security, and a reduced GHG footprint linked to transportation from farm to market, the per unit cost is a considerable barrier. The scale of production on this farm is considerably lower than a typical dairy farm, and the more technology intensive nature of the operation both drive up the price of the final product. Only through "willingness to pay" campaigns and appealing to sustainability-minded can they overcome the price differential – it is unclear if such initiatives will suffice.

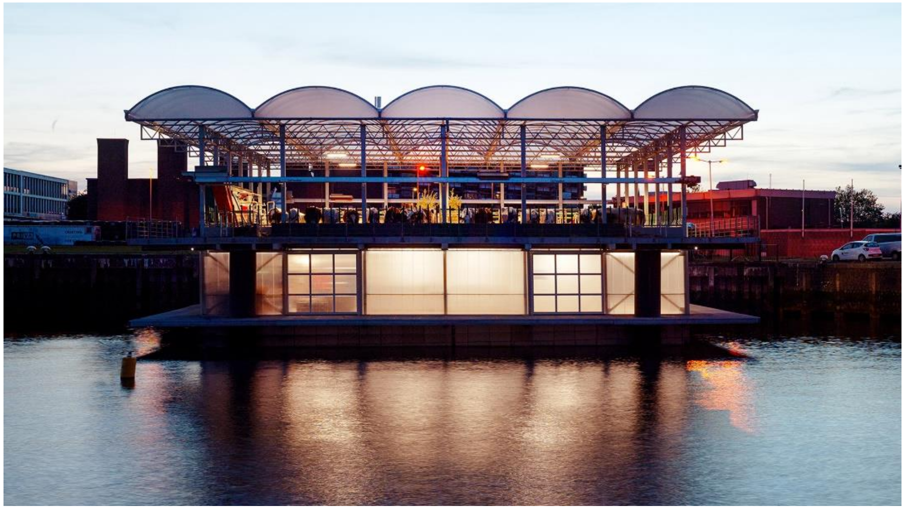


Photo 3.10: Outside view, The Floating Cow Farm, taken by (Dario Kleimee, 2019)

4. Dalhousie Greenhouse

The greenhouse located on the eight-floor top of the Life Science building (Photo 3.11) and belongs to the Biology Department of Dalhousie University; it is used for research and teaching purposes. The greenhouse's heating system is attached to that of the rest of the building. Two different mechanisms have been used to cool the greenhouse: active cooling linked to the same HVAC as the rest of the building and passive cooling using a series of levered windows in the roof and walls. Lighting can be used in the greenhouse depending on the research projects, but the lights are not LED and increase the electricity consumption of the greenhouse during shoulder seasons and winter.

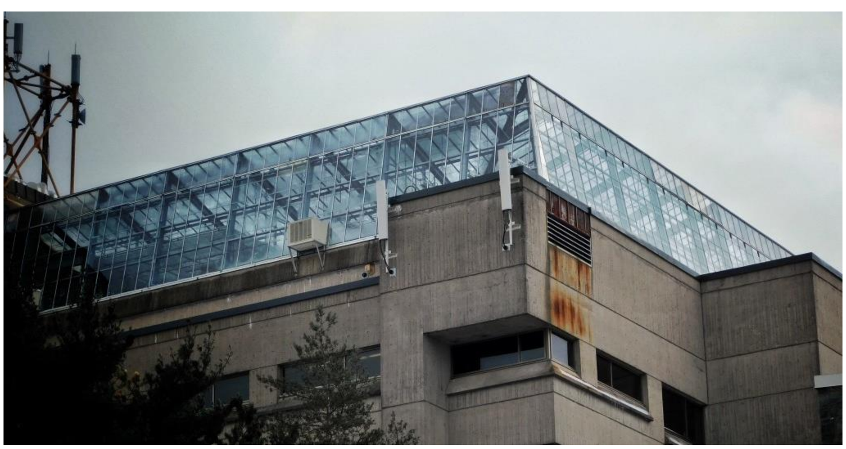
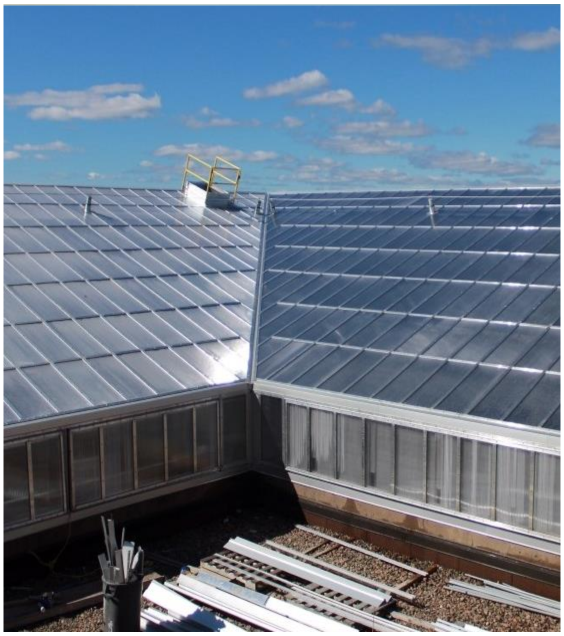


Photo 3.11: Dalhousie Greenhouse Outside view, source (Alumitech, 2018)

The most interesting point about this greenhouse is that it designed climatically, according to environment conditions. For example, the ceiling is designed to distribute anticipated snow load using a particular arc design (Photo 3.12).



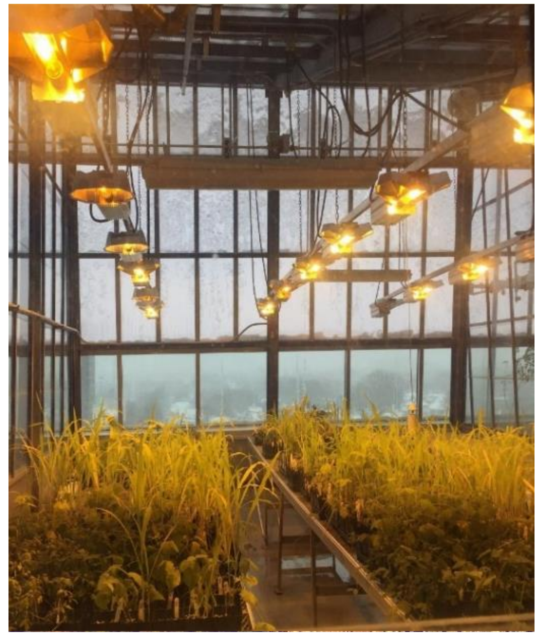


Photo 3.12: Dalhousie Greenhouse ceiling source design (Alumitech, 2018)

Photo 3.13: Dalhousie Greenhouse, in a rainy day (Bashirivand, 2019)

However, the lack of having a symbiotic relationship with the building reduces the efficiency of the greenhouse. The greenhouse could more effectively use the exhaust (waste heat) from the building in winter for its heating and reduce its operational costs significantly. As it is proven that the heating system of greenhouses in Canada are responsible for 20-35% of their operational costs (Andrews & Pearce, 2011; Pearce, 2011). Although the greenhouse could have a water collection system to store cold water from snow or rainwater for building ventilation as well as greenhouse irrigation and cooling system, due the high cost of retrofitting the current structure – it has not been considered. The greenhouse has some insulation factor from double glaze plastic panels which has a thin structure that increases the greenhouse solar gain capacity (Photo 3.14).

Photo 3.14: Dalhousie Greenhouse in a sunny day, taken by (Bashirivand, 2019)

As the Dalhousie greenhouse is a part of the Life Science building, there is no disaggregated data available regarding the greenhouse's electricity consumption and operational costs. However, as the facility has yet to convert to LED lighting (Photo 3.13), uses active cooling in the summer and high heat demand in winter, the operational cost is expected to be high.

5. Truly Green Farms

The Truly Green Farms greenhouse is a commercial greenhouse which is integrated into a micro-Eco Industrial Park in Chatham, Ontario, Canada (Photo 3.15). The operation utilizes the waste heat and carbon dioxide from the nearby Green Field Ethanol plant to reduces operational cost by 40%, while also reducing the net impact of the Green Field Ethanol plant in regard to the GHG emissions intensity per unit operation.

Photo 3.15: Green Field Ethanol plant and the Truly Green greenhouse, source (Green Energy Futures, 2019)

The name Truly Green was chosen to depict the environmentally friendly or carbon neutral way to grow tomatoes. Tomato is chosen to make optimal use of the available carbon dioxide; growth operations began in October 2012 with 22.5 acres to grow tomato. It will increase the scale of production to 90 acres by the end of 2023, creating 400 direct and indirect jobs. The project received a non-repayable contribution from the province of Ontario for nearly 3.2 million dollars and has an already established market – delivering tomatoes to the Mastronardi Produce's site in Lamington, Ont. (Truly Green Farms, 2013).

Photo 3.16: The location and orientation of the Truly Green greenhouse, source (Google Map, 2019)

The greenhouse uses a hydroponic system and its structure is that of a typical commercial greenhouse, although it does include a water collecting system for runoff water that is reused for irrigation purposes. Truly Green is located in an industrial setting which can impact its resource requirements as well as design factors (Photo 3.16). The heating system of the greenhouse fueled by the wastewater of the power plant nearby which reduces the operational costs of the greenhouse significantly. In terms of orientation, Truly Green has a southeast-northwest orientation which is the best in terms of sun and wind direction in this province (Photo 3.16). The east side of the building insulated by facility section to decreases the wind pressure on the greenhouse structure. Considering design factors, such as orientation and firm structures reduces environmental effects on the greenhouse. Although the greenhouse is covered by glass, the wind and snow load damage are negligible (Photo 3.17). Furthermore, the commercial function and the huge scale of the crop, can compete in the market with other companies and guarantee the success of the project.

Photo 3.17: Truly Green greenhouse in winter, taken by (Dodge, 2019)

6. Generalized Findings

The scale and function of greenhouses play a significant role in the greenhouse design factors as well as the specific resource requirements. Integration within an Industrial ecosystem can reduce operational costs significantly (note 40% for Truly Green). Aligning greenhouse requirements with available resources from surrounding operations and developing symbiotic relationships can positively influence the success of the project. However, the QO hotel and New Urban cases reveal that - for urban greenhouses, at least - being integrated into the ecosystem around apart from the building, can reduce the operational cost inevitably. These greenhouses are likely smaller than industrial greenhouses and consequently the design factors, the efficiency of the operating systems, as well the consequence of financial burdens have a great impact on the successful operation. The table below is the summary of case studies, the efficiency of their operational systems, as well as integrations into the ecosystem/building around.

	The New Farm	QO Hotel’s Greenhouse	The Urban Cow Farm	Dalhousie Greenhouse	Truly Green Farms
Symbiotic Relationship					✓
Likelihood of provisioning	✓	✓	✓	✓	✓
Climate Adaptive Design				✓	
Efficient in terms of heating				✓	✓
Efficient in terms of cooling			✓	✓	
Efficient in terms of light	✓		✓	✓	✓
Water collecting system					✓
Urban/ Industrial ecosystems	Urban	Urban	Urban	Urban	Industrial
Function Type	Commercial	Marketing	Tourism and Research	Research	Commercial
Type of Greenhouse: Standalone/ integrated	Integrated	Integrated	Standalone	Integrated	Integrated
Integrated to the ecosystem /building	Building	Building	-	Building	Ecosystem

Table 3.1: The summary of cases studies

The table presents how potential ecosystem integration can significantly increase the efficiency of the greenhouse, as well as the system. Although the likelihood of provisioning is high in most cases except one case none use the potential available services and make symbiotic relationships. In terms of urban greenhouses, they can have several functions, while industrial greenhouses mostly have commercial functions. In this respect, the market could be a challenge for urban greenhouses. Operational costs are also high for urban greenhouses, so having a symbiotic relationship with nearby facilities can significantly affect the success of the project. Furthermore, for an urban greenhouse, design factors can make a big difference and need more considerations, regarding they are integrating into a much-complicated ecosystem.

CHAPTER FOUR: THE DESIGN GUIDELINE

Introduction

Environments consists of two types of ecosystems: natural ecosystems and human-made ecosystems. Natural ecosystems typically experience slower, more gradual change than found in human-made ecosystems, which tend to be more dynamic. Furthermore, it is often difficult to determine boundaries between these two types of ecosystems as humans have spread across the planet, and – in some cases – integrated new "natural" ecosystems into their constructs. Ecosystems provide a myriad of services essential to the support of human activities, such as material cycles and energy flows. Natural environments are more sustainable in this regard as the complex nature of these flows support resiliency and gradual adaptive changes, while human made ecosystems, such as EIPs and urban environment can be susceptible to prompt and drastic changes that are not well-reflective of natural systems. However, when one considers the industrial ecological notion that EIPs be designed to mimic the natural ecosystem as much as possible, one can suggest that the services provided by the human made ecosystems (EIPs) – diminished as they may be - can be considered as the *ecosystem services* of these alternative ecosystems.

Understanding the differences, opportunities and synergies between these to overarching types of ecosystems can contribute to the more sustainable development of systems of production and consumption, supporting material, and energy flows that are more reminiscent of natural ecosystems. To aid the designer of such systems, there is a need for a set of design criteria that must be considered that ensure not only the proper allocation, but also identification and quantification of the various ecosystems services. The intent is to develop human based ecosystems that operate more synergistically internally and – perhaps more importantly - with the natural ecosystems; therefore, decreasing the burden of human activity on the natural world.

1. Regenerative Method

In the literature review chapter, the regenerative method is discussed. Regenerative design is a holistic approach that considers human, biotic and abiotic components of ecosystems and their relationships to the whole ecosystem (Mang and Haggard, 2016). The reason that this method was chosen for this design guideline is the fact that regeneration is about an evolutionary aspect of ecosystem services through landscape functioning. Humans are changing the landscape to make it more suitable to their perceived needs; therefore, ecosystems services and landscape functions also change. Altering an ecosystem, will alter the available ecosystem services as well. Thus, this design guideline is intended to explicitly integrate consideration of such new environment potentials and then add the greenhouse according to availability of resources. In fact, the regenerative perspective emphasizes alignment with nature's evolution.

In spite of differences between natural and human made ecosystems, humans and their manufactured ecosystems are also part of natural ecosystems; the changes in these ecosystems should be used as opportunities for creativity (Mang and Haggard, 2016). Regeneration reflects how diversity and interrelationship of ecosystems can improve the health of the ecosystems and contribute to the cascade of material and resources throughout whole ecosystems. This design guideline aids the designer to emulate the evolution of nature in human-made ecosystems. Identifying available resources, ecosystem services, and their provisioning schedule (when available) contributes to supporting the development of a resilience system.

2. The Aim of Design Guideline

The aim of this design guideline is to support a design process that delivers benefits to both human communities and natural ecosystems. The intention is to aid designers identify potential ecosystems services that can be optimized through the integration of the greenhouse's material and energy flows into a larger ecosystem. This design considers both ecosystem services provided by natural environment and potential connectivity between greenhouse component and the ecosystem with the goal of having a positive impact on local ecosystem services [or at least not negative]. The primary focus is the ecological aspect of the regenerative design rather than social and economic aspects. However, it is understood that human well-being is connected to the positive benefits of ecological regeneration. Regenerative design intends to reduce resource depletion, as well as mitigate climate change by reducing GHG emissions through sustainable methods. The regenerative design guideline is not only about reducing damages to the environment, it is also about how to optimize an integration into an environment. In this context, some parts of the guideline have been developed to address the dynamic nature of human-made environment.

3. Design Process

This design guideline leads the user through a series of questions within four categories; the intent is to ensure the designer has considered various aspects and elements that will help optimize the design within the context of EIP integration. The main aim of this design guideline is to aid in the development of a system that improves the resource productivity and useful output, while reducing the negative impact of human made systems. The intent is to use the waste of individual industrial operations as a source of material and energy resources to increase the efficiency of the whole system. Therefore, this design guideline will drive the designer to seek available resources in any kind of ecosystems around and design a sustainable and efficient greenhouse.

4. Principles and Steps of Guideline

1. The regenerative design process should mimic natural approaches as closely as possible. Understanding the complexity of the ecosystem and ecosystem services will contribute to developing healthy human-made ecosystems.

2. This design guideline can be applicable to an EIP, a micro EIP or an urban ecosystem

3. It can imply different approaches according to different conditions. For example, natural ecosystems in a cold climate area provide different ecosystem services compared to natural ecosystems in warm climates.

4. Energy production is the most important part of an ecosystem. Every ecosystem produces its own energy. Placing the greenhouse within a closed loop energy cycle in an ecosystem can optimize the greenhouse efficiency as well as the whole system. To do this, the designer should seek energy sources and loops and co-locate the greenhouse where waste heat and/or under-utilized energy and other resources are available.

5. Supplied energy could be renewable, or it could be sourced from the waste of other companies. The renewable energy can be strengthened in an EIP.

6. Human-made ecosystems can sometimes result in the creation of micro-climates that different from the local, natural climatic conditions. In such cases, EIPs can provide additional ecosystem services beyond those naturally available thereby increasing the potential of whole system. For example, the PHP micro-EIP is a hot humid ecosystem which located in a cold climate natural ecosystem. Both ecosystems can provide different types of energy and services.

7. Climate change and its future effects must be considered such that potential future condition and available resources in the ecosystems are accounted for. In terms of EIP, apart from climate change effects drastically and prompt changes in an EIP also should be considered.

8. Consider long-term circumstances for adding the greenhouse to the ecosystem

9. Food could be a by-product of the system and reduce the burden of the EIP on natural ecosystem

10. The greenhouse depends on the supporting and provisioning services of the ecosystems. Therefore, either the natural or human-made ecosystems can enrich the ecosystem services of the other.

11. In a regenerative system the capacity of the ecosystems will determine the capacity of the greenhouse. The greenhouse's size and capacity can be different according to nearby ecosystems' potentials.

5. Process of The Design Guideline (Questions)

This design guideline is intended to be generic and can be applied to any kind of EIP. The following sections outline the various steps in the design guideline. The first section is about the possible questions according to the greenhouse (as an integrated part), then natural, urban, and EIP ecosystems. In this project, the EIP is the host ecosystem, as a result, most of the questions are according to EIP ecosystem.

To apply the design guideline the designer/manager should follow the following steps:

1. **List the local greenhouse requirements based on climate and micro-climate type of the site**
2. **Create a table of natural services of the site**
3. **List ecosystems EIP and urban services available in the site (backed up with empirical quantitative data where possible)**
4. **Create a table for ecosystem's challenges for the site**
5. **Map the site based on availability of services (based on site-specific quantitative and qualitative data)**
6. **Create a table for each available location on the site and list pros and cons**
7. **Select the best location for the greenhouse**
8. **Make a table of challenges for the final location and propose solutions for these challenges**
9. **Identify the type and intensity of the available ecosystem services for the final location, and if there is any way to strengthen available ecosystem services for this location**
10. **Use bio-climate passive method to mitigate challenges to the greenhouse while increasing the efficiency of the desired ecosystem services**

The following charts outline the possible questions that should be investigated according to where in the system the designer is focused – i.e. the greenhouse, or natural, EIP, and/or urban ecosystems. These questions will help the designer to identify the greenhouse needs and find the possibilities of provisioning resources from ecosystems.

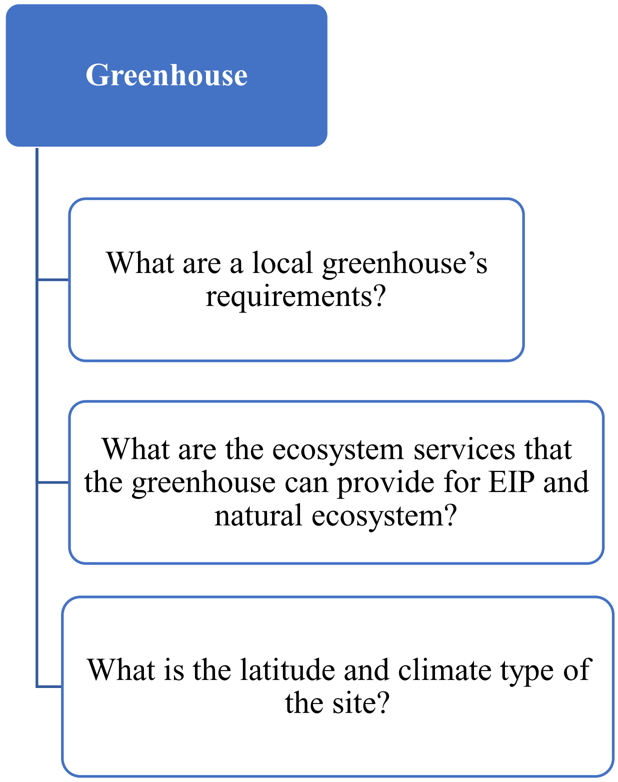


Figure 4.1: Questions regarding greenhouse requirements

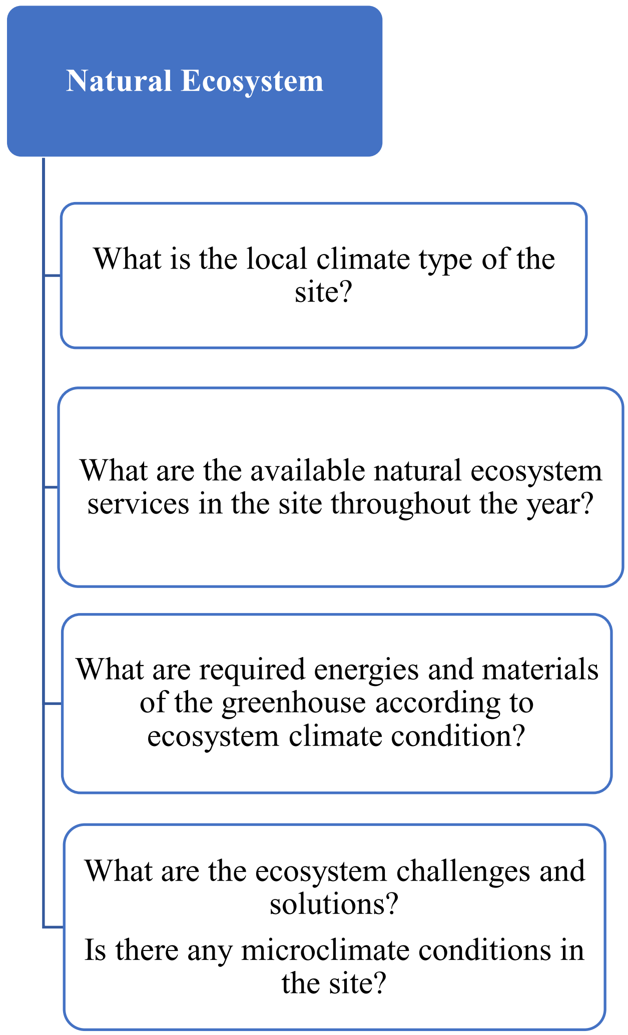


Figure 4.2: Questions regarding natural ecosystem conditions and services

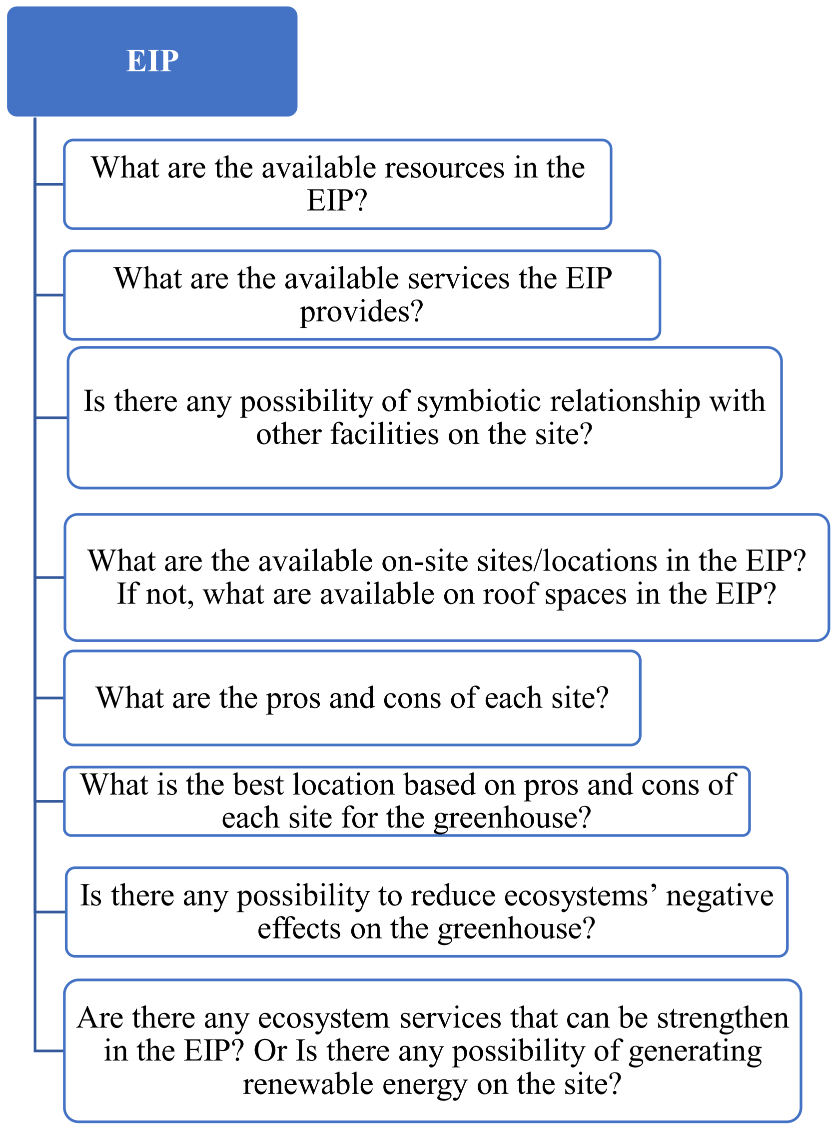


Figure 4.3: Questions regarding EIP ecosystem conditions and services

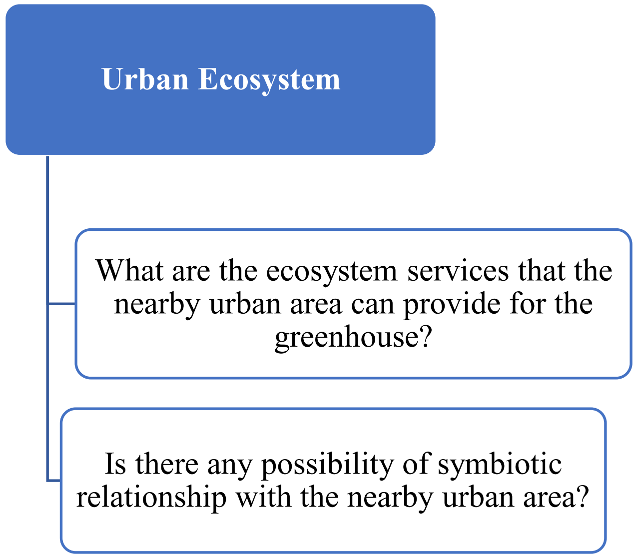


Figure 4.4: Questions regarding urban ecosystem conditions and services

6. The Process of Design Guideline (Suggestion Process)

Following charts are suggested steps processes to manage data according to the greenhouse requirements, design consideration, and natural, EIP, and urban ecosystems services and conditions. The suggested steps include tables, possible solutions, and methods that contribute to delivering the best result for the designer.

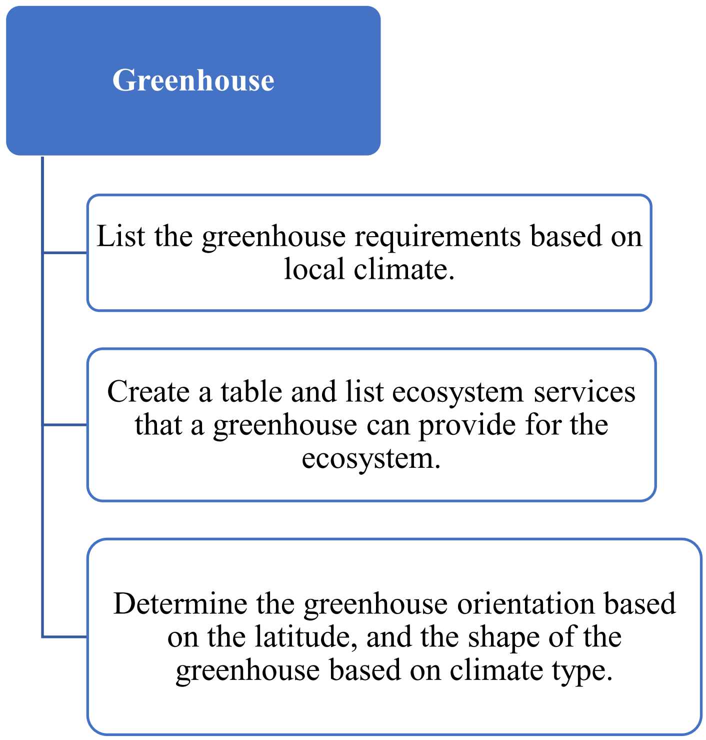


Figure 4.5: Suggestion steps for listing greenhouse requirements and design considerations

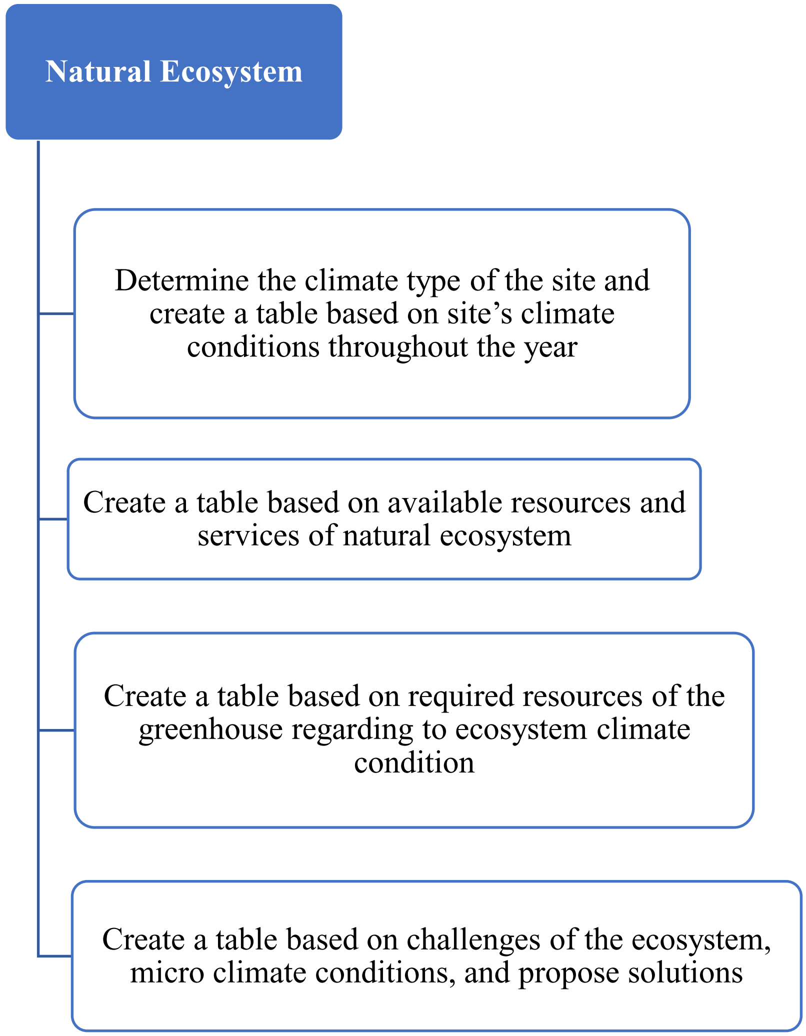


Figure 4.6: Suggestion steps for listing natural ecosystem condition and available services

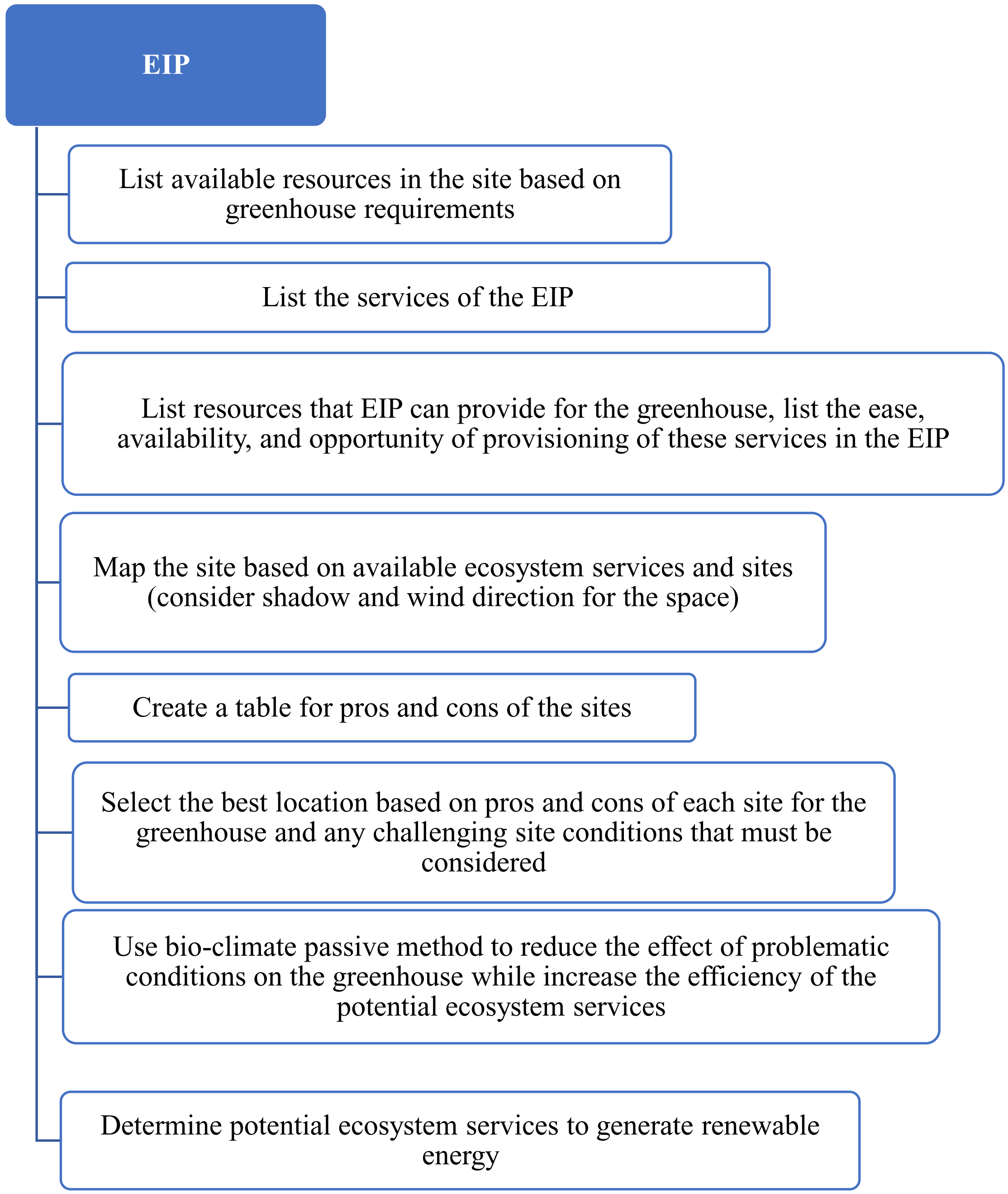


Figure 4.7: Suggestion steps for listing EIP ecosystem condition and available services

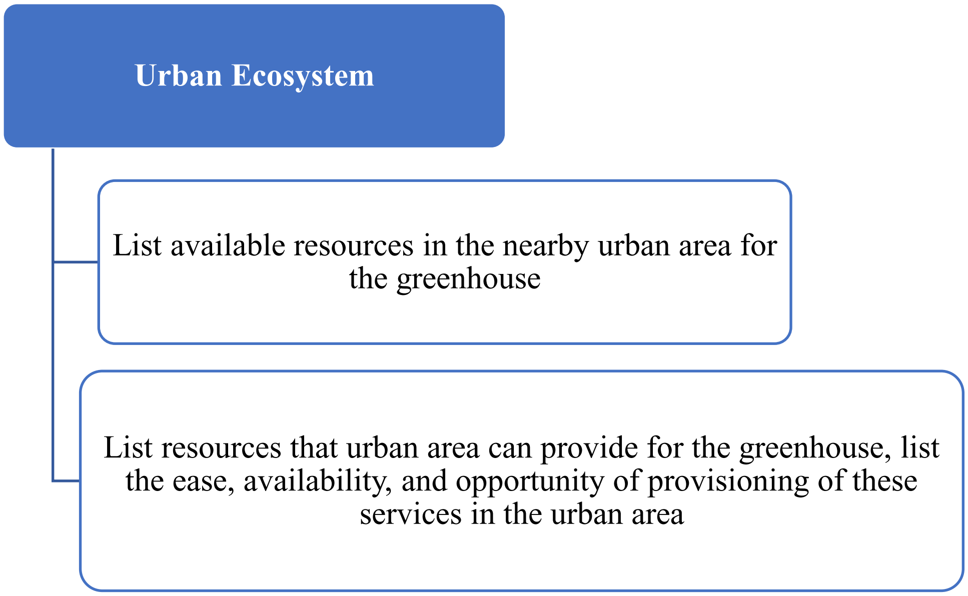


Figure 4.8: Suggestion steps for listing urban ecosystem condition and available services

Part I: Greenhouse Requirements

In this section, the greenhouse requirements will be listed, along with the design considerations, and proposed steps.

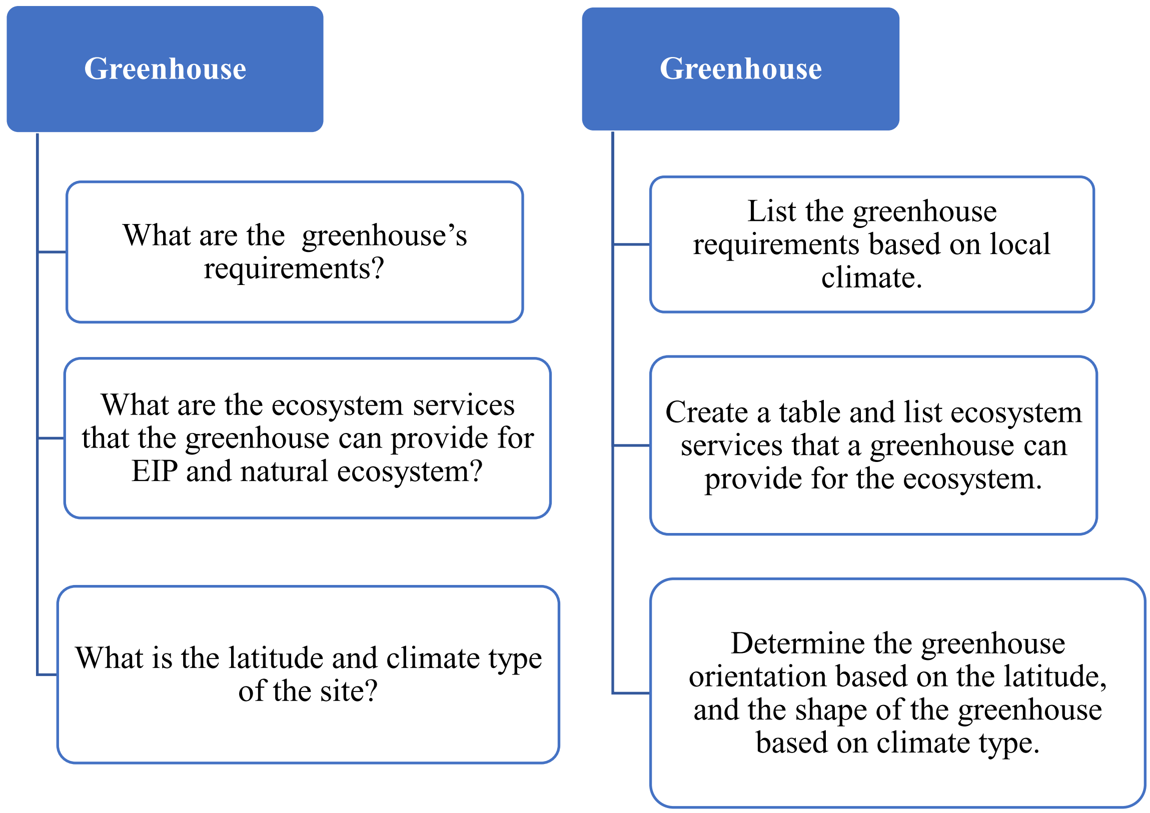


Figure 4.9: Questions and suggestion steps regarding greenhouse requirements

I.1. What are the local greenhouse requirements? List the greenhouse requirements based on local climate.

Greenhouses require various resources including heat, lighting, cooling system, water, carbon dioxide, nutrition, labour, clean air, as well as infrastructure and logistical connections, such as roads and transportation hubs. However, specific greenhouse requirements will depend on climate and environment condition of the site as well as the intended crop.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	CO_2	Windbreak	Material and infrastructure	Nutrition	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													

Table 4.1: The greenhouse requirements based on local climate

Notes on ranking:

High: The greenhouse's operation completely depends on these resources.

Medium: The greenhouse's performance will be affected by the lack of these resources.

Low: The greenhouse's performance will not affect by the absence of these resources.

I.2. What are the ecosystem services that the greenhouse can provide for EIP and natural ecosystem? Create a table and list ecosystem services that a greenhouse can provide for the ecosystem.

I.2.1. Greenhouse Services

Including greenhouse operations within in an EIP integrates a living system and improves the EIP's ecosystem services as well as assists natural ecosystem services. It links the natural ecosystem and the EIP. By including greenhouse services in an EIP, one can strengthen the ecosystem services and improve the resiliency of the whole ecosystem. Regenereative design can help to strengthen ecosystem services with the addition of EIP services, while providing greenhouse resource requirments, such as the provision of renewable or efficient energy. The greenhouse uses both EIP and natural services, while providing services back to these ecosystems. A greenhouse depends on supporting, regulating, and provisioning services of EIP while improving provisioning, supportive and cultural services of the EIP significantly.

A greenhouse in an EIP can play the part of a living system; it can become a link between the natural ecosystem and the EIP. The provisioning of the greenhouse services in an EIP, one can strengthen the ecosystem services and improve the resiliency of the whole ecosystem (Table 4.2)

Greenhouse services		
Natural ecosystem	**EIP ecosystem**	**Urban ecosystem**
Absorbing Co2 (regulating)	Aesthetic (cultural)	Agriculture products (provisioning)
Reducing resource depletion	Assisting circular economy (supporting)	Career (provisioning)
Moderating temperature in the site (regulating)	Accessing greenspace (cultural)	Educational (cultural)
Maintaining biodiversity (supporting) e.g. Pollinators	Increases resiliency of the EIP (supportive)	

Table 4.2: Greenhouse services

The services of the greenhouse can be varied according to the size and function of the greenhouse.

I.3. What is the latitude and climate type of the site? Determine the greenhouse orientation based on the latitude, and the shape of the greenhouse based on climate type.

The following charts are the summary of relationship between latitude, climate type and general principles for orientation and shape of the greenhouse.

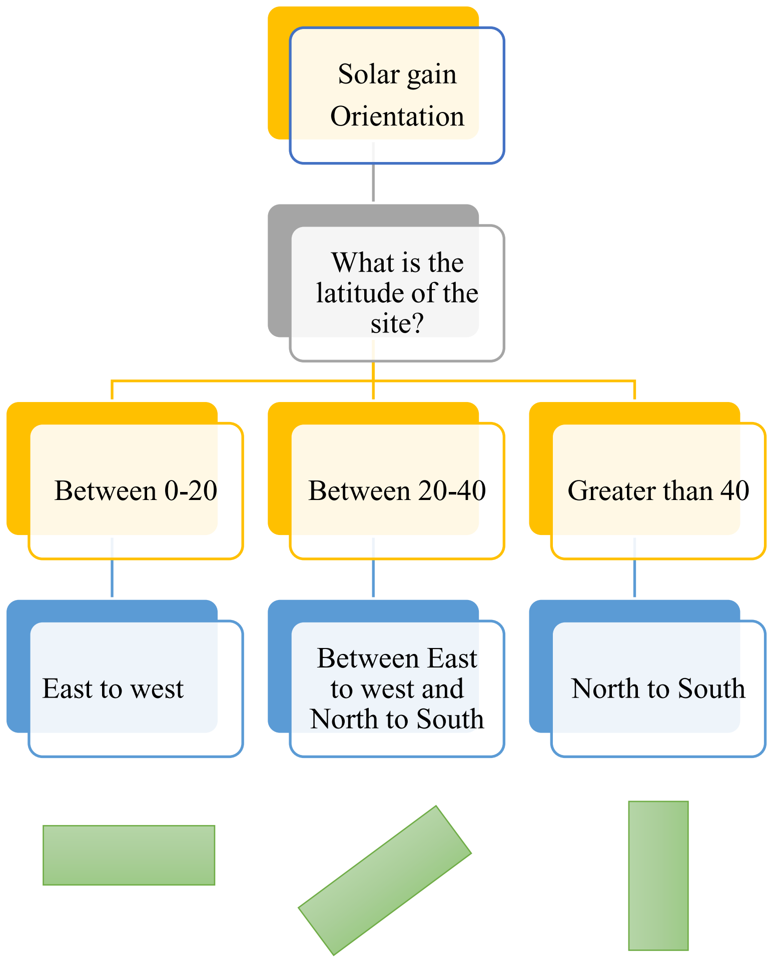


Figure 4.10: Site’s latitude and suggestion greenhouse orientation relationship

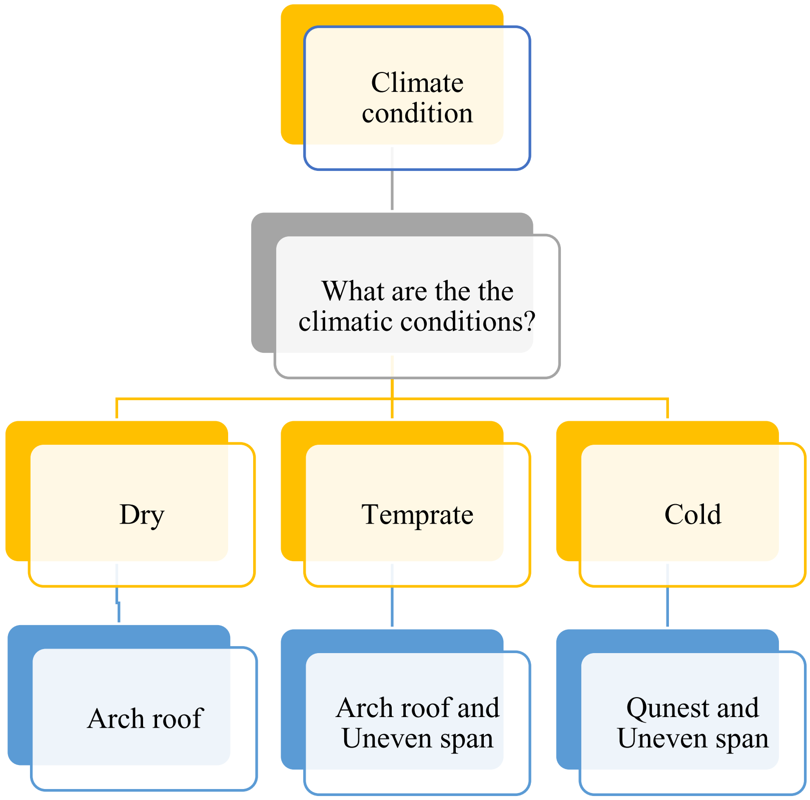
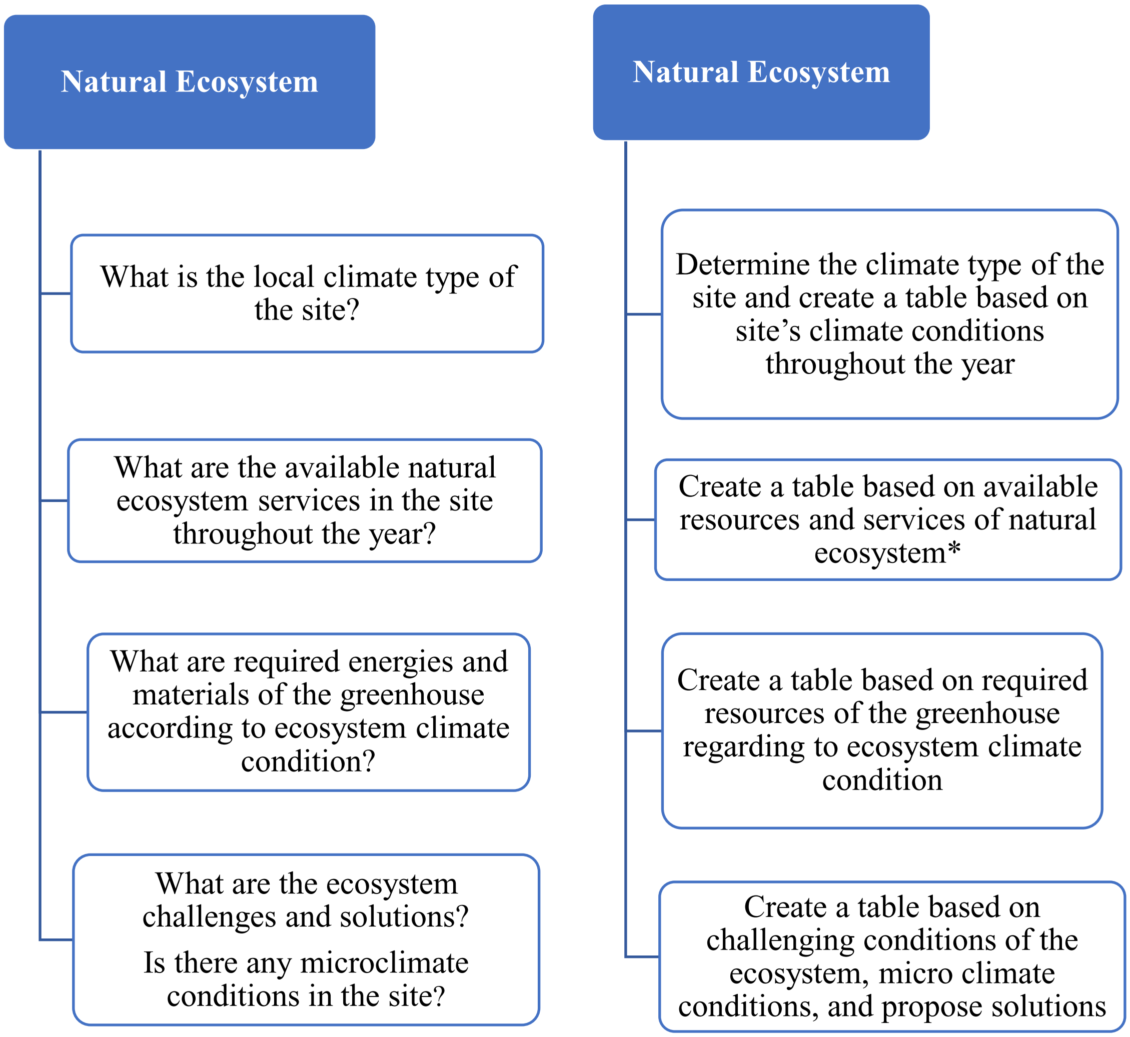


Figure 4.11: Climate condition and suggested greenhouse structure

Part II: Natural Ecosystem

In this section, natural ecosystem conditions and services will be listed. Furthermore, possible solutions for using available natural services and mitigating negative effects will be proposed.



* Where possible, it is recommended that the design team empirically measure the provision of such services (solar radiation; average wind duration, direction and velocity, etc…)

Figure 4.12: Questions and suggestion steps regarding natural ecosystems condition and available services

II.1. What is the local climate type of the site? Determine the climate type of the site and create a table based on site's climate conditions throughout the year.

II.2. What are the available natural ecosystem services in the site throughout the year? Create a table based on available resources and services of natural ecosystem.

Climate condition	Months											
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**
Cold season												
Hot season												
Period of prevalent winds												
Raining periods												
Snowy periods												
Period of prevalent sun												
Period of prevalent cloud												
Humid periods												

Table 4.3: General climate condition of the site

II.3. What are required energies and materials of the greenhouse according to ecosystem climate condition? Create a table based on available resources and services of natural ecosystem.

Required Resources	**Months**											
	Jan	**Feb**	**March**	**April**	**May**	**June**	**July**	**August**	**Sept**	**Oct**	**Nov**	**Dec**
Heating												
Active Cooling												
Passive cooling												
Water collecting system												
Heating												
Active Cooling												
Lighting												

Table 4.4: Available natural ecosystem services and required resources

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Material and infrastructure	Nutrition	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													
Required time													
Natural Ecosystem Service													
Availability of provisioning													
Provisioning and enhancement opportunity													
Likelihood of provisioning													

Table 4.5: The summary of greenhouse requirements and availability of natural ecosystem service

Notes on ranking:

High: The greenhouse's operation completely depends on these resources.

Medium: The greenhouse's performance will be affected by the lack of these resources.

Low: The greenhouse's performance will not affect by the absence of these resources.

II.4. What are the challenging ecosystem conditions and solutions? Are there any microclimate conditions in the site? Create a table based on ecosystem's challenges, microclimate conditions, and propose solutions.

Greenhouse Requirements	Heating	Cooling	Light	Air quality	Structure
Challenging ecosystem conditions					
Solution					

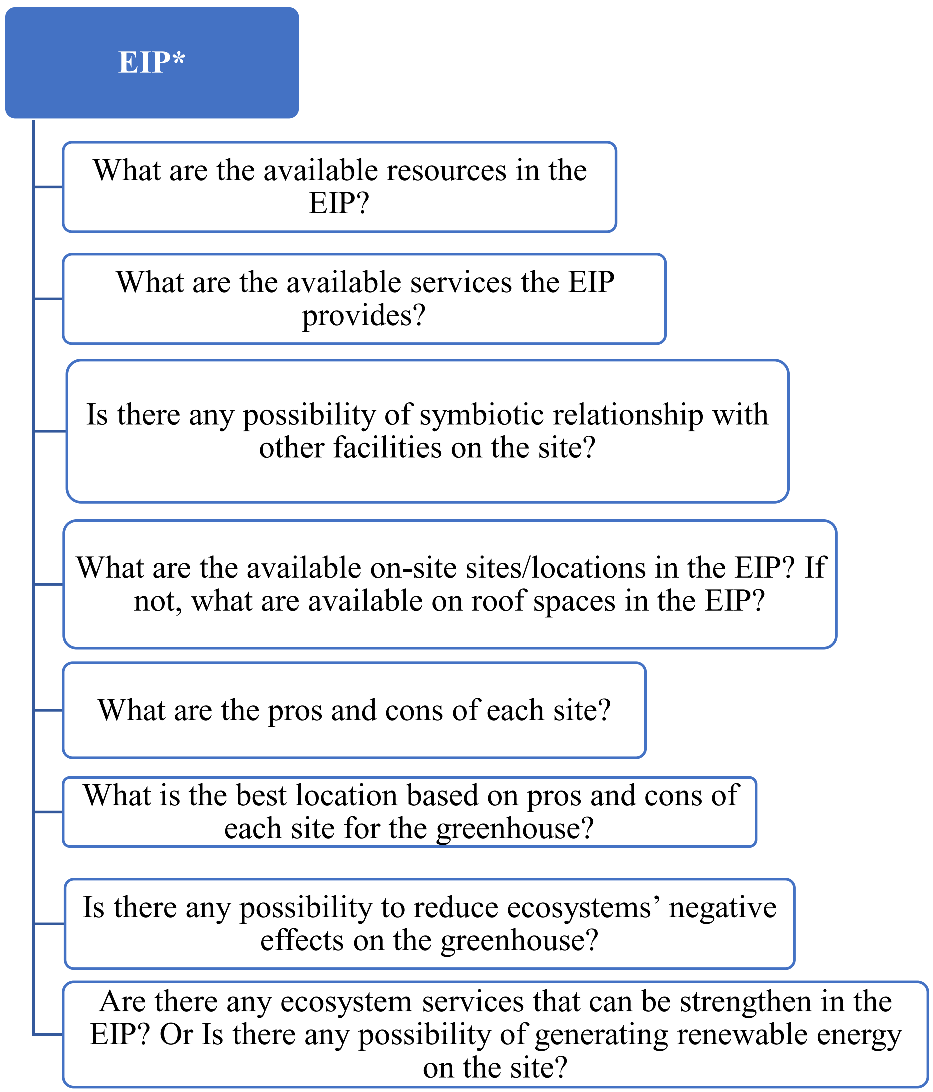
Table 4.6: The List of ecosystems challenges and suggestion solutions

Month	Day time	Natural available light	Day light + dormant time	Required light time
January	Sunrise-Sunset= X_1	X_1	$X_1+8=Y_1$	$Y_1-24=Z_1$
February	Sunrise-Sunset= X_2	X_2	$X_2+8=Y_2$	$Y_2-24=Z_2$
March	Sunrise-Sunset= X_3	X_3	$X_3+8=Y_3$	$Y_3-24=Z_3$
April	Sunrise-Sunset= X_4	X_4	$X_4+8=Y_4$	$Y_4-24=Z_4$
May	Sunrise-Sunset= X_5	X_5	$X_5+8=Y_5$	$Y_5-24=Z_5$
June	Sunrise-Sunset= X_6	X_6	$X_6+8=Y_6$	$Y_6-24=Z_6$
July	Sunrise-Sunset= X_7	X_7	$X_7+8=Y_7$	$Y_7-24=Z_7$
August	Sunrise-Sunset= X_8	X_8	$X_8+8=Y_8$	$Y_8-24=Z_8$
September	Sunrise-Sunset= X_9	X_9	$X_9+8=Y_9$	$Y_9-24=Z_9$
October	Sunrise-Sunset= X_{10}	X_{10}	$X_{10}+8=Y_{10}$	$Y_{10}-24=Z_{10}$
November	Sunrise-Sunset= X_{11}	X_{11}	$X_{11}+8=Y_{11}$	$Y_{11}-24=Z_{11}$
December	Sunrise-Sunset= X_{12}	X_{12}	$X_{12}+8=Y_{12}$	$Y_{12}-24=Z_{12}$

Table 4.7: Available natural and required artificial light throughout the year

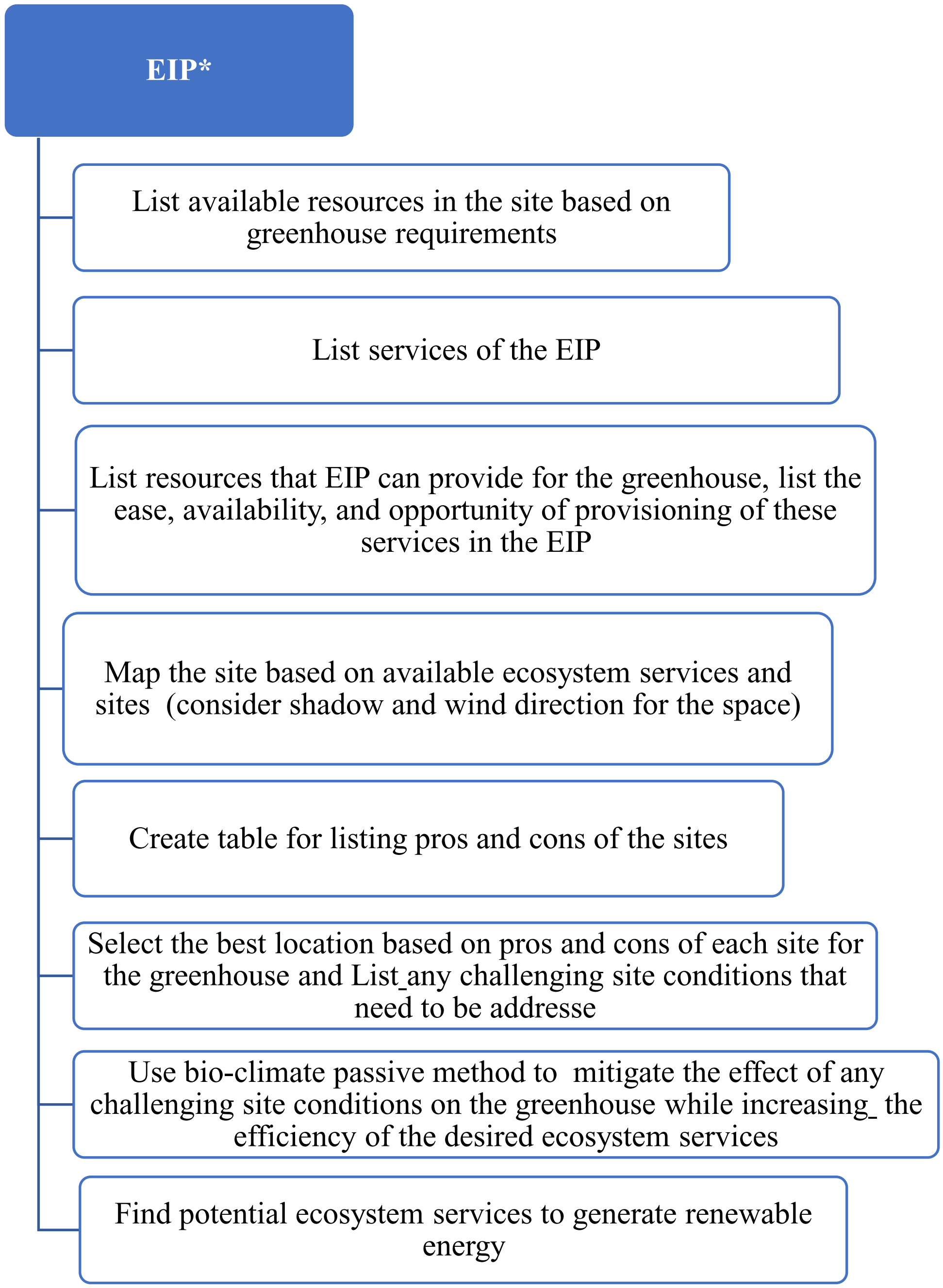
Part III: Eco Industrial Park

This section addresses site considerations, potential EIP services and the potential symbiotic relationships. The intention is to select the best greenhouse location based on EIP conditions and available resource, as well as identify possible solutions for mitigating any associated negative effects.



* Whenever possible, empirical, quantifiable site data should be gathered and applied. Generalized data is a good starting point but the designer will need to ground-truth all data related assumptions.

Figure 4.13: Questions regarding EIP condition and available services



* Whenever possible, empirical, quantifiable site data should be gathered and applied. Generalized data is a good starting point but the designer will need to ground-truth all data related assumptions.

Figure 4.14: Suggestion steps regarding EIP condition and available services

III.1. What are the available resources in the EIP? List available resources in the site based on greenhouse requirements.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Material and infrastructure	Nutrition	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													
Required time													
EIP Ecosystem Service													

Table 4.8: Available EIP services

Notes on ranking:

High: The greenhouse's operation completely depends on these resources.

Medium: The greenhouse's performance will be affected by the lack of these resources.

Low: The greenhouse's performance will not affect by the absence of these resources.

III.2. What are the available services provided within an EIP?

Ecosystem services are the source of material and energy for EIPs. Therefore, EIPs services depending on natural ecosystem services (Liu & Côté, 2017). In addition, EIPs can strengthen natural ecosystem services and reduce ecosystem degradation and resource depletion. Therefore, EIPs not only can provide ecosystem services for humans, but also can strengthen natural ecosystem services and improve the performance of the whole system. For example, generating renewable electricity or treating polluted water are ecosystem services that can be done by EIPs and strengthen natural ecosystem services or reduce the negative impact on the natural ecosystems. EIP services can be organized into two main categories: services that the EIP provides for humans, and services that it provides for natural ecosystems. EIP services and natural ecosystem services are interlink together (Liu & Côté, 2017). EIPs are using natural services and providing services for human other ecosystems (Figure 2.8). Climate type, biodiversity, and the stage development of the EIP can significantly impact the EIP services. For example, EIPs that are located at boundaries of marine and terrestrial ecosystems can obtain benefits from both environments, and both gain and provide more ecosystem services compare to terrestrial EIPs.

III.2.1. Supporting Services

The most important and fundamental ecosystem services of EIPs are supporting services that can make the delivery of other services possible. In terms of EIP services, the circularity of material, information, resource, and economic flow can be considered as supporting services (Table 4.9). Such services are mostly provided by primary producers and management services of the park which highly depend on biodiversity in an EIP. In addition, EIPs ecosystem services can be significantly influenced by the climate type, productivity and the services of the natural ecosystem of EIPs' site. Supporting services of an EIP has a direct relation with supporting services of the ecosystem services of the site’s environment. Therefore, increasing pollution, land use, and climate change by the EIP can not only decrease ecosystem services of natural ecosystems but also reduce supporting services within the EIP itself.

III.2.2. Regulating Services

Regulating services are the benefits gained from regulating processes in an EIP, in which management plays a key role. In addition, water treatment, air purification, and waste management are regulation services of EIP (Table 4.9). For example, in PHMEIP producing sludge that can be returned as a soil amendment could be viewed as a kind of regulating service for the natural ecosystem around it. Another type of regulating services in an EIP is reducing impacts of natural forces on human and managing the environment. For example, protecting facilities from heavy rain and the following flood or intense winds.

III.2.3. Provisioning Services

Supplying and delivering food and resources for human and industries are provisioning services of EIP. Managing provisioning services can increase the efficiency of other services in an ecosystem significantly. Another important provisioning services is landscape functioning which is the capacity of land to delivering services (Kienast et al., 2009). In most EIPs ecosystems are rich by landscape functioning. corridors, roads, and airports are different shapes of landscape functioning in an EIP. Kienast et al. (2009) defined four landscape functions: production, regulation, habitat and information functioning. Generating renewable energy, producing biochemical, medicine, and providing genetic resources in an EIP are also EIP provisioning services (Table 4.9).

III.2.4. Cultural services

Educational, aesthetic, and ecotourism are some of the cultural services of EIPs. This type of services has less economic value compared to other types of EIP services. Cultural services can improve the natural ecosystem in an EIP. This type of service can be a link between EIP and natural ecosystems. By improving these services, natural biodiversity can be improved in an EIP and increased the economic value of cultural services. For example, having a greenhouse in an EIP not only improves the provisioning services of an EIP, but also adds cultural services to the EIP by attracting truisms and improving workplace. Another example would be the inclusion of a living machine as water treatment system (regulating), providing the EIP with aesthetic services, improving the workplace environment for employees and attracting tourists to the site.

III.3. Is there any possibility of symbiotic relationship with other facilities on the site? List resources that EIP can provide for the greenhouse, list the ease, availability, and opportunity of provisioning of these services in the EIP

EIP Services			
Supporting	**Provisioning**	**Regulating**	**Cultural**
Water, energy, and material cycling	Providing nutrients	Moderating temperature in the site	Educational
Storage of resources	Providing material and resources	Waste management (decomposition)	Tourism attraction
Career opportunity	Generating energy (e.g. renewable energies)	Water purification	Aesthetic
Circular economy	Delivering food and resources	Air purification	
Information circularity	Providing medicine and health services	Protection from natural hazard such as strong winds	

Table 4.9: Available EIP services to all ecosystems

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Material and infrastructure	Nutrition	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													
Required time													
EIP Ecosystem Service													
Availability of provisioning													
Provisioning and enhancement opportunity													
Likelihood of provisioning													

Table 4.10: The Summary of available EIP services and time provisioning of services

III.4. What are the available on-site greenhouse sites in the EIP? If not, what are available on roof spaces in the EIP? Map the site based on available ecosystem spaces.

III.5. What are the pros and cons of each location? Create table for listing pros and cons of the sites

Site									
Resources	**Sun radiation**	**Cold water access**	**Wind exposure**	**Hot water and steam access**	**Fresh water access**	**Expansion opportunity**	**Accessibility**	**Climate resiliency**
Condition								
Pros								
Cons								
Solution								
Consequence								

Table 4.11: List of greenhouse sites conditions in the EIP

Pros	Sun radiation	Cold water access	Wind exposure	Hot water and steam access	Fresh water access	Expansion opportunity	Connections	Climate resiliency
Site 1								
Site 2								
Site 3								
Site …								

Table 4.12: The summary of greenhouse sites pros

Note for ranking: 10 Fulfill the requirement totally; 8 Almost fulfill the requirement; 6 partially fulfill the requirement; 4 rarely fulfill the requirement; 2 Almost do not fulfill the requirements (where possible this should be supported with empirically generated, site specific, quantifiable data)

Cons	Ocean's negative effect	Wind exposure negative effect	Microclimate heating negative effect	Increase energy consumption	Climate exposure
Site 1					
Site 2					
Site 3					
Site …					

Table 4.13: The summary of greenhouse sites cons

Notes on ranking: 10 High negative effect; 8 Moderate negative effect; 6 Partial negative effect; 4 Rare negative effect; 2 Negligible negative effect (where possible this should be supported with empirically generated, site specific, quantifiable data)

III.6. What is the best location based on pros and cons of each site for the greenhouse? Select the best location based on pros and cons of each potential location and list any challenging site conditions that must be considered.

The best location for the greenhouse in the site will be the site which has fewer cons and more pros.

III.7. Is there any possibility to reduce ecosystems' negative effects on the greenhouse? Use bio-climate passive method to mitigate the effect of any challenging site conditions on the greenhouse while increasing the efficiency of the desired ecosystem services.

Greenhouse Requirements	Light	Wind negative effect	Heat gain	Avoid overheat	Heat loss reduce	Cooling	Water
Passive solutions							

Table 4.14: The final site conditions and solutions to reduce negative effects on the greenhouse

III.8. Are there any ecosystem services that can be strengthen in the EIP? Or is there any possibility of accessing generating renewable or sustainable energy on the site? Find potential ecosystem services to provide renewable/sustainable energy.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Materials and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													
Required time													
Natural Ecosystem Service													
Availability of provisioning													
Likelihood of sufficient provisioning													
Provisioning and enhancement opportunity													
EIP Services													

Service provider													
Availability of provisioning													
Provisioning and enhancement opportunity													
Likelihood of sufficient provisioning													
Possibility of Symbiotic													

Table 4.15: The Summary of natural and EIP services

Part IV: Urban Ecosystem

In this section, available services in nearby urban ecosystem and the possibilities of making symbiotic relationships will be considered.

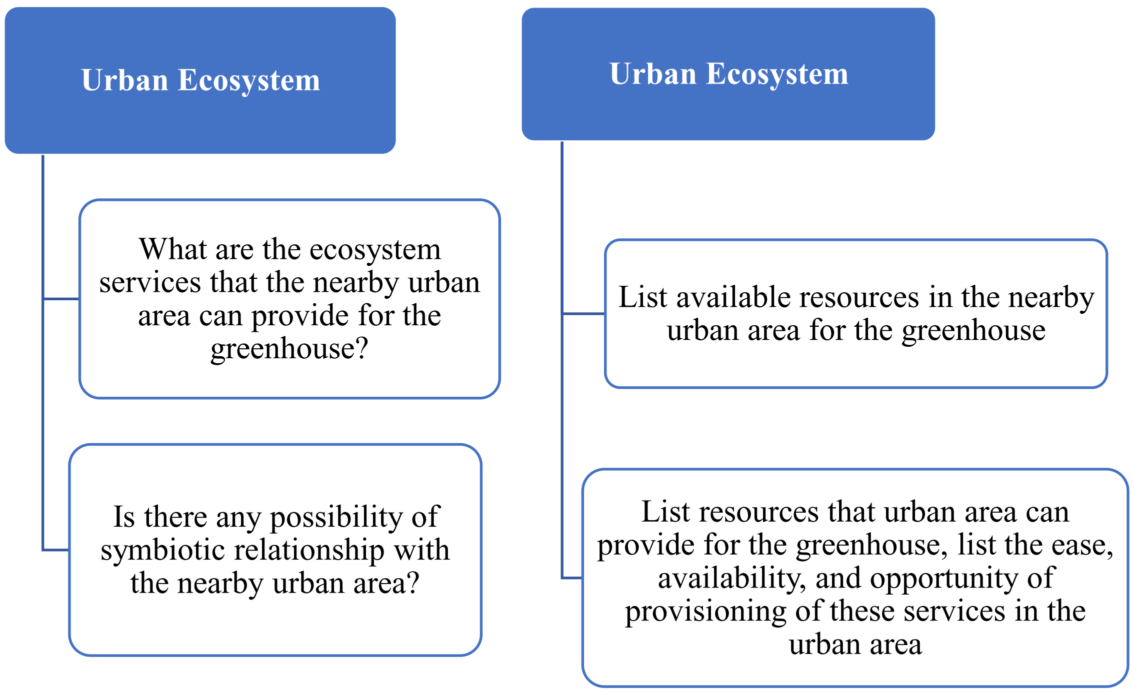


Figure 4.15: Questions and suggestion steps regarding Urban ecosystem and available services

IV.1. What are the ecosystem services that the nearby urban area can provide for the greenhouse? List available resources and services of the nearby urban area for the greenhouse.

Table 4.16: Urban ecosystem services

IV.2. Is there any possibility of symbiotic relationship with the nearby urban area?

Urban services		
Supporting	**Provisioning**	**Regulating**
Water cycling	Delivering food and resources	Moderating weather
Energy cycling	Knowledge	
Circular economy		
Information circularity		
Material cycling		
Human (labor)		
Market		

List resources that the urban area can provide for the greenhouse, also identifying the ease, availability, and opportunity of provisioning of these services from the urban ecosystem.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Material and infrastructure	Nutrition	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													
Required time													
Urban Ecosystem Service													
Availability of provisioning													
Likelihood of sufficient provisioning													
Provisioning and enhancement opportunity													

Table 4.17: The summary of Urban ecosystem services

The figure below shows the interaction of the greenhouse as an integrate organism to EIP, natural and urban ecosystem. The greenhouse as a new part is using the services of the ecosystems and providing servicses to the ecosystesms through increasing the diversity of the ecosystem

Figure 4.16: The integration of the greenhouse into natural, EIP and urban ecosystems

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Materials and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking													
Required time													
Natural Ecosystem Service													
Availability of provisioning													
Likelihood of sufficient provisioning													
Provisioning and enhancement opportunity													
EIP Services													
Service provider													

Availability of provisioning													
Provisioning and enhancement opportunity													
Likelihood of sufficient provisioning													
Urban Services													
Availability of provisioning													
Likelihood of sufficient provisioning													

Table 4.18: The summary of availability and likelihood of all ecosystems' services

Part V: Lenses and Interrelationships of The Design Guideline

The figure below is the design guideline in which three different contextual lenses have been considered; in some cases, there will be some overlap. These lenses contribute to finding available resources and use appropriate strategies to use the resources. Reusing resources can be done through symbiotic relationships. Additionally, finding opportunities to reduce the energy consumption of the greenhouse can be done through via the lens dealing with resource-use reduction. The "produce" lens includes steps that find the resources or conditions that have the potentials to produce energy, additional resources and reduce the burden of the newly integrated part into the ecosystem. All these processes and steps attempt to mimic what is already done by nature in an ecosystem automatically before adding an integrated part. In fact, the conditions of the ecosystem and its potentials provide the opportunities for adding the integrated part.

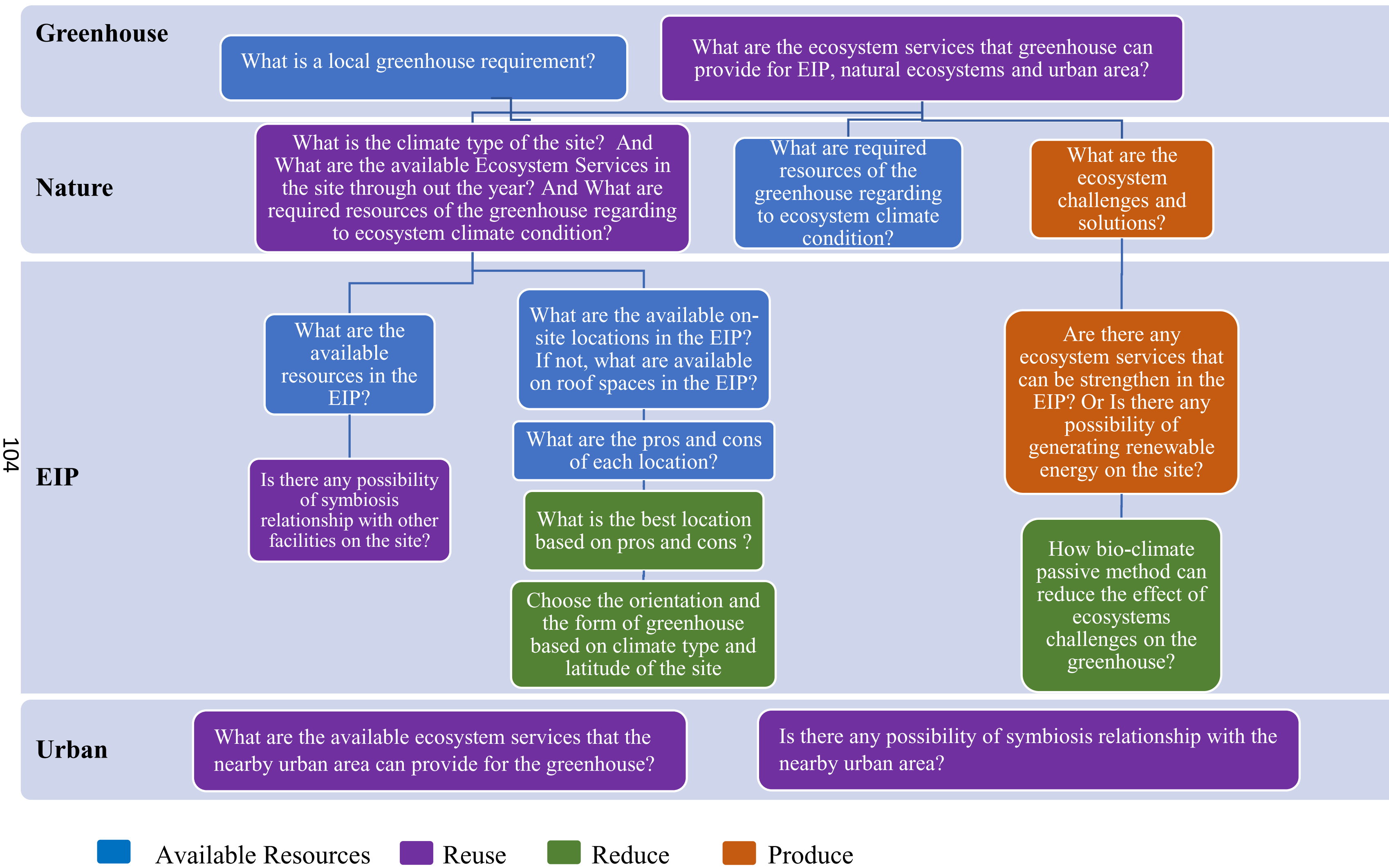


Figure 4.17: The design guideline with three lenses

V.1. Available Resources

The blue elements of the diagram represent attempts to find the requirements and available resources to fulfill the requirements of the greenhouse. This step is a crucial contribution to success of other next lenses. Finding available resources and materials will help the designer to increase the efficiency of the system through using appropriate strategies.

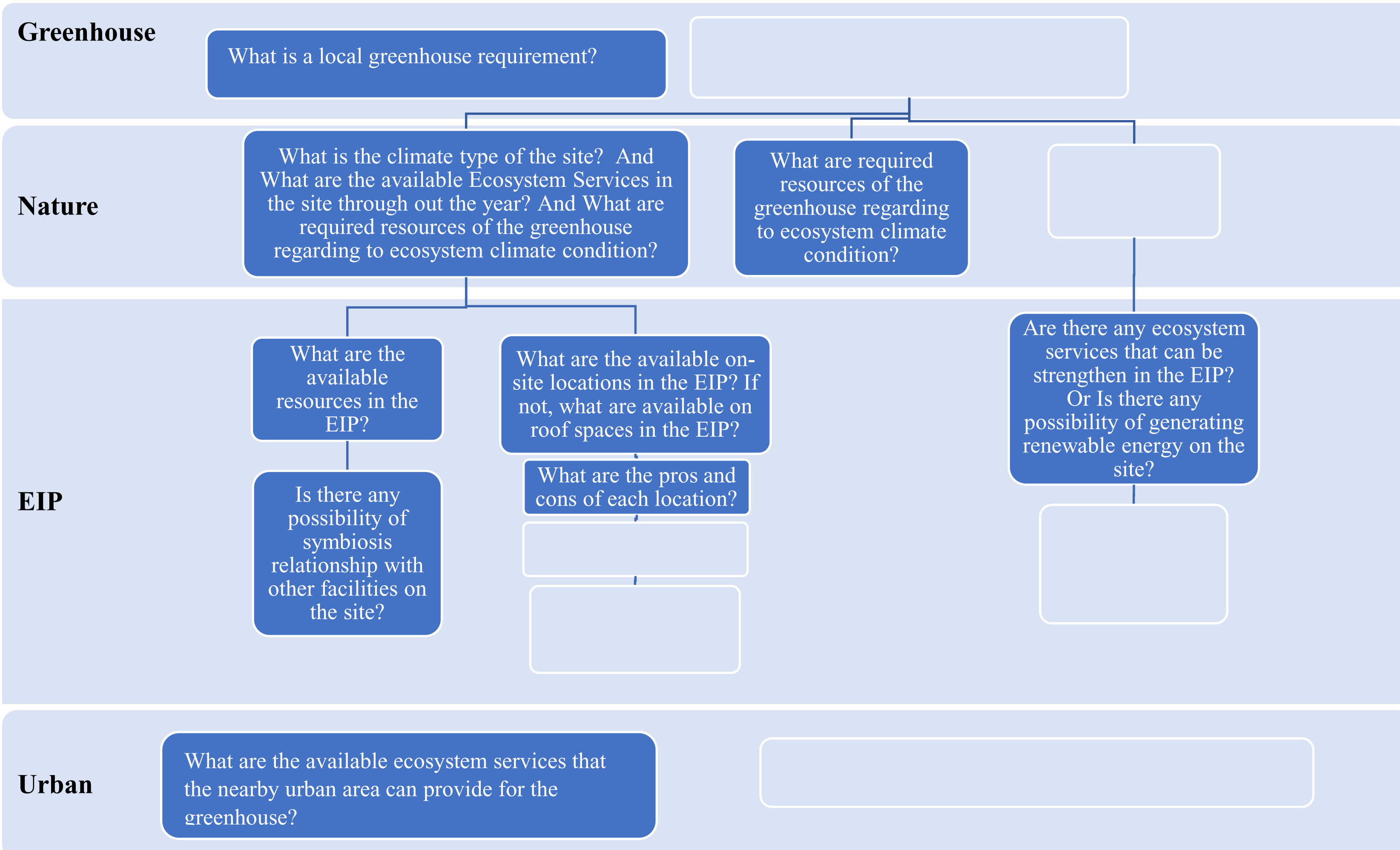


Figure 4.18: Assessing potential symbiotic relationship

V.2. Reuse Lens

The purple elements reflect opportunities to reuse resources. The reuse lens can guide the designer to find the opportunities to make symbiotic relationships through cascading or closings material and energy loops.

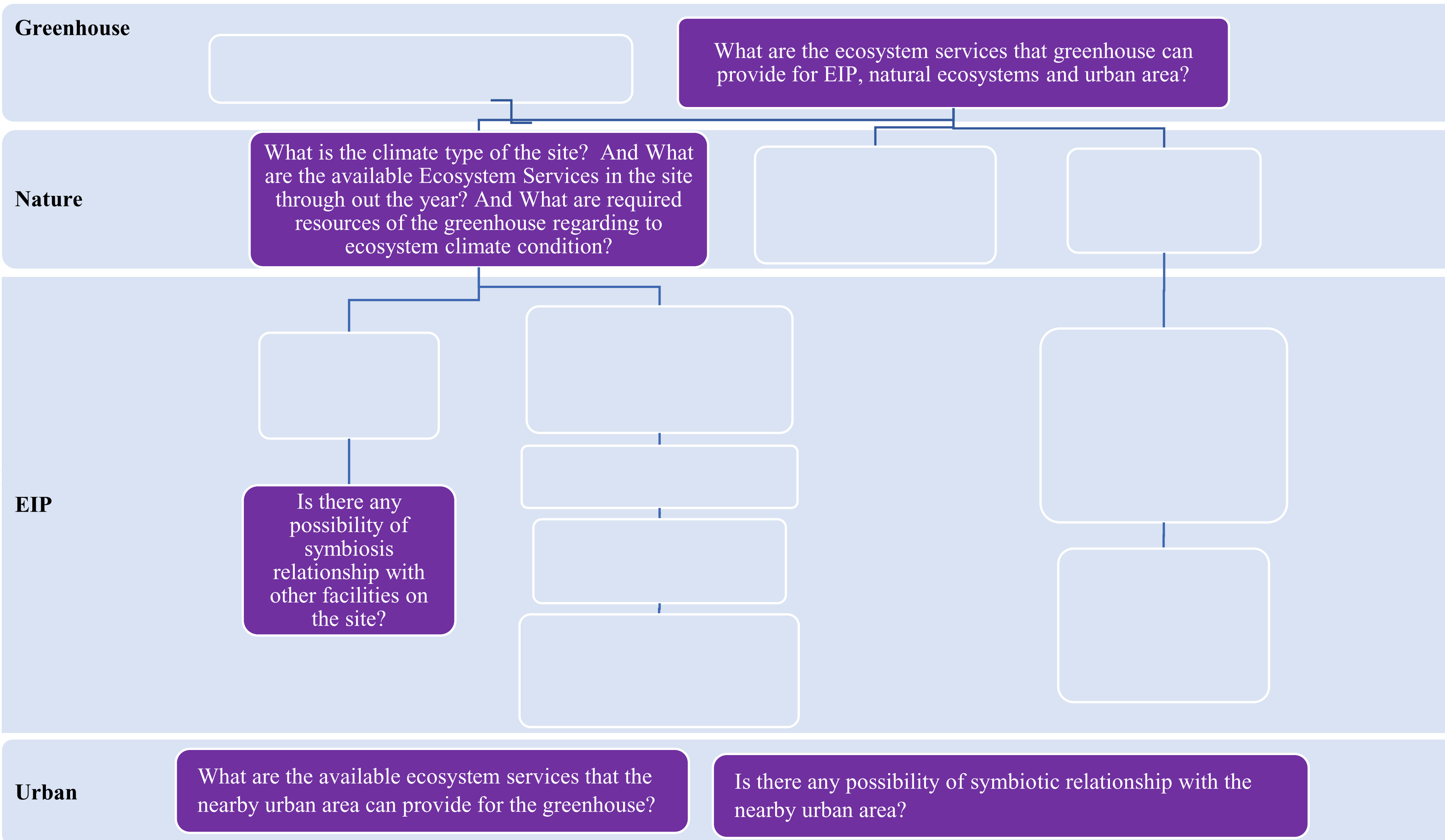


Figure 4.19: Reuse lens of the design guideline Figure

V.3. Reduce Lens

The green elements reflect the necessity of ensuring the most efficient use of energy and resources has been considered (that are not captured by reuse or diversion). These steps are about the strategies that reduces negative effects on the greenhouse and solutions for challenges on the site to reduce resource consumption of the greenhouse and increase its efficiency. The numbers illustrate the order that the steps that should be taken during guideline process. Each arrow has a number and the aim of the steps are defined below.

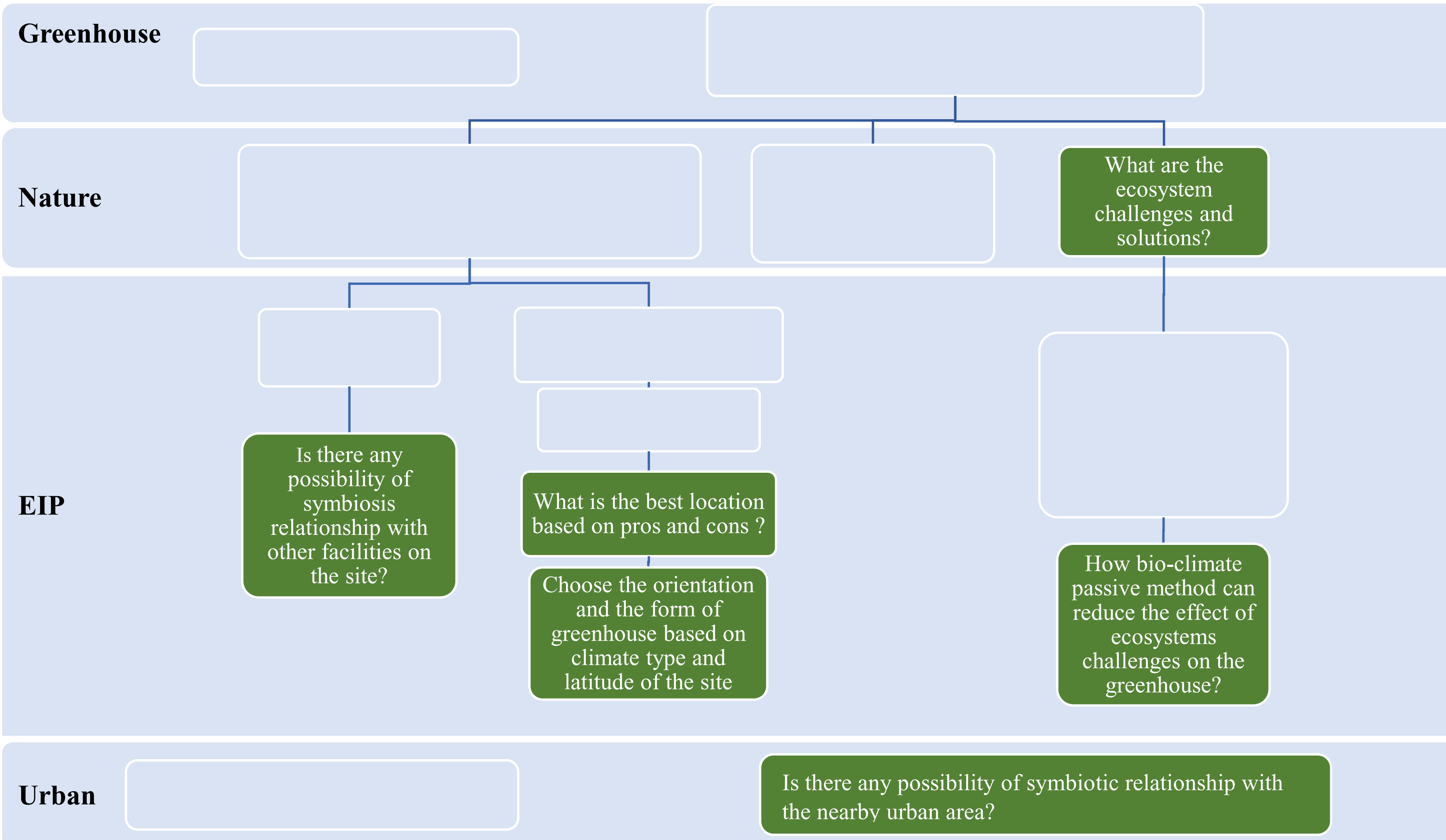


Figure 4.20: Reduce lens of the design guideline

V.4. Produce Lens

The orange elements reflect the potential opportunities for enhancing and/or producing resources and energy. The ‘produce’ lens guides the designer to seek opportunities within both the natural and industrial ecosystems to produce energy and resources. The contribution of this lens can be different according to the capacity and conditions of the integrated ecosystems. This lens has a significant role to improve the health of ecosystem and reduce the burden of human made ecosystems, decrease resource degradation and increase the capacity of the ecosystem for future expansion.

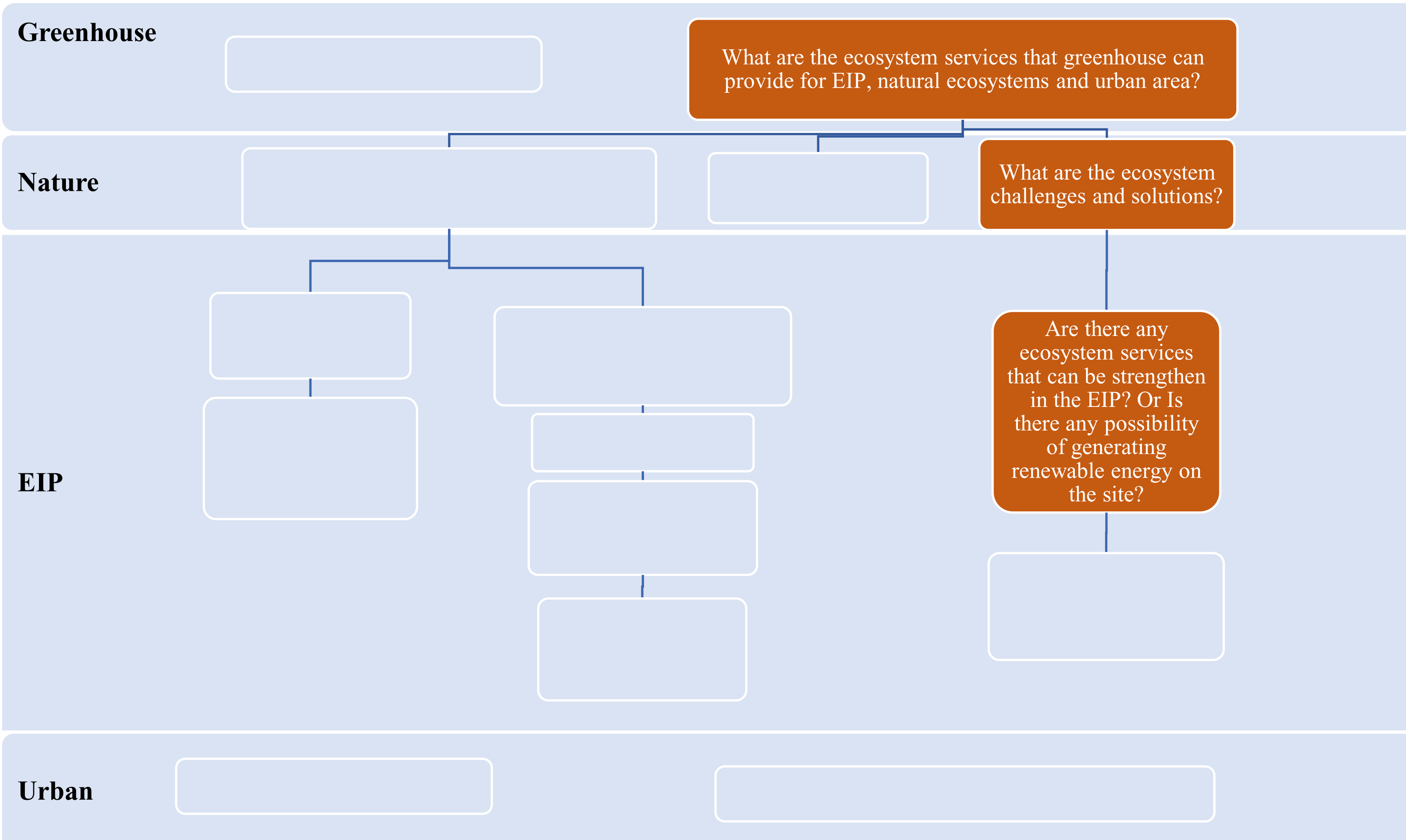


Figure 4.21: Produce lens of the design guideline

V.5. Inter-Relationships of The Design Guideline

The figure below demonstrates the inter-relationships between the different parts of the design guideline. Some of these steps should be done at the end of design guideline, and some should be done during the process.

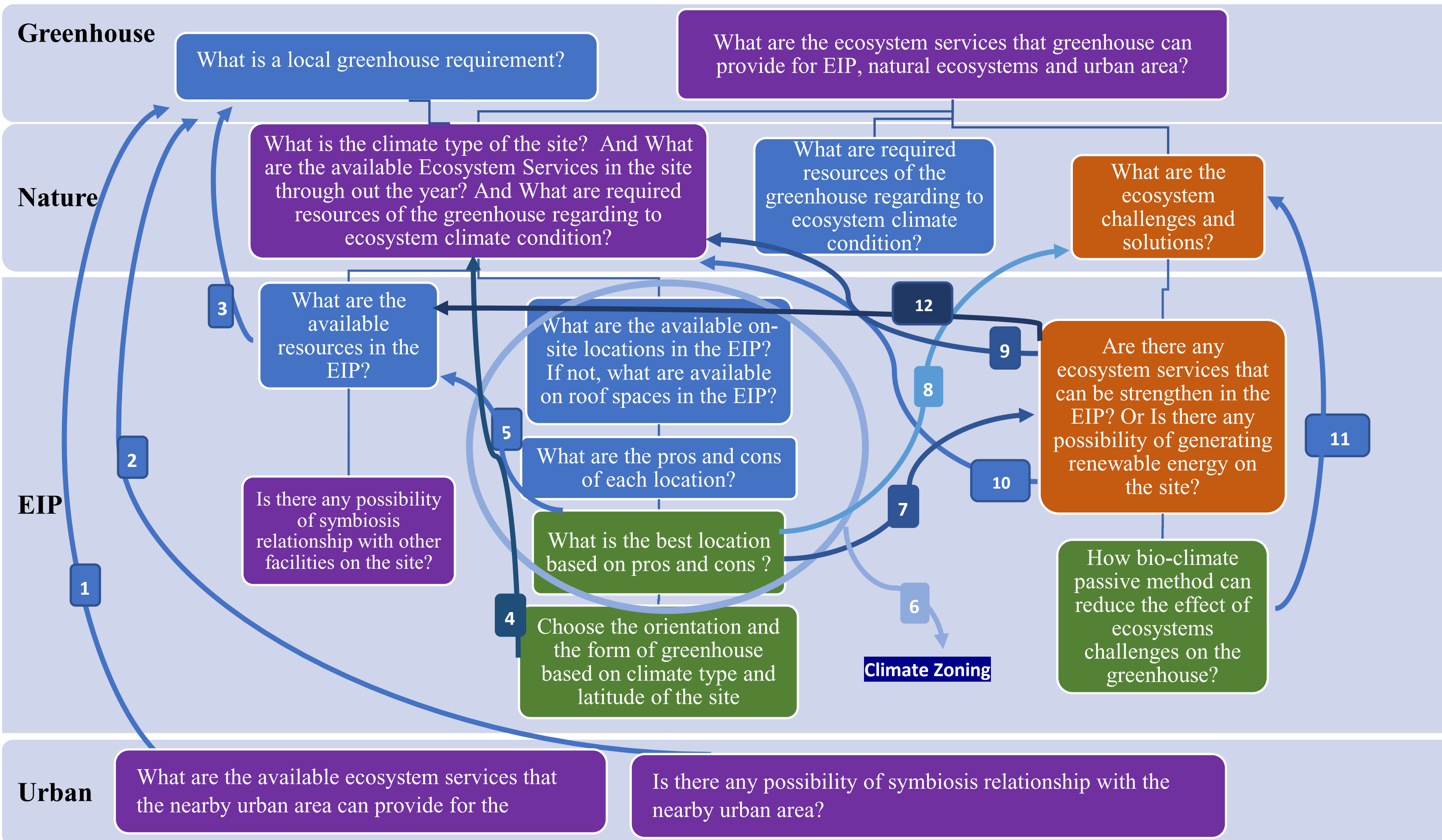


Figure 4.22: Interrelationships among different steps of the design guideline

Following the points clarifying the design guideline arrows and the intention of these steps.

Steps 1 & 2. To list available urban ecosystem services and possible symbiotic relationships for the greenhouse, the local greenhouse's requirments should be considered.

Step 3. To list available resources of the EIP, the local greenhouse's requirements should be considered.

Step 4. To determine the best orientation and form of the greenhouse, based on climate and natural ecosystem's condition.

Step 5. The determine the best location for the greenhouse based on the availability of the ecosystem services in the EIP (the ecosystem that greenhouse has settled in).

Step 6. Use climate and site zoning to assess the impact of climate on the different sites

Step 7. To increase the efficiency of the final location, one should consider strengthening the available ecosystem services in the final site.

Step 8. To choose the best location, one should consider challenges of the sites.

Step 9. Strengthen the natural ecosystem services in an EIP based on the availability of both natural ecosystem services and those potentially generated within the EIP

Step 10. Use bio-climate passive design can improve the greenhouse's building conditions according to the climate and ecosystem condition.

Step 11. Use bio-climate passive design to address challenging ecosystem conditions and increase greenhouse efficiency at the building level. (Bio-climate passive design will reduce the impacts of ecosystems on the greenhouse and optimizes the greenhouse's building into the environment).

Step 12. Consider the available natural and EIP resources available to produce/provided renewable/sustainable energy on the site.

These steps assist the designer to go through the design guideline process, review it for finding resources and solutions to improve whole system, and make interactions among the steps. The intent is to optimize the greenhouse integration and [attempt] to improve the health of ecosystem. These steps will contribute to increase the resiliency and the sustainability of the whole system. If over time the greenhouse function change and the requirements according to the greenhouse change - or in case of any changes in one of the ecosystems and their available services - these steps will assist the designer to apply the changes and optimize the greenhouse integration. The guideline uses the integration as an opportunity to improve the eco-efficiency at the system level.

CHAPTER FIVE: THE APPLICATION OF THE DESIGN GUIDELINE TO THE CASE STUDY

Introduction

This chapter presents the application of the design guideline to a Micro-Eco Industrial Park (MEIP) located in Port Hawkesbury, Cape Breton Island, Nova Scotia, Canada. The MEIP consists of Port Hawkesbury Paper (PHP) and its adjacent facilities. The diversity of the EIP is less than a typical EIP in that there is a single anchor tenant seeking to valorize their by-products and residual energy; for this reason, we refer to it as a MEIP. PHP generates large amounts of unharnessed energy that is discharged as waste heat (hot water, hot air and steam). This excess energy is intended to be used as a source of heating for the greenhouse; other sources available on the site will also be considered. Additionally, the PH MEIP case study was completed without a complete data set to underpin a fully objective assessment. Therefore, much of the evaluation was based on qualitative insight from discussion with those knowledgeable of the site and generalizable regional data. This resulted in some subjectivity in the final evaluation of some of the criteria. Ideally, when applies in reality the designer will have specific quantitative metrics/data to allot the application of the guideline to a specific site.

This chapter has four main sections. Following the guideline laid out in the previous chapter, we will explore the specific application to this site through an assessment of a) greenhouse requirements; b) adjacent available natural ecosystems services; c) MEIP characteristics and available services; and d) surrounding urban services.

Part I: Greenhouse Requirements

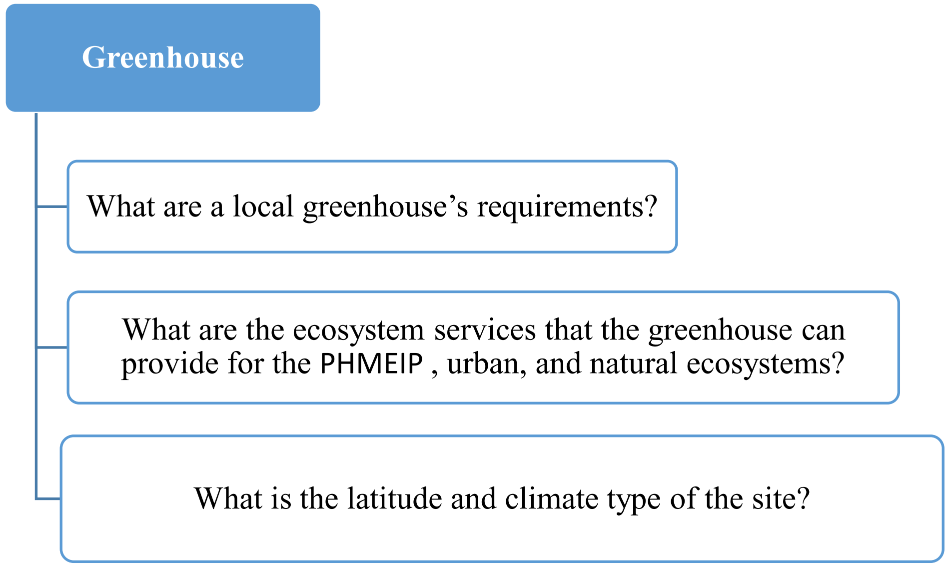


Figure 5.1: The greenhouse requirements (question)

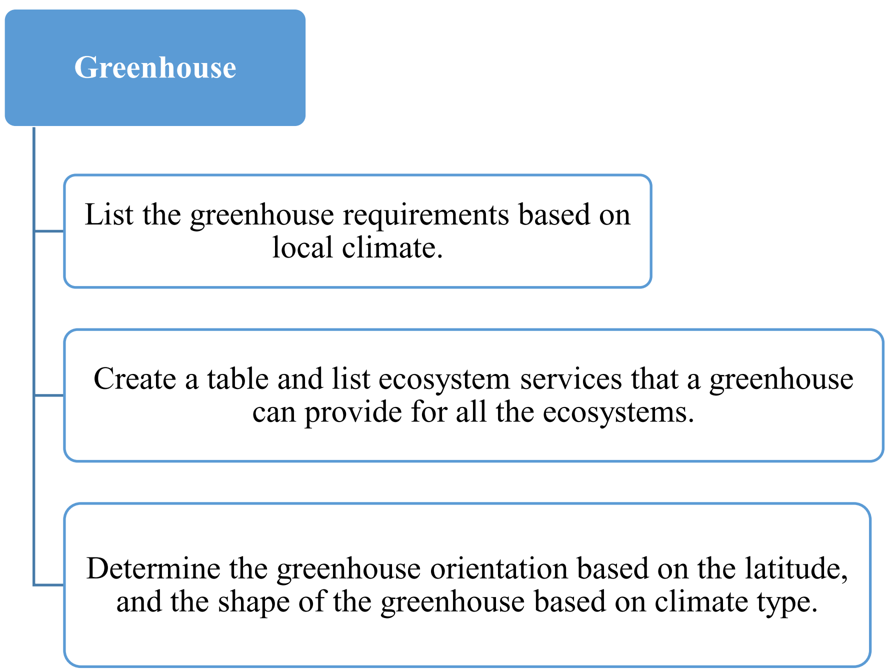


Figure 5.2: Possible solutions for the greenhouse requirements questions

I.1. What are the local greenhouse's requirements? List the greenhouse requirements based on local climate.

The greenhouse requirements are listed and ranked in the Table 5.1; the ranking criteria are also defined. Port Hawkesbury is in Northern hemisphere; any greenhouse

located in this region requires more heating and lighting [energy] resources compared to that of a greenhouse located in a lower latitude. However, due to high solar radiation and absence of wind during the summer in this region, the greenhouse also needs more cooling resources in the summer.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Material and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and knowledge	End user
Ranking	High	High	High	High	High	Medium	Low (	High	High	Medium	High	High	High

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Table 5.1: Greenhouse requirements and raking the requirements

Notes on ranking:

High: The greenhouse’s operation completely depends on these resources.

Medium: The greenhouse’s performance will be affected by the lack of these resources.

Low: The greenhouse’s performance will not affect by the absence of these resources.

I.2. What are the ecosystem services that the greenhouse can provide for both the MEIP and natural ecosystem? Create a table and list ecosystem services that a greenhouse can provide for the ecosystem.

I.2.1. Greenhouse services

The services of the greenhouse can be varied according to the size and function of the greenhouse. The decision regarding crop and style has not yet been taken in this instrance, so the table 5.2 for the greenhouse services will reflect a more general assessment of potential services.

Greenhouse services		
Natural ecosystem	**MEIP ecosystem**	**Urban Ecosystem**
Observing Co2 (regulating)	Aesthetic (cultural)	Agriculture products (provisioning)
Reducing resource depletion	Assisting circular economy (supporting)	Career (provisioning)
Moderating temperature in the site (regulating)	Accessing greenspace (cultural)	Educational (cultural)
	Increasing resiliency of the MEIP (supportive)	
	Biomass (provisioning)	

Table 5.2: Available greenhouse services

I.3. What is the climate type and the latitude of the site? Determine the greenhouse orientation based on the latitude, and the shape of the greenhouse based on climate type.

1.3.1. Location of Study: Port Hawkesbury

Port Hawkesbury is a small town which located in the southwest of Cape Breton Island, Nova Scotia, Canada. The climatic conditions are similar to the rest of Eastern Canada, with temperatures varying from -9°C to 24°C (on average). The cold season (-9°

C <-1°C) lasts for ~3 and a half months, and the warm season (15° C <24°C) lasts for ~3 months (Weather Spark., 2017). Port Hawkesbury's climate condition varies seasonally, thus the greenhouse requirments will change accordingly.

Solar radiation is directly influenced by the latitude of the site. Port Hawkesbury's latitude is about 45° N and therefore, the best orientation to optimize the accessible solar radiation at this latitude is North to South (Figure 5.4). Based on the climate condition, high snow load and intense prevailing wind are expected – based on this, the guide suggests that a Quonset shape is the optimal (Figure 5.5).

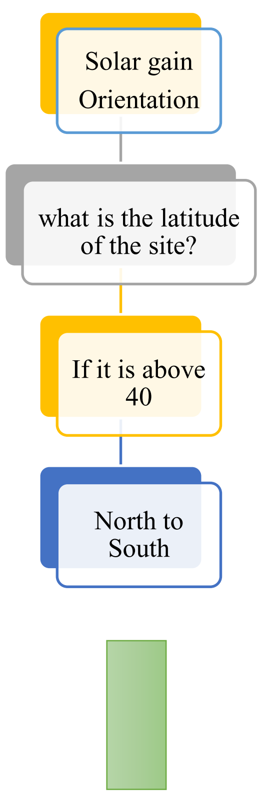

Figure 5.3: Guide for Greenhouse orientation selection

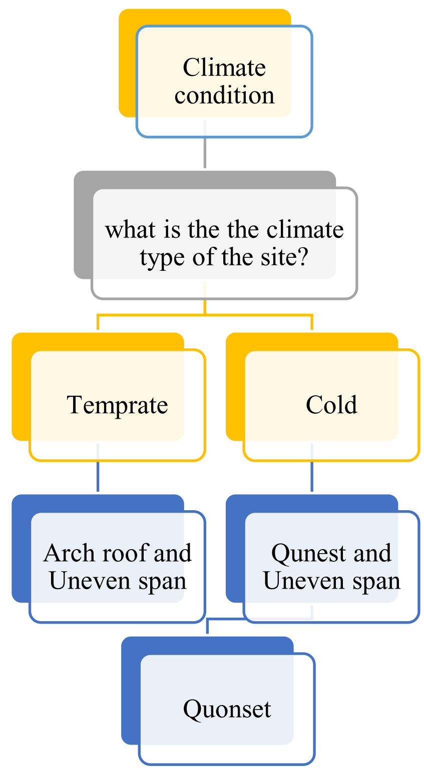

Figure 5.4: Guide for Greenhouse shape selection

1.3.2. Greenhouse Materials

According to the climate condition and the recommended structure (Quonset), the material selected for the structure is galvanized steel and ethylene tetra fluoroethylene (ETFE) as cladding material for the greenhouse (Table 5.3).

Material	Galvanized Steel	ETFE
Advantages	High resistance, High shock resistance, Flexible	Low weight, UV resistance, Easy to repair, Flexible, High light transmission, Recyclable, Self-cleaning, High durability
Disadvantages	High cost, Low thermal resistance	High cost, High light transmission increase internal heat, High tech material

Table 5.3: The greenhouse material

Part II: Natural Ecosystem

The natural ecosystem conditions at Port Hawkesbury and the MEIP site are assessed and possible solutions for using available natural services [while mitigating negative effects] will be proposed.

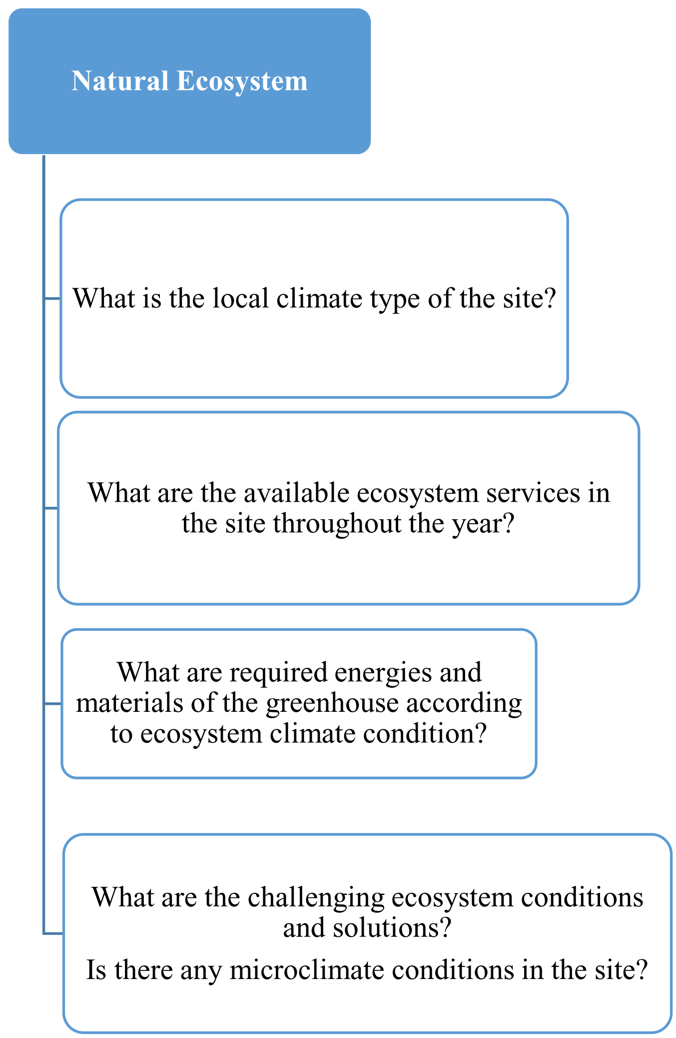

Figure 5.6: Questions regarding natural ecosystem conditions and services

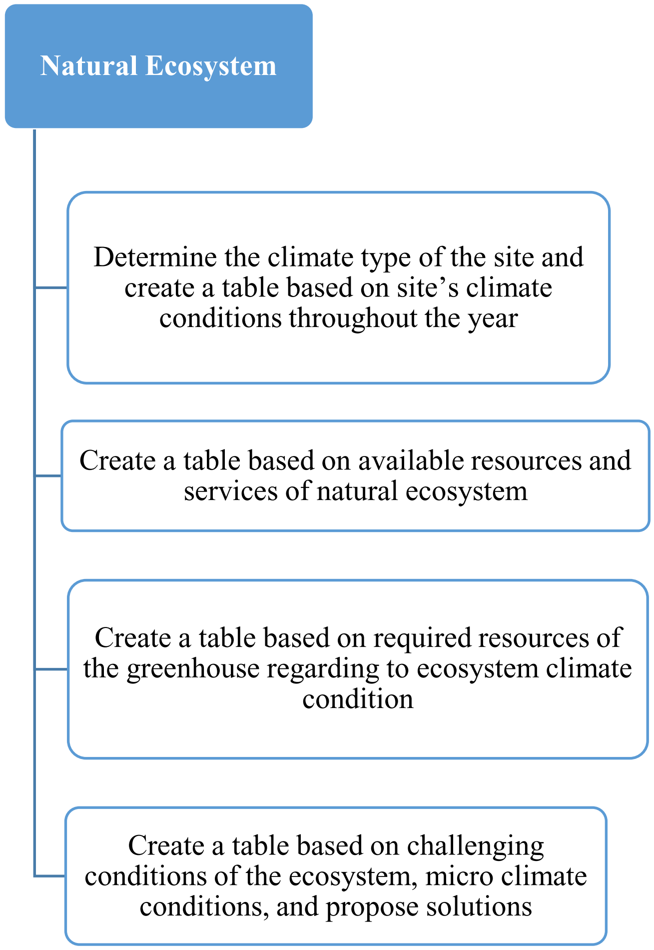

Figure 5.7: Suggestion steps for listing natural ecosystem condition and available services

II.1. What is the local [micro] climate of the site? Create a table based on site's climate conditions throughout the year

II.1. 1. Climate Condition of Port Hawkesbury

The climatic conditions are similar to the rest of Eastern Canada, with average temperatures varying from -9°C to 24°C (depending on the month), and seldom below -17°C or above 28°C. The cold season (-9° C < -1°C) lasts for ~3 and a half months, and the warm season (15° C <24°C) lasts for ~3 months (Weather Spark., 2017).

II.1. 2. Annual Mean Temperature and Seasonal Differences

Figure 5.8 presents the regionals temperature trends; the warm season (10° C < 24° C) starts in about mid-July and ends in mid-September. The warmest months of the year are July and August.

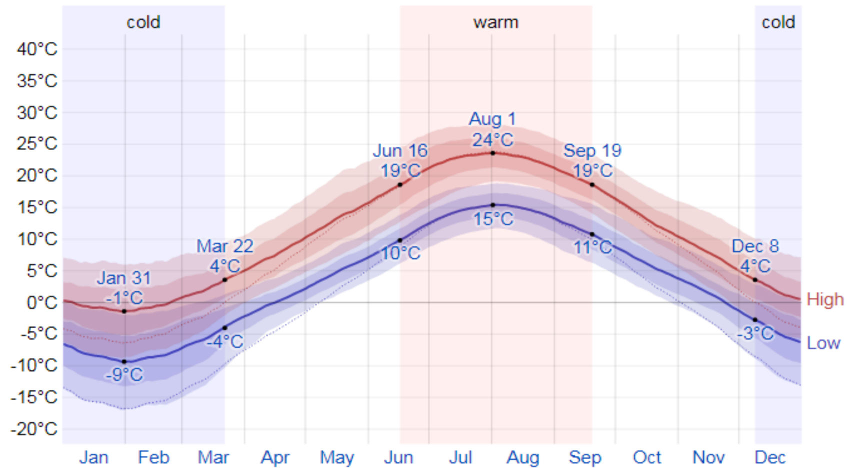

Figure 5.8: Daily average high (red line) and low (blue line) temperature, source (Weatherspark,2019).

The cold season (-9° C < -1°C) starts in early December and ends in late March, with average temperatures between -9 to -1 °C. The coldest months of the year are January and February. Figure 5.9 shows that from early December to late March the average temperature is below the freezing point; this represents more than 50% of the total seasonal hours.

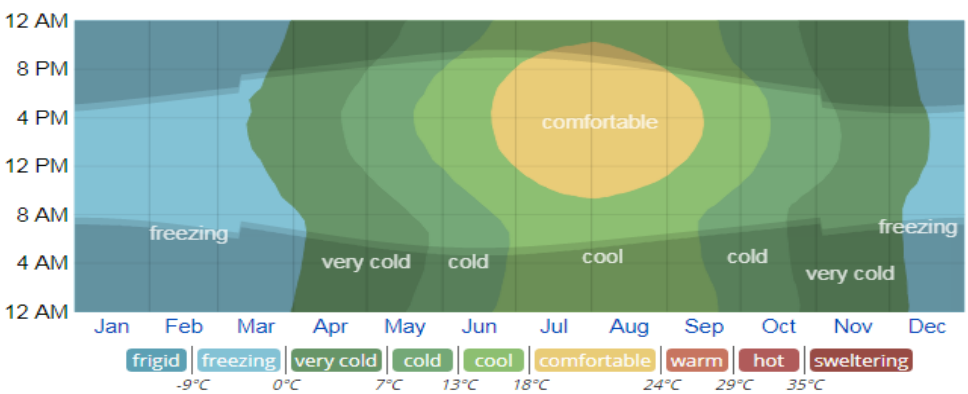

Figure 5.9: Average hourly temperature (color coded into bands), source (Weatherspark, 2019). Note: Shaded overlays indicate night

II.1.3. Cloud Cover

In Port Hawkesbury, cloud cover diminishes to less than 50% of the time beginning in mid-June ending in early November. The increased cloud cover is found after early November and persists for approximately the next 7 months (Figure 5.10).

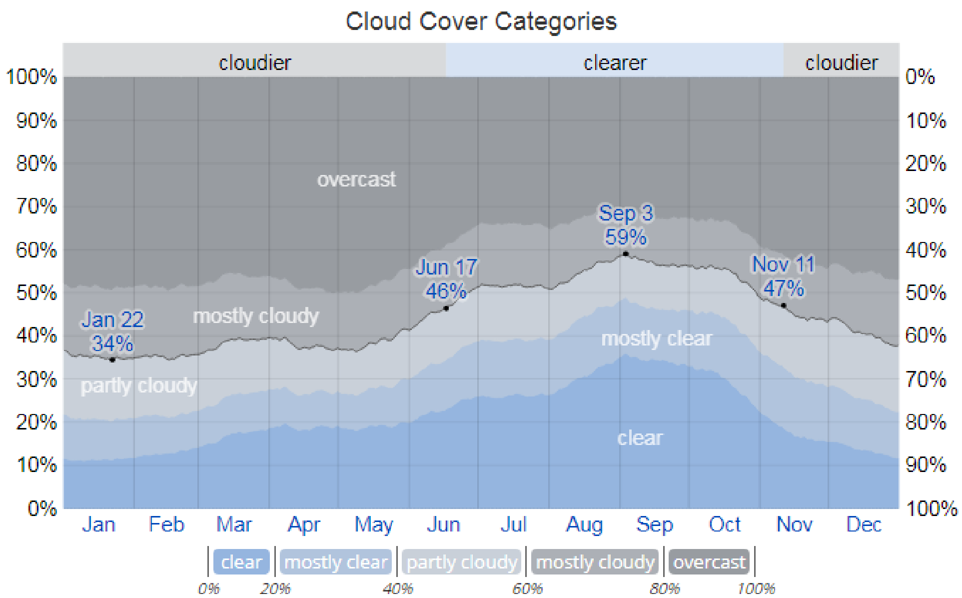

Figure 5.10: Percentage of time spent in each cloud cover band - categorized by percentage of cloud cover, source (Weatherspark, 2019).

The season corresponding to the warmest temperatures is also the part of the year with the least average cloud cover. This can increase the temperature in a greenhouse considerably and therefore require cooling.

II.1.4. Precipitation

As the figure below (Figure 5.11) shows, the chance of precipitation is consistent throughout the year in Port Hawkesbury; however, more of that precipitation falls as snow and mixed precipitation in between early January and mid-April.

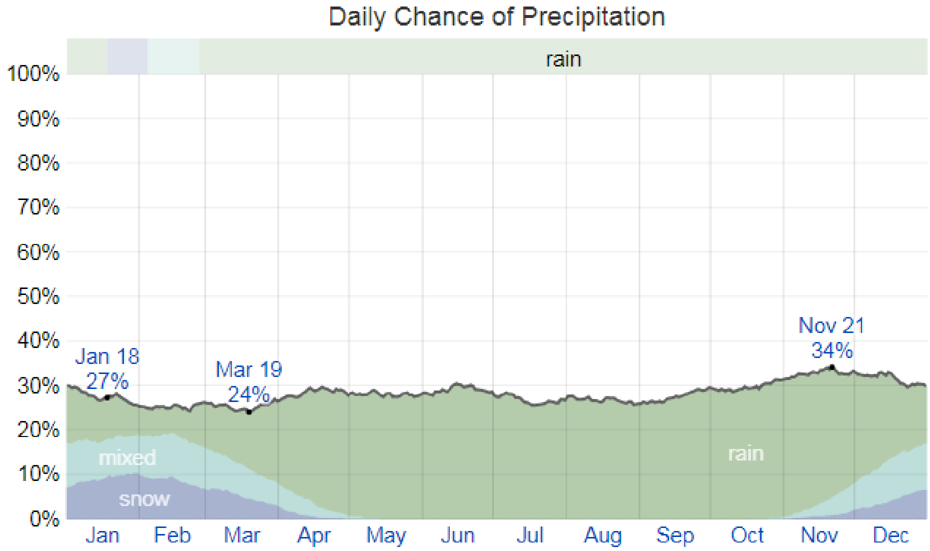

Figure 5.11: Percentage of days in which various types of precipitation are observed (this excludes trace quantities), source (Weatherspark, 2019).

II.1.5. Rainfall

November and October are the rainiest months in Port Hawkesbury, with average accumulation of 83 millimeters. The least rain falls around February and March (Figure 5.12).

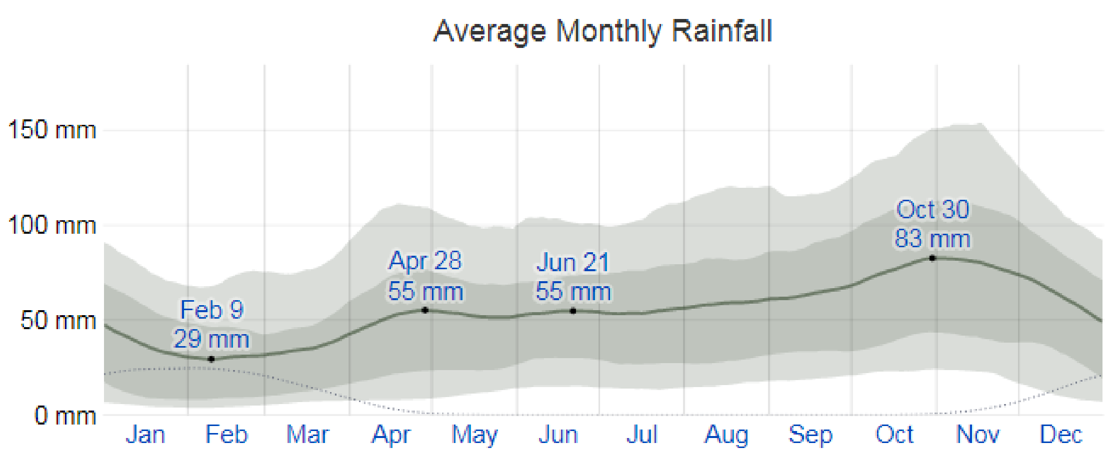

Figure 5.12: Average rainfall (solid line) accumulated over the course of a sliding 31-day period (shows 25th to 75th and 10th to 90th percentile bands). Thin dotted line represents average liquid-equivalent snowfall, source (Weatherspark, 2019).

II.1.6. Snowfall

Snow accumulations in Port Hawkesbury starts in mid-November and ends in mid- April (Figure 5.13) with the greatest accumulation averaging between January and mid-February.

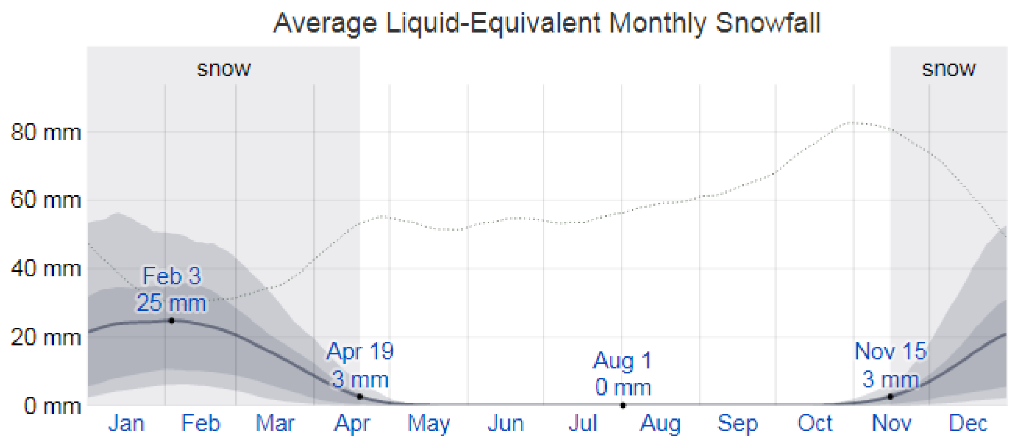

Figure 5.13: Average [liquid-equivalent] snowfall including 25th to 75th and 10th to 90th percentile bands, source (Weatherspark, 2019).

II.1.7. Solar Energy (Solar Intensity)

Solar energy varies considerably at this latitude. The greatest amount of solar radiation occurs between mid-May and August. Average energy per square meter is above 5.5 kWh at this time of the year in Port Hawkesbury. Between November to mid-February it falls to 2.2 kWh per square meter (Figure 5.14)

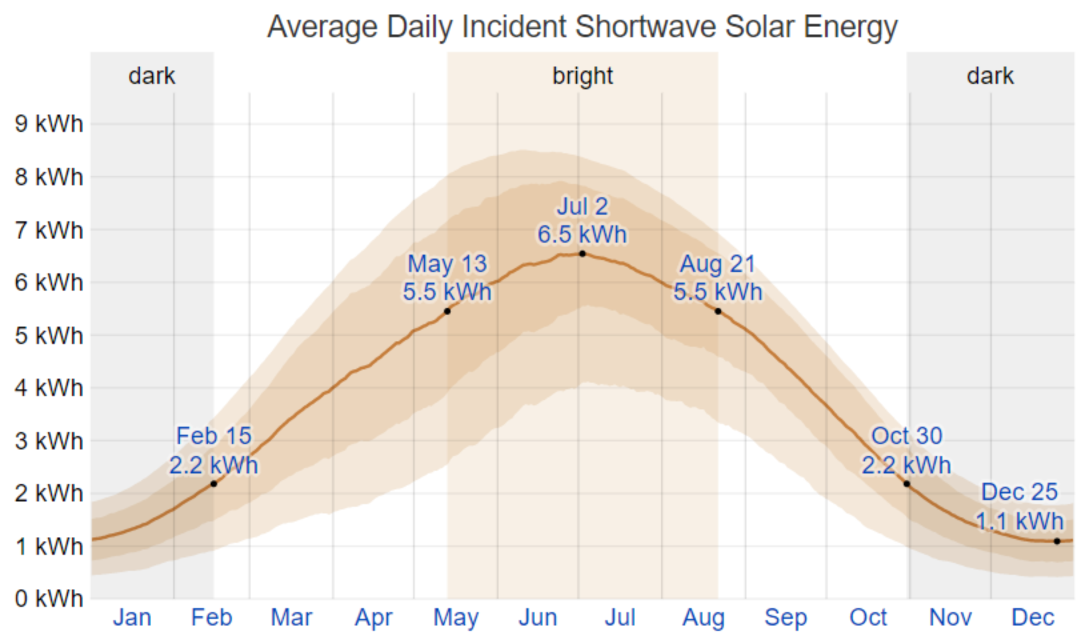

Figure 5.14: Average daily solar energy reaching the ground per square meter: 25th to 75th and 10th to 90th percentile bands are included, source (Weatherspark, 2019)

II.1.8. Day Length

Day length varies in Port Hawkesbury from about 9 hours to 15 hours. The shortest day is in December and the longest day is in Jun (Figure 5.15 and Table 5.3).

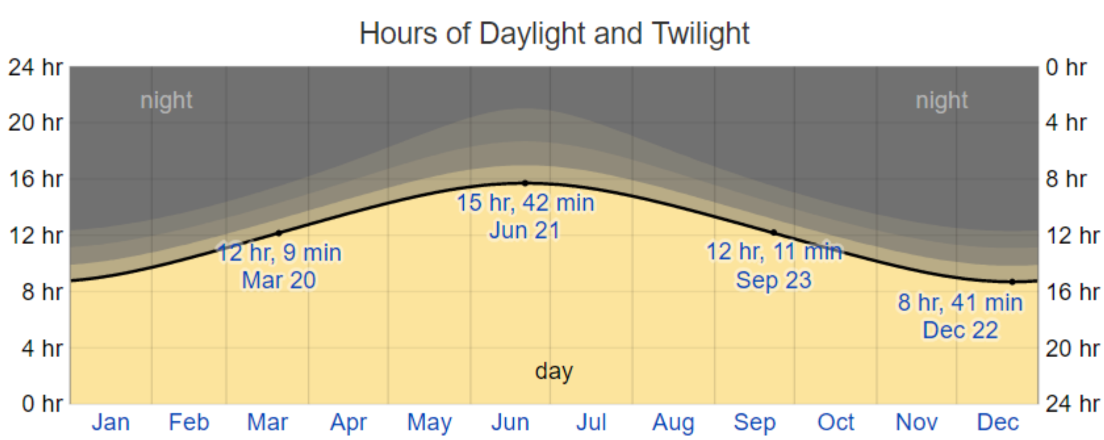

Figure 5.15: Number of daylight hours, source (Weatherspark,2019)

Month	**Day time**	**Natural available light**
January	7.42-16.47	9.06
February	7.07-17.31	10.24
March	7.18-19.10	11.53
April	6.20-19.51	13.31
May	5.34-19.29	14.55
June	5.15-19.56	15.41
July	5.30-20.51	15.21
August	6.05-20.13	14.06
September	6.43-19.17	12.27
October	7.21-18.20	11.59
November	7.04-16.35	9.31

Table 5.3: Natural available light for the greenhouse

II.1.9. Humidity

The most humid period is from late June to late September (Figure 5.16).

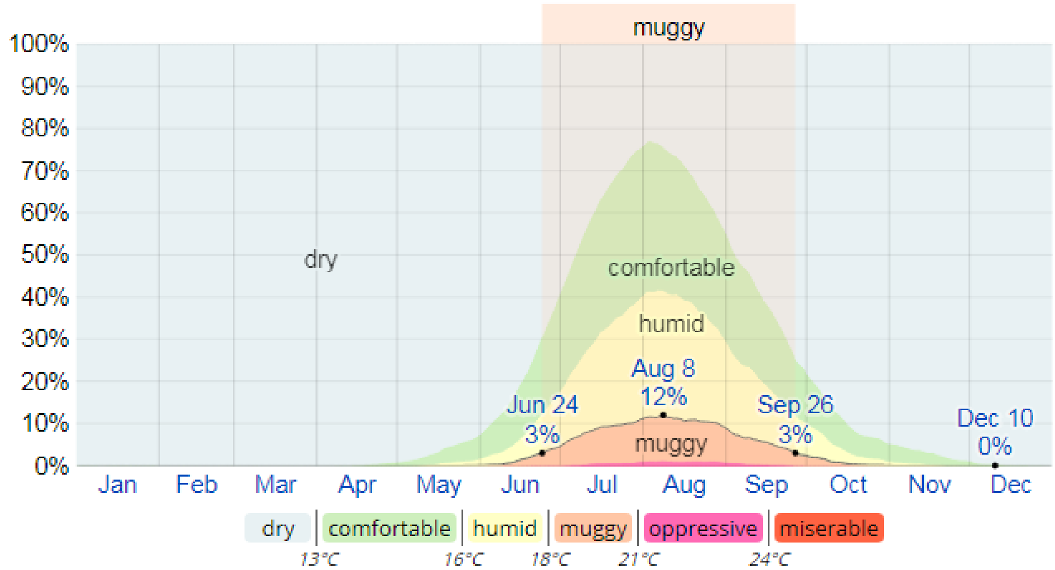

Figure 5.16: Percentage of time spent at various humidity comfort levels, categorized by dew point, source (Weatherspark, 2019).

II.1.11. Wind Direction

The prevailing winds are strongest from October to Mid-April, with average wind speeds of more than 5.0 meters per second. The windiest time of year is mid-January, with an average hourly wind speed of 6.1 meters per second (Figure 5.17). Figure 5.18 shows wind direction in different at different times of the year. In the coldest six months, from September and ends in March, the wind is more typically from the west. Beginning in April the prevailing winds shift to a more southerly direction.

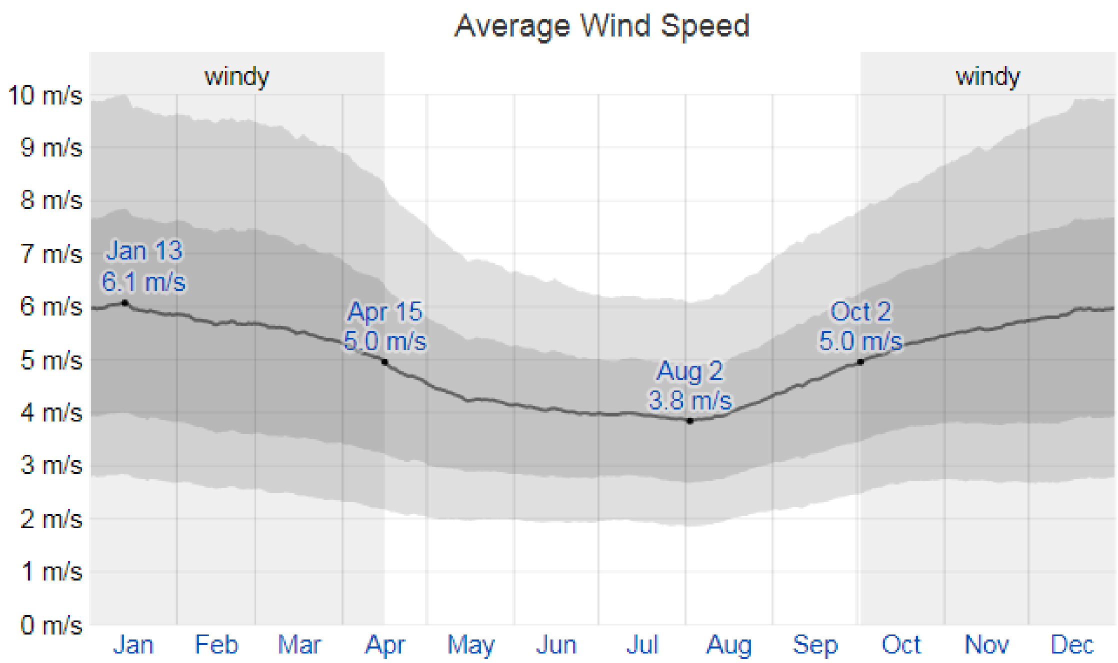

Figure 5.17: Average mean hourly wind speeds; include 25th to 75th and 10th to 90th percentile bands, source (Weatherspark, 2019)

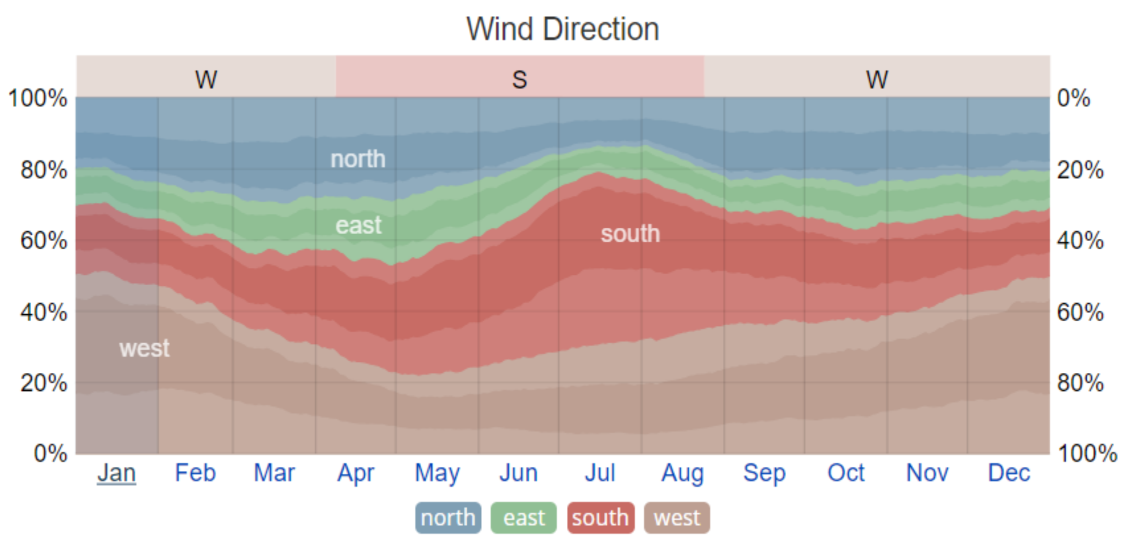

Figure 5.18: Percentage of hours in which the mean wind direction is from each of the directions (excludes hours where the mean wind speed is less than 0.4 m/s). Lighter colors at the boundaries represent the percentage of time spent at intermediate directions (e.g. northeast, southeast, etc.), source (Weatherspark, 2019).

II.1.12. Water Temperature

Port Hawkesbury is located adjacent the Atlantic Ocean; water temperature varies throughout the year. From late-December to early May the average temperature is below 3°C; the warmest water lasts for about 2.5 months, from mid-July to early October, with an average temperature of 14 °C. However the ocean's water temperature reduces by about 10 degrees at 15 meters in depth (The Concord Consortium, 2010). Additionally, the ocean temperatures fall about 2 months behind the land temperatures, so in June and July, the ocean's water is still cool and could be used for the active cooling system.

II.1.13. Growing Season

The growing season can be different depending on the species in question. If consistent temperature above 0°C degrees is considered as the growing season, Port Hawkesbury's growing season is ~5 and a half months, from early May to late October.

II.2. What are the available natural ecosystem services in the site throughout the year? Create a table based on available resources and services of natural ecosystem.

The greenhouse requirements will vary throughout the year; for example the heating and cooling will be seasonal dependent, while CO_2, water and clean air are year-round requirements. The likelihood of provisioning of resources varies according to the ease of provisioning and availability of the necessary resources. For example, the availability of wind and solar driven electricity is considered "high" based on the site locations. Due to the higher cost and regulatory barriers linked to the development of distributed renewable energy systems, the likelihood of provisioning is reduced to a "medium" ranking..

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Materials and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and Knowledge	End user
Ranking	High	High	High	High	High	Medium	Low	High	High	Medium	High	High	High
Required time	Seasonal	Seasonal	Year round	Year round	Year round	Year round	Seasonal	Sometimes	Year round	Year round	Year round	Year round	Seasonal
Natural Ecosystem Service	Sun (Passive)	Wind (Passive) Snow, cold water (Active)	Sun	Rain, Snow, fresh water	Regula ting air	Natural Co2 that existed in the air	Barriers for wind speed reduction like trees	Structure material, such as wood	Extractin g from nature	-	Wind, Sun and tidal energy	-	-
Availability of provisioning	Mid-Jun to Mid-Nov	October-Mid-April	Mid-Jun to Mid-Nov	Octobe r-March	Year round	Year round	Depends on the location on site	-	-	-	Year round	-	-
Provisioning and enhancement opportunity	Storage	Storage	-	Storag e	-	-	-	-	Storage	-	Storage	-	-
Likelihood of provisioning	High	High	High	Mediu m	High	High	Medium	Low	Low	-	Medium	-	-

Table 5.4: Summary of natural ecosystem services, availability, and provisioning

Notes on ranking:

High: The greenhouse's operation completely depends on these resources. **Medium**: The greenhouse's performance will be affected by the lack of these resources. **Low**: The greenhouse's performance will not affect by the absence of these resources

II.3. What are required resources of the greenhouse regarding to ecosystem climate condition? Create a table based on required resources of the greenhouse regarding to ecosystem climate condition.

II.3.1. Output

The coldest months of the year have the shortest daylight, the lowest temperatures, the highest snow load, and strong prevailing winds (Table 5.5). The greenhouse requires different resources in different time of the year. Sometimes, the climate condition increases the demand of energy resources, such as heating during cold seasons; while, in the warmer season (mid-June and ends in mid-September), the cooling demand of greenhouse increases due to increased solar radiation, the absence of wind and cloud cover. The climate conditions of Port Hawkesbury show that a greenhouse in this region requires considerable energy for heating and cooling, as well as lighting system.

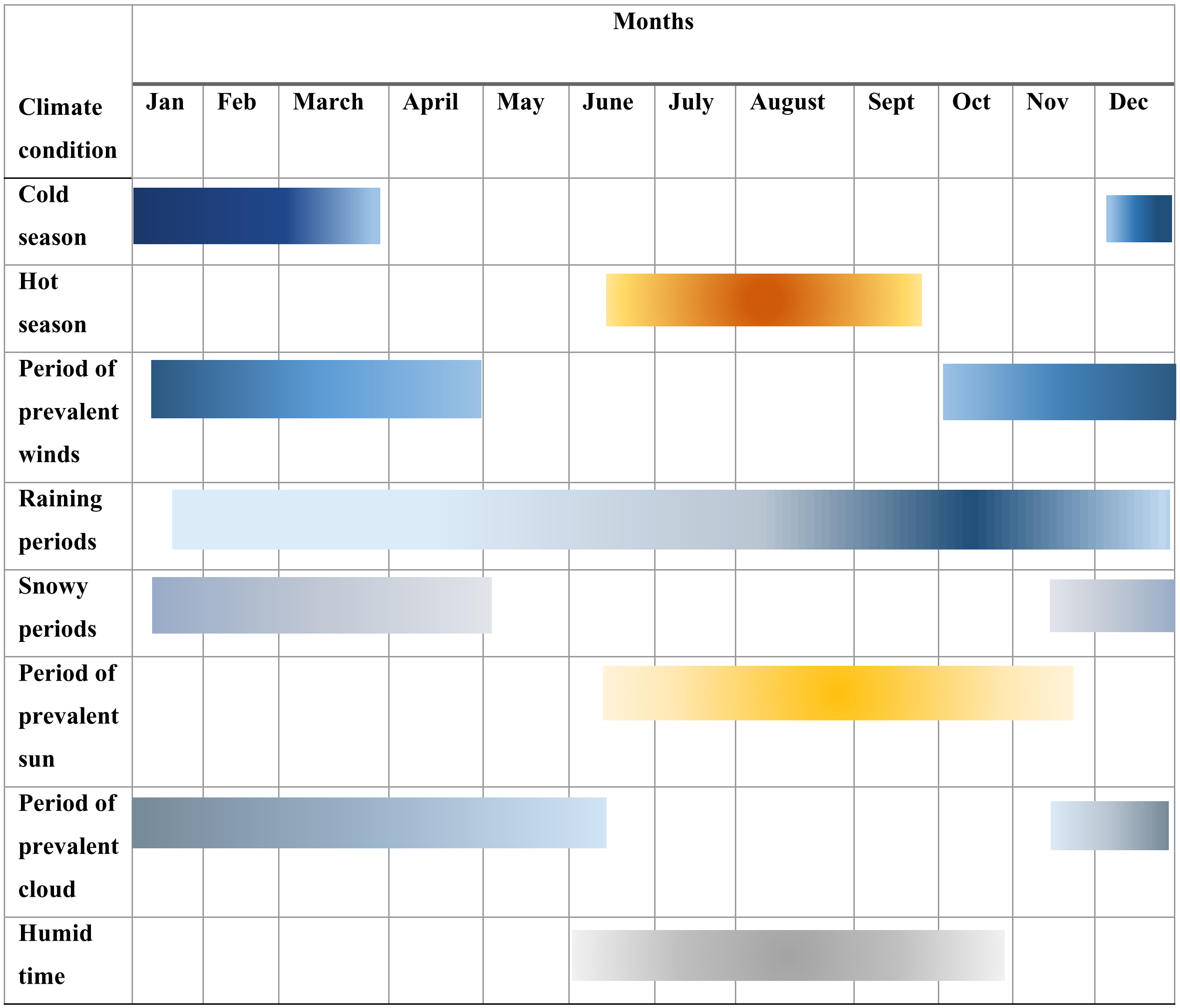

Table 5.5: Summary of Port Hawkesbury climate condition

Given climate condition of Port Hawkesbury between early November to late April, the greenhouse needs active heating system. From mid-April to mid-June and then again in October, the greenhouse can use passive cooling system (if cooling is required) due to the presence of a stronger prevailing wind. From mid-June to late September, the lack of consistent wind may influence a need for more active cooling system within the greenhouse. In addition, the absence of significant cloud cover, and higher intensive of solar radiation increases the necessity of more active cooling (Table 5.6). Increased cloud cover and reduced solar radiation (weaker and shorter periods of daylight) also affect operations in that the greenhouse as it requires more lighting than is naturally available to grow the plants (Table 5.6).

The greenhouse requirements	Months											
	Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec
Heating												
Active Cooling												
Passive cooling												
Water collecting system												
Heating												
Active Cooling												
Lighting												

Table 5.6: Summary of greenhouse resource requirements based on climate condition

II.4. What are the challenging ecosystem conditions and solutions? Are there microclimate conditions in the site? Create a table based on challenging conditions of the ecosystem, microclimate conditions, and propose solutions.

Table 5.7 outlines the some of the undesirable climate condition in Port Hawkesbury - high snow load and strong winds during cold seasons. The suggested solution for that is having a firm structure and using a double façade for insulation. Another solution could be a movable layer that can protect the greenhouse during snowy days and decrease the load of snow on the structure, as well as wind exposure. In hot months, in addition to high temperatures, the absence of wind and cloud increase the need for active cooling system in the greenhouse.

Greenhouse Requirements	Heating	Cooling	Light	Structure
Challenging Conditions of Ecosystems	High Snow load & Strong wind	High solar radiation in the summer Absence of wind Steam release	Cloudy days	High Snow load & Strong wind
Solution	Firm and climatically designed Structure form and double façade	Using Cladder and active cooling system	lighting	Firm and climatically designed Structure form

Table 5.7: Ecosystem challenges and the solutions

During the more overcast time of the year the greenhouse needs more lighting to support the growth of the plants. Additionally, in winter and autumn the greenhouse requires more lighting due to the short days. If eight hours is the time required for plants to sleep, one should supply lighting the rest of the day (Table 5.8).

Month	Day time	Natural available light	Day light + dormant time	Required light time
January	7.42 a.m.-16.47 p.m.	9.06	+8=17.06	**7.44**
February	7.07 a.m.-17.31 p.m.	10.24	+8=18.24	**5.36**
March	7.18 a.m.-19.10 p.m.	11.53	+8=19.53	**4.07**
April	6.20 a.m.-19.51 p.m.	13.31	+8=21.31	**2.29**
May	5.34 a.m.-19.29 p.m.	14.55	+8=22.55	**1.05**
June	5.15 a.m.-19.56 p.m.	15.41	+8=23.41	**0.19**
July	5.30 a.m.-20.51 p.m.	15.21	+8=23.21	**0.39**
August	6.05 a.m.-20.13 p.m.	14.06	+8=22.06	**1.54**
September	6.43 a.m.-19.17 p.m.	12.27	+8=20.27	**3.33**
October	7.21 a.m.-18.20 p.m.	11.59	+8=19.59	**4.01**
November	7.04 a.m.-16.35 p.m.	9.31	+8=17.31	**6.29**
December	7.38 a.m.-16.21 p.m.	8.43	+8=16.43	**7.16**

Table 5.8: Required artificial light for the greenhouse

Part III: Eco Industrial Park

The available sites, services in the MEIP, and the possibilities of making symbiotic relationships must be investigated. Furthermore, based on the MEIP conditions, availability of resources, climate and micro-climate conditions, the best location for the greenhouse will be chosen. Additionally, possible solutions for mitigating negative effects on the greenhouse will be proposed. In this case the diversity of the MEIP is less compared to a typical EIP given there is a single anchor tenant. Therefore, the greenhouse depends mainly on PHP and any adjacent natural resources to supply its requirements.

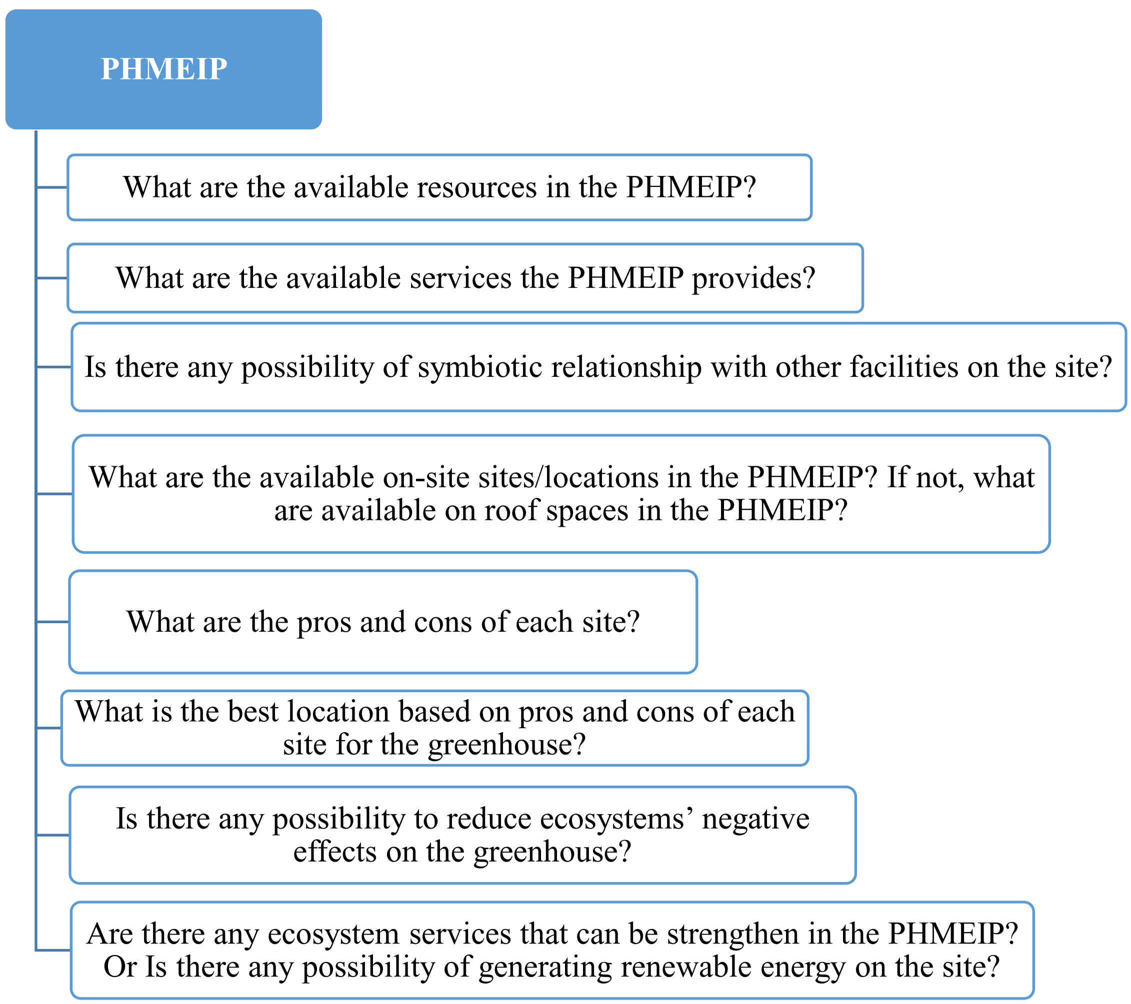

Figure 5.19: Questions regarding PHMEIP ecosystem conditions and services

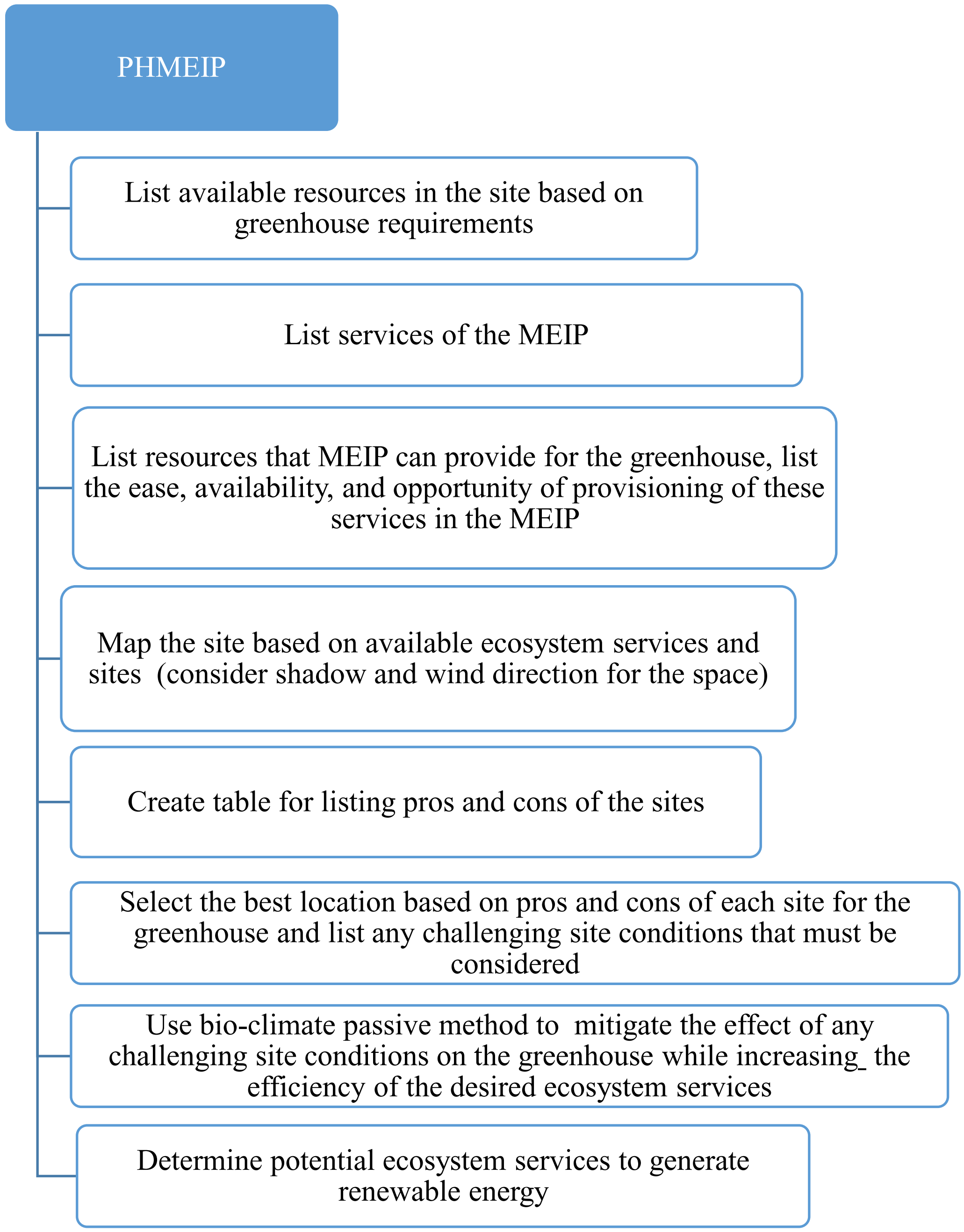

Figure 5.20: Suggestion steps for listing PHMEIP ecosystem conditions and available service

III.1. What are the available resources in the PH MEIP? List available resources in the site based on greenhouse requirements

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	CO_2	Windbreak	Materials and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and Knowledge	End user
Ranking	High	High	High	High	High	Medium	Low	High	High	Medium	High	High	High
Required time	Seasonal	Seasonal	Year round	Year round	Year round	Year round	Seasonal	Sometimes	Year round	Year round	Year round	Year round	Seasonal
PHMEIP Services	Hot water, Hot air, Steam	Cold water, Electricity	Electricity	Threated water	Regulating air	Available	Barriers for wind speed reduction like greenhouses	Materials for covering structure, such as plastic	-	To transport material and human	Wind, Sun and tidal energy can be converted to electricity	Available by EIP	-

Table 5.9: Greenhouse requirements and PHMEIP services

III.2. What are the available services the PHMEIP provide? List services of the PHMEIP.

PHMEIP Services			
Supporting	**Provisioning**	**Regulating**	**Cultural**
Water, Energy, and Material cycling	Providing Material and resources	Moderating temperature in the site	Educational
Storage of resources	Generating energy (e.g. renewable energies)	Waste management (decomposition)	
Career opportunity	Delivering food and resources	Water purification	
Circular economy		Air purification	
Information circularity		Protection from natural hazard such as strong winds	

Table 5.10: PHMEIP services

III.3. Is there any possibility of symbiotic relationship with other facilities on the site? List resources that PHMEIP can provide for the greenhouse, list the ease, availability, and opportunity of provisioning of these services in the PHMEIP

III.3.1. Heat Resource

Port Hawkesbury Paper produces about 9000 m3/day of hot water effluent at temperatures between 40 and 70C. The water contains clay which must be filtered out prior to the effluent being directed to a heat exchanger.
The water temperature will decrease after filtration but is expected to still be at a high enough temperature to be used in the heating system of a greenhouse. The reuse of waste heat in an EIP is well established and has been implemented successfully in several different contexts as discussed in the literature review.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	Co_2	Windbreak	Materials and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and Knowledge	End user
Ranking	High	High	High	High	High	Medium	Low	High	High	Medium	High	High	High
Required time	Seasonal	Seasonal	Year round	Year round	Year round	Year round	Seasonal	Sometimes	Year round	Year round	Year round	Year round	Seasonal
EIP Services	Hot water, Hot air, Steam	Cold water, Electricity	Electricity	Threated water	Regulating air	Available	Barriers for wind speed reduction like greenhouses	Materials for covering structure, such as plastic		To transport material and human	Wind, Sun and tidal energy can be converted to electricity		
Availability of provisioning	Year round	Year round	Year round	Year round	Year round	Year round	Year round	Year round	---	Year round	Year round	Year round	Year round
Provisioning and enhancement opportunity	Storage	-	-	Storage	-	Storage	-	-	-	-	Storage	-	-
Likelihood of provisioning in EIP	High	High	Medium	High	High	High	Medium	Medium	Low	High	High	High	High

Table 5.11: Availability, Provisioning, and Likelihood of PHMEIP resources

III.4. What are the available on-site greenhouse sites in the MEIP? If not, what are available on roof spaces in the MEIP? Map the site based on available ecosystem services and sites (consider shadow and wind direction for the space).

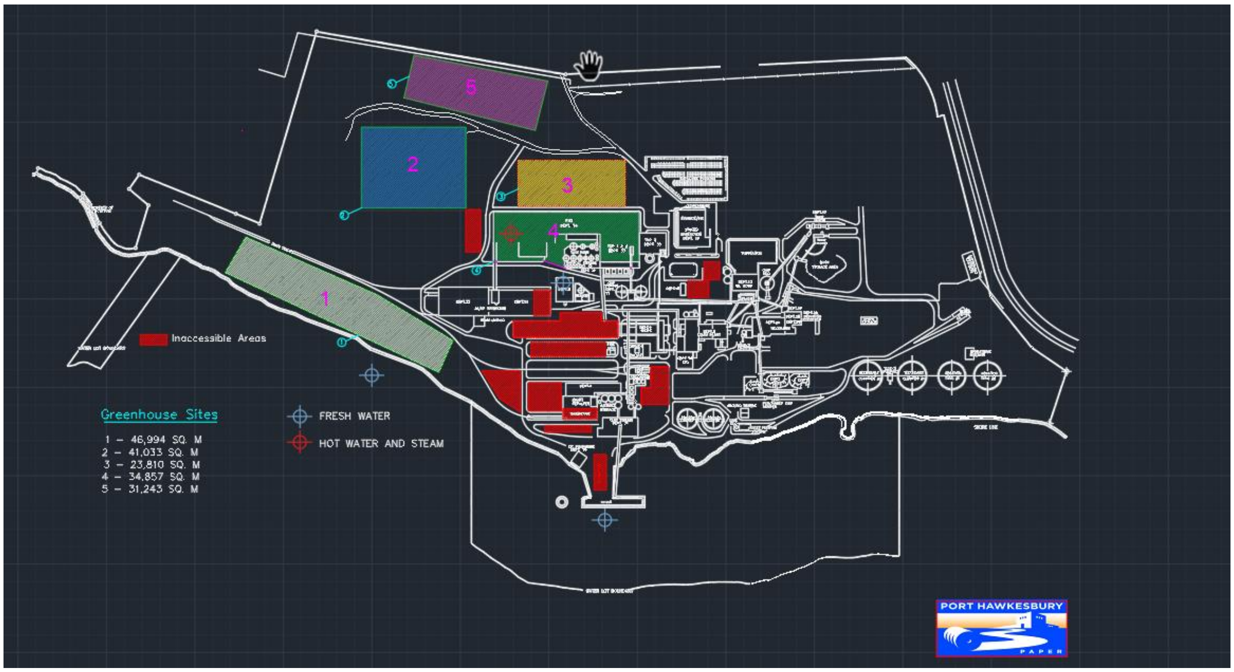

Figure 5.21: Available greenhouse sites and resources in the PHMEIP

Zoning the site based on availability of resources and microclimate conditions (Figure 5.21).

III.4.1. Site 1

The longest side of the greenhouse is exposed to strong westerly wind. It is near the ocean which facilitates the use of cold water for the cooling system. However, the greenhouse in this site will lose heat to the cold winds coming off the ocean, thereby increasing heating demand. Wind also impacts negatively in that it increases the risk of damage and collapse. The site is located near the sea and is vulnerable to climate effects such as sea level rise and storms. However, a positive note is that the site face south, with the south-facing wall of the greenhouse faces the sea; on sunny days this will increases the solar gain of the greenhouse through sun reflection from the sea (Table 5.12).

Site 1									
Resources	**Sun gain condition**	**Cold water access**	**Wind exposure**	**Hot water and steam access**	**Fresh Water access**	**Expansion opportunity**	**Connections**	**Climate resiliency**
Condition	There is no shadow in this part of the site	The greenhouse is near ocean	The length of the greenhouse is exposed to the west wind	The greenhouse is far from hot water and steam resources	The greenhouse is close to freshwater resources	One side of the greenhouse is facing the sea and the other road.	It is near the sea and the road	The site is located near the sea
Pros	The greenhouse will receive more sun radiation by water reflection	Near cold water in the summer	Increases passive cooling efficiency	-	Reduces pumping cost		Close to the road and sea	
Cons	More heating during the summertime	Heat loss through transmissions and infiltration during cold seasons	Expose to strong wind, lose heat and increase risk of collapse	Loss of heat energy on the way to the greenhouse		There is no opportunity for expansion	Occupied shipping side of the site	It is exposed to strong winds and sea rise
Solution	-	Use double glaze façade	Wind break cannot be used in this part of the site			-	-	There is no solution for this site to decrease the effect of climate
Consequence	Needs more cooling in the summer and less heating in the winter	Increases cooling efficiency	Decreases heating efficiency and increase cooling efficiency	Decreases heating efficiency	Reduces electricity consumption	There is no opportunity to expand the greenhouse nearby	-	This site is susceptible to any kinds of climate change

Table 5.12: Site 1, summary of the site condition

III.4.2. Site 2

This site is far from the sea, which increases the climate resilience of the greenhouse (Table 5.13). There are enough spaces around the greenhouse for installing a wind break and for future expansion of the greenhouse. The greenhouse is located in the center of the EIP and is close to heating resources, which increase the efficiency and decrease the loss of the heating systems. The greenhouse in this location is exposed equally through the length and width to the west and south winds.

Site2								
Resources	**Sun radiation condition**	**Cold water access**	**Wind exposure**	**Hot water and steam access**	**Fresh Water access**	**Expansion opportunity**	**Connections**	**Climate resiliency**
Condition		The greenhouse is far from ocean water	The width of the greenhouse is exposed to the west wind	The greenhouse is close to hot water and steam resources	The greenhouse is far from the freshwater resource	One side of the greenhouse is road, but there are two available areas for expansion	It is near the road and close to the sea	The greenhouse in this site is exposed to west winds
Pros	There is no shadow in this part of the site		Exposed to strong wind, Increases passive cooling efficiency	Reduce pumping cost and electricity		The greenhouse can expand in two directions	Close to the road and sea	There is space for a wind break around the site
Cons	-	Far from cold water, which increases energy to pump and increase cold water temperature	Exposed to strong wind heat loss	-	Increase pumping cost and electricity	-	-	
Solution	-	--	Plant trees to break the wind	-	-	-	-	There is space to install wind breaks and it is far from the sea
Consequence	There is no problem in terms of solar gain	Decreases cooling efficiency	increases cooling efficiency and heat loss	Increases heating efficiency	Increases electricity consumption	There is more available area to use for the greenhouse facilities and opening the greenhouse in spring	Easy to export food and import material	There is a solution to increase the site's climate change resilience in this location

Table 5.13: Site 2, summary of the site condition

III.4.3. Site 3

The greenhouse in this site is located behind the factory building which produces hot water and steam. Almost half of the greenhouse on this site will cover by the shadow of the greenhouse besides. The southern wind exposes the greenhouse to the steam produced by the factory. The climate resilience of the greenhouse is high due to surrounding buildings and its distance from the sea. Significantly, this site is that it does not meet the initial requirement of common greenhouses which is solar radiation gain (Table 5.14).

Site 3								
Resources	**Sun radiation condition**	**Cold water access**	**Wind exposure**	**Hot water and steam access**	**Fresh Water access**	**Expansion opportunity**	**Connections**	**Climate resiliency**
Condition	The site is located behind a 50 ft high building	The greenhouse is far from ocean water	The width of the greenhouse exposed to the west wind	The greenhouse is close to hot water and steam resources	The greenhouse is far from the freshwater resource	One side of the greenhouse is road, and the other side is the factory greenhouse	It is near the road and close to sea	The greenhouse located behind the main greenhouse in the EIP
Pros			Exposed to strong wind Increases passive cooling efficiency	Reduce pumping cost and electricity			Close to the road and sea	It can be supported by other buildings and receive less intense winds
Cons	shadow will cover the most part of the greenhouse	Far from cold water will increase energy demand of the pump and increase cold water temperature	Exposed to strong wind and lose heat	The heat of the site will increase the greenhouse temperature in the summer	Increase pumping cost and electricity	There is no space for expansion	-	
Solution	-	--	Plant trees to break the wind	-	-	-	-	There is space to install wind breaks and it is far from the sea
Consequence	This site is not suitable for the greenhouse	Decreases cooling efficiency	increases cooling efficiency	Increases cooling demand	Increases electricity consumption	The greenhouse's space is limited	Ease of exporting food and importing material	There is a solution to increase the site's climate change resiliency in this location

Table 5.14: Site 3, summary of the site condition

III.4.4. Site 4

The greenhouse on top of a roof needs more electricity to cover pumping demand. Hot and cold water will be needed for heating and cooling systems. The irrigation system also needs water which should pump to the greenhouse on top of the greenhouse. The excess heat of the greenhouse exhaust through the roof increases the temperature on top of the roof around the greenhouse. There is no expansion opportunity for this greenhouse. All the facilities, people and crops would be needed to transport to the roof which increases electricity consumption and its considerations. Although wind can improve passive cooling system in this site, the wind break cannot be used to control the negative effects of the wind, such as reducing heating efficiency and wind pressure on the structure of the greenhouse (Table 5.15).

Site 4								
Resources	**Sun radiation condition**	**Cold water access**	**Wind exposure**	**Hot water and steam access**	**Fresh Water access**	**Expansion opportunity**	**Connections**	**Climate resiliency**
Condition	The site is located on top of a 50 ft high building (on roof)	The greenhouse is far from the ocean	The width of the greenhouse will expose to the west wind	The greenhouse is top of the building which produces hot water and steam	Apart from being far from the fresh the water resource the site is located on top of the building	The greenhouse limited by the roof of the greenhouse	It is near the road and close to the sea but on top of the building	The greenhouse will be exposed to strong wind and snow load on top of the greenhouse
Pros	There is no shadow in this part of the site			Hot water and steam can reach the greenhouse immediately			Close to the road and sea	-
Cons		Far from cold water and being 50 feet high will increase energy demand to pump and increase cold water temperature	Exposes to strong wind which leads to heat loss	The heat of the site will increase the greenhouse temperature in the summer	Increases pumping cost and electricity consumption	There is no space for future expansion of the greenhouse	On top of the building which requires more considerations	The greenhouse will be vulnerable to climate condition
Solution	-	--	Wind break cannot be used for this site on top of the building	-	-	-	-	-
Consequence	There is no problem in terms of solar gain	Decreases cooling efficiency and increase electricity demand	increases the chance of collapse by strong wind	Increases cooling demand in the summer	Increases electricity consumption	The greenhouse's space is limited by the roof boundaries	Ease of exporting food and importing material	Collapse and damage

Table 5.15: Site 4, summary of the site condition

III.4.5. Site 5

This site is located on the edge of the EIP which restricts its potentials. The length of the greenhouse is exposed to west winds and there are no places to install wind breaks. The opportunity for expansion is restricted by the EIP boundary and the road on both sides of the greenhouse. Being far from the sea (cold water resource) will increase the energy consumption of the greenhouse. The greenhouse is far from the hot water source, which leads to decreasing heating efficiency in the winter. The location of the greenhouse also increases the cooling demand due to the greenhouse's exposure to the south wind, which brings the steam of the factory to the greenhouse in the summer (Table 5.16).

Site 5								
Resources	**Sun radiation condition**	**Cold water access**	**Wind exposure**	**Hot water and steam access**	**Fresh Water access**	**Expansion opportunity**	**Connections**	**Climate resiliency**
Condition	On site location	The greenhouse is far from ocean water	The width of the greenhouse will be exposed to the west wind	The greenhouse is far from hot water resource and the greenhouse will exposure to steam of the site by western wind in the summer	The greenhouse is far from the freshwater resource	One side of the greenhouse is facing to the road, but other is facing to available area for expansion	It is near the road and close to the sea	This site is located on the edge of the EIP
Pros	There is no shadow in this part of the site					There is an expansion opportunity for this site	Close to the road and ocean	It is far from the ocean
Cons		Far from cold water which increases energy demand for pumping and increasing cold water temperature	Exposed to strong wind leads to heat loss	The heat of the site will increase during summer which reduces passive cooling efficiency	Increase pumping cost and electricity consumption	There is a road between the available future exposition and the greenhouse		There are some limitations according to making changes around the greenhouse, such as wind break installation
Solution	-	--	There is no space in the EIP to reduces the wind effect	-	-	-	-	-
Consequence	There is no problem in terms of solar gain	Decreases cooling efficiency and increases electricity consumption	Increases the chance of collapse by wind	Increases active cooling demand	Increases electricity consumption	The greenhouse's space is not limited	Easy to export food and import material	It is vulnerable to strong wind

Table 5.16: Site 5, summary of the site condition

III.5. What are the pros and cons of each location? Create tables for listing pros and cons of the sites.

Pros	Sun radiation	Cold water access	Wind exposure	Hot water and steam access	Fresh Water access	Expansion opportunity	Connections	Climate resiliency
Site 1	**10**	**10**	**10**	**4**	**10**	**2**	**10**	**2**
Site 2	**8**	**6**	**8**	**8**	**4**	**8**	**8**	**8**
Site 3	**2**	**4**	**6**	**10**	**4**	**4**	**8**	**8**
Site 4	**8**	**2**	**10**	**10**	**2**	**2**	**2**	**2**
Site 5	**8**	**2**	**6**	**6**	**2**	**8**	**10**	**8**

Table 5.17: Summary of sites Pros

Note for ranking: 10 Fulfill the requirement totally; 8 Almost fulfill the requirement; 6 partially fulfill the requirement; 4 rarely fulfill the requirement; 2 Almost do not fulfill the requirement. This scale is used to characterize the site based on the selective best judgement of the designer. In reality, these scales should reflect the upper and lower ranges of the factor under consideration.

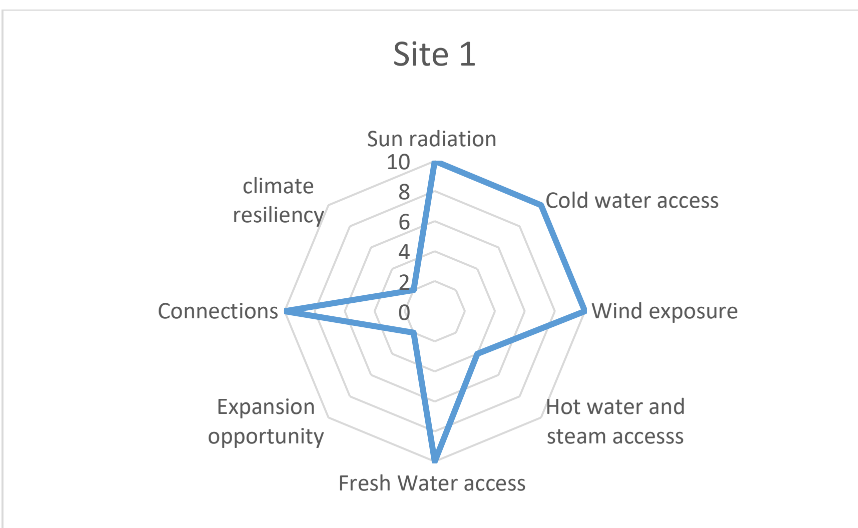

Figure 5.22: Pros of site 1

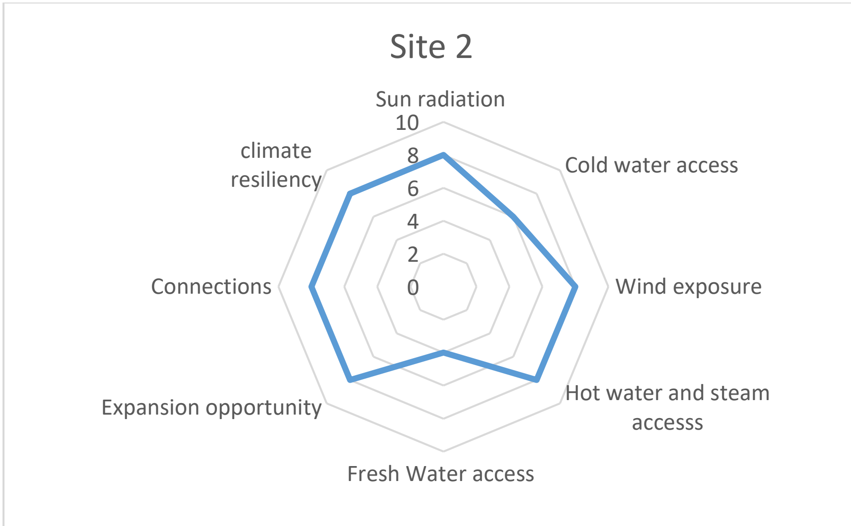

Figure 5.23: Pros of site 2

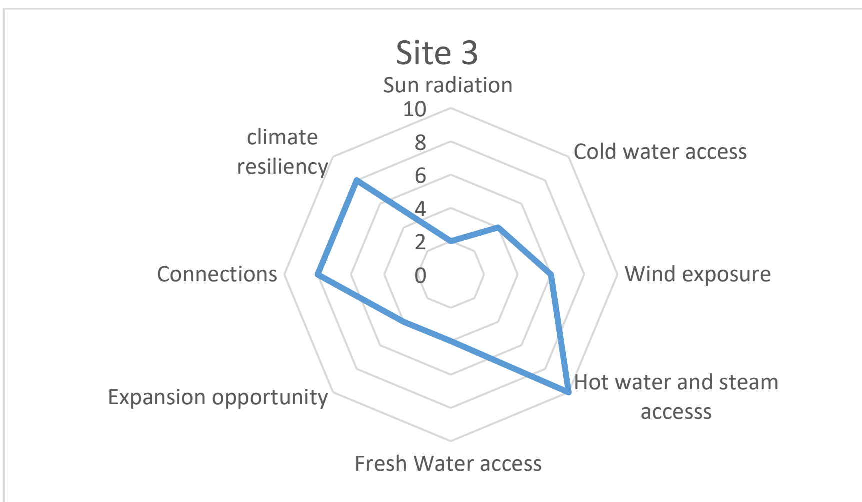

Figure 5.24: Pros of site 3

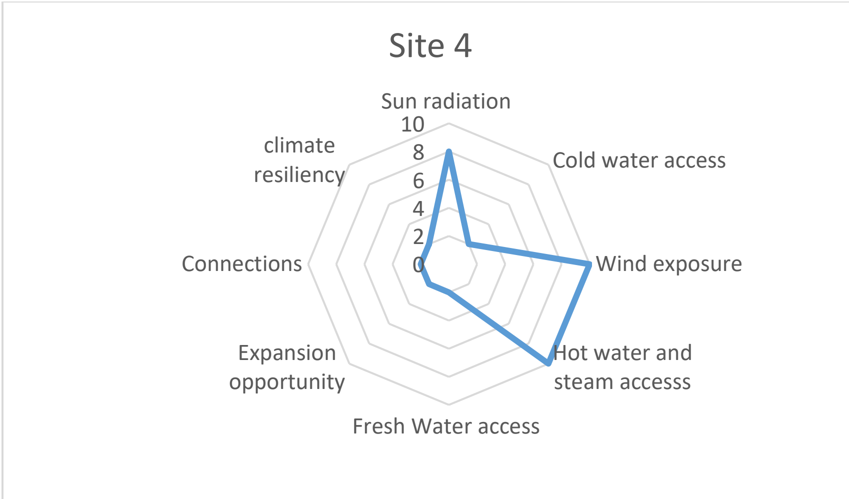

Figure 5.25: Pros of site 4

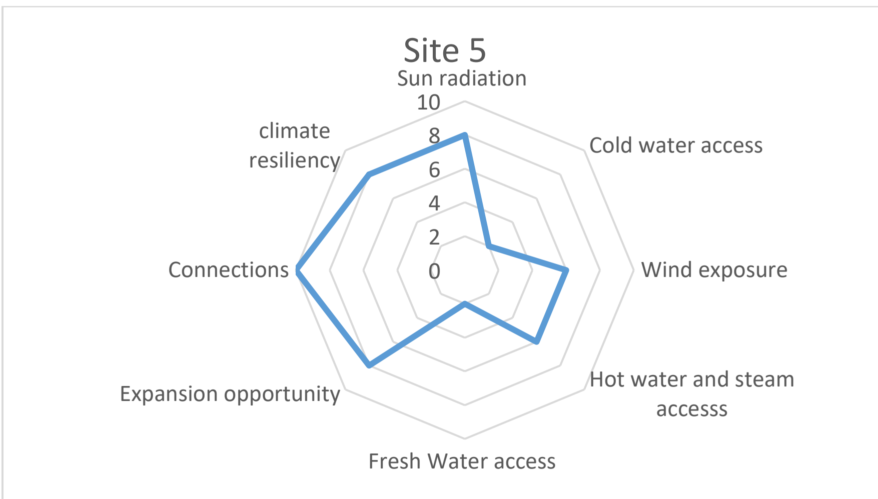

Figure 5.26: Pros of site 5

The table below is the summary of the site's challenges.

Cons	Ocean's negative effect	Wind exposure negative effect	Micro-climate heat negative effect	Increase energy consumption	Climate exposure
Site 1	**10**	**10**	**2**	**6**	**10**
Site 2	**2**	**4**	**4**	**4**	**6**
Site 3	**2**	**2**	**6**	**4**	**4**
Site 4	**2**	**10**	**10**	**10**	**10**
Site 5	**2**	**4**	**6**	**8**	**6**

Table 5.18: Summary of sites Cons

Notes on ranking: 10 High negative effect; 8 Moderate negative effect; 6 Partial negative effect; 4 Rare negative effect; 2 Negligible negative effect. This scale is used to characterize the site based on the selective best judgement of the designer. In reality, these scales should reflect the upper and lower ranges of the factor under consideration.

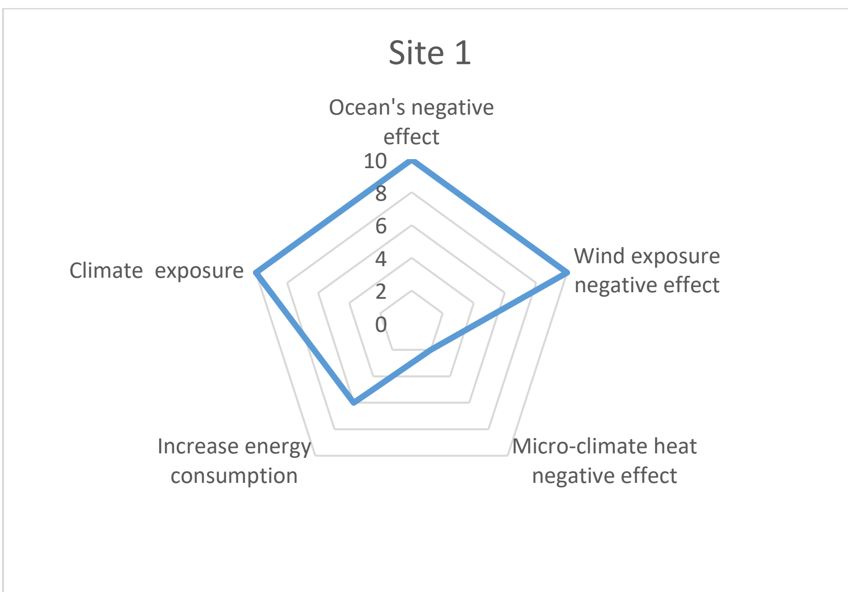

Figure 5.27: Cons of site 1

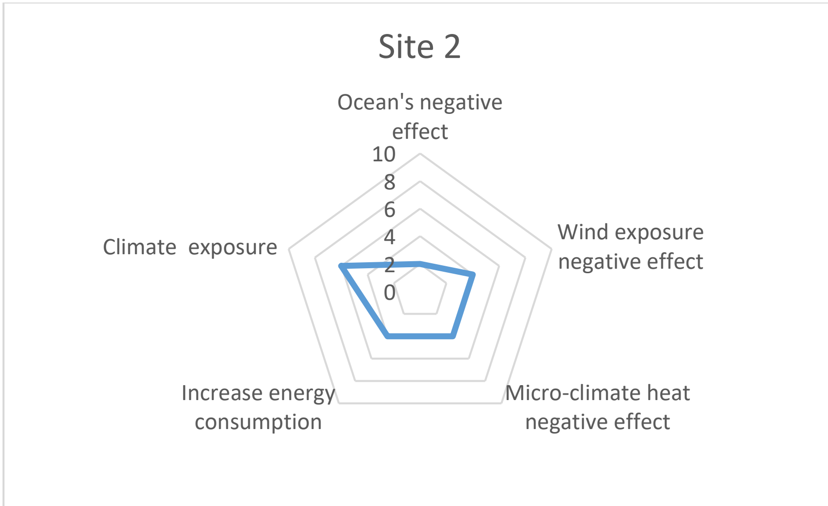

Figure 5.28: Cons of site 2

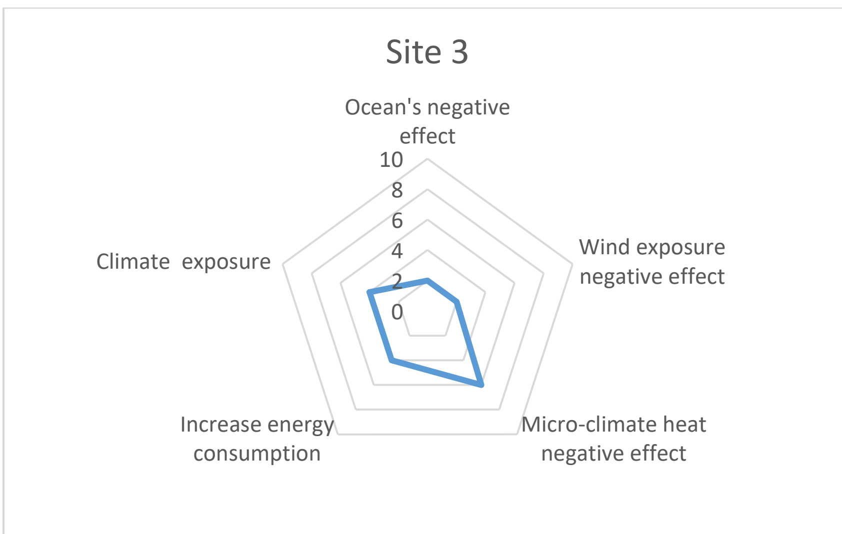

Figure 5.29: Cons of site 3

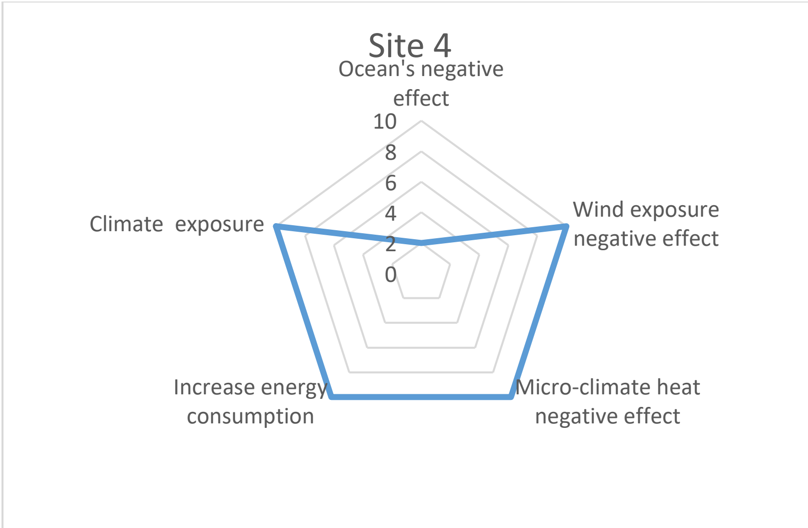

Figure 5.30: Cons of site 4

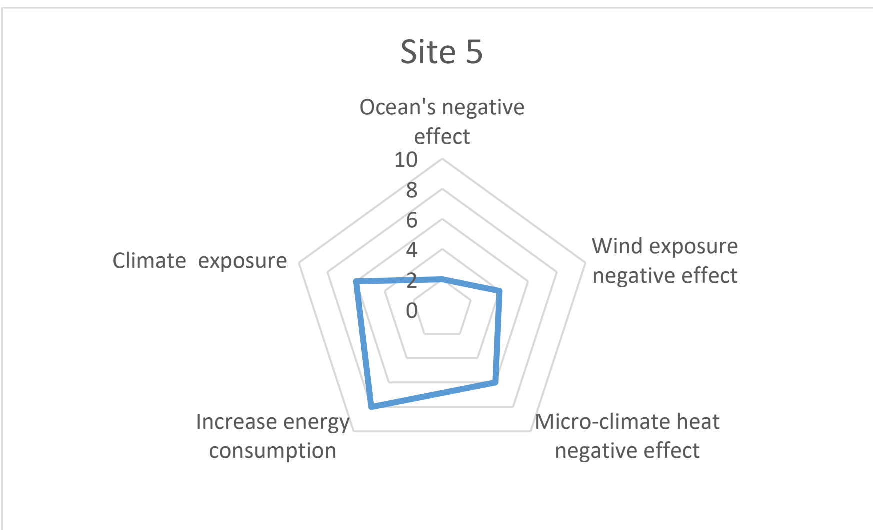

Figure 5.31: Cons of site 5

III.6. What is the best location based on pros and cons of each site for the greenhouse? Select the best location based on pros and cons of each site for the greenhouse and List any challenging site conditions that must be considered

Site 2 has the highest scores for pros and the lowest scores for cons compared to other greenhouse sites on the EIP. This site locates on the center of the EIP and has access to all resources. Site 5 and Site 1 locate near the borders of the EIP which susceptible the greenhouse to negative environment conditions

Figure 5.32 : Site 2

III.7. Is there any possibility to reduce ecosystems' negative effects on the greenhouse? Use bio-climate passive method to mitigate the effect of any challenging site conditions on the greenhouse while increasing the efficiency of the desired ecosystem services

Bioclimate passive design recommendations can reduces the resource requirements of the greenhouse significantly (Table 5.19).

Greenhouse Requirements	Light	Wind negative effect	Heat gain	Avoid overheat	Heat loss reduce	Cooling	Water	Snow load
Passive solutions	Single façade on South and East side	Install wind break on west side (set back about 2.5 times their height) (natural recommended)	Single façade on South and East side	Use blinders reflecting surfaces, and shaders in the summer	Double façade on North and West side Installing insulating blinders Stone wall on the west side and for beds Use energy heat curtains	Use cooling walls on south and west sides Open the greenhouse's roof for wind driven ventilation Use ground duct ventilation	Use water collect system	Cascade heating system's hot water to the roof and melting the snow on the roof

Table 5.19 : Solutions to reduce climate and micro-climate conditions on the greenhous

III.8. Are there any ecosystem services that can be strengthen in the EIP? Or Is there any possibility of generating renewable energy on the site? Find potential ecosystem services to generate renewable energy

The cold water of the ocean nearby is one of the available ecosystem services in the site that can be used over summer for cooling system. The greenhouse needs active cooling from June to November. Water temperature (Figure 5.33) varies during this time.

Unfortunately, there is no data about the exact temperature throughout the year in this part of ocean. If we consider water temperature and use the assumption of a 10C drop per 15 meters in depth (Figure 5.34). And the fact of lagging the ocean temperature about 2-5 months behind the land temperature (The Concord Consortium, 2010). The greenhouse can use the ocean temperature for cooling system. In the case of having warm water during July, August, and September, it can be cooled down by a heat pump before using it for cooling purposes.

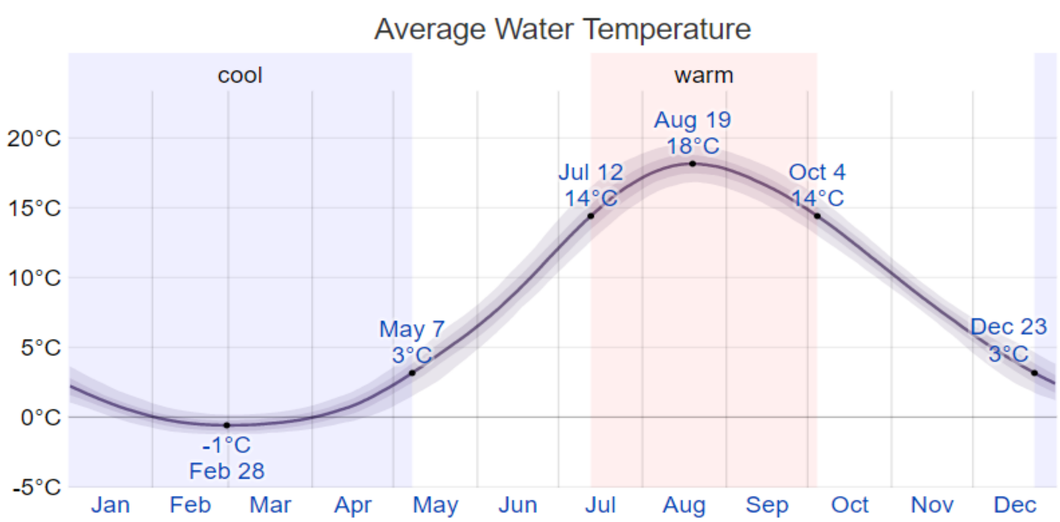

Figure 5.33: Average surface water temperature, source (Weatherspark, 2019)

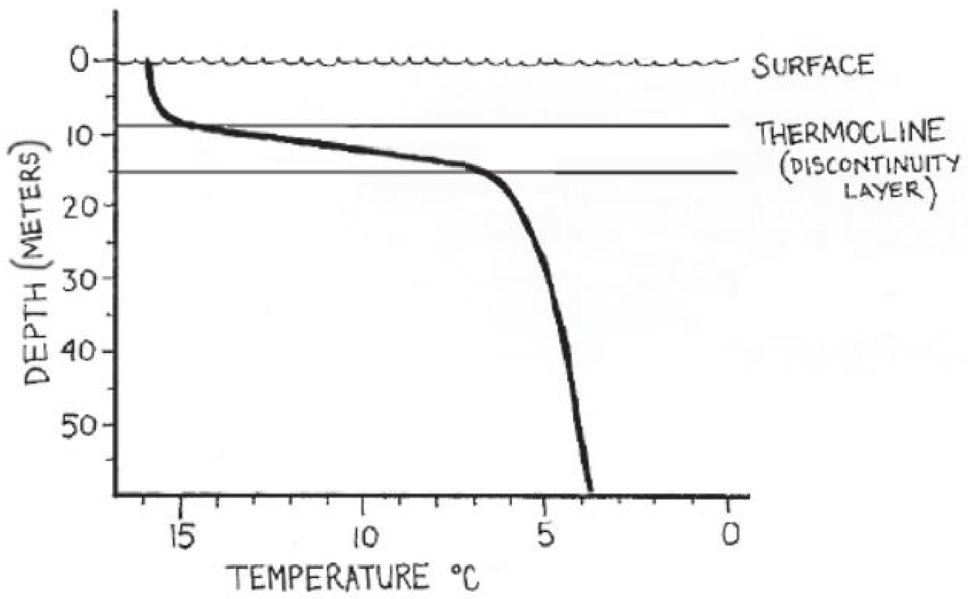

Figure 5.34: Water temperature in ocean, source (The Concord Consortium, 2010)

The Solar energy available on the site that has a potential to generate renewable energy. From mid-May to late August, solar energy is high in this region. Photovoltaic solar panels can absorb sunlight as a source of energy to generate electricity for the cooling and lighting systems of the greenhouse (Figure 5.35).

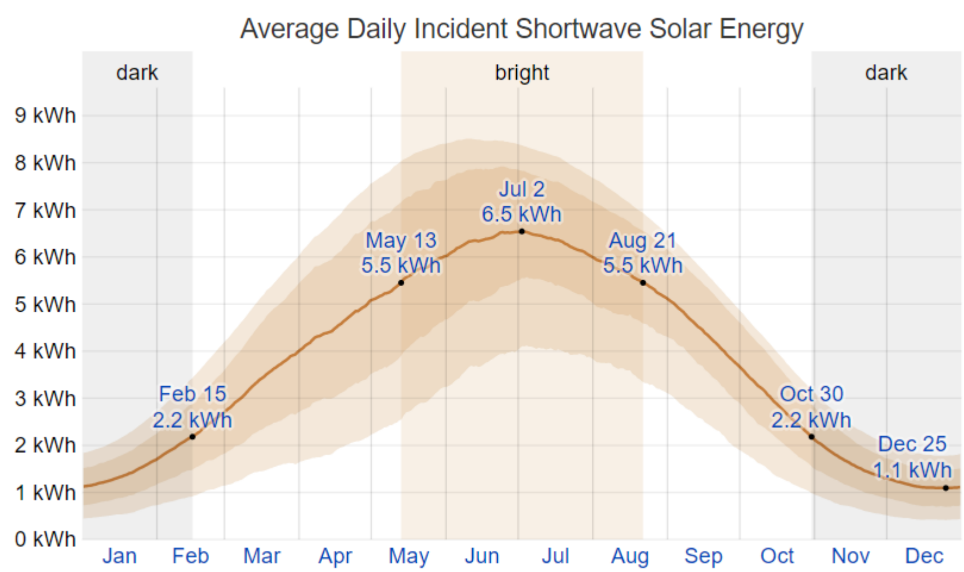

Figure 5.35: Average daily solar energy reaching the ground per square meter: 25th to 75th and 10th to 90th percentile bands are included, source (Weatherspark, 2019)

Another type of available ecosystem resource that can generate electricity in the region is wind. The wind speed is high for about six months of the year, from October to mid-April (Figure 5.36). This energy can be used by small wind turbines on the site.

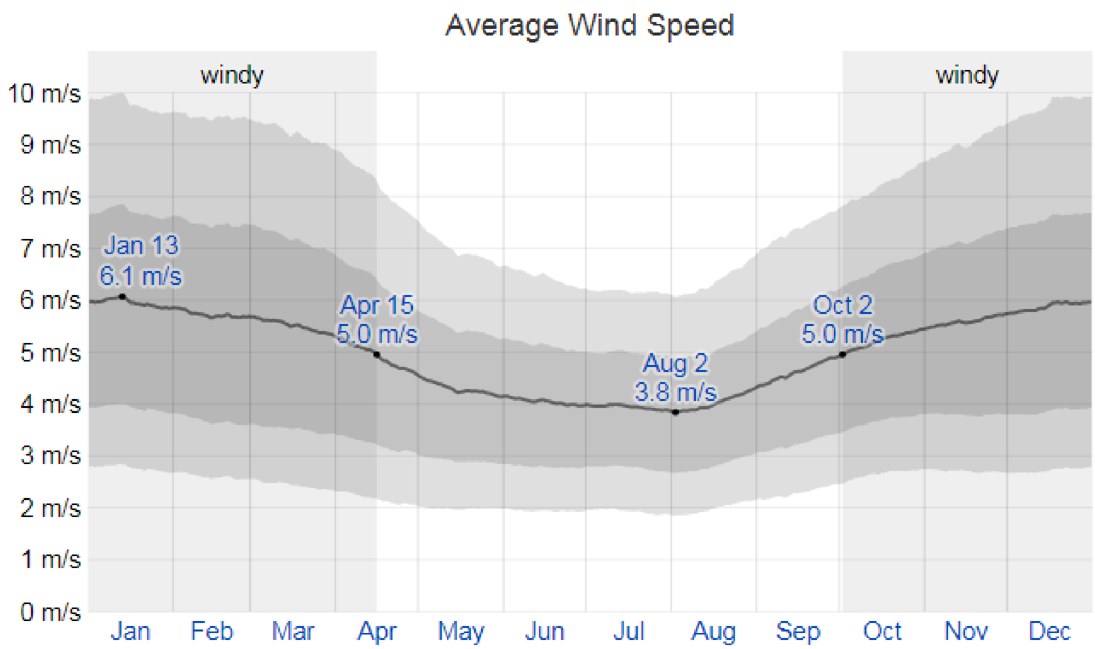

Figure 5.36: Average mean hourly wind speeds; include 25th to 75th and 10th to 90th percentile bands, source (Weatherspark, 2019).

Part IV: Urban Ecosystem

Urban systems can make considerable contributions that make a difference for the success of the project. There are various factors that engaged in this contribution which can be different according to the greenhouse type, location, and its requirements. Available ecosystem services of an urban area depend on its metabolism and capacity are varied.

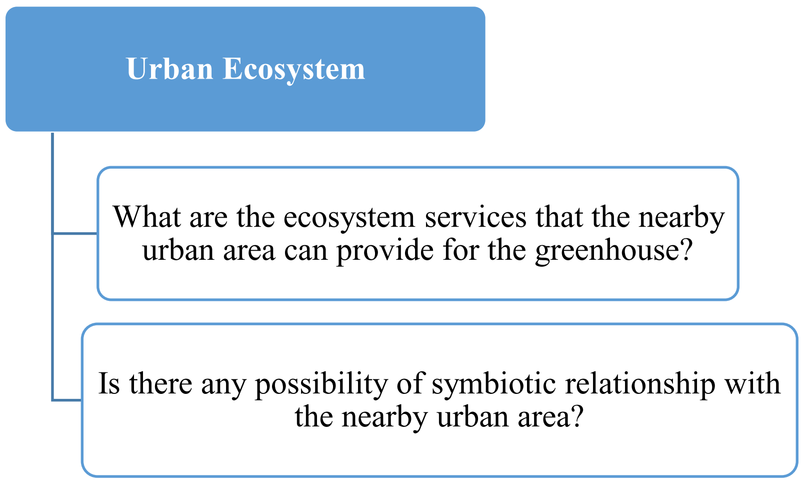

Figure 5.37 : Questions regarding urban ecosystem services

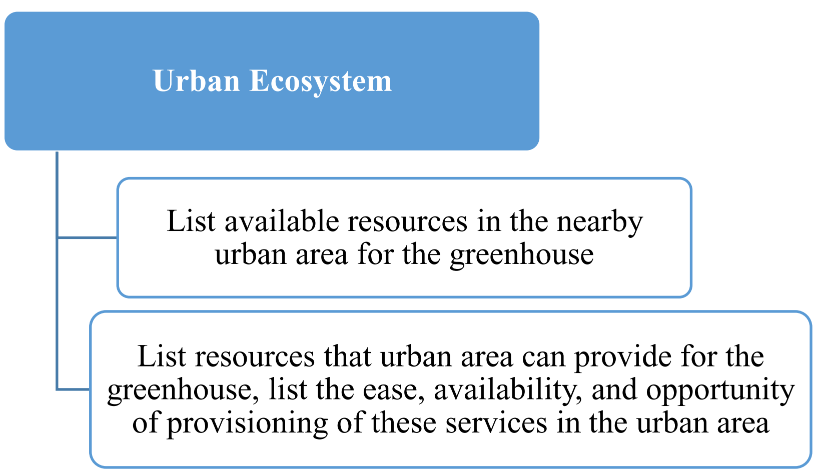

Figure 5.38: Suggestion steps for listing and provisioning urban ecosystem services

IV.1. What are the ecosystem services that the nearby urban area can provide for the greenhouse? List available resources in the nearby urban area for the greenhouse.

IV.2. Is there any possibility of symbiotic relationship with the nearby urban area? List resources that urban area can provide for the greenhouse, list the ease, availability, and opportunity of provisioning of these services in the urban area.

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	CO_2	Windbreak	Materials and infrastructures	Nutrients	Transportation hubs	Electricity	Human resource and Knowledge	End user
Ranking	High	High	High	High	High	Medium	Low	High	High	Medium	High	High	High
Required time	Seasonal	Seasonal	Year round	Year round	Year round	Year round	Seasonal	Sometimes	Year round	Year round	Year round	Year round	Seasonal
Urban Services	-	-	-	-	-	-	-	-	-	In urban area	-	Labor	Market
Availability of provisioning	-	-	-	-	-	-	-	-	-	Year-round	-	Year round	Year round
Likelihood of sufficient provisioning	-	-	--	-	-	-	-	-	-	High	-	Moderate	High

Table 5.20: The summary of urban ecosystem services and their availability, and provisioning conditions

Greenhouse Requirements	Heating	Cooling	Lighting	Water	Clean air	CO_2	Windbreak	Materials and infrastructure	Nutrients	Transportation hubs	Electricity	Human resource and Knowledge	End user
Ranking	High	High	High	High	High	Medium	Low	High	High	Medium	High	High	High
Required time	Seasonal	Seasonal	Year round	Year round	Year round	Year round	Seasonal	Sometimes	Year round	Year round	Year round	Year round	Seasonal
Natural Ecosystem Service	Sun (Passive)	Wind (Passive) Snow, cold water (Active)	Sun	Rain, Snow	Regulating air	Natural Co2 that existed in the air	Barriers for wind speed reduction like trees	Structure material, such as wood	Extracting from nature	-	Wind, Sun and tidal energy	-	-
Availability of provisioning	Mid-Jun to Mid-Nov	October-Mid-April	Mid-Jun to Mid-Nov	October-March	Year round	Year round	Depends on the location on site	Available	-	-	Year round	-	-
Provisioning and enhancement opportunity	Storage	Storage	-	Storage	-	Storage	-	-	Storage	-	Storage	-	-
Likelihood of provisioning	High	High	High	Medium	High	High	Medium	Low	High	-	High	-	-
EIP Services	Hot water, Hot air, Steam	Cold water, Electricity	Electricity	Threated water	Regulating air	Available	Barriers for wind speed reduction like greenhouses	Materials for covering structure, such as plastic		To transport material and human	Wind, Sun and tidal energy can be converted to electricity		

Availability of provisioning	Year round	Year round	Year round	Year round	Year round	Year round	Year round	Year round	---	Year round	Year round	Year round	Year round
Provisioning and enhancement opportunity	Storage	-	-	Storage	-	Storage	-	-	-	-	Storage	-	-
Likelihood of provisioning in PH MEIP	High	High	Medium	High	High	High	Medium	Medium	Low	High	High	High	High
Urban Services	-	-	-	-	-	-	-	-	-	In urban area	-	Labor	Market
Availability of provisioning	-	-	-	-	-	-	-	-	-	Year-round	-	Year round	Year round
Likelihood of sufficient provisioning	-	-	--	-	-	-	-	-	-	High	-	Moderate	High

Table 5.21: The summary of all ecosystems services and their availability, and provisioning conditions

V. Conclusion

This pilot application of the design criteria addresses several aspects of greenhouse integration into an EIP. Firstly, an EIP's ecosystem services have a direct relationship with the diversity and the stage developmental of the EIP. The lack of diversity and maturity of an EIP reduces the ecosystem services of an ecosystem as a result, the residency also decreases. Secondly, the climate type of the EIP and surrounding natural environment can affect the type of ecosystem services that they provide. In our case, the PH MEIP is located in a variable climate area; this environment can provide cold water as well as wind for the cooling system of the greenhouse during high temperature months. However, PHP factory can also create a hot micro-climate in the site which provides hot water for the heating system of the greenhouse. Therefore, in the case of having a contrast between the climate type of natural environment and human-made ecosystems (EIPs), the diversity of ecosystem services will increase. Additionally, the greenhouse uses the services of ecosystems around it, provides services for those ecosystems, and contributes to improving the health condition of all ecosystems. Furthermore, due to lack of accurate on-site data (e.g. exact quantities and qualities of waste heat streams) the PH MEIP evaluation had a certain level of subjectivity. In order to apply this guideline to a real situation, there would be a need to collect quantitative data according to available services.

CHAPTER SIX: KEY OUTCOMES AND OBSERVATIONS

1. Key Outcomes

The main objective of this study was to create a sustainable design guideline that applied the contribution of ecosystems services to optimize existing or low-carbon energy resources to increase the efficiency of greenhouse integration into an EIP. To this end, the actual needs of the greenhouse operations - as an integrated part of an EIP – was based upon the concept of regenerative design as a nature-based method to integrate more sustainability into the development of the EIP and form the basis of design guideline.

Information and data related to five existing food-related production systems was combined with more general literature to inform the design factors. Where applicable, the operational conditions of the case studies were discussed with inference to links with more general systems. The analysis indicated how potential ecosystem integration can significantly increase the efficiency of the greenhouse as well as the all ecosystems through the lens of symbiotic relationships. Finding available resources and understanding the likelihood of provisioning, can significantly reduce the operational costs of the greenhouse. Additionally, design considerations can make a big difference on operational cost of an urban greenhouse as a result the success of the project increases, regarding the fact that urban greenhouses have limited production and profit.

The second aim of this study was to create a sustainable design guideline to support the optimal design for a greenhouse intended to be integrated into a broader EIP. As noted, this was founded on the concept of regenerative design, which guided the ultimate aims, processes, steps, and its three different contextual lenses (reuse, reduce, and produce).These lenses not only can increase the resiliency of the integration over time, but can also redirect material and energy flows in less impactful ways within the EIP. The inter-relationship of the design guideline steps was presented to assist the designer apply the guideline appropriately. These steps aim to increase the resiliency and the sustainability of the whole system by highlighting where changes can be addressed as the system evolves over time. For example, in case of any changes according to greenhouse functions or EIP's available services regarding the fast-growing nature of

EIPs, the guideline steps can assist the designer to respond to these transitions in a way that still optimize the wholistic nature of the system integration.

The third and fourth objectives of this study were to identify and better understand the available ecosystem services for greenhouse and determining the services that a greenhouse provides for other ecosystems. To achieve these aims, the EIP, urban, and natural ecosystems services listed as well as the relationship amongst them were analyzed. This element of the research provides the designer with a deeper understanding of the types of available services, the nature of their availability (temporally and spatially), and potential provisioning. This understanding also assists the designer to observe the resource flow and lack of services in whole ecosystems and find opportunities to improve ecosystems through providing new services. For example, at our pilot site, the greenhouse depends on provisioning and supporting services of natural and EIP ecosystems, but could be developed to also provide cultural and regulating services for the broader ecosystem.

When the design guideline was applied to Port Hawkesbury's Micro-Eco Industrial Park (MEIP), it revealed that a lack of diversity and maturity of the integrated ecosystem (EIP) can decrease the resiliency of the whole ecosystem and potentially impact of the integrated part in the long term. Furthermore, due to lack of biodiversity and the immaturity of the PH MEIP the fulfillment of the greenhouse requirements completely depends on the PHP factory, as a result the resiliency of the ecosystem decreases. Finally, the climate type of the EIP (micro-climate) and surrounding natural environment can affect the type of ecosystem services that they provide. For example, if there is a time that there are no natural services providing a key element, there may be other ecosystems that can fulfill the greenhouse requirements (e.g. heat in the winter from the PH MEIP to augment the lack of heat during winter months). However, it should be reiterated that the PH MEIP evaluation was completed with incomplete data regarding energy and material flows and the exact nature of the facility's infrastructure. Therefore, some of the rankings were based upon the subjective interpretation of the researchers. In order to apply this guideline, there is a need to collect quantitative data that accurately reflect the actual available and potential services.

2. Limitations and Generalizability

The Port Hawkesbury MEIP is an example of an immature ecosystem, which increased the dependency of the greenhouse on the one service provider and reduced the resiliency of the overall EIP. To decrease the risk of failure in the future, an additional lens for analysis the 'produce' lens was created to try and predict where resources could be created internally rather than relying solely on existing materials and flows with the systems. This lens not only will reduce the dependency of the integrated part (greenhouse) on the EIP but could also provide the opportunity of achieving a zero-energy system by implementing sustainable approaches, such as producing renewable energy.

This guideline could be used to aid in the design/development of any type of industrial and urban ecosystems, with the aim of developing sustainable human-made ecosystems and improving the health of conditions of the whole system through nature-based approaches. Additionally, the integrated part will be dependent on the collective ecosystems (natural, EIP and). For example, to fulfill the requirements of an urban greenhouse, the urban ecosystem has the main contribution in providing the integrated greenhouse's requirements. Moreover, the agricultural production will require continuous development to minimize resource consumption/inputs; thus, there is a need to increase its efficiency through symbiotic relationships. To do this, designers should continuously consider the new agricultural techniques, their requirements with desperate, and seek other sectors (i.e. EIPs) available resources to make symbiotic relationships.

3. Recommendations for Future Research

The greenhouse/EIP integration has been witnesses within several projects in Canada and the Netherlands. Creating a design guideline to optimize this integration into an ecosystem, based on the utility of available ecosystem services is new. The following recommendations for future research include:

3.1. Financial Aspect: Additional research is required to integrated any fiscal or economic considerations directly into the guide. This could be done using fiscal data to inform the ranking of different options, for example, but will also need to be integrated in the final implementation process. This will influence the viability of the project as it speaks to issues such as operational and constructional costs of the greenhouse. Economic assessment of the symbiotic relationships (using the waste heat of the adjacent factory) and its comparison with other energy sources is also another financial aspect of this project that can be investigated in the future.

3.2. Environmental Impact: It would be important for future research projects to fully investigate the contribution of the symbiotic relationships in reducing the negative environmental impacts, such as GHG emissions.

3.3. Crop Choice: Additional research is necessary to determine the need and the food type preferred by the local community. Moreover, the environmental condition of the site can also affect the crop choice of the region throughout the year.

3.4. Social Aspect: The contribution of this study to creating job opportunities for the local people and increase the food security of the community also are social aspects of this research that can be investigated in the future.

3.5. Development Aspect: Another important line of research is the application of system dynamics to the development of EIP. Considering the integration of other food production systems, such as vertical farming and aquaponics; their correlation and possible symbiotic relationships among them are also other aspects of EIP development that can be studied in the future. The next step after this design guideline is collecting quantitative data and analyse the final conditions according to the actual data. Based on these data the potential capacity of the greenhouse can be determine.

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APPENDIX

LIST OF PHOTOS