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OPTIMIZATION OF URBAN SYSTEMS USING A NEXUS BASED URBAN ALGAE PRODUCTION

BY

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ABSTRACT

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Title: Optimization of Urban Systems Using a Nexus Based Urban Algae Production

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Global urbanization–triggered resource stress and climate change have become the prime motivators for sustainable development goals among countries. A system based nexus in the main three resources—food, water, and energy—is now the leading approach to better integrating ecology and urban development by 2030. Indeed, sustainable nexus-driven food security and development is becoming significant in Qatar's 2030 Future Vision, and several crop production, clean energy, and water technology initiatives have been launched in the past few years, some which include ecological services found in algal species toward greening water systems. Nevertheless, Qatar's food security remains exceedingly vulnerable. The recent geopolitical stress in the region, caused by a blockade of the neighboring countries from which Qatar most actively imported its food, resulted in a rapid shift toward increasing the locally produced food industry and structures, amplifying an already existing high global footprint due to the absence of synergy between the existing urban infrastructure and the growing food production system. The research approaches the nexus from a food-entry perspective to highlight algae-based product systems as a new paradigm through which to integrate existing systems within urban contexts possessing specific socioeconomic characteristics. This product can simultaneously contribute to redirecting the silo-food and resource infrastructure systems within the cycle of urban food, energy, and water toward higher productivity and efficiency. Through a body of literature and previous nexus-based initiatives, a nexus framework is identified and expanded upon to guide the research discussion toward developing high-level integration between existing urban resource and fabric systems and algae as an agriculture production system. In a series of numerical calculations and system dynamic models on a local district (Qatar University Campus), the research will evaluate the effect of the manifest system based on the environmental considerations of the nexus framework, which will also highlight the compatibility between the surrounding latent city's urban socioeconomic needs and the overall footprint crisis.

DEDICATION

"To my greatest blessing, my parents, children and family"

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ABBREVIATIONS

1. Food, energy and water resource (FEW)
2. Carbon dioxide (Co2)
3. Ecological footprint (EF)
4. Global food security index (GSFI)
5. Human development index (HDI)
6. Gross domestic progress (GDP)
7. Sustainable consumption and production (SCP)
8. Integrated resource assessment IRA
9. Material Flow analysis (MFA)
10. International Ergonomics Association (IEA)
11. Human beings (HB)
12. physical spaces (PS)
13. Objects and machines (OM)
14. Science and technology (ST)
15. Political and legislative (PL)
16. Social and cultural (SC)
17. Economic and finance (EF)
18. Ecological and geographical (EG)
19. Facilities management (FM)
20. Building management systems (BMS)
21. Closed circuit (CC)
22. Building Information Modeling (BIM)
23. Social, environmental, economic, demand and supply (SEEDS)

24. Qatar University (QU)

25. United Nations (UN)

26. Ministry of Municipality and Environment (MME)

27. Qatar general electricity and water corporation (KAHRAMAA)

28. Public works authority (ASHGHAL)

29. Geographic Information System (GIS)

30. Gulf Cooperation Council (GCC)

31. Environmental policy (EP)

32. Leadership in Energy and Environmental Design (LEED)

33. Qatar National Vision (QNV)

34. Qatar National Development Strategy (QNDS)

35. Treated sewage effluent (TSE)

36. Movable Nexus (M-NEX)

37. Extended sustainability (ES)

38. Nitrogen (N)

39. Phosphorus (P)

40. Potassium (K)

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CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter aims to provide a holistic picture of the research chapters and main motivations behind choosing the research subject. The output of this chapter will determine the main concepts reviewed in the literature (Figure 1).

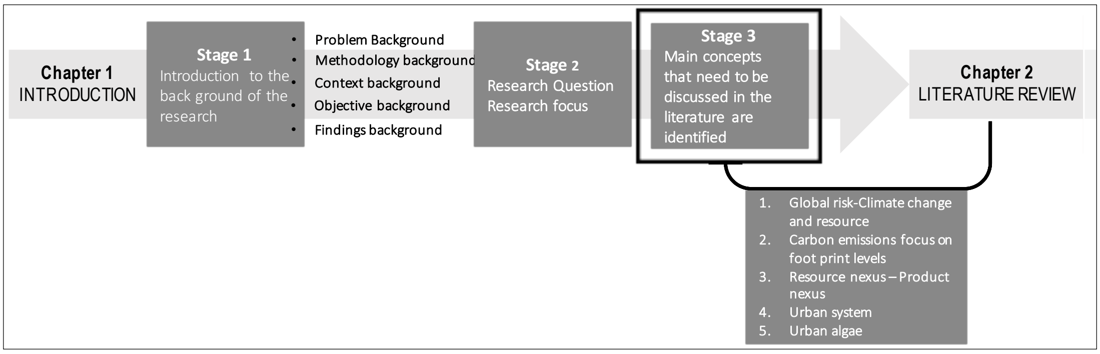


Figure 1. *Introduction chapter 1-subsequent stages.*

1.2 Background of Research Problem-Research Motivation

This research begins by outlining the main problem—a global resource crisis. What it is and how it occurred are described in this section as the main research motivation; additionally, motivations are scaled down to the regional and local contexts to highlight more specific outlooks on the research motivators.

1.2.1 The global resource crisis

Earth's system is dynamic yet in constant equilibrium. Earth's processes and natural cycles are comprised of multiple components—land, atmosphere, oceans, and living beings. Changing any of these components in a local region can have significant effects on a planetary scale. Such changes are often negative, such as temperature changes, droughts, and changing rain patterns, and are referred to in this research as global climate change (Hettiarachchi & Ardakanian, 2016).

Climate-change consequences have challenged mankind for thousands of years. Many of these changes are linked to urbanization and successive generations of human activity that release growing levels of carbon dioxide CO_2 and other greenhouse gasses into Earth's atmosphere, destabilizing their natural levels (Table 1). Specifically, these changes interrupted natural reliance on Eco services and "the benefits people derive from ecosystems." Besides providing services are beyond water and energy, they also include plant pollination, soil erosion control by plants, materials, plants and microorganisms that purify water naturally and also the cultural and sense of place these services provide.

Table 1 Climate Change Related Greenhouse Gases.

Water vapor	Water vapor increases as the earth's temperature rises. When human beings release CO_2 into the atmosphere, it causes warming, which boosts evaporation, which in turn increases the warming.
Carbon dioxide (CO_2)	An important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO_2 concentration by a third since the Industrial Revolution. This remains the most important and long-lasting 'forcing' behind climate change.
Methane	This is a hydrocarbon gas produced naturally as well as through human activity, to include the decomposition of wastes in landfill sites, agriculture – expressly rice cultivation – as well as ruminant digestion and manure management associated with domestic livestock.
Nitrous oxide	A powerful GHG produced by soil cultivation practices, expressly the use of commercial and organic fertilizers, fossil fuels, nitrous-related production and burning biomass.
Chlorofluorocarbons	These GHGs are synthetic compounds of industrial origin that have a number of applications. See Table 1 for a comparison of GHGs.

Consequently, the current disruption of Eco services and, ultimately, the risk for resource availability for human use are critical. This urgency results from the global change phenomenon's link to human natural recourse consumption and the destabilization of Earth's equilibrium in favor of accelerating informational complexity, extreme velocity, and volumes of FEW flowing long distances among continents, countries, and cities, a process known as urban metabolism. The latter is a consequence of urbanization and a much-needed characteristic for the advancing technologies of mankind resulting in significantly higher levels of education and health. This result is shadowed by extended life-expectancy rates and a default increase in agricultural production for an extreme upsurge in food demand (McDonough & Braungart, 2010).

Urbanization, also known as city formation, results from complex population morphologies, mainly environmental- and anthropocentric-related drivers. It is expected to sustain all future population progression patterns by manifesting itself through these changes and the subsequent transformations in land cover as it alters and occupies natural land. Urban areas present complex tangible and intangible systems by population and built environment.

The stress from urbanization began during the industrial era, which took the Earth's ecosystem from a stability period known as "Holocene" toward an unsure era, the "Anthropocene" era, with rapid changes in the number of droughts, rain patterns, and sea levels that directly affect cities. Climate change is indirectly presented in disruption of food resources supply chain, which can result in systemic migration threats.

Global climate change is not deterministic and thus fails to mitigate and control environmental deterioration, which will continue to produce aggregate resource crises, water shortages, and most significantly, food crises. Collectively, these consequences will distort livelihoods and cause population dislocation. Such dislocation affecting urban areas is identified in this research as a hotspot scenario for the global crisis (Figure 2).

Although adapting to these challenges has been made possible by tremendous growth in technologies and methods, for example, bio fuels, and the shift toward reassessing waste into secondary processes, the recent speed of the changes is overwhelming, causing growing concerns and ecological supply and human need mismatches. These mismatches continue to threaten socioeconomic stability, FW security, access to services and energy, and access to nature's Eco services for future generations.

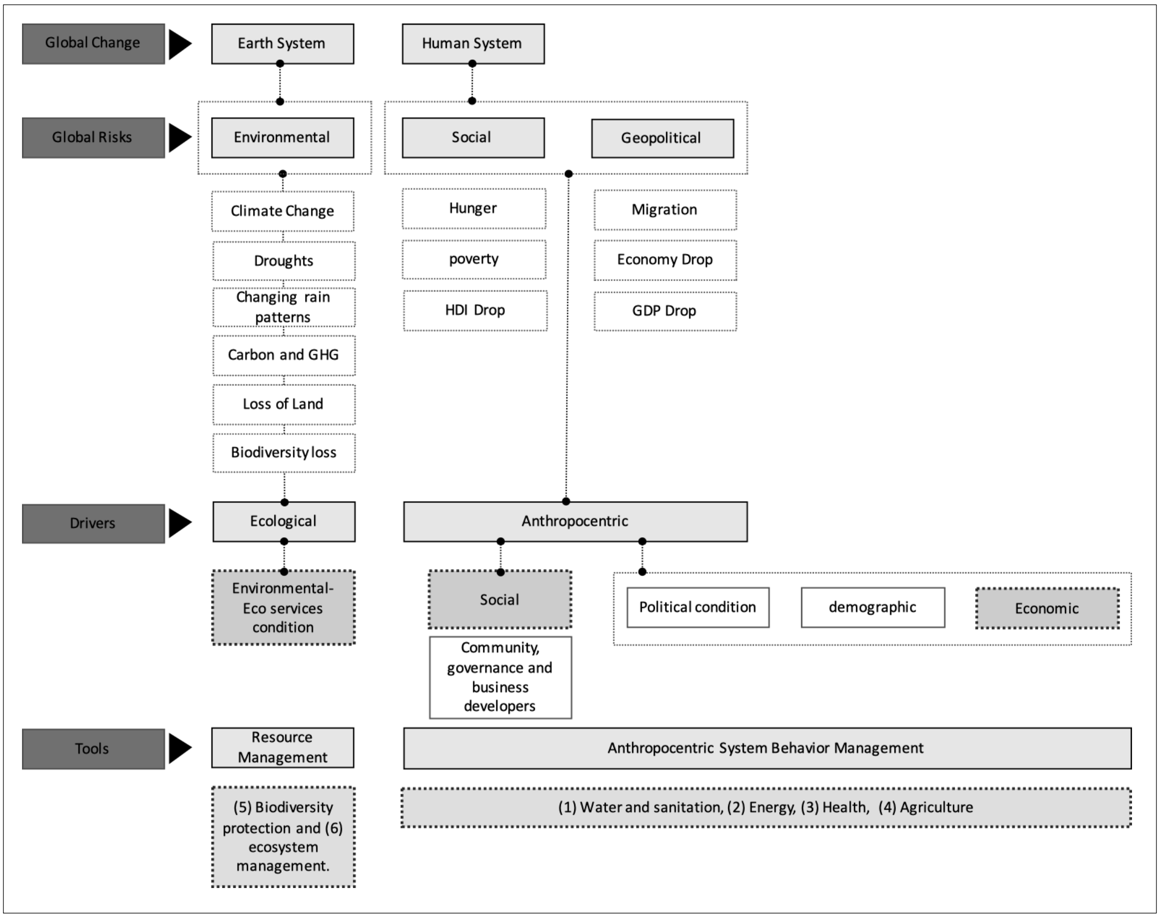


Figure 2. *Associations between Global change, risks and Drivers*

1.2.2 Food resource crisis

Food accompanied by water plays a vital role in human settlement locations, making it a vital player for the way water and energy relate as resources. It comes before economic and urban development.

In the process of securing food, differences between food availability and sufficiency must be distinguished.

From the seventh edition report, “global food security index (GFSI)” defines food security as follows:

> A complex, multifaceted issue influenced by culture, environment and geographic location. While the index does not capture intra-country nuances, by distilling major food security themes down to their core elements it provides a useful approach to understanding the risks to food security in countries, regions and around the world.

The GFSI displays the level of urgency of different countries and looks beyond hunger at aspects that affect food security towards resilience from climate change risks and adaptation flexibility in cases of crisis. Like the ecological footprint, the GFSI ranks across 113 developed and developing countries by the quality, affordability and availability of food as main parameters.

Efforts to achieve hunger elimination goals are progressing, as 70% of countries included in the index have seen their scores rise throughout improvements to infrastructure, increased production capacity, and relatively stable food prices (Beddington et al., 2011; Béné, Headey, Haddad, & von Grebmer, 2016). The latter is to be achieved through agriculture to reach specific goals by 2030; indeed, most developing countries have set their improvement goals toward aggregating the already ecologically stressed conditions caused by the industry (FAO, 2017).

Nevertheless, these positive developments are all under threat from existing global risk areas. Understanding these risks and how to address them is essential to building food systems' resilience and thereby ensuring food security for future generations (Beddington et al., 2011; Béné et al., 2016).

This progress is also defined by cities' incomes. Lower- to medium-income cities have seen a faster transition in food security due to direct improvements in their agricultural infrastructures. However, the same is not true of higher income countries that are heavily exposed to the impact of climate and natural resource risks. For example, Singapore claimed the top GFSI rank in 2018. Its improvement was measured based on the rapid increase in the country's GDP per capita, 30% since 2012; moreover, the its percentage of household expenditures spent on food is the second-lowest on the index (after the United States). The country also has the lowest agricultural import tariffs of any country in the index, which helps reduce its food import costs. But Singapore remains largely at risk due its heavy reliance on imports for processed food stuffs, exceeding 90% of its total food supply, leaving it vulnerable to trade and supply chain disruptions, which can drive up food costs.

Consequently, in the battle to become food secure, availability and sufficiency must be viewed from a resilience perspective. Some countries buy their way out of the problem using economic resources. This approach only relocates the stressors associated with agriculture elsewhere. Other countries resort to covering sufficient self-supply of food by increasing agriculture and other livestock-involved industries. If not viewed from a global risk perspective, this approach will result in inefficient water/ energy supply planning and the lack of a waste management plan or even a local economy analysis, ultimately augmenting resource pressure by the underlying carbon emission, greenhouse gasses, energy consumption, and water stress involved in the process. According to the U.S. Department of Agriculture, food security facilitates resilience from possible crisis which involve climate disruptions as well as wars and shipping disruptions from economic and political instabilities.

Consequently, three main crosscutting risk areas are distinguished: financial risks, trade risks, and the geopolitical risks (Figure 3). The way population morphologies coexist within these three risk areas is a true reflection of multiple dynamics that constantly emerge in urban systems, all of which present diverse system pressure and consequences that interconnect on planetary and human scales, depending on the distinctive conditions presented in geographically and economically diverse city systems.

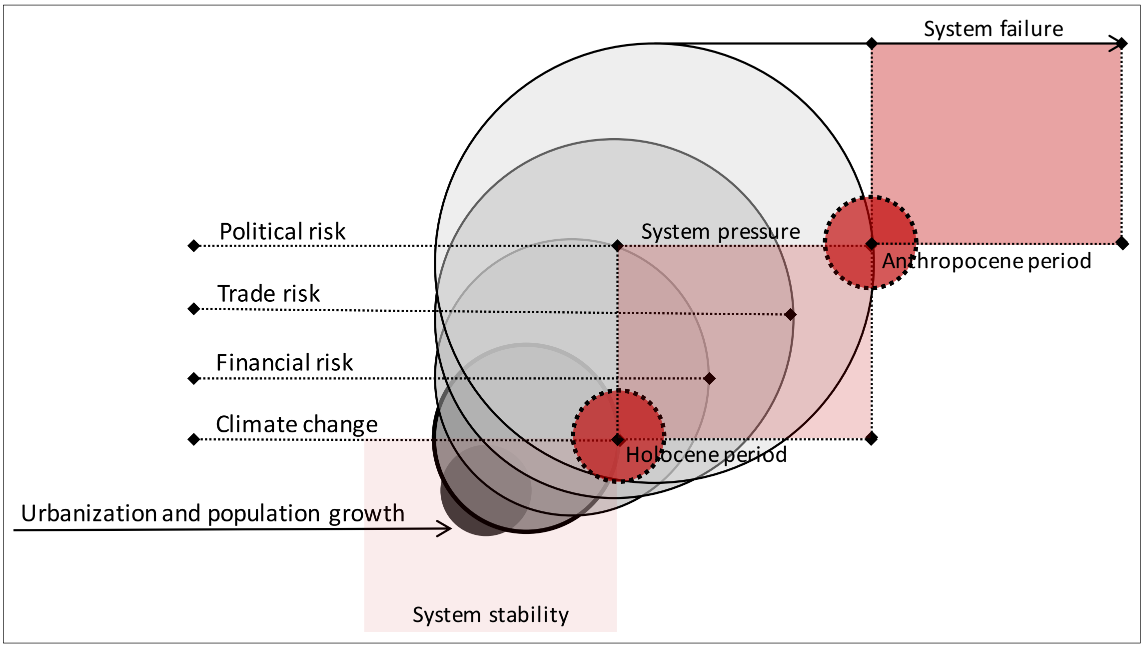


Figure 3. *Global Risk and progression diagram*

1.3 Background of Research Context-Cities As A Place For Resolution

Although cities only occupy 2% of the Earth's total land, they are responsible for 70% of the world's carbon footprint, consume 66% of the world's energy in the process of industrialization, and producing 70% of global gross domestic product GDP in the progression toward achieving economic prosperity and increasing political power for an ever-growing population (Web. 1). "If the present growth trends in world population food production, industrialization, pollution, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next 100 years" (Meadows, Meadows, & Randers, 1992). Cities' urban infrastructures alter and revert these flows into the environment, which is critical in addressing issues of sustainability and the anthropocentric influences of a given urban area that exhibits complex economic and social systems embedded within the ecological system (Béné et al., 2016).

The concerns over food security and resource stress, whether regional or local, is thus a global issue. According to the UN's sustainable development protocols, the risk results from the combination of continued urbanization and economic progression, climate change, and population growth. The state of city development is important in understanding urbanization patterns because cities undergo fluctuating periods of development until reaching a steady growth level.

Once this level is achieved, countries are considered to have reached major development goals and to be in a state of improving existing development or slowly expanding. Conversely, developing cities are experiencing 43% higher levels of urban development. Although developing countries are estimated to reach a level of steady development in the coming decades, the current escalating resource demand will leave behind growing concerns that threaten future generations (United Nations, 2000).

Appropriately, the UN's 2003 sustainability protocols in 2003 concluded that endorsing common principles of development and their implications on global security starts in cities, resulting in the "think globally and act locally" slogan. Civil society and authorities are the building blocks underlying development shifts.

Considering the Gulf region as the larger context and Qatar and Doha City as the city context from where resolutions derive, the multiple aspects that define their ecological footprint characteristics must be clearly identified to trigger new development models that alter current ecological scenarios. These models are examined in Chapter 4 to relate the research objective in a more customized manner to the city scale.

1.4 Background of Research Objective-Sustainability Responses

Sustainability responses are the larger objective of this research. This section discusses sustainability responses and the protocols for resource supply and demand upon which this research objective is built

1.4.1 The global response

On an international level, sustainable development began over concerns about environmental degradation and biophysical interfaces. Deliberations began shifting to a more anthropocentric approach as society shaped development and industrial decisions to consider future generations' wellbeing. Chief deliberations were once held at the UN level during international environmental conferences that highlighted multiple concerns within contemporary development models and social contexts and set global agendas that reflect these concerns. The first significant effort to establish shared sustainability goals among multiple countries was the 1992 Earth Summit, part of the UN Conference on Environment and Development (UNCED) in Rio de Janeiro, during which world leaders joined efforts to classify sustainable development concerns and draw a blueprint for it (Keating, 1994). Following the specific definition of sustainable development: ‘improving the quality of human life towards wellbeing while living within the carrying capacity of supporting eco-systems.’ (Brown, Hanson, Liverman, & Merideth, 1987; Santillo, 2007), the UN developed specific metrics for both concepts in the definition: “well-being for all,” as measured by the HDI, a reflection of the social aspects of each country and its endowment and ability to trade, and “within the means of nature” is measured by the EF”. Ecological footprint (EF), a resource accounting tool, helps cities recognize their ecological budget and provides the data needed to efficiently manage resources and build secure resilient cities

Most countries are seeing steady growth in both HDI and EF. Critical to this growth is the question of resource systems, food, water, and energy (EWF) security/ sustainability as they pervade aspect of ecosystems, human systems and economic activity (Web. 1).

Since the 1970s, there is a demand for resource e that exceeds the ability of earth to regenerate, this is called and ecological overshoot. “Today humanity uses the equivalent of 1.7 Earths to provide the resources we use and absorb our waste through overfishing, overharvesting forests, and emitting more carbon dioxide into the atmosphere than forests can sequester in the process of making cities” (Web. 1).

Cities were recognized as the instrument for sustainable development. Consequently, sustainable cities are now central to urban policy in many countries. The city is an interactive and dynamic system that emphasizes the interactions and connectivity of multiple flows as a result of population growth, industry, and development causing aggregate urban manifestation animated by anthropocentric needs and cultural normality. The Rio Earth Summit highlighted the social and business sectors’ role in damaging natural resource systems. By engaging stakeholders and business developers, the Summit was able to draw attention to issues of industrialization, population growth, and social inequality. This attention highlighted the stages necessary for more effective realization of local agendas and national objectives. Therefore, cities' development requires consideration of the role of governance and civil authorities on international, national, and more importantly, local levels in achieving these global agendas. The term global compact was also proposed by UN Secretary Kofi Annan at the World Economic Forum on 31 January 1999:

The Global Compact "is a voluntary corporate citizenship initiative seeks to provide a contextual framework to encourage innovation, creative solutions, and good practices among participants, it relies on the enlightened self- interest of companies, labor and civil society to initiate and share substantive action in pursuing the principles upon which the Global Compact is based" (Compact, 2002)

The Forum sought to engage business leaders in international initiatives concerning a more inclusive global economy and value-based management that would generate fertile ground for companies, UN agencies, non-governmental organizations, civil-society actors, and labor to work following universally endorsed and supported values. Based on UN evaluations, the private sector represents the main industry.

The Global Compact is based on nine human rights, labor, and environmental principles. These principles derive from universal consensus based on the broad UN goals (Compact, 2002). They focus on domains that seek to achieve the UN's millennium goals. At its core is the Global Compact Office and four UN agencies: the Office of the High Commissioner for Human Rights (OHCHR), the International Labour Organisation (ILO), the United Nations Development Programme (UNDP), and most importantly, the United Nations Environment Programme. For the aim of this research, environment-related principals are considered as follows: "Principle 7 supports a precautionary approach to environmental challenges, 8 undertakes initiatives to promote greater environmental responsibility, and 9 encourages the development and diffusion of environmentally friendly technologies" (Compact, 2002).

Founded on the above, the MDG was announced during a UN General Assembly resolution and drew eight targets for sustainable development. However, the focus of this agenda was mainly driven by the reduction and ultimate elimination of poverty while looking at the drivers in a more holistic sense (Figure 4). While intended to excel, in sustainable progress, specifically in developing regions and countries below the mid-income line, the MDGs were to some extent criticized when findings disclosed shortcoming in the agenda's implementation process. A study that reviewed 50 geographically, demographically, and economically diverse countries post 2005 and measured the extent to which national plans have tailored the Millennium Development Goals to their local contexts revealed that the more a country's human development index (HDI) increases, the less its national strategies align with those of the MDGs. Also, a disconnection between the planning and implementation raised questions about how national funds are spent, bringing an economic/ global compact perspective to the table, thus requiring strategies to be more transparent in their financing funding agents, as the process of increasing local health may be well beyond laidback when base socio-economic conditions are geographically different and disconnected. Cities differ in their complexities which require different sustainability actions resulting in multiple conceptualizations of cities. In this regard, moving toward a context-focused approach and strategies that align with local system issues followed the MDGs.

The same government agencies, NGOs, and agencies that set a shared goal to develop these targets worked on increasing the goals' capacity and complexity in the next 15 years. A set of six essential elements where identified for improving the outcome of the targets: dignity, people, planet, partnership, justice, and prosperity spanning the 17 development goals sustainable development goals (SDGs) announced at the World Summit on Sustainable Development (Figure 4).

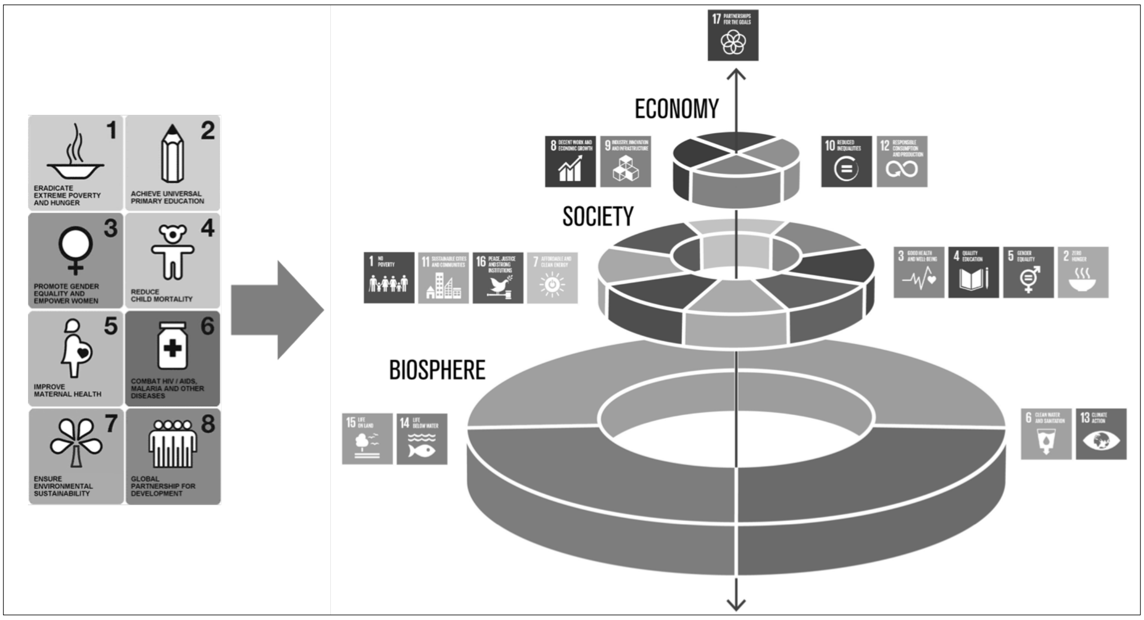


Figure 4. *Left, Millennium Development Goals. Right, Sustainable Development Goals and three pillars of sustainable development, Reference: United Nations 2015*

The 17 goals highlighted the three pillars of sustainable development and added depth to their operational level set towards 2020(Pradhan, Costa, Rybski, Lucht, & Kropp, 2017): (1) economic development, which includes the eradication of poverty and improving living conditions and life quality in high-income sub regions (UN 2015); (2) social development, which urges active community participation on all levels, focusing on women and education alongside a supporting governance; and (3) resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement resilience and disaster risk management at all levels of influence—local (horizontal), national, regional, and global (vertical) (Figure 5).

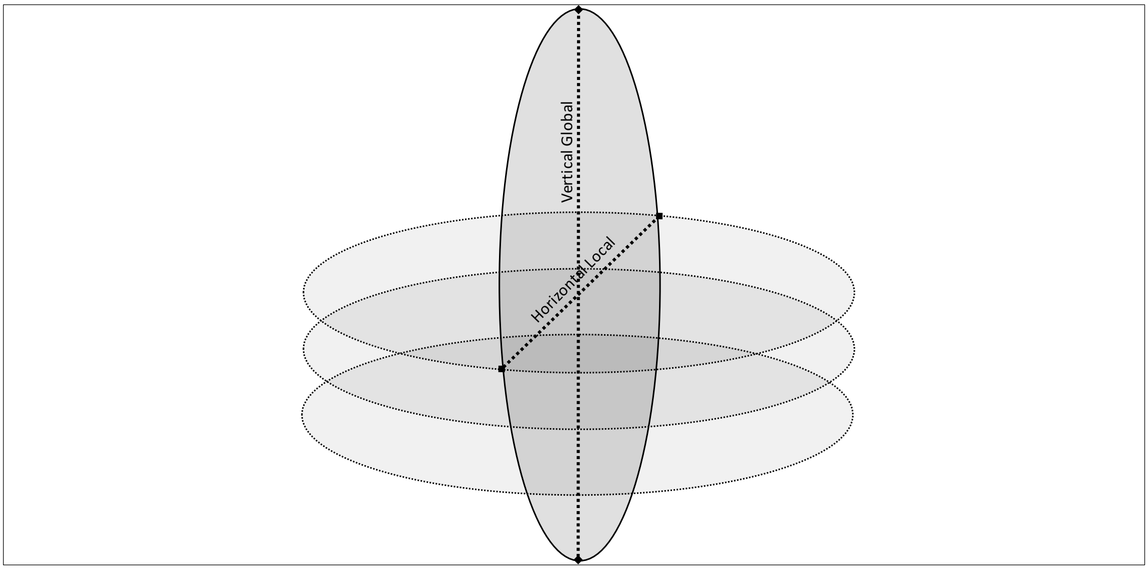
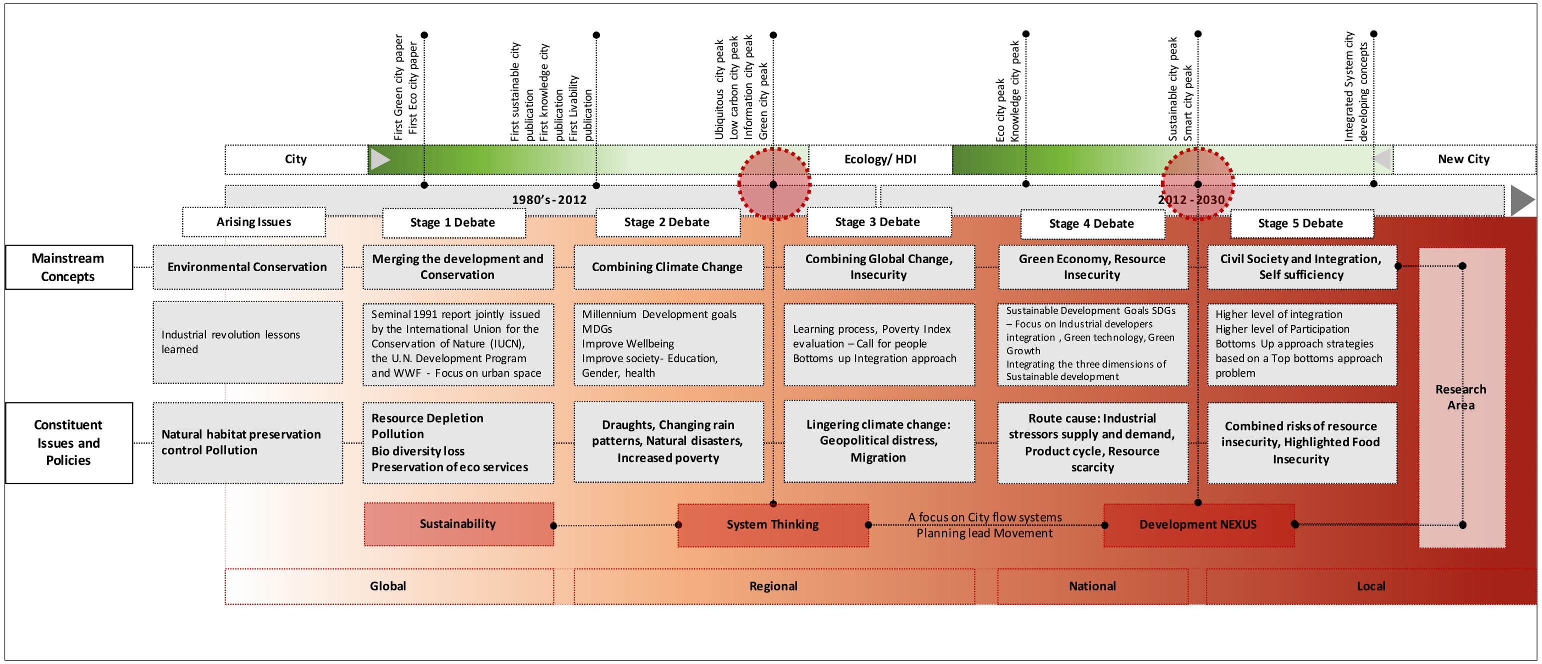


Figure 5. *Local horizontal and global vertical concerns and responsibilities intersection.*

Furthermore, action agendas in key thematic areas facilitated the means of approaching the global crisis. The five key areas emphasized by UN Secretary-General Kofi Annan were (1) water and sanitation, (2) energy, (3) health, (4) agriculture, (5) biodiversity protection, and (6) ecosystem management. Each of the development goals are interconnected through a cycle of these five key areas, revealing multiple encounter areas. Considering the flow nature of the above-mentioned key areas, it is critical to define the characteristics, level of integration, and resource efficiency of the urban infrastructure that carries them and the technologies that facilitate them. Hence, the literature on the urban system and integrated strategies in design, practice, and assessment is essential in facilitating comprehension of the interconnectivity among multiple aspects of a city system or metabolic flow while also approaching the problem of cities from top-down and bottom-up perspectives to achieve global agendas. Based on lessons learned from the MDGs, Helen Clark, a UN administrator, and a report by the World Bank emphasized factors that will be key to accelerating the shared goals for 2030. Some of the factors are related to this research: increasing engagement with local communities, together with civil society as a driver for investments in sustainable industries of food, water, and energy while controlling the consumption and conserving biodiversity and natural resource. (Figure 6) showcases the transformation of the sustainability approaches milestones that have led to today's integrated, inclusive system-thinking focus, which aims toward formulating principles for new sustainable and resilient city development.


First Green city paper
First Eco city paper
First sustainable city publication
First knowledge city publication
First Livability publication
Ubiquitous city peak
Low carbon city peak
Information city peak
Green city peak
Eco city peak
Knowledge city peak
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Stage 2 Debate
Stage 3 Debate
Stage 4 Debate
Stage 5 Debate
Mainstream Concepts
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Merging the development and Conservation
Combining Climate Change
Combining Global Change, Insecurity
Green Economy, Resource Insecurity
Civil Society and Integration, Self sufficiency
Industrial revolution lessons learned
Seminal 1991 report jointly issued by the International Union for the Conservation of Nature (IUCN), the U.N. Development Program and WWF - Focus on urban space
Millennium Development goals MDGs
Improve Wellbeing
Improve society- Education, Gender, health
Learning process, Poverty Index evaluation – Call for people
Bottoms up Integration approach
Sustainable Development Goals SDGs – Focus on Industrial developers integration , Green technology, Green Growth
Integrating the three dimensions of Sustainable development
Higher level of integration
Higher level of Participation
Bottoms Up approach strategies based on a Top bottoms approach problem
Research Area
Constituent Issues and Policies
Natural habitat preservation control Pollution
Resource Depletion
Pollution
Bio diversity loss
Preservation of eco services
Draughts, Changing rain patterns, Natural disasters, Increased poverty
Lingering climate change: Geopolitical distress, Migration
Route cause: Industrial stressors supply and demand, Product cycle, Resource scarcity
Combined risks of resource insecurity, Highlighted Food Insecurity
Sustainability
System Thinking
A focus on City flow systems
Planning lead Movement
Development NEXUS
Global
Regional
National
Local

Figure 6. *Debate milestones between the first Environmental aware approach in planning to post SDGs.*

Fittingly, higher integration and "engagement" approach is considered an important link in the indication of appropriate streams that must be evaluated in new cities'. Beyond the city context scale, a higher level of evaluation takes place in the city industries which formulate its socioeconomic behavior.

1.5 Background of Research Methodology

Grounded on lessons learned from the MDGs and SDGs, sustainable development principally targets harmonious integration between environmental, social, and economic dimensions for all product systems as part of metabolic flows and the capacity of Earth systems.

Addressing these flow systems in isolation will not grant access to sustainable food, water, and energy for all within the planetary boundaries; indeed, greater integration is critical, even when only dealing with a single-product system. Looking at them as part of a wider social and economic system with multiple influences across the full life cycle and finding products, technologies, and renewable resources accordingly (Kenway, Lant, Priestley, & Daniels, 2011).

An environmentally concerned urban-planning (UP) process can present multiple opportunities and challenges due to the different stages of changes in population and economies among cities and requires an integrated viewpoint that can allocate and tailor these opportunities to the city. The "nexus" is potentially a very appropriate approach to enhancing sustainable development outcomes. Despite its increasing popularity, there is no universal set of sectors to be analyzed when studying the nexus. Depending on the context, it provides a view point on urban metabolic activity that is largely linked to specific characteristics of city industrial, economic, and social development (de Strasser, Lipponen, Howells, Stec, & Bréthaut, 2016). Without a clear definition, it is difficult to determine what constitutes a good analysis, yet it is strongly distinguished by being a multi-centric approach rather than sector- or resource-centric (de Strasser et al., 2016).

Hence, to identify the nexus typology and limit the analysis process, an entry point from one of its resource sectors must be identified where linkages with the other two or more sectors can be identified and translated into an urban framework that can be evaluated and measured based on its influence on the city's environmental, social, and economic fabric (de Strasser et al., 2016).

In this regard, there is no clear methodology or tool that specifies the exact extent of resource degradation and the environmental effects to food systems that intersect with a specified product system and identifies synergies within the same context. However, "systems thinking can help us manage the integration complexity because it gives us a structured way of thinking about the whole system rather than its parts, and about connections rather than just content. It comes with a large set of mathematical formalities for looking at systems in a rigorous way, and offers us a considerable toolkit of techniques and tools relevant for studying nexus problems" (Alcamo, 2017).

1.6 Background of Research Findings-Future Paradigms

FEW resource sectors, in the context of product systems, can significantly reduce resource depletion and environmental degradation. Reducing it requires product systems that can be used interchangeably with urban and industrial systems and should be developed in conjunction with and in consideration of, where possible, supporting ecosystem services (i.e., natural sub-systems).

When seeking a footprint reduction in response to greenhouse gases, carbon accumulation, and natural-resource exploitation, the resource between FEW selected for improvement determines which product and technological innovation is proposed. From a food urban infrastructure viewpoint, while taking advantage of urban habitants, optimizing urban agricultural products, as already indicated above, has a profound effect on greening city systems. Recent studies have shown that "algae in wastewater treatment plants could beneficially decrease the amount of carbon release from renewable energy by 66%, with potential annual revenues of food and pharmaceutical products and $58 M from fuel production" (Walker, Beck, Hall, Dawson, & Heidrich, 2014). This new approach in using ecological services by introducing algae into the system of flows not only has great potential to reduce carbon problems, but it has also become part of the production process per se, presenting a "multi-use sustained-yield" analytical framework applied to resources (de Strasser et al., 2016).

Assessment or enabling methodologies related to the above have dominated the integrated resource assessment IRA that will be examined in the literature review. The term nexus is common to the comprehension of the complex non-linear relationship of FEW within IRA; as such, any strategy taken toward one of FEW sectors' management, production, or consumption will cause unpredicted consequences.

1.7 Research Focus

The larger focus of this research is concentrated on finding interlinkages between the smallest product system and FEW system flows in a series of inputs and outputs of the multiple variables of a specific technological ground (integrated assessment model) in addition to the guiding principles from case studies of infra-structure for product system can generate a framework that will recognize the implications of product choices and actions based on the relative impact chain that will help identify solutions that simultaneously reduce resource depletion elsewhere in the cycle and ultimately have a generic but significant role in mitigating environmental conflicts within city flows. Moreover, how this system integrates with social and economic systems must be identified and measured.

A specific focus of food and agriculture as a prime consumer of fresh water resources worldwide, and the energy used to process and irrigate water and facilitate related services which adds up to more than one quarter of global energy.

While populations continue to increase and climate uncertainties escalate, the existing agriculture patterns may change, leading toward a phase of food scarcity. Global studies estimate a critical need to increase food production from 60% to 110% by 2025. Debates, chiefly by individuals with a persistent confidence or investment in technological advancements, push toward increasing agricultural activity to overcome this threat; however, this approach will likely not be enough to limit food insecurity, especially with the abovementioned conflicting stresses of agricultural activity on the environment (Francis, 2013) and a lack of a holistic urban infrastructure remains.

Since food encompasses ecological resources and services of climatic features, water, and land availability and soil quality, delivering resilience in food security means looking at the broader sufficiency and availability and their shared environmental, economic, and social fluxes through the analysis of interlinkages of new product systems and social, institutional, and political contribution roles (Lehmann, 2017).

Within the context of Qatar as the hotspot case scenario, food and agricultural systems are a critical aspect that requires specific crop types that can be sustained under the country's climatic and geographic pressures or produced through cultivation techniques that are customized to the purpose and placed to redirect food urban infrastructure system management within the city's water and energy cycle. In this regard, a literature review on the nexus systems approach, algae product system, and urban system is required to deliver a framework for design, practice, and evaluation of the system.

This paper therefore proposes a praxis-based "urban nexus science," a framework to identify integrated and synergistic pathways to achieving urban sustainability using an algae product system in an urban-city context.

1.8 Research Question and Objective

By approaching the nexus from a food entry perspective, the research considers algae-based product systems as a new paradigm for integrating with existing systems in a given urban context with specific physical and socioeconomic characteristics. The integration aims to accomplish a lower footprint scenario when applied on an urban scale.

An urban theoretical framework will be translated into actionable practices that display a product system through which to redirect food urban infrastructure system design and evaluation-based management within the water and energy cycle. In this regard, the research question is as follows: How can a literature review of cutting-edge FEW intervention initiatives, research, and analyses of nexus system tools be employed to construct a comprehensive nexus framework that can be used to model an algae product system nexus and be translated into an actionable intervention praxis to inform the design of nexus hotspots "cities" from building to urban infrastructure in a collaborative design process that can be translated into an urban living lab or pilot scenario to measure its effect on longer-term temporal scales of maturing socioeconomic and ecosystems?

To answer the main research question, the research examines algae as an urban intervention praxis and a way to optimize urban ecological relations in light of the need to increase food resources. Algae is identified as a high potential product that will be examined to answer what, where, how, and when these interventions will take place when approached from integrated UP paradigms.

While integration may take multiple forms and levels depending on the urgency areas, the literature on these initiatives has identified main indicators based on UN's definition of sustainability, which is further explored in the literature aimed at turning toward a sustainable downward-up approach that targets higher integration on a national level, including environmental, social, and economic aspects, and is guided by global security motivations.

However, questions pertaining to the type of intervention are based on the research focus area—algae in urban production that targets a carbon emission crisis while considering the extended interconnections that may be presented by it. Where these interventions may take place is based on analyzing urban systems, specific application opportunities in algae cultivation as a product, and is specific to the context of study. Questions of how are answered based on the urban system and processes of urban flows in relation to algae cultivation system flows ultimately merging into a socioeconomically and environmentally beneficial system that can be challenged and tested for efficiency. Questions of when these interventions must take place are discussed in terms of the process of urban development and systems, allocating different types of intervention to different temporal extents.

1.9 Research Structure

The research follows a deductive approach. Each step/ chapter plays a vital role in the alignment of knowledge and instructional data, which will help in drafting an intervention strategy specific to the goal or product of the research. The intervention knowledge is applied through the literature and calculation-based factorial relationship design-based evidence for the purpose of capturing the complexity and performance of interdependencies between urban algae and the urban resource nexus (Figure 7).

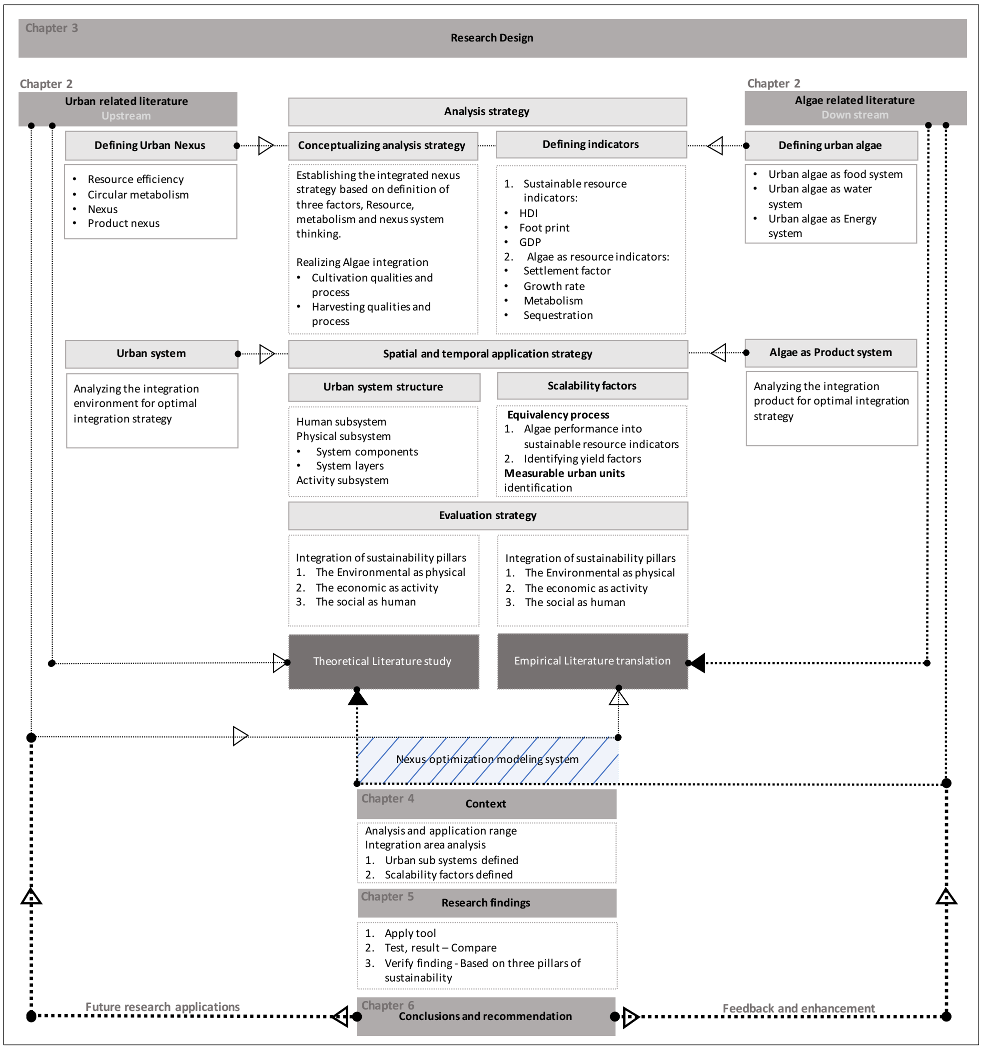


Figure 7 Research structure diagram.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

For food as a resource which is at the heart of this study, the literature is focused to inform the process of which a practice towards higher level of integration may be applied considering all related resources and context.

More specifically, the literature of both the nexus and urban system is essential to engage an algae product system-based intervention which will ultimately deliver a set of recommendations for the design, evaluation and praxis as per the research objective. The sequential goals of this chapter are as follows (figure 8):

- The problem based literature: Although food security generators extend further than climate change, the literature is focused more on how climate change and resource stress relates to it, while also stating the further connections it has on the other socio economic and political factors which have been defined as crosscutting risks within the cycle of natural resource instability.
- The methodology based literature which focuses more towards integrated systems approach in future paradigms. This section aims to provide insight into the complex interplay and trade-offs between city flows, of food, water, energy and the materials and land involved within these flows using the concept of urban metabolism. The nexus approach presented in this fold explains interactions between urban systems and the supply and demand of resource. It aims to demonstrate the relevance of the global resource nexus to food system and product subsystems to be strategically used to demonstrate the specific adopted nexus framework in chapter 3 which will ultimately scale down the perspective towards a (Morpho-functional one) local one (Bekkers, Gehem, de Ridder, de Jong, & Auping, 2014; Hackett & Dissanayake, 2014; Hettiarachchi

& Ardakanian, 2016). The knowledge gained from this literature shall contribute to bridging a road map to the methodology for evaluating the design of sustainable systems.

- The context based literature. The discussion in chapter one highlighted cities as a place to generate solutions, accordingly, this section extends the definition and understanding of city systems, it discusses these interconnections from planning perspective based on urban system components, layers and drivers. The knowledge gained from this literature shall contribute to bridging new strategies in the design of sustainable systems.
- The findings based literature. This section begins with highlighting advancements of algal use within food, water and energy sustainable practice. Guided by the methodology based literature, the knowledge gained from this literature will deliver the necessary knowledge needed to bridge the product based system within the larger city system components and layers at a higher level of integration.
- The literature will end with a list of instructional data and recommendations for integrated product system in the design, evaluation and praxis in participatory integrated manner.

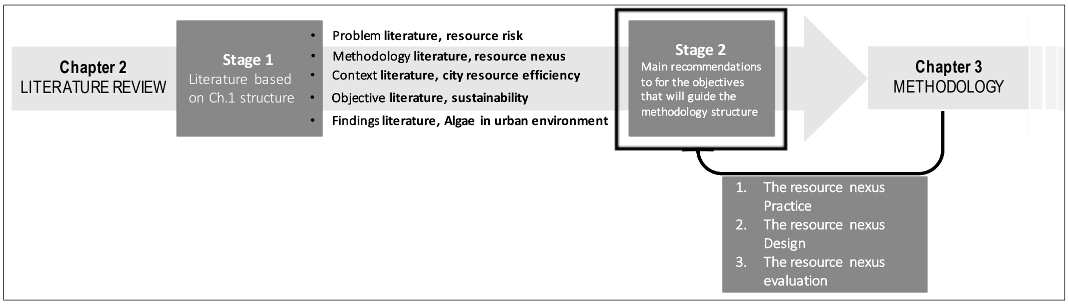


Figure 8. *Literature review chapter 2-subsequent stages.*

2.2 Problem Based Literature

Referring to the problem background in chapter one, this section discusses urban resource in more climate risk depth while putting focus on the higher motivation in regard to food security and its related industries and production.

2.2.1 Urban resource

The United Nations Environment Program (UNEP) defines resource as anything that comes from nature which can be utilized in human related production. In Biology and Ecology disciplines, “a resource is a substance or object in the environment required by an organism for normal growth, maintenance, and reproduction”, when Anthropocentric stressors take the role of an organism, the stress of growth shifts from essential life and reproduction needs to scale of answering questions of ‘how much is enough to run the urban margin of anthropocentric needs? Like living organisms, cities require natural resources such as materials, water, energy to maintain socio economic activities and the daily needs of human inhabitants towards achieving wellbeing (Kennedy et al., 2007). Earths bio capacity determines the availability of resource. “Bio capacity is the ecosystems’ capacity to produce biological materials (supply) used by people and to absorb waste material generated by humans, under current management schemes and extraction technologies which deliver the (demand) for end pipe resource, UN" Web1.

Referring to the UN sustainable development definition in chapter 1, the specific metric (1) "well-being for all" measured by HDI; human development index, a reflection of the social aspects of each country and its endowment and ability to trade. (2) "within the means of nature" is measured by the EF (EF)". In other words, reflects the *demand* of humans on and *supply* of nature by tracking six indicating classifications of resource productive surface area, these are "cropland, grazing land, fishing grounds, built-up land, forest area, and carbon demand on land/ Carbon footprint" UN.

Clearly there is a distinction between resource material or immaterial, renewable or non-renewable characteristics that result in different scenarios when used excessively. Resources which may no longer be obtainable for the same purpose once harvested as a result of changed characteristics may result in negative outcomes along the line of its production chain (Kennedy et al., 2007). For example, excessive harvesting of forest wood disrupts natural carbon sequestration and result in rising levels of carbon globally and subsequent loses such as changing rain patterns, bio diversity devastation due to these atmospheric imbalances. Aggregating this problem is the loss of forest land ability to expand due to agricultural activity and livestock, all which are anthropocentric food related activities. Non-renewable resource which need long geological periods to be formed and cannot be replenished once they have been collected which puts them at risk when depleted. These include metals, fossil fuels and mostly for energy and manufacturing, also minerals used at industry and construction levels such as roads and buildings.

2.2.2 Food resource

In relation to food as resource, agricultural crops, forestry and water are also at risk of depletion if no balance strategies and contamination policies are at place. Furthermore, overfishing and fish species loss, soil sealing preventing natural forestation, excessive water abstraction which result in increased salt levels in coastal aquifers or contamination by dumping waste in oceans ultimately escalating climate change factors, footprint and ecological deficit- are all examples of consumption beyond regeneration capacity.

The dependency between food resource security and climate change studies is substantial. While agricultural industry and products is a supplier for food systems, it also heavily relies on natural resource both renewable and non-renewable provided by a network of infrastructural system which mainly include intense dependence on water and energy. Together with their significant role in GHG emissions that contribute to the greenhouse effect where gases responsible are mostly carbon dioxide (CO2), methane (CH4), nitrous oxide (NO) and fluorinated gases. Based on UN measuring standards, the GHG emissions are translated in carbon emission equivalents for ease of measuring gas related stress.

This is displayed in the latest GFSI report 2018, which focused on food security resilience meaning the capability of a country to bounce back from a crisis and improve previous methods in its food systems which will deliver new innovative methods that elevate the resource system as a whole throughout its food production and provisioning interconnectivity. The report’s findings are fundamental for this research as they display some major aspects on how climate change mitigation relates to the overall food resilience. Five main points will be discussed in the essence of global resource risk (Figure 3).

First, the Natural resource of land, fresh water and oceans make up the foundation for food security. The larger dependence of food supply is on soil health for agricultural purpose for food, animal feed as well as fuel production. For large mass industry, soil is replenished by natural or chemical based fertilizers. The replenishment helps in reducing cropland sprawl, however, it presents a large set of embedded and direct emissions some which are based on average CO_2 emission factors for NPK are, 2.792 kg CO_2 equivalents / kg N, 0.738 kg CO_2 equivalents / kg P_2O_5, 0.352 kg CO_2 equivalents / kg K_2O. Also, there are emissions to be considered from fertilizer processing and use. A life-cycle assessment for Nitrogen based fertilizers revealed emissions during the production (410 Mt CO_2-equivalents/year) which is equivalent to 0.8% of the global GHG emissions. Water is a limiting factor for food agriculture and must be available in high quality, proximity and chemical composition to sustain food industries. Oceans are the main source of fisheries and can be substituted by aquaculture.

Second, the growing number of people and demand for food is causing agriculture to slip away from being a provider for well-being into becoming a risk factor in terms of global resource stress and ecological disruption. Climate change is affecting all countries in by draughts, floods, increased temperatures and limited precipitation which will intensify the above resource stressors, disrupt physical systems and cause agricultural crop growth uncertainty by limiting natures ability to regenerate as well as manage and sink all organic and chemical waste. However, the case is worse in the Middle East. The sea water quality is increasingly declining in terms of increased salinity, contamination from industries, and over fishing which stresses managing it as a water source and reliance on fisheries as a main food source. Today this is managed through aquaculture which also disposes large contaminants and organic matter in the ocean and land depending on the type and location causing dead zones, acidification and hypoxic scenarios.

Third, Financial risks that accompany countries dealing with food and food stuffs imports, subsidizing their water and agriculture industry by high cost technological solutions, that threaten food affordability for all income levels. The result of these dependency areas present social mistrust, food price shocks, which trigger conflict and can better be resolved through an internal investment in local food production within the resource limitations and trade opportunity areas which also becomes a safety net for short term shocks.

Accordingly, the fourth point is Political stability. It is essential to allow a steady flow of material and diversifying food resource and relieving agricultural production agglomeration. Hence, conflict and political instability becomes a main player in disrupting supply threads which diversify production sources through trade. Also, extreme political crisis includes damaging food production areas, infrastructure transport routes, water and energy resource flow.

Fifth, Trade, which is vulnerable by increasing isolationism product type silos where each country prospers in a distinct industry. Ideally, all countries should participate in global food trade which result in stable food prices, buffer fluctuating produce and allow room for global agreements which protect global resource. However, achieving a sustainable global scenario means all countries must have storage, infrastructures and transport reliability.

2.2.3 Agriculture and food industry

Traditionally, food resource efficiency has been focused on production and consumption for the supply and demand of an urban society. The dominant centralized system type in agricultural industry today is described as monoculture input-intensive practice (Figure 9). This has enabled higher yield of essential staple crops such as maize, millet, sorghum and wheat and food production by the controlled intensive resource flow. Main resource related to the industry are fertilizers, water and energy demand.

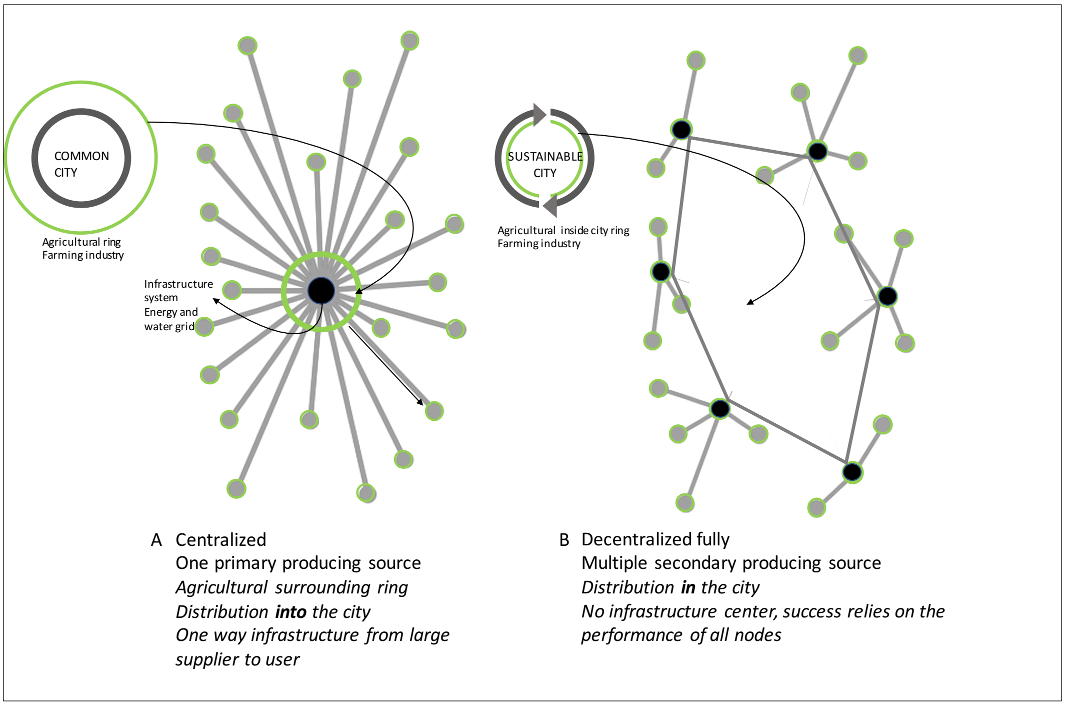


Figure 9. *Centralization and decentralization of agricultural systems*

The centralization is not only on the level of production process, it is entrenched in the centralized infrastructure physical urban system which enables the transportation, water and energy access.

In Case A, the system is largely centralized where main supplier for agricultural produce and infrastructure flow is dominating the system. Infrastructures are decentralized when buildings become suppliers of energy or recycle water. However, in most cases, the larger energy and water grid remains an essential factor in the large-scale performance of the city and cannot be excluded or effected by externalities easily as in the case B. Both systems present benefits and restrictions which must be considered in an overall systems goal (Table 2).

Today's sustainable approaches include the use of decentralized systems in order to achieve higher goals of integration and inclusion. An advantage of decentralization is the ability to make decisions faster which allows higher level of experience for management individuals as well as the ability adapt to sudden changes such as demographic changes or resource source change.

Table 2 Characteristics of Decentralized and Centralized Systems

	Centralized	*Decentralized*
Distribution		
Management	All the decision making and authority are focused on the top tier of management.	Delegates authority throughout the organization and to all levels of management.
	Has low involvement of public participation	
		Is highly based on inclusion of public society input.
		Decentralization typically entails restructuring public enterprises by making them accountable to local governments rather than central line ministries.

Reliability	*Large infrastructure systems are designed to deliver services in a way that balances a variety of potentially conflicting objectives including economic cost, environmental impact and reliability.*	Accounting for economies of scale and externalities is especially important when decentralizing decision making and responsibility to low levels, and when infra- structure projects cover multiple jurisdictions, such as in managing water resources across large water- sheds or trunk roads that connect regions. Promoting equity, harmonizing standards, and ensuring efficient revenue collection may also argue for limiting decentralization.
Alteration	*Become particularly challenging when societies face the potential for rapid infrastructure transitions*	*Easily altered and managed without effecting the larger system performance*

Another factor in the larger regional and global perspective on decentralization is countries with low soil fertility and climatic restrictions that rely majorly on imports from countries that have rich soil, mostly developing countries where manpower and crop is abundant in lower prices. This has been identified as a risk that extends the impact and environmental externalities from demand of one country to another.

Economy is largely responsible for this pattern of industry, specifically in food and energy where fossil fuel exporting countries take a hit from high ecological foot print per capita whereas most of the energy is consumed elsewhere. Thus, financing food production in local allocations is a key measure. The problem extends also to the geopolitical security of importing countries and the long-term food security of their ever-growing population(Amer, Adeel, Böer, & Saleh, 2016).

A distinction was made between security and self-sufficiency to emphasize on the need for today's cities to become more sufficient in order to release environmental pressure globally. (Figure 10) illustrates the levels of security from the import point of view.

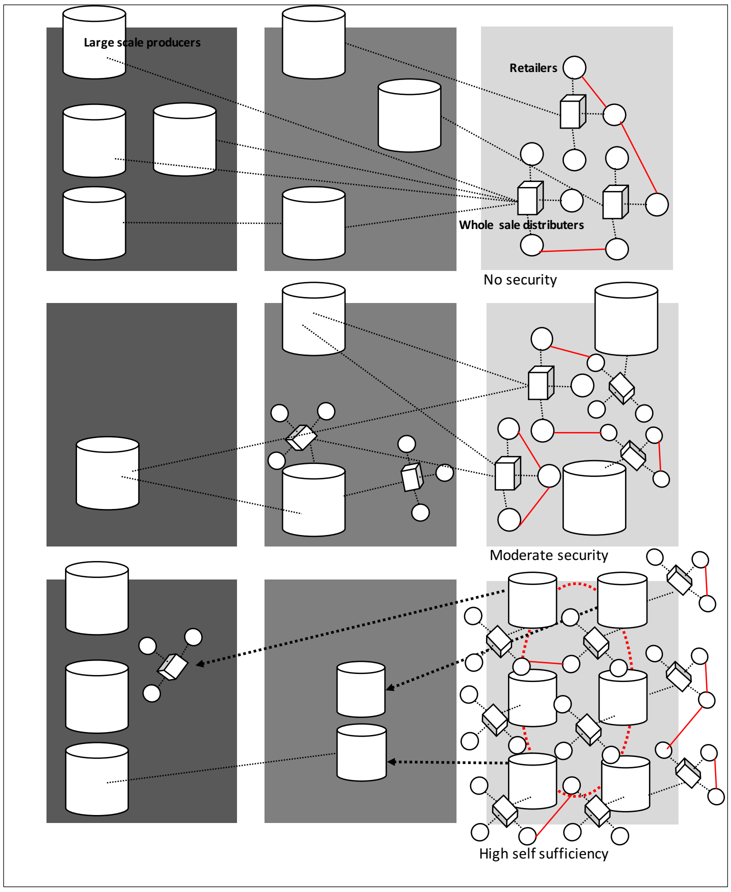


Figure 10. *Food industry security related import system.*

Looking at the broader picture of the urban chain, sustainability in food production begins with an industrial attitude shift, that is more ecologically sound and a supportive governance and political stability (Figure 11) (Dufour, Kauffmann, & Marsland, 2014; Sassi, Sassi, & Acocella, 2018)

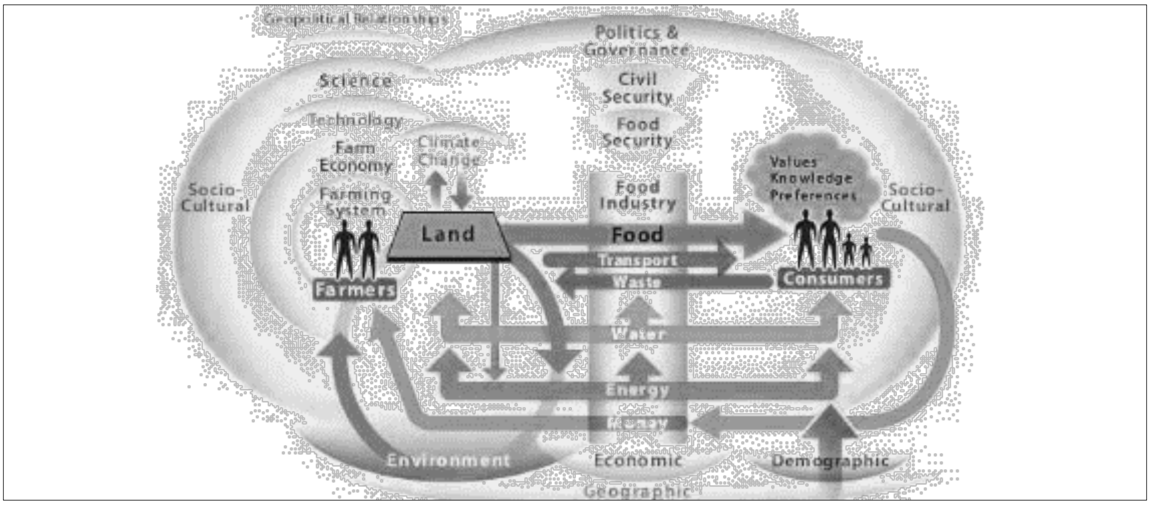


Figure 11. *Food industry relation between human social, economic and environment.*

2.2.4 Industrial ecology

One major factor to consider in industries is that while many resource and services we get from nature might be renewable, the use of non-renewable resource does not need to be as forward as it sound. Mimicking natures resource production with the help of technology and innovation has allowed a once considered nonrenewable resource to become renewable within the urban ecological chain of supply and demand.

Industrial ecology relies on clear understanding of the initial product metabolism/resource flow chain and lifecycle habitat consideration which can be mimicked to either reproduce the same resource in an optimum timeframe or manipulating conditions to enhance the product quality as fitted to the endues or market need. Examples include, biomass into biofuels by controlling temperature and pressure atmosphere which in nature would take hundreds of years as well as mass agricultural production by changing cultivation conditions to enhance productivity.

To achieve such control, an infrastructural system and physical environment is required by which planning becomes a lead player in the allocation and design of the system in relation to resource flows.

Industrial ecology involves sustainable empowerment of industrial systems using ecological services. The ability to develop cities, deliver and process resource from raw material to fully functioning food, water and energy aspects stresses on the strong relation between industry and ecology. By studying the interaction between living organisms and the physical world including urban environments, a deeper understanding of biological systems present opportunities for establishing new ecological service-based relations into the urban industrial system. Industrial introduced organism accordingly can conduct activities throughout resource cycles which may showcase benefits both environmentally and economically.

Furthermore, possibility to manipulate organisms throughout their life cycle using controlled environments and systems can inflate or redirect these benefits. Two types of industrial systems are identified in industrial ecology discipline, the (fast replacement system) and the (slow replacement system). Both these systems work on the lifetime and stages a material or substance needs to travel from the start point of production until consumption endpoint. By extending the time and stages it implies that we are finding interceptive uses of the substances which could become more circular rather than linier in the fast system direction. This brings positive impact on the resource depletion and environmental consideration during the life time and disposal of things. Third stage is the replenishing system which creates a spiral economy system which minimizes the use of matter and resource without restricting economic development. It relies merely on the “Four R’s” using technological advancements to reach the full potential of a material in the following loop phases, these are, reuse, repair, recondition and recycle. The idea is to avoid recycling materials which can be directly reused, or which would require a smaller level intervention to allow it to enter back to the system (Figure 12).

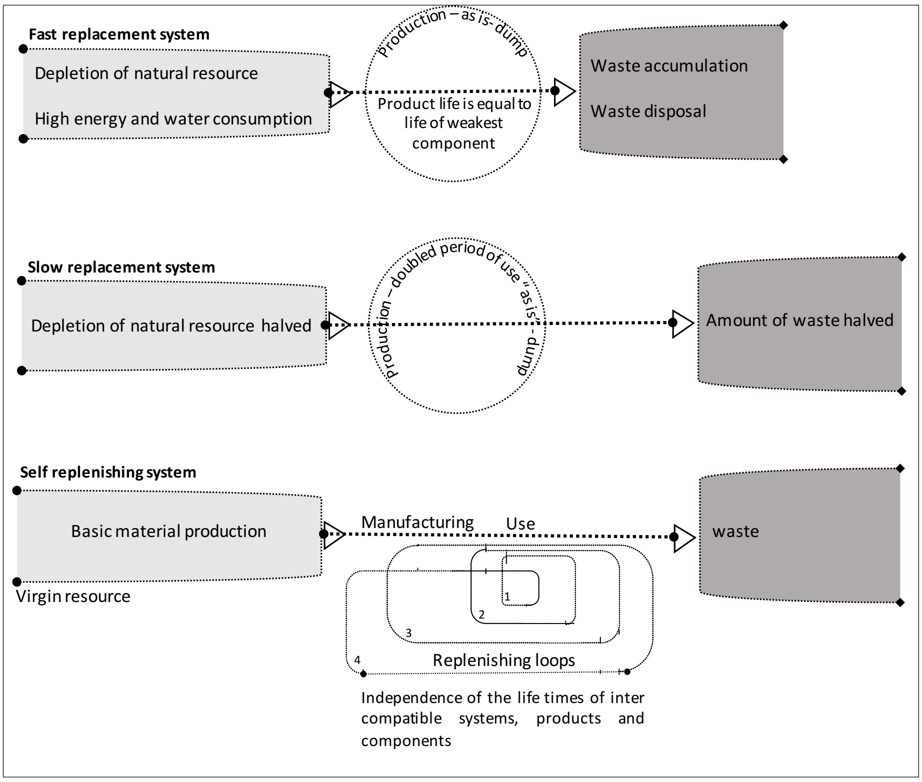


Figure 12. *Fast replacement system, slow replacement system and self-replenishing system. Source: Author 2019-adapted from (Al-Ansari, 2015; Graedel & Allenby, 2010).*

2.3 Methodology Based Literature, Evolution Of Multidisciplinary Concepts

In order to become resource efficient, two main aspects are at the forefront of any resource driven approach, these are the supply and demand factors/ consumption and production related aspects. Sustainable consumption and production (SCP) is an approach towards finding a balance between resource use and the carrying capacity of the natural system. That means developing more sustainable productive ways of using resources throughout their life cycle in order to decouple economic and social growth from resource use and its environmental impact.

2.3.1 Urban Metabolism

As a result of this new paradigm, Urban metabolism concept becomes a more suitable approach in looking at resource urban encounters and flows. Urban metabolism enables looking at the city systems functioning and performance in a sense of inputs and outputs with measurable entities along the flow line (Musango, Currie, & Robinson, 2017). The beginning of this concept did not originate from urban perspectives, initially, the concept was used by scientist to deliver analytical results around materials which enter in specific system flows (Chen & Chen, 2016).

2.3.2 Integrated resource assessment IRA

Integrated resource assessment IRA is increasingly related to urban metabolic analysis by which it provides a snapshot of food, water, energy and waste flows to identify opportunity for a higher level of circular metabolism.

It is commonly achieved by the involvement of specialist individuals together with planning to assess practical steps towards resource savings and value(Alpopi & Manole, 2013; Letcher, Croke, & Jakeman, 2007). IRA is merely focused on producing policies which guide city development decisions. It is mostly used as a business development analytical tool as a set of interconnected diagrams with multiple domains and their variables identified. Each variable is presented by a set of indicators of supply and demand, consumption and production, not restricted to any specific scale of study (Bringezu et al., 2017). However, the main idea behind IRA is to expand the view point towards a resource problem to inform business solution which can decouple development models from environmental impacts (Figure 13).

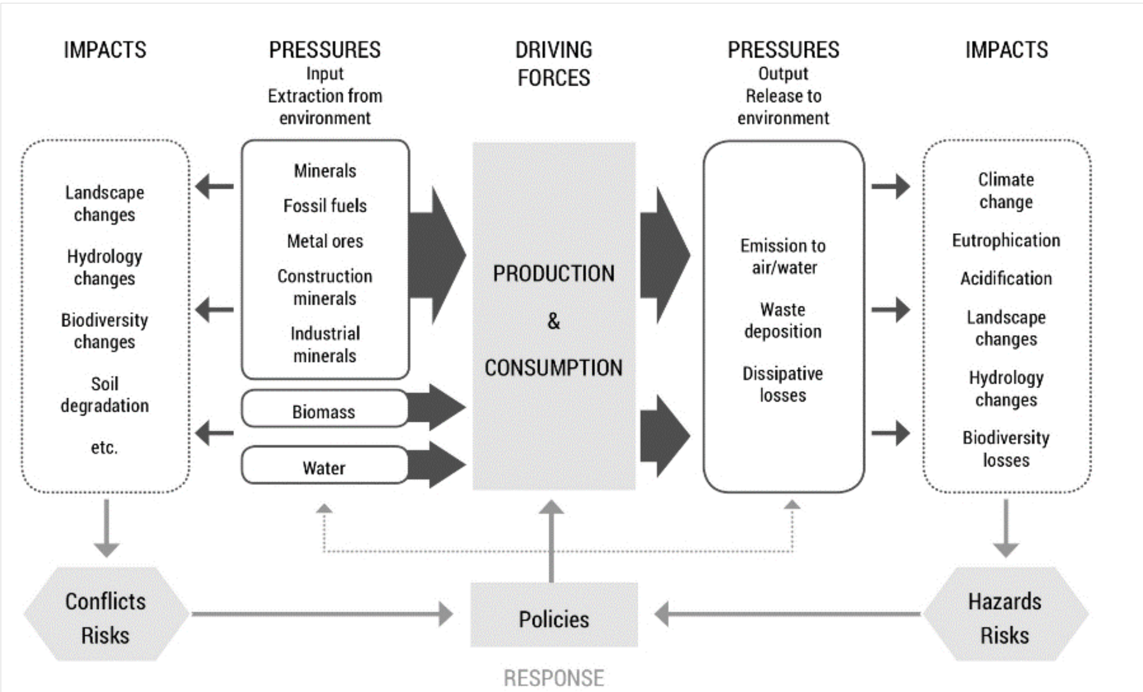


Figure 13. *An IRA response diagram used to allocate pressure areas resulting from production and consumption for intervention. Source: (Bringezu et al., 2017).*

Today, cities are considered as mega organisms which exhibit multiple loops of resource entering as input, undergo some transformation and exiting as output or convert back into the system as inputs with new purpose along the circular metabolic cycle. This provides a morphological framework to study the interactions of natural systems and socio-economic processes that occur in urban regions and turn outputs into inputs which is essential for the continuity of the environmental system of its habitat. Also, understanding that natural and urban systems have limits in processing input and output as a series of filtration, absorption, storing and producing which must be considered from the smallest production locally up to the largest scale of its global involvement.

For the convenience of business models, Today's most widespread approach to urban processes consists on "a linear model of production, consumption (of resources) and waste disposal"(Bekkers et al., 2014), this is due to the streamlined approach to production models of this era where economic concerns overshadow environmental wellbeing (Figure 14). Environmental needs voice within that stream can only become more evident with the support of national policies and governance legislations within the industrial stream (Howarth & Monasterolo, 2016).

Below, the block scenario presents the city as industrial, social and economic form that is in constant growth and imposed on the natural surface of bio capacity(Figure 14). The idea is to increase the integration level of the metabolic thinking towards the larger context of the city social, economic and the environmental characteristics (Howarth & Monasterolo, 2016).

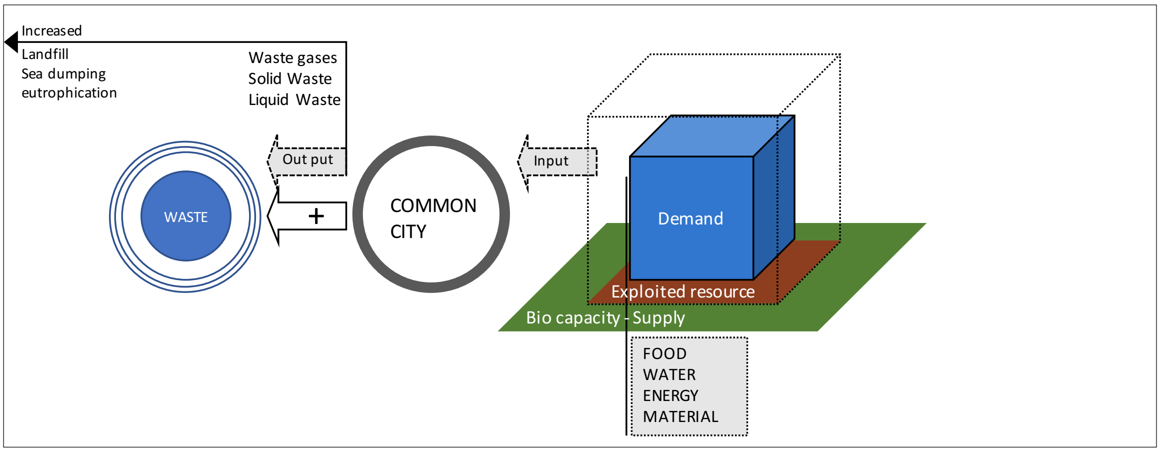


Figure 14. *The linier block scenario of the city model.*

Although the industrial production economic and social management factor may be retreated in current circular urban metabolic frameworks, the approach has stabilized a significant bridge for environmental concerns in the urban development model (Kenway et al., 2011). An example in New Chaiten was established to create a relationship between the urban design and flows to achieve sustainable settlement. Chaitn is categorized as an extreme urban settlement which presented a set of inequity scenarios due to the isolation and mismanagement of its linier flows. The study focused on the application of circular management of resources flowing into the urban development/city. The methodology of this study was based on three milestones.

First the deep analysis of the areas context (macro region) in terms of landscape, ecosystem, biodiversity, geology, hydrology, microclimate and geotechnics. Second, providing the design tools, the illustration of Chaiten's main resources in a set of diagrams which represented the flow of water, energy and waste. Third was the development of the design which best fits the context of the area and its specific situation (Allen, Griffin, & Johnson, 2017). Based on Steven wheeler, "to achieve the environmental goals of (urban) sustainability, the physical design should reflect the local climate, ecosystems, materials, energy flows, water and resources". The first set of diagrams illustrated the actual resource linier line of flow, the second was based on a circular metabolic management with technology integration scenario where both were compared for efficiency.

This concludes four main steps in resource circular metabolism solutions, (1) conceptualization of the resource condition and context involved, (2) Configuration of the functions involved in the which includes the design, technical planning and financial planning to ensure the feasibility, this is displayed by architectural plans, building information modeling BIM, operation modeling. (3) Implementation, the construction phase which effectively distributes the resource supply channels. (4) Operation that involves continuous improvement and quality control based on feedback about resource inputs and outputs lifetime during the lifetime of the project.

Appropriately, the questions is how we can reduce the resource stressors without slowing development of social and economic domains of the city(Chen & Chen, 2016). In the building sector of city development, answers may lie by the technological and human acting elements. Finding links between primary industries and urban development is the way forward. It is through the understanding of evolutionary practices of the urban system we can deliver new lens for transitioning away from resource intensive silo practices such as ones seen in intensive food production (Kenway et al., 2011).

2.3.3 Agro-Ecology

Agro ecological efforts and industrial ecological systems are forming new production ways to cope with the growing population and demand as well as the changing lifestyles which have led to the current silo practice (Haug, 2018). Argo ecology relies on finding interaction and productivity across agricultural systems as a whole which can integrate new resource systems over time and space. The movement is a step towards sustainable food systems as it reconnects the human resource flows into the agricultural production cycle that value community participation and empowerment (Haug, 2018). A large part of the system is based on recycling with minimum external input and high nutritional produce through diversifying systems- which include seasonal rotations, animal integration, polycultures, green manures and organic amendments led to the investigation of agriculture incorporated into urban areas. This relies on identifying the farm basic system components, plants, soli, water, climate, animals, and people in the context of the local farmers knowledge, geographic, climatic and ecological qualities to reach a best sustainable outcome for the area.

The diagram below (Figure 15) showcases urban farming model that utilizes landscape lots for growing local produce. Connections are established from the infrastructure of water and energy feed into a household and output flows of waste water and nutrient feeding back in to the system expanding into another set of connections of small scale food agricultural production (Thompson & Scoones, 2009; Tuzhyk, Hewelke, & Hewelke, 2017).

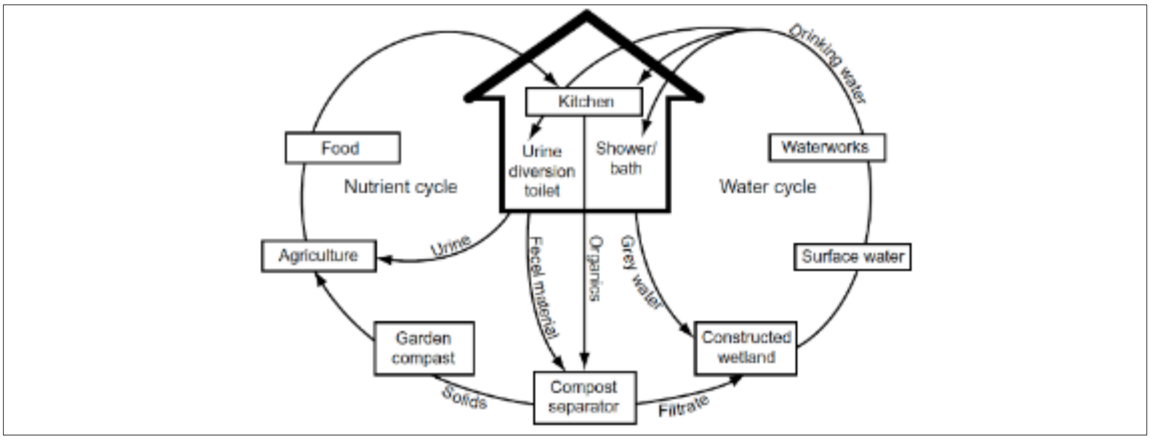


Figure 15. *Urban agriculture circular model from a household. Source, (Thompson & Scoones, 2009; Tuzhyk et al., 2017).*

Growing crop and food in urban areas shows great potential when considering space utilization. In some cities, urban landscape has transformed into production and community centered production place. The approach brings a new perspective to the flow of agriculture by presenting urban output as input after some minor filtration and material management is done. This is capable of increasing yield beyond economic and large-scale industry. As such presenting a key towards decoupling environmental stress and food production to considerable limits(Pickett et al., 2001). It also brings a new light to financing agricultural produce through empowering society with self-sustained and sufficiency lifestyle (Thompson & Scoones, 2009; Tuzhyk et al., 2017).

However, the climate and natural condition of an urban region influences the level of production, maintenance and complexity of growing food. For that reason, best practices remain guided by the ecological system best suited for the area as learning from indigenous ecological service sand biodiversity to find best type, process and intervention strategy that can be well sustained over the years. Hence, acknowledging the high reliance level for information related to applied agricultural system, practice and context knowledge to enable agro ecological systems(Gliessman, 2014).

2.3.4 Ergo-ecology

Considering diversifying agricultural systems into urban applications which are considered the physical space made by humans to fulfil livelihood needs, literature on ergo ecology is relevant. The term merges ergonomics and ecology into one.

According to International Ergonomics Association (IEA), Ergonomics is “the scientific discipline concerned with the understanding of the interactions among humans and other elements of a system, and the profession that applies theoretical principles, data and methods to design in order to optimize human wellbeing and overall system performance”(García-Acosta, Pinilla, Larrahondo, & Morales, 2014).

The merge is established by focusing on the interactions between the main elements of ergonomics; human beings (HB) with the physical environment that consists of (1) physical spaces (PS) and (2) objects and machines (OM) which altogether coexist and interact with the ecological system (figure 16).

The new multidiscipline extends the scope of both the built physical and the natural of this century’s human led problems through new concepts and principles which aim to provide tools to reach sustainability in production and environmental preservation.

From the urban physical environment perspective, The ultimate goal of ergo ecology is to reduce the gap between the built and the natural environment(Lange-Morales, Thatcher, & García-Acosta, 2014). This is presented in three main ways mainly around the idea of humans transforming the material world for their needs based on characteristics and limitations which ultimately create a production between action and result(Lange-Morales, García-Acosta, & Bruder, 2014)

UP is a human triggered change of the physical environment for large scale needs. This change results in inputs into the physical system and output flows which are achieved through a technological and administrative systems. However, ergonomics does not consider the interaction of the built environment on the larger natural system when buildings, streets and other physical products interact with the human and beyond. Which leaves room for natural environment and resource negligence.

This interaction falls into (Science and technology (ST), (political and legislative) (PL), (Social and cultural) (SC), (economic and finance) (EF), (ecological and geographical) (EG) categories identified as surroundings. It is in that sense, ecology is brought together with ergonomics. It can be established that Ergo-ecology is the result of interface between the ergonomic system and the surrounding categories with specific focus on the main source of resource for achieving built environment, the ecological and geographical category (Figure 16).

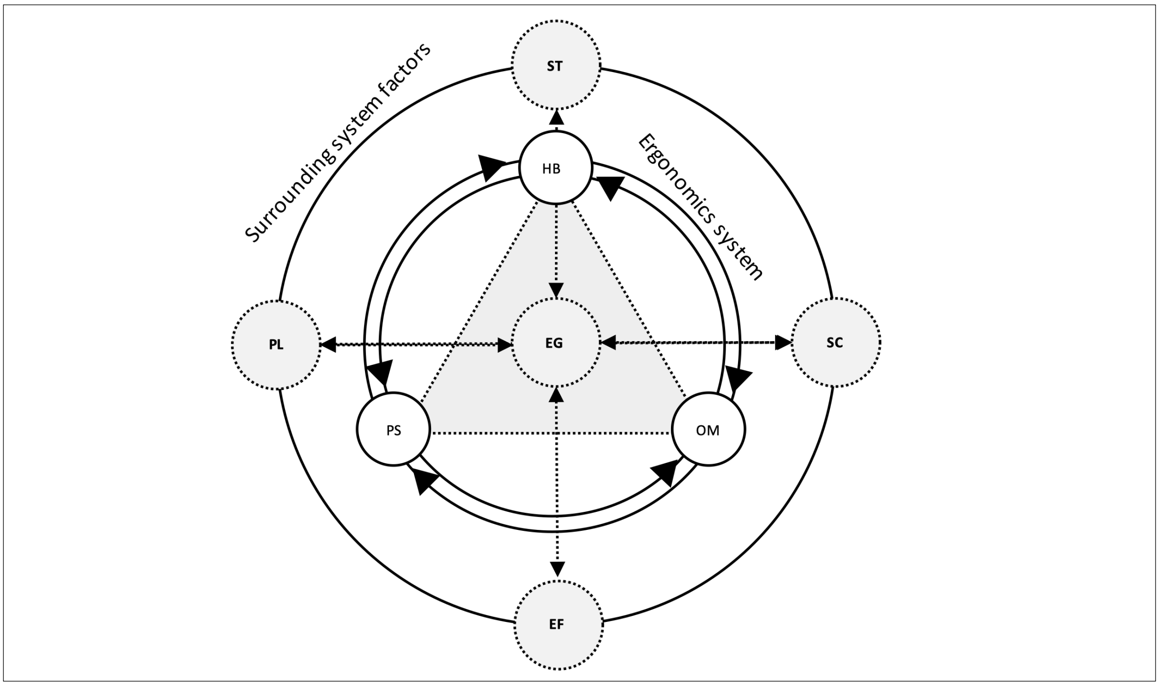


Figure 16. *Ergo ecology between ergonomics and urban physical environment concepts. Source: Adapted from Garcia Acosta 1996, (García-Acosta et al., 2014), Author 2018.*

The discipline highlights that objects and machines cannot be considered independent from the physical built environment. The relationship between building and machine is thus considered integrated and bilateral with different inputs, outputs and results along the two sides (García-Acosta et al., 2014). In addition, the approach is highly Anthropocentric in the way it considers physical design decisions in conjunction with the machines which enable these physical aspects in specific time and space or continuously weather static building blocks or dynamic supply flows in an urban physical setting with the humans who influence these decisions in the sense of innovation, use, need, demand and consumption or are influenced by them in the sense of how they behave in regards to decisions, consumption, use as well as the cultural acceptance and social interactions presented by this two sided relationship.

2.3.5 Resource Nexus

"Nexus" is a potentially very appropriate approach to describe these the complex interplays and enhance sustainable development outcomes in both the tangible environment and the intangible systems which connect to it. A term which is common to the comprehension of the complex non-linear relationship between FEW resources.

Two types of nexus outlooks are distinguished by the level of integrative thinking, the latent and manifest nexus which in both cases "expands the range of choices available for solving a problem by broadening our thinking and helping us articulate problems in new and different ways"(Walker et al., 2014). The nexus approach to the problem at hand may be risk based or opportunity based depending on the main drivers of the nexus analysis. In most cases, related to climate change, risk based assessments are dominant (Bekkers et al., 2014) (Al-Ansari, 2015)

The (1) manifest nexus, an extension of the metabolic flow of single elements is completed by further interconnected analysis of the raw material processed into the metabolic system and the direct, well-defined exchangeability of these materials between socio economic domains of the city before finally linking the emissions and stress of these flows. A downward up approach to the single resource performance. The second nexus category is the (2) latent nexus which seeks to untangle the hidden relationship between system resource flows and the socioeconomic behavior interwoven with the built and natural environment of the city. It could also be argued as the behavior of consumption and production directly related to the human aspect. Latent and manifest nexus definitions are similar to the UN definition of sustainable development, they both aim to connect environment wellbeing with hidden socioeconomic factors (Lehmann, 2017).

An environmental concerned UP process can present multiple opportunities and challenges due to the different stages of changes in population and economy between different cities, it is destitute to an integrated viewpoint that can allocate and tailor these opportunities to the city (Bekkers et al., 2014). The focus on urban scales is a major factor for developing the most suitable approach towards any integrated analysis. Specifically, towards different contexts. This is because city scales involve multiple system cycles, full system, sub system. In a large scale analysis, main centers of metabolic flows can vary, some which are centralized and some which are decentralized (Roberts & Kanaley, 2006). This is where a manifest and latent view can bring together resource and development system cycles under one viewpoint that results in "eco-efficiency and eco-productivity as measurements for how balanced (or not) the relationship is between these systems"(Alcamo, 2017). "Eco-efficiency is understood as a rational and balanced management of economic, social and natural resources, while eco-productivity is understood as the ability to produce any kind of products without generating negative impacts on the environment" (Alcamo, 2017; Huesemann, 2003).

2.3.6 Product nexus

Scaling down, all resource flows are comprised of multiple industrial production cycles. A single resource flow study contains combined product systems analysis of intermediate, secondary and primary flows across the system boundary. These flows may interconnect by the waste or process factor and shall be taken into consideration. The product system is at the center of the industrial prospect of ergo-ecology, it relates human activity systems to natural systems. All human services and resource production are industry based. The different subsystems of physical and flow aspects of the industrial activity in an urban area are central to finding synergies along the flow line of a single unit or product starting from raw material extraction to the end product life line by which an integrated product is established (Al-Ansari, 2015) to improve product manufacturing and design and for promotion of their uptake by consumers.

2.3.6.1 Material flow analysis MFA

MFA is commonly used as an analytical tool for industrial product scales of a well-defined system as it relates to different industrial sectors. “It is based on the principle of mass conservation changes: Mass of input flows = Mass of output flows + stocks” (Pincetl, Bunje, & Holmes, 2012). It assesses the flow of materials entering and crossing a city system and their related stocks. MFA are useful accounting tools for urban activities and their interaction with the environment, they need to be used in conjunction with other approaches to get a comprehensive picture of the urban metabolism and its implications(Pincetl et al., 2012).

Together with the larger outlook if IRA, MFA becomes a significant data analysis tool that quantitatively presents system results in reproducible, understandable, transparent fashion which integrated solutions are derived from. It is an important tool to study the bio-physical aspects of human activity on different spatial and temporal scales to review sensitivities, and uncertainties. It is considered a core method of nexus metabolism analysis (Figure 17).

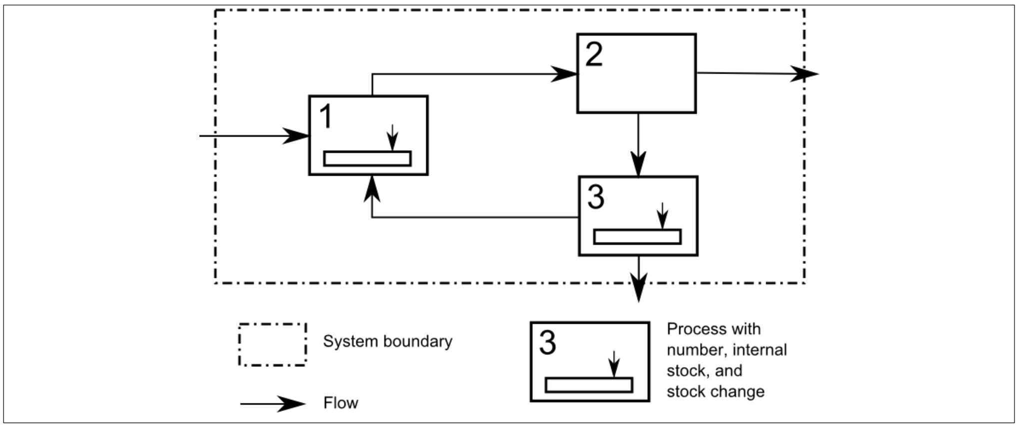


Figure 17. *Material flow analysis example including flow lines, quantified indicators and system boundary, Source: Cadmium, EU, 27-2009.*

2.3.7 Nexus scales

The approaches discussed above have been adopted by many organizations through the visualization of a global resource nexus that brings forward an expanded scale to sustainability perspectives. The Ergo, Agro and product nexus frame work discussed sets a framework sample of how a nexus portrays local actions into global improvements.

Nexus frameworks can vary in their scale. Three main aspects determine the scale of a nexus, these are, the number of resources considered which are largely food, water and energy. (2) The inclusion or exclusion of drivers considered which may vary in the depth of their analytical consideration such as some external elements which do not change or are assumed very slow in change or irrelevant to the problem.

An example on Qatar Environment and Energy Institute QEERI shows the focus on all three sustainability pillars through social, demographic, economic and environmental drivers (Figure 18). Climate change is by far the most dominant risk identified in all city resource stress drivers.

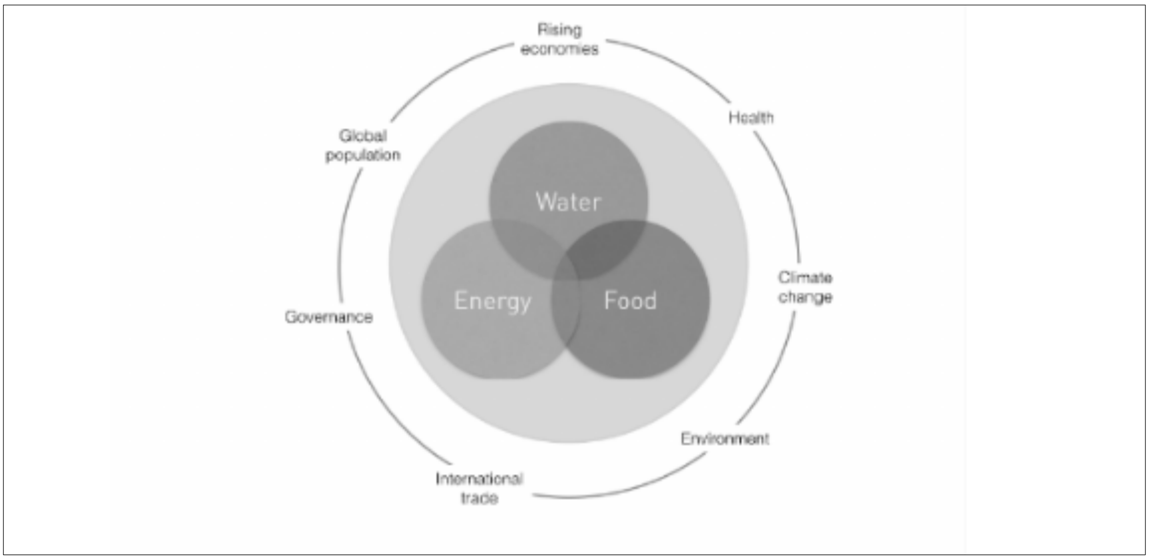


Figure 18 . *Qatar Environment and Energy Institute QEERI nexus framework. Source: (Bekkers et al., 2014).*

Climate change is by far the most dominant risk identified in all city resource stress drivers. Coupled with lingering threats of growth and the current dislocation of population as per 2050-2100 census (Figure 19) makes management of resources a vital point in global security and the answers lie within city systems.

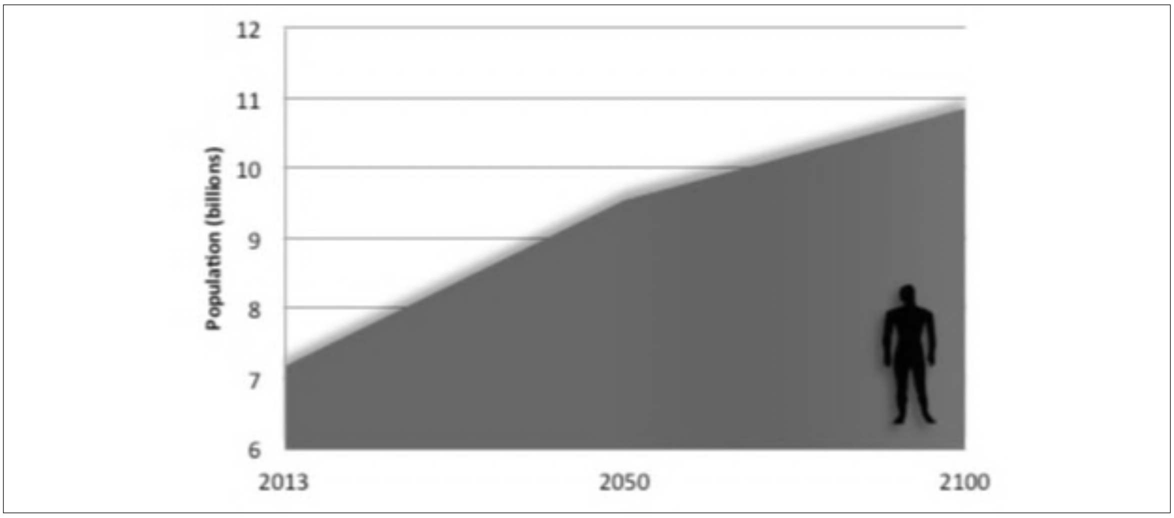


Figure 19. *World population increase 2013- 20100. Source (Bekkers et al., 2014)*

2.4 Context Based Literature

City social and economic systems are fully dependent on the availability and efficiency of resource systems. A mismanagement of resource results in undesirable societal and economic magnitudes instigating chronic obstructions in social stability and economic growth (Epstein, 2018). Cities are not only engines of the economy and home of their citizens, they are also the home of municipalities that manage, supply and control various public goods and services to residents and businesses. They also influence the majority of resource use, energy consumption and harmful emissions during any agriculture or other production by the policies and land use governance.

Accordingly, this section extends the definition and understanding of city systems. It discusses interconnections from a planning perspective based on urban system components, layers, drivers and activities - and involved indicators within spatial, temporal and functional scope to support practical alignment of urban algae product nexus.

2.4.1 Urban system

Urban systems are identified by three main subsystems, the tangible-physical and intangible-activity and human subsystems which are dynamic at multiple levels and central to global risk factors on the three thematic levels (Figure 20). These are, (1) the environmental level, critical to resource supply for growth, (2) the economic level, critical to industry and development type and direction of growth, and (3) the social level which deliberates the sets of rules, and regulations, laws and legislation, ordinances, including habits, ethics, and traditionally established codes of conduct(Simmonds, Waddell, & Wegener, 2013).

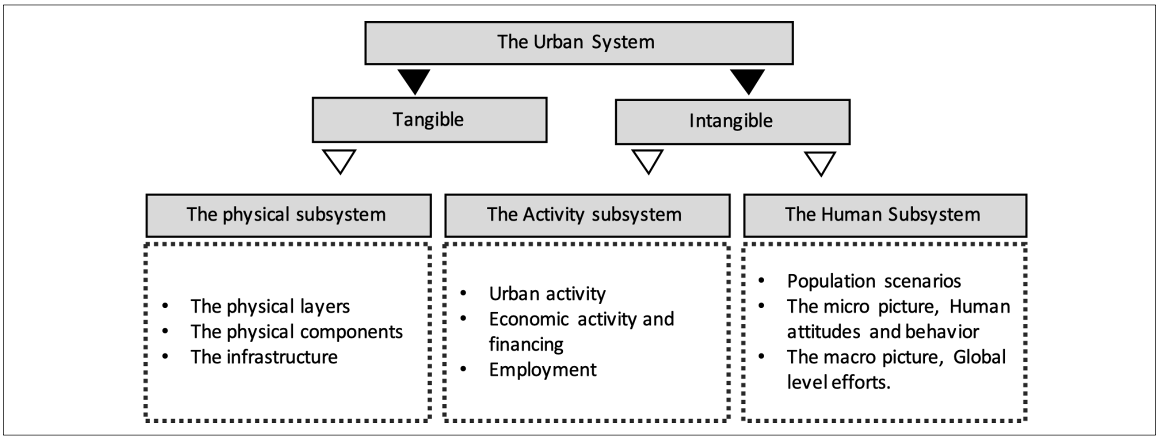


Figure 20. *Urban subsystems and the main components of each.*

2.4.1.1 The Human Subsystem

This section differentiates between two human systems. (1) The micro which includes the public society and their influence on the demand, consumption and social habits involving resource within a city system. (2) The macro which includes the individuals and organizations involved in legislation and policy making that influence and enforce behavior towards social, economic systems and their relation with the environment. While both are largely related to the consumption level, they have different involvement and control levels towards the resource problem.

2.4.1.1.1 Population

Most countries are seeing a steady growth in population, HDI and EF when ideally opposite growth patterns are expected. HDI is an alternative measure of economic prosperity from a social or human perspective. Referring to the Global Human Development Report in 1990, HDI is compositely measured by three main dimensions, health, education and income all which present specific census indicators applied on the population census data(Béné et al., 2016).

Studies of UNDP have shown HDI and environmental resource depletion have a positive relationship. This is a result of a coupled relationship due to the expanded need for resource consumption, accompanying GHG exceeding what nature can sequester by economic activity expanding to fulfil the growing need of the physical and social fabric of the city. Specifically, towards food, the fact that cites will be home of two third of the world's population by 2050, 9.8 billion people living in urban areas increases necessity to find solutions within human/social city systems (Figure 21-23).

Ideally, population, economy and development should be able to grow without posing pressure on ecological assets, a decoupling of production processes can release this pressure.

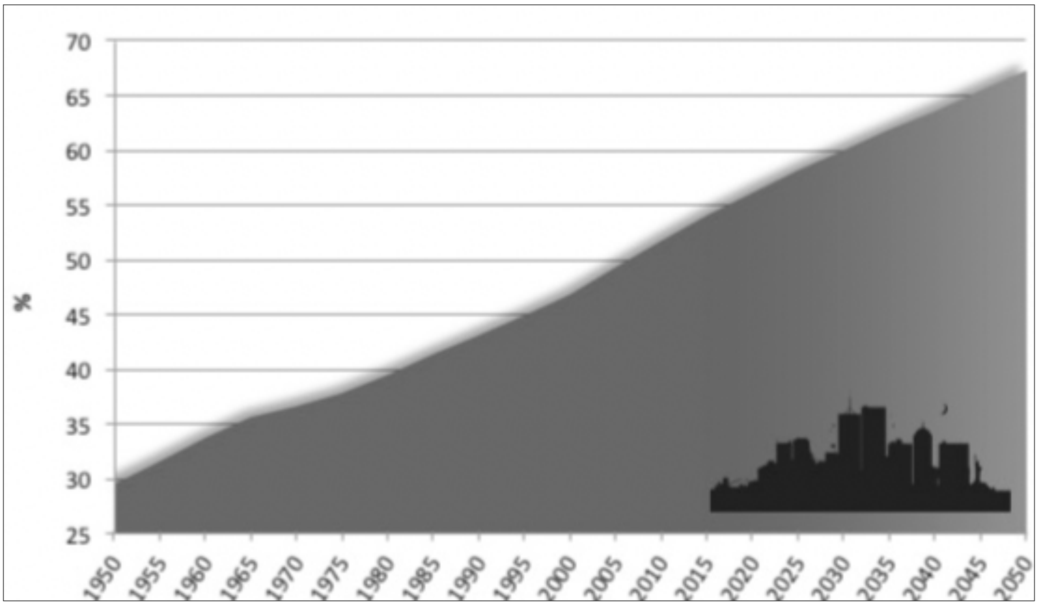


Figure 21. *World urban area populated by 2050. Source (Bekkers et al., 2014).*

Very high human development countries are the biggest contributors to climate change, with average carbon dioxide emissions per capita of 10.7 tons, compared with 0.3 ton in low human development countries. Human-originated carbon data are expressed in tons per capita and equivalent loss of forest land accordingly (Figure 22).

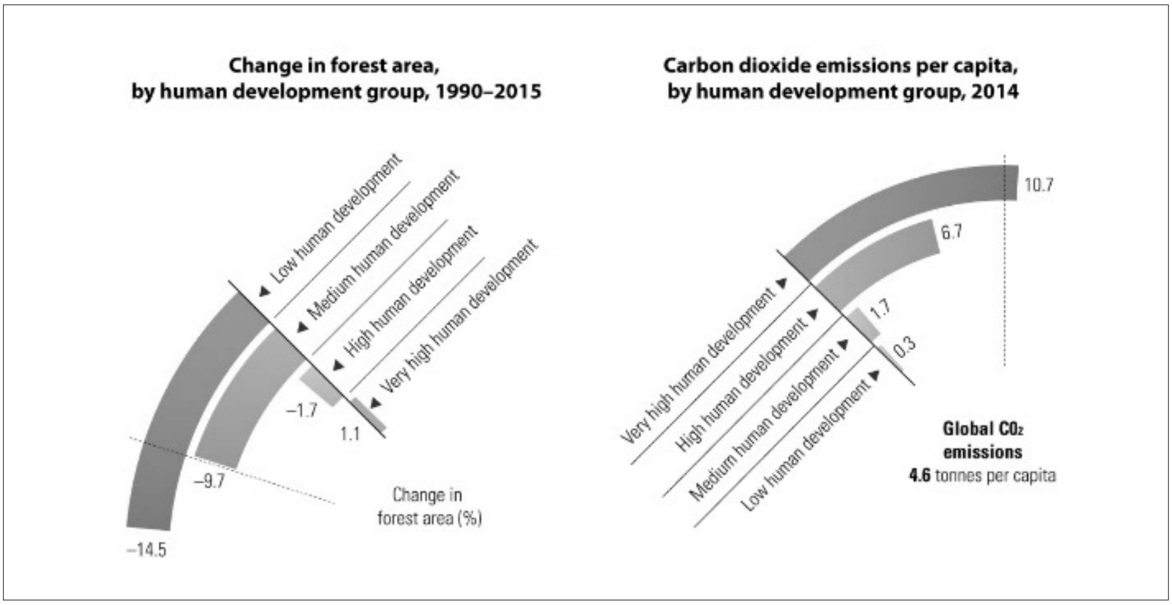


Figure 22. *Environmental degradation and HDI relationship. Source, UNDP, Human development indices and indicators 2018.*

Accordingly, the most relevant also measurable variable that can distinguish levels of resource stress is population census. Population dynamics may be a result of (1) natural growth, (2) rural dwellers moving to urban areas as a reflection of the need for higher levels of livability, (3) migration caused by severe occurrences such as ones associated with climate change and, (4) the administrative redefinitions which may impose boundary changes(Stecklov, 2008). It is important to identify which of these components is leading local population instability, particularly in developing countries which may encounter city planning and service provision misperceptions (Stecklov, 2008).

Commonly, population growth is a result of rural to urban migration. However, in some countries, international migration is a major contributor to population dislocation causing abrupt fluctuations in population levels and pressure on demand from economic and social perspectives eventually leading towards resource stress. The measurement of international migration population census is also disrupted when migration life expectancy, mortality, gender levels are constantly changing. For that reason, profiling a countries population growth and urban growth general character is essential when sustainable efforts are involved especially within sensitivity areas where abrupt population change and environmental stress exist (Stecklov, 2008) .

2.4.1.1.2 Micro level

The design, planning and administration of the built environment is structured around the population morphology, level of expected well-being and house hold structure, income, demography and the awareness of related resource and environment factors. The population behavior and attitude is therefore a reflection of the way specific organizations or groups react to the process of development more specifically to sustainability vs the society's and economy's demand for resource (Kharas, 2010). Three factors are currently changing resource demand.

1. The global rise of consuming class as a result of increasing urban population and incomes. As per global census, 150 million people will enter the middle class yearly until 2030 leading to higher purchase including food stuffs and ultimately natural resource demand. 65% of the world's economy will be generated by 600 cities.
2. Second is the changing household structure and living expectation in cities. Generally, with the increasing population, number of developing buildings, appliances, installations and households in increasing. There is a variation in the way different cities and cultures evolve in household size. Cities in the gulf region witness increased birth rates, high income and living standards which leaves considerable effect on larger preference of

household size that pressures resource by the intense land occupation and sprawl.

Largely associated with rapid urbanization, the anticipated 70% increase in agricultural production and food in general with population growth 2050 brings forward diet transitions from the current high footprint meat and dairy rich diet towards energy-dense high nutrient and fat diets, particularly saturated fat, sugar and salt and low in micronutrients, dietary fiber and important bioactive phytochemicals (figure 23) leading to rise health problems and low activity lifestyles.

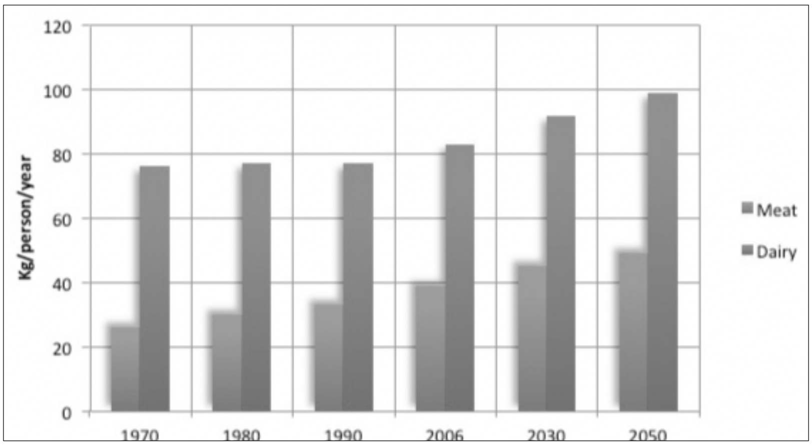


Figure 23 World meat and dairy requirements by 2050. Source (Bekkers et al., 2014).

In this sense, the way agricultural industry is planned and designed reflects the level of management of sustainable development awareness and application (Gliessman, 2006).

2.4.1.1.3 Macro Level

On the scale of the built environments and good practice, local authorities have the capacity to implement sustainability responses on multiple scales. Mostly government, influenced by design and planning teams who allocate and calculate loads, supply and demand of water and energy.

Facilities management is a domain which applies local policies in the provisioning and monitoring of services and resource flows by which it is able to obtain temporal data and view consumption patterns which are used to develop national and global resource flow patterns. FM sustainability concerns in urban planning include energy efficiency, water efficiency, waste management, indoor environment, material management, cultural aspects and site quality.

Governments, the private sector and the non-governmental sector will all have vital roles to play in supplying short-term relief and long-term development funding and assistance. The review of countries across the Human Development Indices and Indicators, 2018 Statistical Update ranked countries HDI in relation to the energy consumption- renewable and fossil fuel, carbon emissions, forest area, fresh water withdrawals, household ambient pollution, unsafe water sanitation and hygiene services. The placement is a motivating tool for governance and policy agendas for resource security.

In regards to the human subsystem, Sustainable consumption-production (SDG 12) and the 11th SDG target display the need to enhance inclusive and sustainable urban development by 2030 which Support positive economic, social and environmental links between urban, per-urban and rural areas by strengthening national and regional development planning(Bringezu et al., 2017; Pradhan et al., 2017) (Horn, Mitlin, Bennett, Chitekwe-Biti, & Makau, 2018). The targets emphasize on the need for a high level of participatory planning to deliver downward up urban solutions which are absorbed and excepted by society more specifically in circular metabolism solutions which include particular attention to air quality and municipal and other waste management *(Horn et al., 2018).*

2.4.1.2 The Physical subsystem

Urban form shapes the way people live, work and move in urban areas. It is made-up of components and layers weaved in a logical manner by UP and design (Fertner & Groth, 2016).

2.4.1.2.1 Urban Components

Urban development areas are physically distinguished by common components which are basic towards population functionality. These are, (1) the buildings which form the urban street walls and shape the sense of place, buildings are identified as main elements which determine the resource trend of a city, the function, size and material for construction are all considered in the resource demand calculations of a building. Three main stages are identified throughout a building formation, (a) the design stage, mainly individual or firm based decisions guided by government and municipal regulations and regimes, (b) planning, this means that buildings are allocated according to the larger city planning protocols which also determine its endues and regulatory physical conditions, (c) the management and operation, this is considered the highest temporal resource demand stage, it means the lifespan of the building and the system resource flow into its internal services and utilities.

Second, (2) the public spaces which physically occupy natural land and are considered a stage for the activities within the city, (3) Streets and transport systems which ultimately occupy 30% of total urban areas thus giving them a significant role in changing land cover in multiple scales between large avenues and pedestrian lines depending on their purpose ranging from automobile, cycling to rail etc.

Last, (4) Urban landscapes, the weaves between city built up spaces ranging from functional areas such as parks or pockets to left out spaces or empty lots (Fertner & Groth, 2016).

These areas are physically changed by humanity during the process of development and growing city scales and are no longer part of the ecologically active land layer due to a usual 30-50% + built areas around them and the human activity within (Lamera, Becciu, Rulli, & Rosso, 2014; Pickett et al., 2001).

For the purpose of this research, conventional urban landscapes are defined as the spaces within urban development area which do not hold a specific and significant role in the function, economic activity or significant social role for the building on site such as pockets, small lots, undeveloped land or unutilized urban space(Pickett et al., 2001).

The above identified components multiply in sequential form defined by land allocated for them which accordingly multiplies into lot, parcel, patch and block) which form a city and determine its capacity, quality and identity. Urban design weaves these components into a functional and coherent physical development by the complex infrastructure defined by urban scales ranging from (building to neighborhood to district to city to region and the layers that unite them (Figure 24).

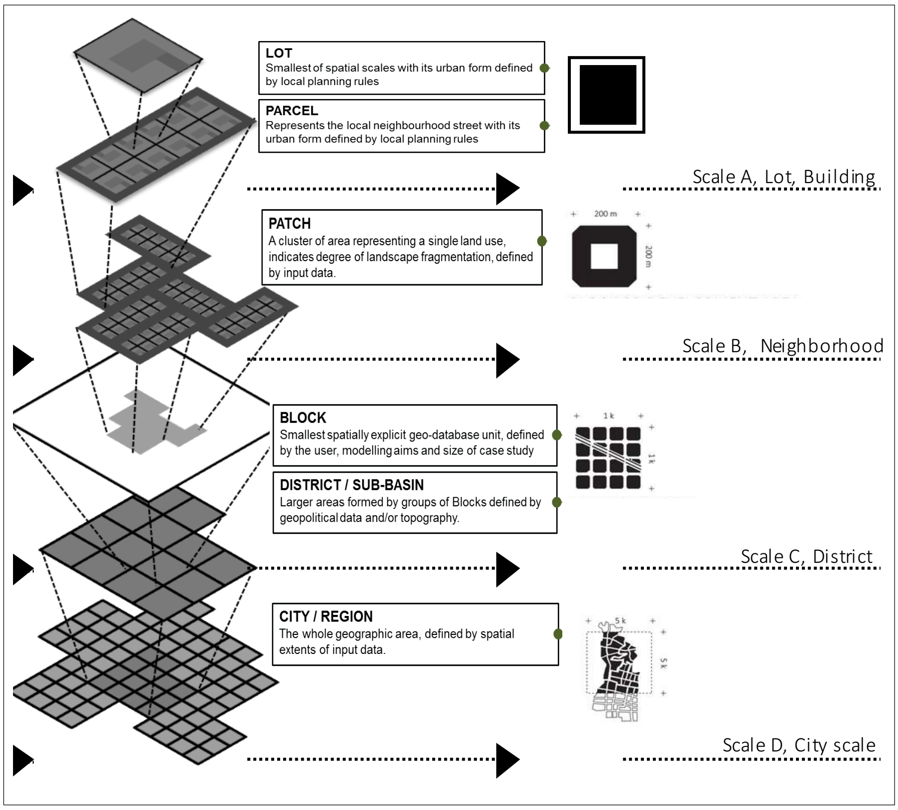


Figure 24. *Multiple urban scales. Source: Author 2018, adapted from Urban Beats 2018.*

2.4.1.2.2 Urban Layers

Four main layers are at the forefront and are largely at the core of economic liability of the city. These are, the environmental layer, infrastructural layer, repartition layer and smart layer (Figure 25).

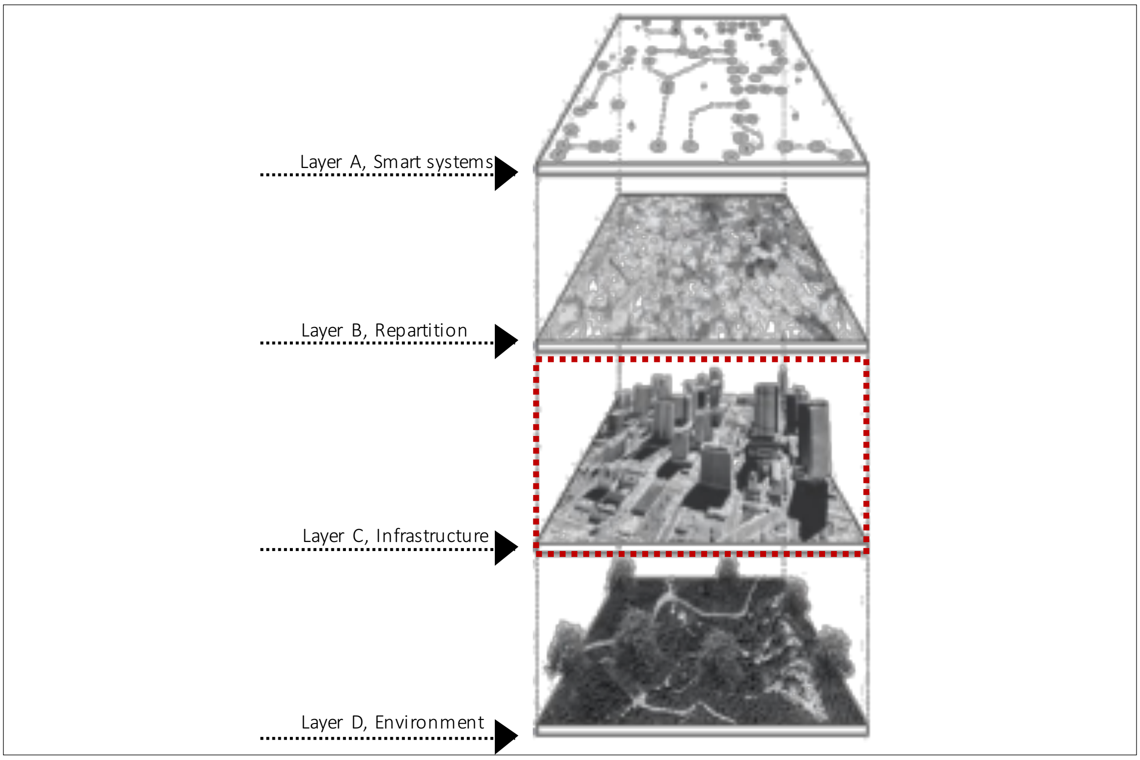


Figure 25. *Urban physical layers. Source: Author 2018, adapted from (Delsante & Bertolino, 2014).*

1. Environmental layer

While natural condition of the land may create certain boundary for development such as high-water table levels or rigid topography, human ability to manage these differences is reflected in the level of technology and economic prosperity. The economic stability and development are also dependent on the natural environment resource asset that characterizes the region and country.

In agricultural sense, natural land and topography are main resource factors which determine the fertility of conventional agricultural activity in a country or region. The availability and accessibility to the latter relates to food security as a leverage for a country to grow staple crops internally despite economic and political dynamics. Hence, it plays a main role in determining the level of security of a region as does fresh water availability and condition.

Natural topographies are also determinants of accessibility by land, air or water to an urban area which may have positive or negative implications on a countries ability to import and export resource and products thus effecting the larger scale of resource security.

2. Infrastructure layer

Second and most relevant to this research is the infrastructure layer. Like the underlying structural support frame of a building, infrastructure is the underlying foundation for cities. It is a necessity for the social and economic functioning of a city as it provides the basic services. Infrastructures may include public governed services as well as private provided physical improvements in the underlying system (Moss & Marvin, 2016). The progression of infrastructural quality this century manifest in the development in industrial and technological sectors and the ever-growing population worldwide.

There are two types of infrastructure, hard and soft. Hard infrastructure is the physical network which includes transport systems such as roads, transit and the underlaying network of water, sewage and energy grids. Soft infrastructure include economic, health, emergency service and educational institutions sectors which determine the management of the city and living standards. (Moss & Marvin, 2016).

Infrastructures are the main player in circular metabolism of city flows which move people, resource and material in, within and out of the city boundary and both above or below urban surface. Like any system which present a physical boundary of function, cities have boundaries and the way hard infrastructures systems flow is managed within these boundaries can be distinguished into two man categories, the centralized and the decentralized system. relatively most cities are commonly developed over a centralized water and energy grid (Weinstock, 2013).

The production, delivery and waste system of these two grids remain diverse between different countries based on the natural resource available weather fresh water, desalinated or other. (Figure 26) showcased different type of water resource .

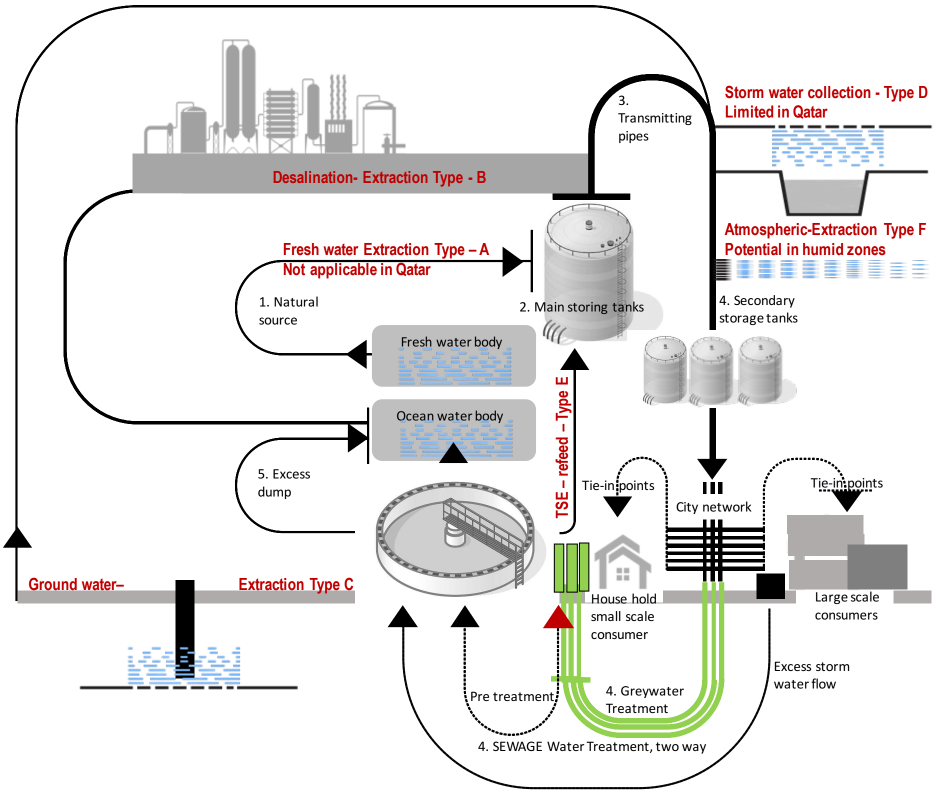


Figure 26. Water source types.

The process of extracting water and deliver it to end-users is divided into five energy intense stages (Corporation, 2016b) (Figure 26). These are, (1) Water Extraction and Desalination phase. (2) Strategic storage usually allocated near to water source. (3) Transmitting phase that connects the main storage tanks closer to cities to be re-stored into secondary tanks. (4) Secondary Storage Tanks: it's the location where the city requirements are stored for the short period use and its allocated in strategic areas to serve the maximum number of zones. (5) In city distribution grids: a pressurized pipe system that run into the city to each zone and feed each plot.

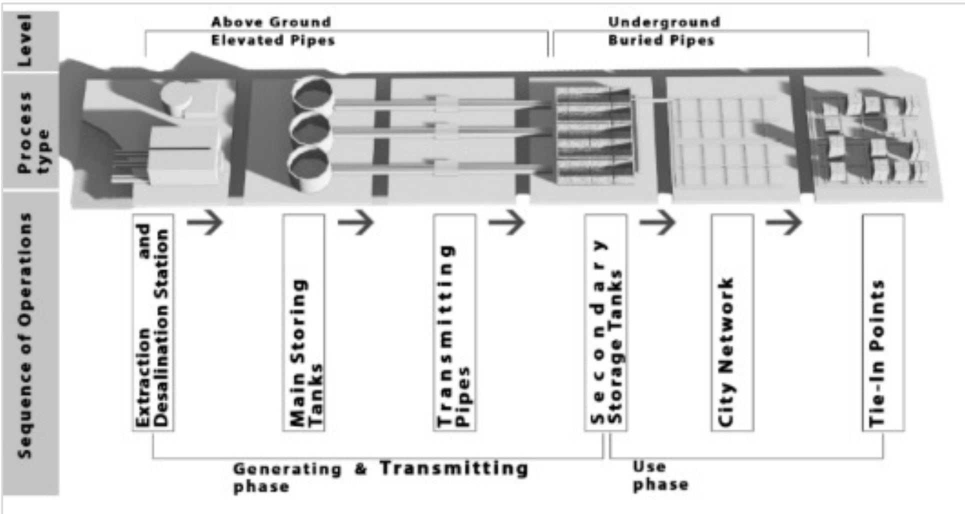


Figure 27. *Water general delivery system structure. Source: Alsaeed.M*

In concerns of water treatment, the type of water output from urban activity studies is categorized as grey water and black sewage, "Characterization of grey water reveals a source water that is similar in organic strength to a low-medium strength municipal sewage influent but with physical and biodegradability characteristics similar to a tertiary treated effluent"(Jefferson, Palmer, Jeffrey, Stuetz, & Judd, 2004). Grey water comes from sink, shower and kitchen mostly.

In case of electrical grid, the general distribution system and the process of delivering low- voltage electricity that is used by end users is divided into five phases.

(1)- Generating phase, (2)- transmission phase: it refers to the process of delivering the electricity to long distances from generating stations to cities borders. (3)- step down phase: the electricity transmitted usually considered as extra high voltage and can’t be used directly. (4)- distribution through cables and secondary substations. (5)- End-users connection tie- in points and in-home substations(Corporation, 2016a) (Figure 28).

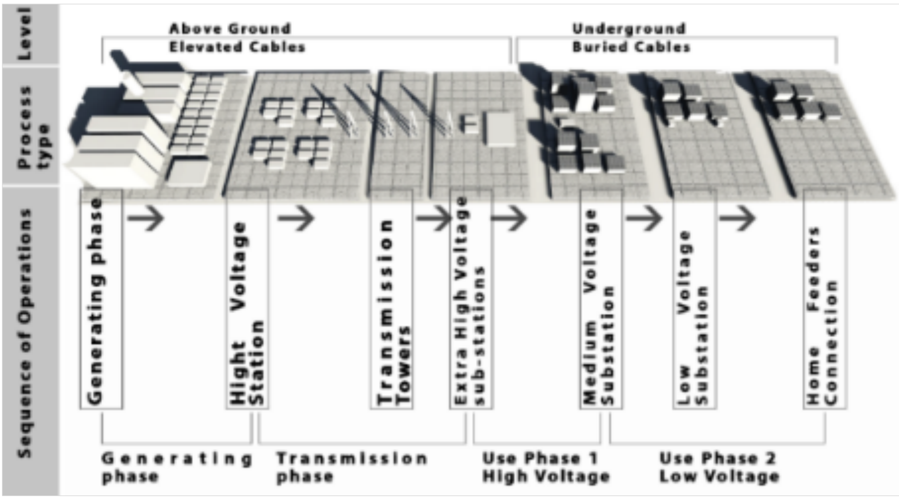


Figure 28 . *Electrical energy general delivery system structure. Source: Alsaeed.M*

Facilities management FM is key to the operation of infrastructural resource systems through building management systems (BMS) and associated monitoring closed circuit (CC) (Kassem, Kelly, Dawood, Serginson, & Lockley, 2015). Calculation of key facility activities in a building design and operation stage is a reflection of the consumption need in terms of mainly water and energy loads. This information is used by planning authorities to structure and allocate infrastructures weather transport related or utility related to ensure a coherent city formation and adequate supply(Abdoh, 2017; Kyrö, Määttänen, Aaltonen, Lindholm, & Junnila, 2010).

3. Repartition layer

Third is the repartitioning layer, this layer is led by land use which will determine the scale, allocation and function of the lots, nodes and area in general as such presenting different implications on the environment, economy and society. Referring to (Figure 24), land use plays significant role in determining patterns of supply and demand as well as other factors such as mobility, accessibility to immaterial natural resource, for example, the level of sunlight, heat islands and air moving in the city. Also, resource inflow and demand from the design stage of the building is based on the larger planning attributes provided in the lots, blocks, neighborhoods and beyond. These are commonly based on governance planning decisions calculated by the number of population, building density and land use.

Small parcels allow small scale construction and are more resistant to change because of their close proximity, these are typically residential areas with similar land use regimes and services delivered. Larger parcels allow more flexibility in building size as well as empty space on ground level, suitable for high commercial activities also high level residential.

4. Smart layer

The fourth layer, smart systems is unique to this century by the intelligent knowledge traveling between different urban scales. These include data, digital sensors and platforms mainly obtained by BMS, which offer a computer based control and monitoring system mainly for above identified hard FM operation areas (Abdoh, 2017; Kyrö et al., 2010).

Smart layer is especially significant in terms of infrastructural services control and monitoring and can be used on multiple levels in evaluating and planning sustainable protocols, examples include monitoring water and electricity using meters which then translates these into geographic information system in the analysis of city land use, natural terrain and more. These can be especially significant in modeling scenarios based on real temporal characteristics of an urban area.

The term facilities management is explored as it relates to both technology and applied Building Information Modeling BIM as BMS outcomes. The tools offered by BIM facilitate architects, engineers and construction planners and design (AEC) predictability, productivity and profitability out look of projects through computational design. The software efficiency is amplified by the data input and accuracy level. These are translated into digitized formulations which are used to deliver customized design solutions throughout a project lifecycle.

According to Paul Jeferies 2016, Computational design becomes achievable when all data related to the physical system and its process is available. It is excellent in dealing with complexity whether it is caused by controlled or uncontrolled interaction of multiple variables.

Advancements in BIM software resulted in generative design applications. These offer a higher level of speed by analyzing maximum number of design options based on algorithmic intended inputs in a range of design responses (Abdoh, 2017; Kyrö et al., 2010) which allows designers to view a wide range of options and scores (Figure 29), these scores could be related to multiple performance aspects weather productivity, environmental foot print, cost etc, all which can be developed by linking the right set of data needed to evaluate the design or construct multiple options with the same result (Azhar, 2011). Benefits of software are increased connection between design and manufacturing and product lifecycle factors, also sustainability factors such as environmental foot print, feasibility, cost etc. all which are preventive measures towards externalities and waste management (Kassem et al., 2015). There is a difference between actual consumption, building resource flows and simulated ones, verification of the results include modeling the results into manageable pilot studies which are then compared to simulated ones (Abdoh, 2017; Kyrö et al., 2010). Parametric design is also high-end smart design system based on generation of geometry from the definition of a family of initial parameters. It’s used in a wide range of modular, high-rise planning and enables designers to explore a variety of possible solutions that the variability of the initial parameters may allow. These parameters are set according to a desired outcome which for example can be a certain food production or energy consumed.

FM as Andrews et .al (2012) argued can benefit from this advancement to premeasure specific parameters and analyze decisions accordingly. However, human behavior has not yet been fully encompassed in the system due to a level of unpredictability in the activity subsystem.

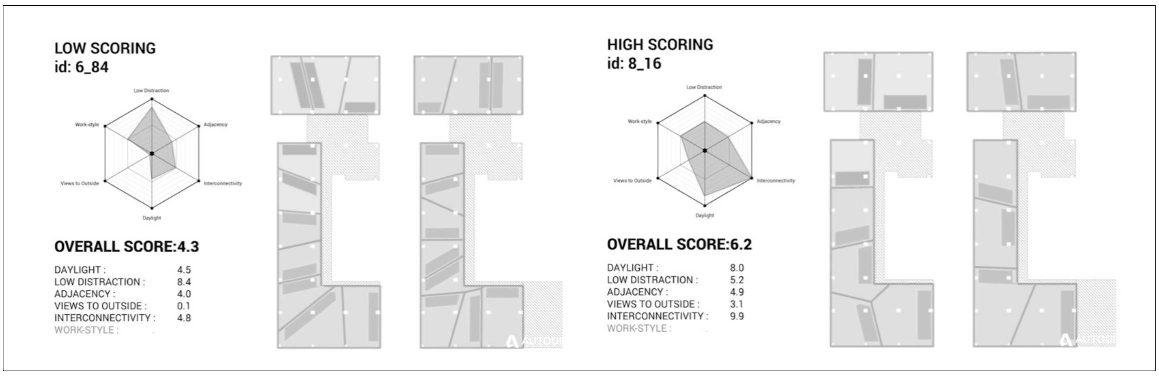


Figure 29. *Generative design applications used for scoring, based on algorithmic intended inputs in a range of design responses. Source: Autodesk 2019.*

2.4.1.3 *Activity subsystem*

In general, the activity subsystem is discussed as the industrial activity which enables economic systems to thrive and animates the socio-economic patterns of the city.

Economic systems are central for both geopolitical stability and resource management. Economy plays a major role in shifting administrative conditions and economic prosperity in cities, meaning, the level of activities and ability to construct physical settlement patterns are consistent with levels of economic performance defined as gross domestic product GDP (L. Xu, Yu, Yue, & Xie, 2013).

GDP is a monetary measure of the goods and services in a specific boundary which can define the level of attraction for migration or geographic relocation as well as geopolitical conditions. GDP measures are used for international comparisons between cities, countries or regions which mirror resource supply factors in geographically diverse boundaries. GDP is a purely economic realm concept.

A country with high GDP mirrors job opportunities as well as good services and life conditions for its occupants (L. Xu et al., 2013). This attracts population growth due to the higher level of services and life quality measured by HDI. It also amplifies demand for resource which accompanies this quality growth.

The way the country runs its environmental resource and economic development is based on social systems and governance which influence the shape of buildings, infrastructures and landscapes that animate the city. For example, countries with high levels of fossil fuel revenue tend to economically rely on energy industries, this is reflected in the type of mainstream job professionals in the city which ultimately influence the social knowledge and norms. while variation in social backgrounds exist in any city social system, the larger area of economic activity plays a bigger role in influencing not only the physical ability to grow, but also the educational and social ability to grow. Urban governance is vital in the growth of social and economic systems in the city.

The latter influences decisions on a government level are key to how resource and social systems interact by the set of rules, laws and regulations that inspire ordinance and over-all ethics consequently leading supply, demand and consumption patterns could be in social micro. With growing industries shaping cities, the type of industry becomes a crucial matter which determines the level of pressure posed on resource.

Nielson book on financing services in growing urbanization highlighted the growing difficulty in providing and financing adequate infrastructure to supply the growing needs of water, electricity, transport, sanitation etc. under the economic imperatives of globalization and new functions (Stecklov, 2008). Decoupling economies from ecological stress at a local level allows transition of the needed infrastructure from a small-scale level ultimately formulating a global network of decoupled city networks and decentralized urban infrastructure (Elmqvist et al., 2015; Newton, 2008).

A question of finding balance between a countries economic power and the cost on environment is constantly acknowledged even when environmental stress release is not achieved. For example, countries with fossil fuel industries are vulnerable for resource and health stress by the growing levels of GHG. While these countries are heavily reliant on these assets to secure food availability, the externalities of this process extend globally effecting food producing countries (Beddington et al., 2011). By acknowledging these factors, financing economic profit ethically becomes an important player in achieving security for all and on all levels. In that sense, food self-sufficiency doesn’t only play the role of securing countries internal need, it also becomes a way of diluting pressure point economies in countries. While this may be debated from an economic sense, the responsibility for safe environments for all population exceeds(Stecklov, 2008).

This means the scale of ecological resource stress must also be acknowledged through local scale where global deficit is not recompensed by trade, especially in cases where countries dilute their ecological stress by trade and allocate resource stressors elsewhere. Opposite to National scales, global ecological deficit is considered an overshoot as it cannot be balanced through trade.

Generally, most cities are running ecological deficits, stressing natures ability to regenerate, but for how long? Others rely on resources from elsewhere, increasing stress as the demand for them grows. Superficially cleanest cities in wealthy countries are at high probability of becoming conflictual, undermining environmental and global security(Slocombe, 1993). They tend to increase their consumption of foods and goods produced elsewhere coupled with the pollution and resource depletion from production which causes other cities to have high EF per capita (Bai, 2007; McGranahan & Satterthwaite, 2002; Roodman, Lenssen, & Peterson, 1995).

The globalization of world trading markets allowed markets to expand their territories, resulting in production displacement away from demand and consuming centers towards cheaper land and manpower. They also tend to reduce their domestic materials extraction through international trade and increasing their imports.

For both energy and food industries, it causes significant emission triggered ecological distress in the atmosphere of production areas and trends of overriding forest land in favor of economic development at a pacing 3% per decade (Jørgensen, 2011).

It's also important to consider the hidden flows which do not enter the economic equation such as the materials extracted, land, energy and water embedded in the product which are produced elsewhere and left out of the footprint calculation. "Calculating raw material equivalents of international trade for 186 countries showed that countries' use of non-domestic resources is, on average, about three-fold greater than the physical quantity of goods traded"(Muñoz, Giljum, & Roca, 2009) which transpire environmental and economic externalities of high EF per capita (Bai, 2007; McGranahan & Satterthwaite, 2002; Roodman et al., 1995).

An example of alternate industries is the production of bio fuels using agricultural waste which ultimately effectively reduces emission stress caused by energy sectors giving earth's surface a better fighting chance in regenerating its natural assets (Gustavsson, Börjesson, Johansson, & Svenningsson, 1995). However, recent studies in Europe have shown that extended acers of bio fuel production efficient crops caused contradicting imbalances in both food efficient crop production as well as the loss of effective forest land (Bekkers et al., 2014).

2.5 Findings Based Literature

Guided by the methodology and context based literature, the knowledge gained from this literature will deliver the necessary aspects needed to bridge the algae product based system within the larger city system components and layers at a higher level of integration.

2.5.1 Urban Algae

Algae is a blanket term for a large group of plants ranging from single celled simple organisms to giant kelps and seaweeds. Algae has a vast diversity which has yet to be fully exposed, there are more than 50000 species in both fresh and saline water with almost 30000 of those that have been fully understood.

Algae play a major role in ecological balance by the carbon and nutrient absorption property they serve ten times more than terrestrial plants.

However, with growing waste from urban industry and activity, algae find more areas to thrive cause by eutrophication. Specifically, in areas where redundant urban water is discarded carrying organic and chemical matter into the aquatic sphere. When this rapidly growing alga die, a decomposition process causes a biological oxygen demand increase eventually starving organisms and fish form oxygen leading to massive areas of aquatic death (Carlsson, 2007; Elrayies, 2018; Wallis, 2013).

Urban algae in this research is defined as the use of algae as biological organisms/ the benefit of urban resource FEW related matters. In the last decade, the use of Micro algae has seen great potential during cultivation in urban waste management as well as the downstream harvesting transformed into multiple products involving animal feed, fertilizer, biofuels and pharmaceuticals (Figure 30). Basically, they use free inputs the sunlight, waste water, heat, and carbon, all which are available in urban areas (Wilkinson et al., 2017).

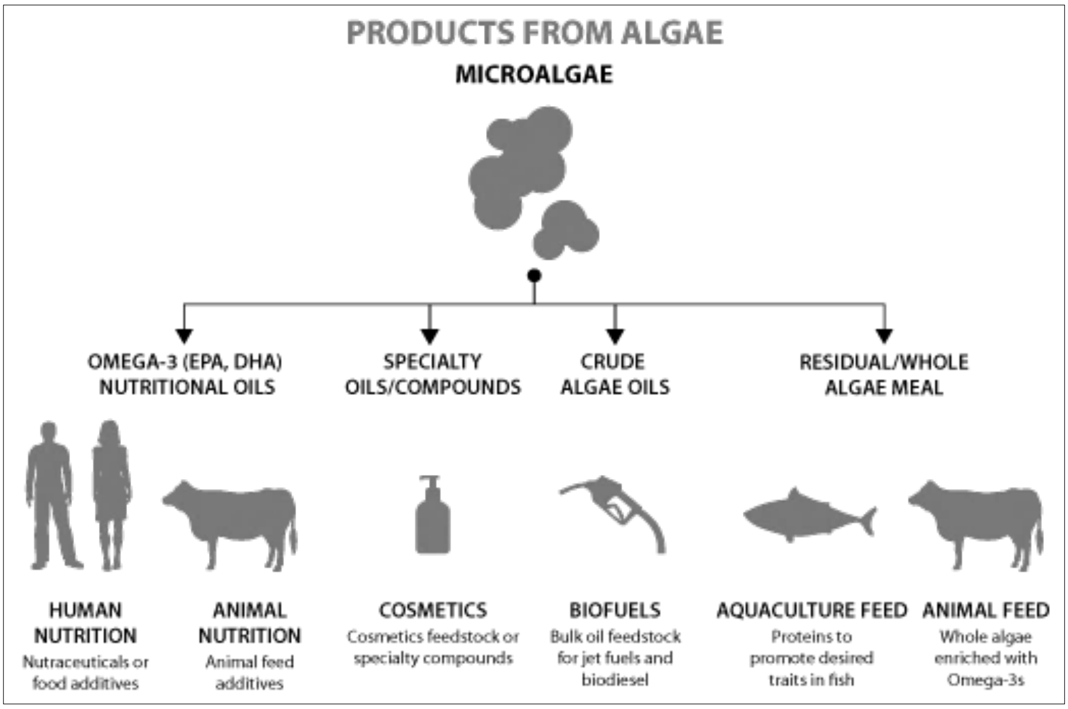


Figure 30. *General diagram of products from algae. Source:(Wilkinson et al., 2017)*

A leading cause of deforestation, climate change and GHG emissions is from crop land for food production, algae produces 40 times more per acre than regular crop (Sathasivam, Radhakrishnan, Hashem, & Abd_Allah, 2017). With respect to biofuels, microalgae have two major advantages over another crop. These include high productivity, reaching up to 70 metric t/ha/yr in dry biomass weight.

Second, microalgae cultivation has the flexibility to be grown in photo bioreactors which are placed vertically, thus it does not require arable land. Also, it can be grown using saline or brackish water (Salerno, Nurdogan, & Lundquist, 2009).

2.5.1.1 Algae taxonomy

Most algae types growth takes the following reaction in terms of essential requirements, Process (Water + Carbon dioxide + Light + Thermal energy ideally between (20-25 ℃)) = Product (Glucose + Oxygen + Water) biomass solution (Svaldenis, 2014). It is important to evaluate triggering components of algae growth such as PH level, contaminants, light exposure intensity which leads to faster growth rate but can also lead to photo inhibition of the algae cells if not monitored and regulated.

Taxonomy of algae is important in distinguishing differences between the cultivation, harvesting and processing system. The qualities of different group types can present different qualities in relation to the growth rate, carbon use, nutrient absorption and other qualities which determine possible uses of the algae product system together with other systems. Hereby, four main types of algae are identified (Table 3).

Mixotrophic algae growth condition has greater potential in urban integration due to the multiple performance factors of its metabolic process involving both energy, nutrient absorption and Gasses with low demand on the light factor and a lower sensitivity factor (F. Xu, Hu, Cong, Cai, & Ouyang, 2004). These are, fast growth which means a faster production, using cheap carbon substrates, high lipid for bio fuel, robust growth under changing conditions such as non-axenic condition, grows within high range of pH specifically for waste treatment strains with significant carbon sink and settlement factors for collection process, it can collect carbon and energy demand using inorganic or organic matter and light simultaneously (Yu, Jia, & Dai, 2009). Meeting these characteristics helps make the strain commercialized and efficient. Isolating strains which fit the profile of growth is currently the most effective in allocating best for use (Ruiz et al., 2016; Svaldenis, 2014).

Table 3 Algae Growth Modes. Source: (Ruiz et al., 2016; Svaldenis, 2014).

Growth mode	**Energy**	**Carbon**	**Light**	**Metabolism**

	source	source	requirements	
Photo-autotrophic	Light	Inorganic	Obligatory	No switch between sources
Hetotrophic	Organic	Organic	Nor requirements	Switch between sources
Photohetotrophic	Light	Organic	Obligatory	Switch between sources
Mixotrophic	Light and organic	Inorganic and organic	Not obligatory	Simultaneous utilization

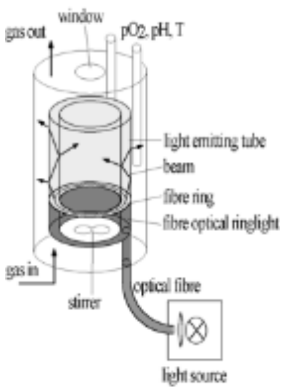
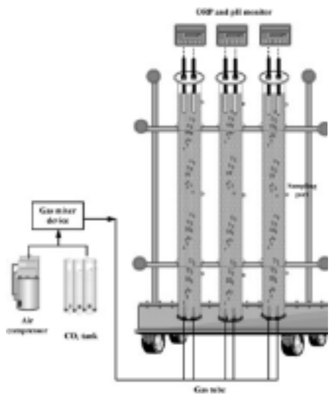
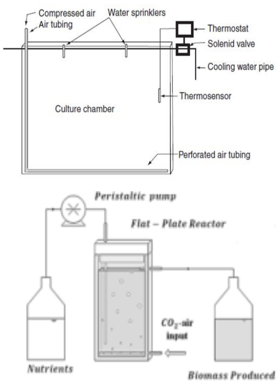
2.5.1.2 Algae cultivation systems

Two types of systems are used to grow algae, the closed system and the open system. Algae production requires heavy labor when considered open pond system. Based on NBT company research, this means more jobs and opportunities. The annual yield profit calculated by this company for Hetotrophic strain use in open raceways was still above the production (cultivation, harvesting, processing) cost. New technologies are currently working on making photo-bioreactor system structure cheap and feasible. Photo bioreactors can take different forms, these are "Tubular Reactors (Horizontal & Vertical), Flat panel reactors, Vertical column reactors, Bubble column reactors, Air lift reactors, Stirred tank photo bioreactors and Immobilized bioreactors (Carlsson, 2007; Elrayies, 2018).

A photo-bioreactor system includes a set of subsystems which determine their performance level, these are "Electrical system Light system, Optical transmission system, Mixing System, Instrumentation system, Air handling & gas exchange systems, Nutrient system. The first three types are increasingly receiving industrial interest (Carlsson, 2007; Elrayies, 2018). The below (Table 4) examines the prospects and limitations of each which can generally reflect the opportunity for integrating each at multiple areas for the urban benefit.

Table 4 Photo-bioreactor Types, Prospects and Limitations. Source: Adapted from (Narsi), Narasimhan 2019.

Type	Tubular photo-bioreactors	Vertical-column photo-bioreactors	Flat-plate Photo-bioreactors
Prospects	Large illumination surface area, suitable for outdoor cultures, fairly good biomass productivities, relatively cheap.	High mass transfer, good mixing with low shear stress, low energy consumption, high potentials for scalability, easy to sterilize, readily tempered, good for immobilization of algae, reduced photo inhibition and photo-oxidation.	Large illumination surface area Suitable for outdoor cultures Good for immobilization of algae Good light path Good biomass productivities Relatively cheap Easy to clean up Readily tempered

			Low oxygen buildup.
Limitations	Gradients of pH, dissolved oxygen and CO_2 along the tubes, fouling, some degree of wall growth, requires large land space	Small illumination surface area, their construction requires sophisticated materials, shear stress to algal cultures, decrease of illumination surface area upon scale-up.	Scale-up require many compartments and support materials Difficulty in controlling culture temperature Some degree of wall growth Possibility of hydrodynamic stress to some algal strains.
Illustration			

All system types also include similar components to run, regulate and monitor the system conditions. These are, “Oxygen & CO2 sensor, Temperature sensor, pH sensor, Light sensor, Conductivity sensor, Recirculation pump, Harvest pump, CO2 injection valve, Substrate pump, Filtrate recirculation valve, Water inlet valve purge valve, Connectors and hoses, Oxygen release system, PLC control panel and Feeding tank (Gevaert, Delebecq, Menu, & Brutier, 2011; Svaldenis, 2014).

2.5.1.3 Algae economics

A study that estimated the cost of dry harvested biomass in a 100 hectare industrial facility by which it analyzed the cost of different cultivation systems including photo-bioreactor, the study concluded that open pond system is simpler and less costly in construction which. However, closed systems are higher in revenue and are considered the way forward based on their higher productivity 34 and 61 ton/ha/year and product quality (Ruiz et al., 2016).

The study also concluded that the flat panel system is the most convenient in construction cost between other closed systems which a production cost of 3.4 euro/kg. the cost can be reduced -0.3 euro/kg if the strains of algae were specifically adapted to temperature rise (Figure 31). This is because the major cost of cultivation is the temperature control as overheating is lethal to micro algae especially in large scale cultivation which is optional between two methods both which rely on heat exchange. The first one is simply by the use of water bodies to spray the surface of the panels which costs 0.8 euro/h flat panels, this is however not convenient as when using a chiller unit which is certainly costlier up to 3.6 pound/kg but also offers a heat into energy opportunity to be studied (Ruiz et al., 2016).

The second main consideration is the biomass from medium separation cost, this is varying between (0.2 to 0.3 euro/kg) – 7% of total cost due to higher biomass concentrations compared to open pond system.

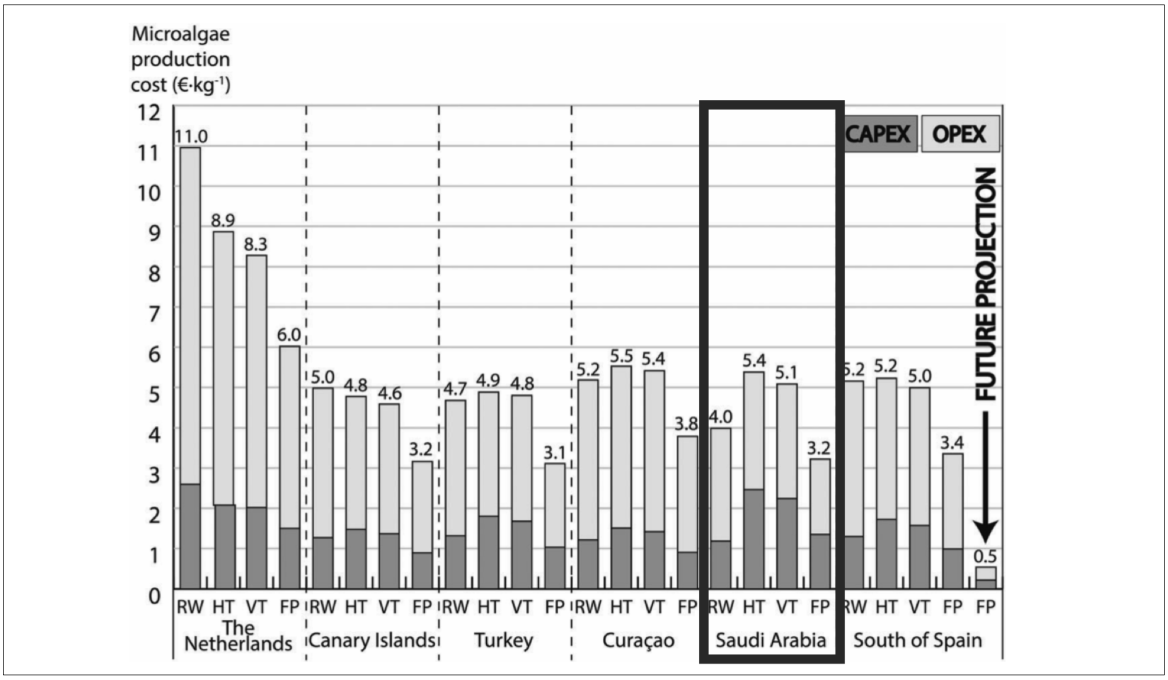


Figure 31. *cultivation and harvesting estimated costs of different, Saudi Arabia. Source: (Ruiz et al., 2016).*

Considering strain type market price, Spirulina which is currently mainly grown in open ponds in China, India and Us are estimated 36 pounds per kg when used for animal or human consumption (Murphy et al., 2015).

2.5.1.4 Hamburg case

In 2013, an exhibition on renewable energy revealed a new apartment complex in Hamburg, Germany. In the five story Bio Intelligent Quotient (B.I.Q.) building, heat and revenue was generated by growing micro algae in 129 flat panel type photo-bioreactors on two sides of the building. "transparent containers which create a controlled environment for photosynthesis." Nutrients and carbon are fed directly into the system while pressurized air is further pumped to promote growth. Scrubbers inside the panels are simple and effective to keep the glass clean(Wallis, 2013). The tanks keep the building cool in the summer while excess heat is funneled into saline tanks to be used later. The closed loop system stimulates the transfers the heat and biomass generated by the façade towards a basement management center (Figure 32).

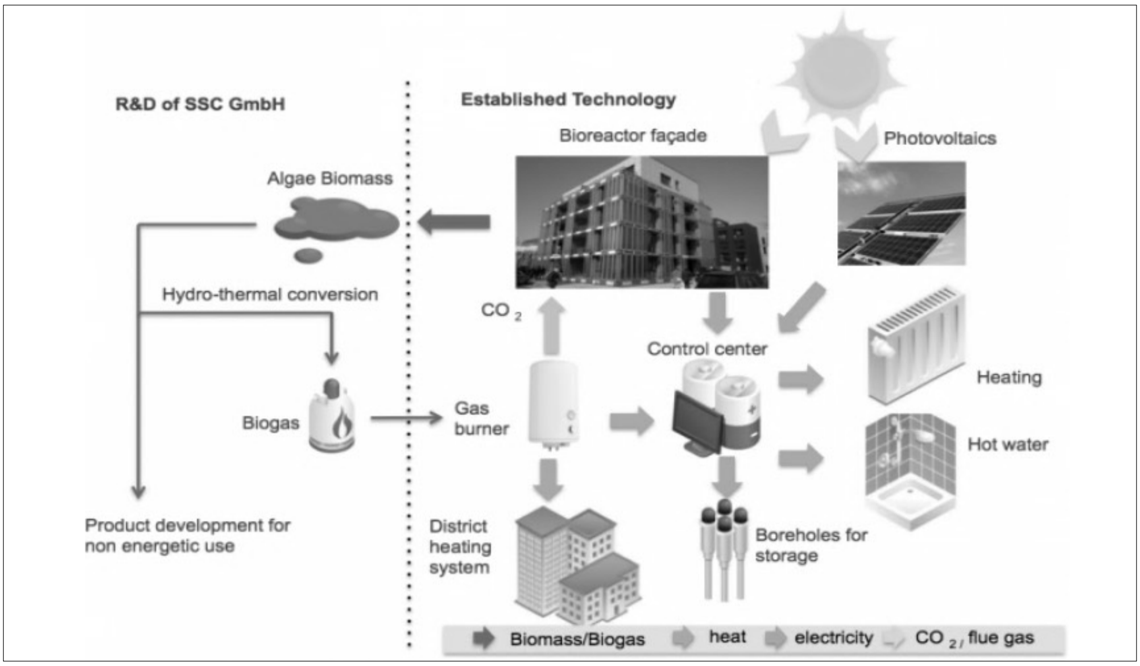


Figure 32. *A general overview of the bio product cycle in the BIQ building, Hamburg, Germany. Source: (Wilkinson et al., 2017).*

Harvesting takes place once the algae have grown enough by taking advantage of the algae natural settlement factor followed by floatation from tanks and transferred into the biomass processor. The bio oil produced is then used to power the building. (Wilkinson et al., 2017).

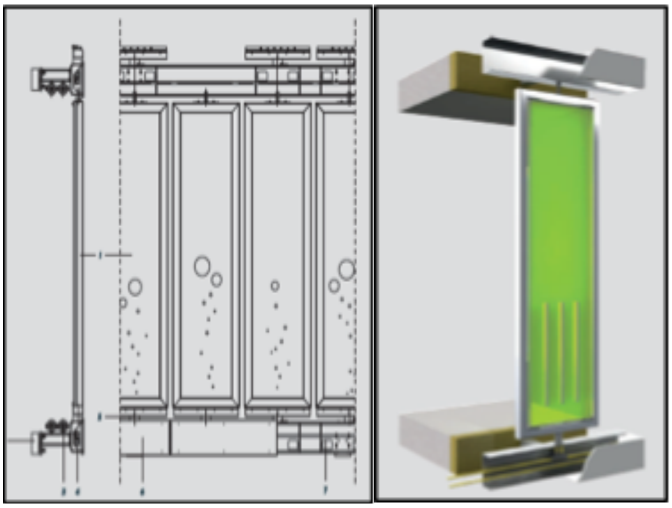


Figure 33 . *BIQ House Hamburg Elevation, BIQ plant room, PBR diagrammatic view. Source: (Wilkinson et al., 2017).*

Founded on the Hamburg building technology, Australian initiatives evaluated the process of converting algae into the building sector. The research took a qualitative form and output. It measured the efficiency of the suggested prototype by the knowledge of stakeholders, technicians, specialists and engineers in all related algae and building fields. A list of social, economic and environmental comments was developed in accordance with the interviews held and the knowledge gained from the Hamburg case to envision implications of the algae in the urban environment (Wilkinson et al., 2017). The figure below illustrates the final suggested outcome of the study while emphasizing on the need to develop the maintenance and economy of scale/cost factors considering upscaling factors to reduce current high manufacturing cost (Figure 34).

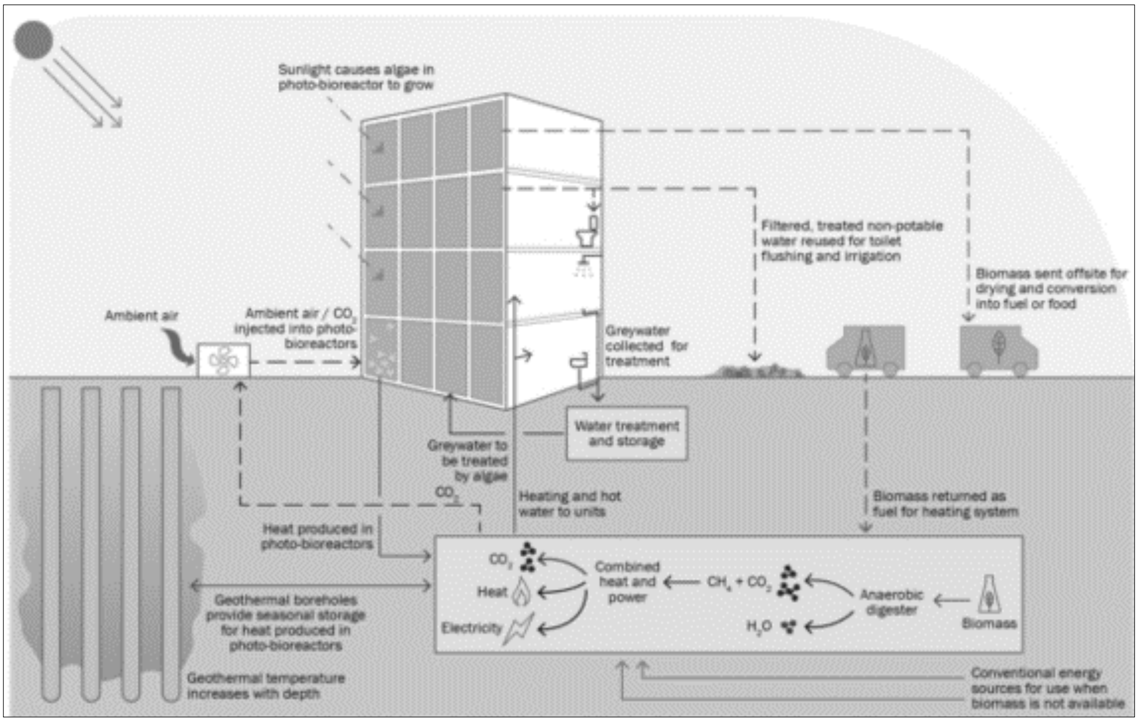


Figure 34. *Sydney proposed algae in building sector closed water and nutrient loop. Source: (Wilkinson et al., 2017).*

The study also highlighted the need for clear methodology for educating "various trades' people, professionals in Universities in engineering, construction, planning, design, architecture and property disciplines". There was no empirical data applied on site in relation to the study so far *(Wilkinson et al., 2017)*.

Another focus area of the study was the climatic factors of the system, due to the wide difference between climate in Hamburg and Sydney, the production will unquestionably vary based on light intensity, higher temperature which cannot exceed 40 degrees Celsius, ultimately resulting into higher amounts of biomass (Proksch, 2013). Maintenance concerns for tempering the water in the system is said to be achieved by speeding up the fluid flow and bubbling as well as by the heat collection at the central plant. Furthermore, the weight and design of the façade panels needs to consider support for dead and live loads. This means high demand to explore light weight technology and manufacturing opportunities.

2.5.1.5 Algae and Food system

In addition to its biofuel possibilities, algae are already being used in all kinds of ways as food products, baby formula, or nutritional supplements like spirulina strain, makeup and pharmaceuticals. Algae contains all-important nutrients, omega-3 and fatty acids for human consumption, it has the best so far ability to solve the shortage of omega-3s in the world at the highest quantity. Moreover, algae are described as functional foods, or nutraceuticals by the fact that they have benefits far beyond the nutritional value such as anti-inflammatory, antioxidants, immunity boosters, and more. A high consideration for algae cultivated for human consumption is contamination and heavy metals in the product, so far studies have shown no harmful contaminates in food produced algae(Mehta & Gaur, 2005). Closed systems are more effective in achieving this control. Furthermore, animal farming and aquatic farming are both seeing a growing benefit in algae as feed.

Dried algae extracts are converted into animal feed and fertilizers. the dry biomass weight is equal to animal feed and fertilizer weight. They have high benefit for improving quality, immunity and fertility, skin and appearance quality of animals. The commercial production of microalgae is approximately 5,000 tons/year of dry matter (Feng, 1998; Sathasivam et al., 2017). "Algae represent a very promising organic source of bio-fertilizer and can be considered as one of the best alternatives to the synthetic fertilizers as they: (1) can be cultivated in arid areas, (2) produce the majority of micro and macro nutrients necessary for plant growth, (3) increase nutrient transfer, (4) increase beneficial microorganisms in *the soil" (Saadaoui et al., 2018)*

2.5.1.6 Algae and Water system

Urban sewage treatment is common to algae advancements field by specific strains known which have the ability to absorb and contain heavy metals, toxic substances, radioactive matter and nutrients. Treating sewage effluent with algae cultivation is commonly achieved on large scale open pond systems. Closed systems are seeing more interest in the recent years, still the quality of water entering the treatment system will determine the quality of the algae produced, for that reason most algae produced by sewage water is used for non-human consumption in renewable energy fields or would undergo a preliminary treatment (Proksch, 2013).

Some level of filtration and contaminants or toxic material is required by the system for algae to perform efficiently where products are used for fertilizing purpose, suggesting possibility to sell fertilizing product locally due to the current small scale of the industry (Fazal et al., 2018) (Nielsen, 2015; Vuppaladadiyam et al., 2018).. A study on algae treating grey water concentration of 700 g/m3 and a flow rate of 40 m3/d could remove all SBOD from grey wastewater which can be reused back into domestic use (Fazal et al., 2018; Proksch, 2013).

The closed system is likely more scalable within urban areas due to its controlled environment; however, this does not exclude the efficiency factor presented in open pond system further from the source where treatment plants are allocated. Also, a study on locating open pond algae on rooftops of buildings presented concerns about smell, contaminants and high maintenance level when connected directly to the household sewage system. This is due to the changing climate, environmental factors and casual system flushing (Fazal et al., 2018).

Current wastewater treatment methods consist of a preliminary and primary treatment to remove large particles and sediment using bars, changing the flow velocity, and by using a sedimentation tank (figure 35). Secondary treatment uses heterotrophic bacteria to reduce the biological oxygen demand (BOD) and to remove organic matter (OM) (Nielsen, 2015; Svaldenis, 2014)

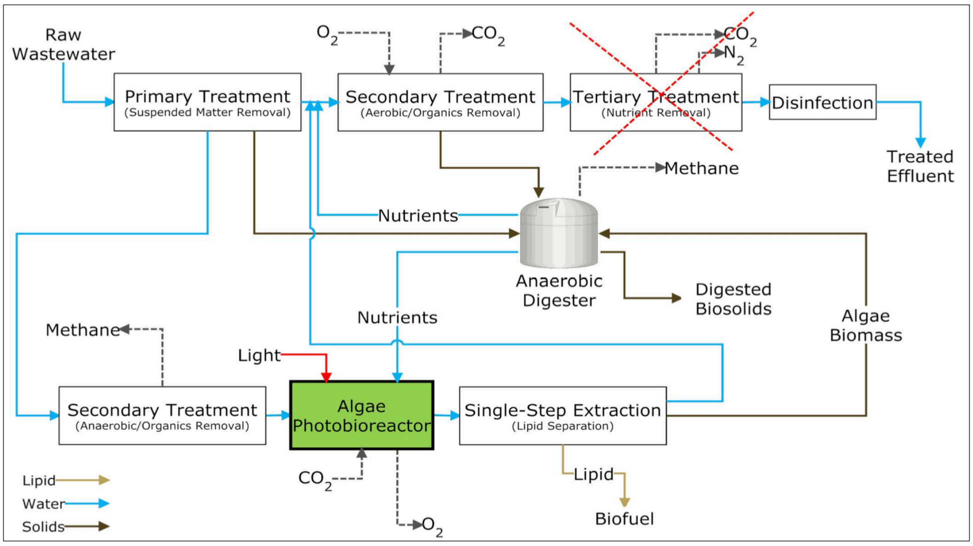


Figure 35 Algae waste water treatment system. Source: Vikram M Pattarkine, PhD CEO / PRINCIPAL (PARTNER), PEACE USA Mechanicsburg, PA 17050

There is a need for the addition of nutrients such as nitrogen (N), phosphorus (P) specifically when intended as fertilizer. Municipal wastewater is high in N and P (with both N and P typically between 10-100 mg/L), so it provides a promising growth medium for microalgae which can also reduce the cost of cultivating using fresh water in addition to nutrients (Nielsen, 2015; Svaldenis, 2014).

2.5.1.7 Algae and Energy system

Algae are a promising feedstock for biofuel production due to their high productivities (10-50 times higher than terrestrial plants) and short harvest cycles (1-10 days). There are three types of liquid biofuels that can be produced from microalgae biomass: biodiesel, bioethanol and bio crude oil (Figure 36) which can be used for multiple energy applications such as electricity, heat generation with on-site combustion also transportation as methane gas. (Saadaoui, Al Emadi, Bounnit, Schipper, & Al Jabri, 2016; Schipper, van der Gijp, van der Stel, & Goetheer, 2013).

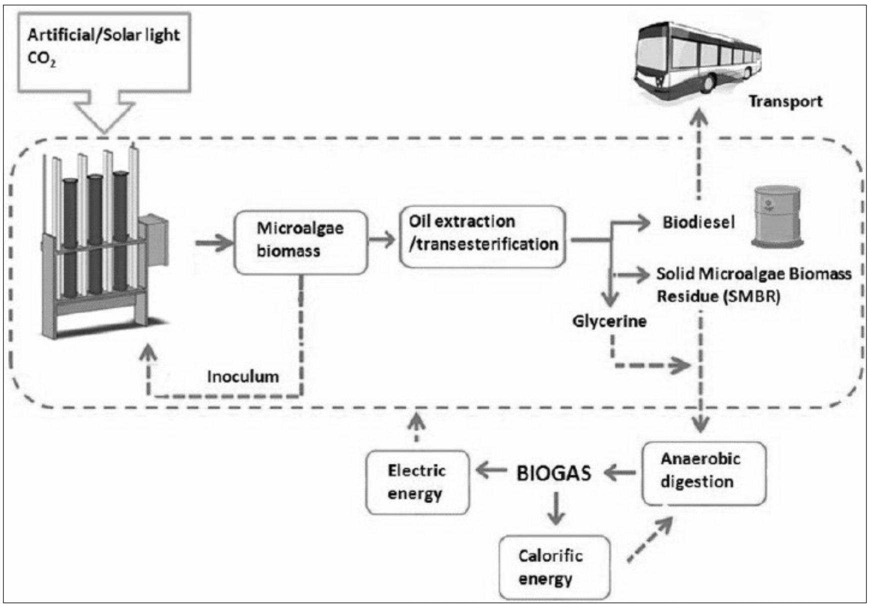


Figure 36. *Energy use cycle by micro algae cultivation opportunity. Source: (Santos-Ballardo et al., 2015*

Overall algae biofuels can reduce GHG emissions up to 90% compared to the gasoline they replace (Saadaoui, Al Emadi, et al., 2016; Schipper et al., 2013). Methane as abundant from specific algae strains. It is typically expressed as liters from the solid mass fed into the anirobic digester(Prajapati, Kumar, Malik, & Vijay, 2014). “High lipid contents in the biomass can be advantageous because the theoretical biogas yield from lipids is generally higher (1390 L/kg VS) than proteins (800 L/ kg VS) or carbohydrates (746 L/kg VS) (VDI 4630 2006)” (Murphy et al., 2015). A study that conducted gray water treatment for the production of clean water and the added biomass production also referred to in the flowrate research concluded that methane biogas can be produced between the range from 0.6 L/L day - 1.2 L/L which Is harvested within a hydraulic retention time of 10 days and considering a high carbon to nitrogen value accomplished through Co-digestion with high-carbon, low-nitrogen substrates which is needed to control desired level of ammonia concentration variable within grey waste water influent(Salerno et al., 2009).

The wet sludge may be harvested and processed directly into biodiesel or methane or in other cases needs to be dried into mass which requires additional consideration for energy and cost.

2.5.1.8 Case of Iowa

A traditional corn ethanol plant is supporting algae production and next generation biofuel. The third of the kernel is starch being converted into a fuel. Third of the kernel is fiber being converted into animal feed is a third left and converted in the co2 in the atmosphere. Co2, waste water and heat all which are part of producing corn ethanol are essentials for growing algae. By using a closed system for growth, the company was able to reduce the space needed to grow by 40 times smaller than in an open system effectively balancing land related cost.

At the Pacific Northwest National laboratory researchers have developed a technology that uses extreme pressure and high temperatures to accomplish in minutes what nature is done over millions of years convert algae into oil. Algae can generate 15 times more oil per acre than other plants used for biofuels. According to their research, algae are the only profitable use of carbon and GHG in the market. Still to be cost effective, algae needs to be grown in high volume, and co-locating algae production with a joined need source of carbon and nutrients.

2.5.1.9 Case of Kentucky

Carbon from energy industry coupled with algae cultivation system is becoming a new counter strategy for mitigating industry related GHG and carbon release. More than 90% of Kentucky's power comes from coal. With federally mandated C02 limits exceeding university of Kentucky considers finding solutions for the future critical. Currently the only feasible option, not for all, is to pump it underground into geologic formations. By using native algae and plastic mailing PVC pipes installed by students, an easy expandable closed system was established. The company was able to highlight community involvement by student work and collaborative research with the university. 5000-gallon feed tanks were installed with two centrifugal pumps. The main tank services as the hub, where co2, nutrients and water return take place. Algae comes out of the photo bioreactors into the harvest tank. Through natural flocculation that helps the algae stick together, it settles to the bottom of the tank. The anaerobic digester is the most forward way to produce methane and can turn the algae into methane that the power plant could burn for fuel. Or using gravity filtration, wet lipid extraction, and upgrading you can make renewable diesel and jet fuel, fish food and animal feed through further moisture removal of lipid content. Bio methane is a main product of the bio energy produced by algae. Currently, international studies are evaluating optimal performance conditions for algae to produce methane(Santos-Ballardo et al., 2015) due to high energy demand of this process which includes temperatures between 300 and 400°C and a pressure range of 120-340 bar (Nanou, 2013).

All the above multi use factors of algae that promise mitigating urban ecological stressors, majorly carbon, and efforts to integrate its metabolic performance with urban metabolism, resource and waste management drives scientists and planners to look at the product system of urban algae in parallel with urban systems holistically from the nexus lens. This poses the question of what strategy and can we apply to algae product to gain the full benefit of urban and ecological system?

2.6 Chapter Summery

The way cities will manage urbanization challenges over the coming years will be key to ensure availability of resources for an ever-growing population and towards achieving Sustainable Development Goals (SDGs) and the New Urban Agenda. In alignment with the research hypothesis, the integration of algae product system and water and energy, particularly in urban flow systems, a generic set of recommendations is displayed on three levels which will reflect on the methodology of the research to facilitate comprehending the interconnectivity between algae and multiple aspects of a city resource systems and metabolic flows while also approaching the problem of climate change in cities from both top down and the bottom up towards achieving the global security agendas by which resource sustainability is discussed in terms of evaluation, practice and design.

2.6.1 Urban resource sustainability evaluation

Environmental sustainability is central to climate change and food, energy and water resource security(Costanza, 1992; Daly, 1977). Carbon footprint, which is a global climate risk indicator is also a main measuring tool of EF, carbon Footprint considers carbon measures as a waste category associated with fossil fuel use weather direct or indirect. Food industry is also a focal GHG emission factor. IRA and MFA have formulated the roadmap towards sustainable development decisions through which areas that can minimize ecological and carbon footprints are identified while simultaneously being productive and efficient considering the socio-economic context needs.

2.6.2 Urban resource sustainability in practice

Following concepts of industrial, agro and ergo ecology which centered mainly around EF factor relevant to the multiple shifts of the industrial activity and pressure areas of different countries, down to the city scale, the way the city approaches industrial growth is key towards sustainable supply and demand chain.

New paradigms with urban planning and development of flow models need to reflect more sustainably on all three scopes, local, regional and global. The importance between the three scopes will vary depending on the diagnosed system target, type, level of development and economic activities between cities which determine the effect that system flows have on both resource and environment. Meaning, the context of the urban area shall determine characteristics and level of integration needed to achieve sustainable goals. Scaling down, "the main challenge is to scale up actions from the simplest, one function, such as a building for housing, or one resource, such as water management, to integrated solutions in a large urban area (e.g. an Eco district) with many functions (e.g. housing, economic activities, green areas, renewable energy production, water harvesting"(Hanasaki et al., 2008).

UN initiatives and the SDGs focused on act small think big scenarios, also think global act local considering that change towards a better production and consumption chain may find best practices close to the product area and the consumer level public.

Governments and NGOs have responded by promoting emission reduction through industries such as agriculture and fertilizers, planning of decentralizing food production into the urban area as well as efforts to minimize water and GHG footprint from agriculture related areas and related industries.

With the help of urban algae industry practice, multiple areas of agricultural growing demand may find resolutions in ecological service practice based production. This means the resource used for a single production must achieve high production with minimum impact on the natural resource cycle and environment. These changes require knowledge and collaboration of different activity groups involving policy and decision, action and production and end pipe user behavior.

2.6.3 Urban resource sustainability in design

The activity and production of algae rely heavily on financial and technological advancements which facilitate modern solution for modern problems. Also, they are deeply reliant on infrastructures efficiency for providing sustainable resource such as water for irrigation, energy for machinery and transport of goods systems.

The challenge is convert todays centralized systems into decentralized ones by which display higher user and consumer engagement and ones which move away from the end of pipe scenario mainly managed by municipalities. The level of decentralization may vary based on urban normality and social preferences (Jepson Jr & Edwards, 2010; Newton, 2008). Also, to consider the larger political and trade externalities which may pose positive or negative threads towards the solution based on the socio-economic opportunities presented by the integration of flows through a wider perspective a nexus framework may offer with a range of material flow analysis and integration assessments applied.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

The chapter objective is four-fold (Figure 37), first the research approach. Each of the sections follows a literature conclusion sequence identified in three main concepts (Practice, Design and Evaluation). Second, the description of the instruments used in the evaluation and design approach as part of the nexus framework process and findings. Third, a classification of the data and the associated rationalizations behind the data choice. A description of main tools used to obtain and categorize data is then explained. Finally, an emphasis of the data morphology needed in the context chapter for profiling, bench marking, and assessment based on the identified scales of analysis.

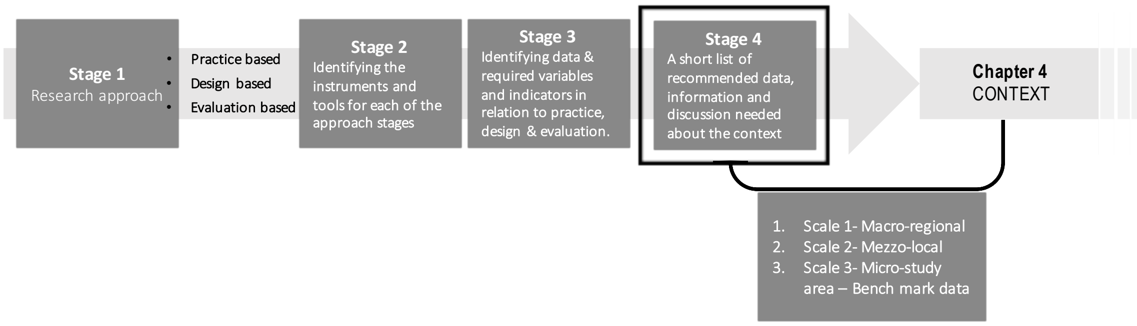


Figure 37. Methodology chapter subsequent stages.

3.2 Research Approach

This section connects all literature covered aspects in a research process sense that follows the sequence of practice, design and evaluation in describing how these are examined, analyzed or applied.

3.2.1 The deductive theoretical approach

By looking at the risk based nexus from a global aspect, the research is able to create a deductive narrative which begins by addressing global concerns and migrate towards the regional then local strategic actions guided by an established framework that can accomplish effective ecological results in some hot spot context's internal and external stressors.

The main approach towards the problem of global risk (Carbon emissions focus) from a resource sustainability perspective, algae as a cultivated agricultural product is aimed to be tested specifically as an integrated urban agricultural feature guided by the nature of algae which can integrate in the urban environment on multiple levels achieving a nexus perspective.

Building on the literature on integrated resource nexus, the study presents the resource nexus by first the identification of the risk based nexus framework which will determine the level of complexity given the number of factors considered within city systems.

3.2.2 The hypothesis

The hypothesis argues that urban algae introduced in infrastructure of the city plays a vital role in improving resource sustainability, ecological, economic and social wellbeing majorly through process of cultivation where algae feeds on what urban output considers harmful to the eco system and transforms it into an input. While these studies have been far from applied on the urban scale, evaluating the hypothesis, a literature of qualitative and quantitative data is needed as the base line of providing analytical knowledge for this subject. Meaning, the way we evaluate a product should be based on the direct and indirect effect it has of the primary urban systems specifically in FEW at most.

3.2.3 Practice approach

The literature focused on delivering a comprehensive discussion on the sustainability nexus approach in current practice. Three main practice concepts have been identified as relevant to the research which centers on food production industry, and ecological concerned production as it relates to the physical urban development domain.

These concepts were chosen based on their profound rootedness in to the nexus system and integrated thinking which bring ecological principles together with the urban system that can ultimately suggest novel management approaches that would have been not contemplated otherwise. The purpose was to identify the different frameworks that these concepts applied in practice in relation to sustainability initiatives which assisted this study to conceptualize a customized framework which allows the sequential discussion towards sustainability.

The goal behind this conceptualization is to proceed towards the food nexus within the complexity of the interrelated systems which accordingly have significant role in shifting analysis results in the next steps of constructing an action plan.

3.2.4 Design approach

A downstream view of algae as algae cultivation and products and upstream algae in urban environments view considers urban knowledge (elements, layers and infrastructure). Meaning, the integration of algae as a product system takes place on the urban level in all three subsystems, the human, activity and physical where associated benefits and products of the whole cycle can be identified discussed. This expands the nexus framework towards social, technological, economic, environmental and political components and discusses their interchangeable relations accordingly.

The design of integrated nexus systems requires two approaches. First the allocation of the design intervention area which is merely based on identifying opportunity areas that present within the system analysis. the larger the system analysis is, the more integration areas can be uncovered. Second, the physical intervention that alters the way the system functions. This require knowledge about the physical aspects of the urban system which involve a large set of component and layer considerations.

3.2.4.1 Allocating the integration

The first step before any integrated urban design is to trace and analyze the circulating as inputs and outputs of an ecological network.

Based on agroecology, industrial ecology and ergo ecology-nexus literature which begins from the cycle of metabolic flows down to a single product system nexus, allocating sustainability design intervention areas takes place first at the materials flow analysis MFA, a life cycle assessment of the supply and demand chain for algae as a product, food system as a process and urban resource system as a whole. This is naturally based on understanding of the way an urban area flows interact which is then followed by an integrated overlay of the systems using IRA that will identify synergy locations for design and analysis interventions.

3.2.4.2 Designing the integration

Designing the integration begins with the physical system understanding. Both the physical system of the algae product and the context are needed.

3.2.4.2.1 Urban physical analysis

The focus on urban scales is a major factor for developing the most suitable approach towards any integrated analysis. Specifically, towards different contexts. This is because city scales involve multiple system cycles, full system, sub system. In a large scale analysis, main centers of metabolic flows can vary, some which are centralized and some which are decentralized (Roberts & Kanaley, 2006). This is where a manifest and latent view can bring together resource and development system cycles under one viewpoint. Linking the two perspectives of urban metabolism and nexus reveals connections between biological and physical flow characteristics of the algae as a product and how these correlates to the manifest and latent behavior of the urban area.

Four main scales are recognized based on their alignment with the earlier identified urban layers as well as repartition which determines the level of variety in land use and services expected in an area as such presenting different encounter levels and opportunities for each of these scales (Figure 38).

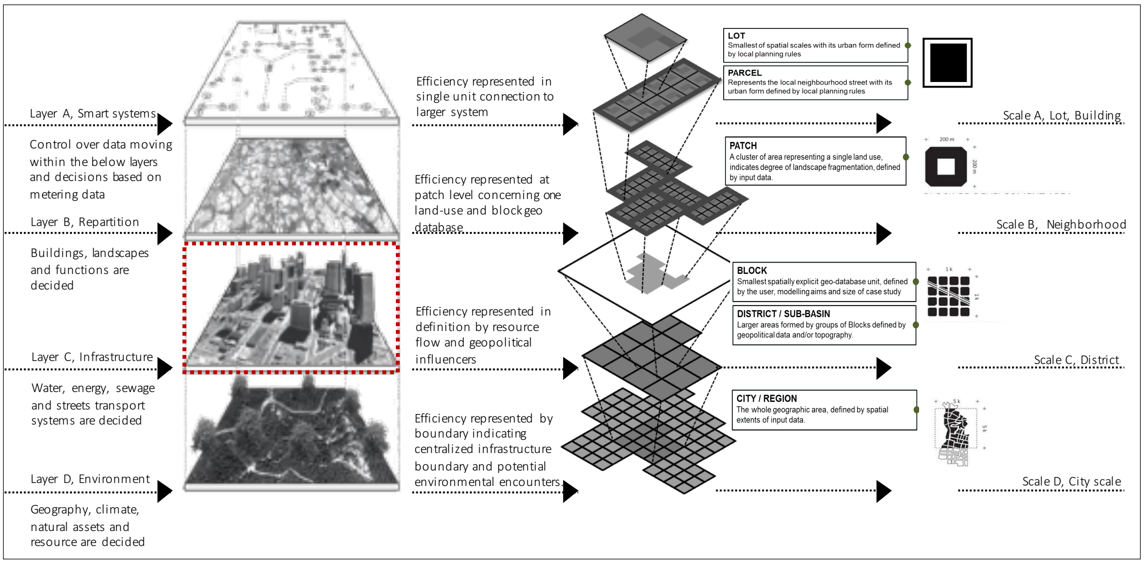


Figure 38. *Urban layers, scales and efficiency, Reference: Author 2018, adapted from Urban Beats 2018.*

The infrastructure layer is the dominant player in this research by the nature of the algae system which is fully dependent on flow of matter, water and carbon. By that two main infrastructures are considered, water and energy grids.

Second main urban aspect are the elements of the city. Buildings are closest to infrastructure behavior as most recourse flows feed into them on different magnitudes depending on their function as well as allocated land use. By that we communicate buildings and land use layer as an important aspect to explore which will unfold the type and cycle of resource flowing into them.

Third is the Urban landscapes formed at the repartition layer are considered a turning point where human innovation, knowledge and Eco services present opportunities for finding resolutions for global problems and environmental threats. The reason for that lies in the alignment of cause and effect (Figure 39) from the point of first anthropogenic needs towards urban settlements and the consequential regression in the natural environment.

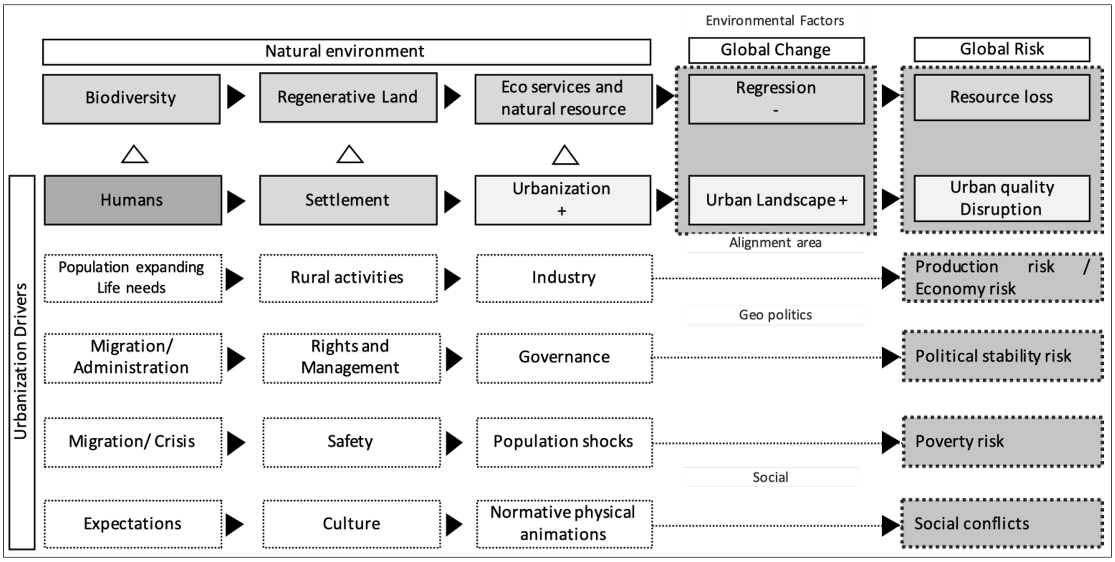


Figure 39. *The significant alignment of urban landscapes between natural system, global change and risk factors*

Unique to this research is the change to the conventional urban landscapes concept, buildings change the land they occupy, however, the fifth façade or roof top areas (Lamera et al., 2014) as well as vertical surfaces 6th facades created by buildings that animate the city are considered as an extended opportunity of urban landscape which show great potential for innovative utilization.

3.2.4.2.2 Algae physical analysis

The design of the photo bioreactor must be considered in terms of ease of application, management and aesthetic consideration and most importantly performance of the system. The environment inside the photo bioreactor is controlled by co2 provision, light intensity by shape and surface exposure and water/nutrient fluid flow by a specified input system. Also, due to the vertical applicability of the closed system photo bioreactors, zero land occupation is considered weather for existing or new buildings with this system applied. This is a significant feature to previously elaborated urbanization sprawl concerns. Furthermore, the system has a high scaling up feature which allows it to grow per demand without disturbance of the existing units attached or existing infrastructure flow performance.

3.2.4.2.3 System type

From the different types of closed photo bioreactor discussed, the flat panel design also demonstrated in the BIQ building shows great potential in the geometric shape application as a façade. The type received much attention due to the large illumination surface area due to the high surface to volume ratio resulting in high photosynthesis performance. It also performs highest between the different closed system types in terms of harmful accumulation of dissolved oxygen concentrations which is relatively low compared to horizontal tubular photo bioreactors.

Subsequently, the system is a vertical applied cultivation system adapted from the BIQ, combined with extended features considered by its instalment on building facades such as a shading devise ultimately cooling the building, also the potential thermal energy harvested from the system could generate heat for the building or harvested and transformed for other.

The system while preferably applied during considered construction phase of the building, is also possible as an add-on to the existing façade given the structural endurance and infrastructure utility connections needed in regard to the water and carbon feed and the filtration tank. It is also important to note that closed systems which can apply as a façade are not restricted to the flat sheet type, in fact, tubular system (Figure 40) has already been designed and implemented. Both design shapes of the photo bioreactor are similar in terms of cultivation, collection and input consideration. However, each present different geometric quality which react differently with heat and solar transfer. Tubular systems are commonly used for intense production not connected to building structures. Additionally, architectural published data about the flat system unit is found to be more accurate to use at this point of research especially in façade type application.

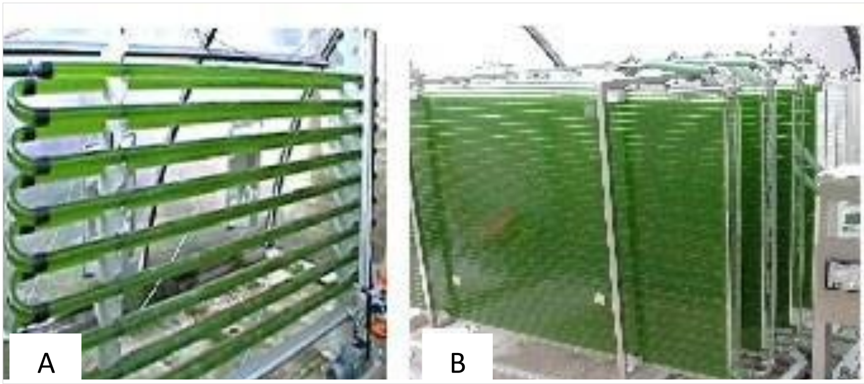


Figure 40. *Different types of closed biospheres, A. Tubular photo-bioreactors, B. Flat sheet panel. Source:(Mata, Martins, & Caetano, 2010).*

Also, different algae color types are currently used to evaluate the aesthetical and physiological value of color illuminated through that algae system surface screen, different films can be applied to minimize the color illumination The system combines the flat panel bio reactor system within a two-sided glazing surface, the visible surface of the façade.

3.2.4.2.4 Dimensions and structure

Dimensions are a combined adaptation from both BIQ building and the upgraded system of the "GSA retrofitted project in LA proposed by HOK"(Kim, 2013; Wallis, 2013). Further conditional calculations for the algae cultivation medium were calculated accordingly as primary data (Figure 41).

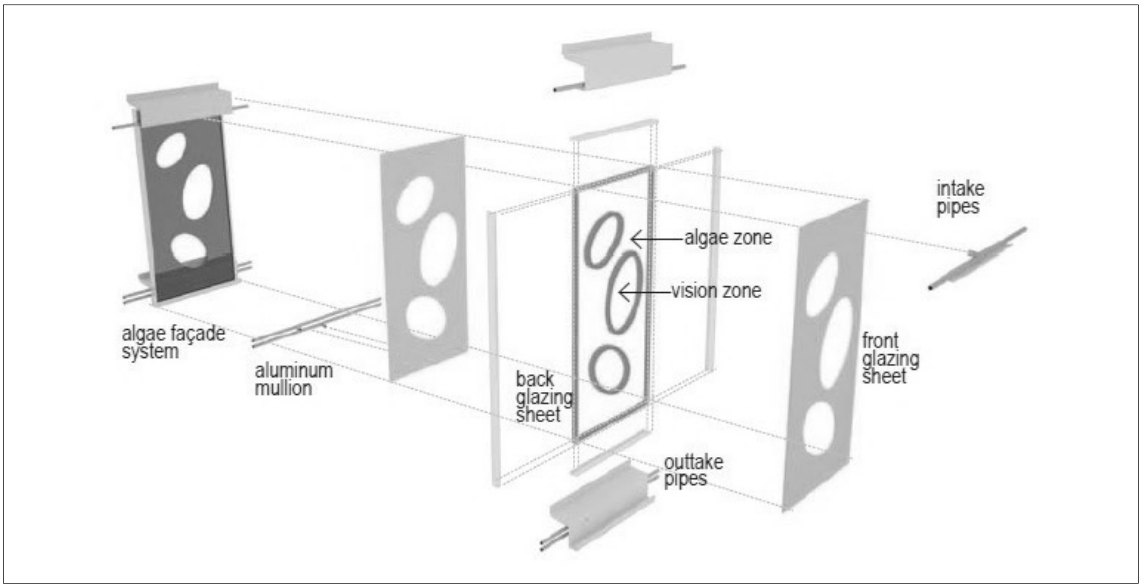


Figure 41. *Adapted typical photo bioreactor panel-components of the system. Source: (Al Dakheel & Tabet Ao).*

Originally, the two-sided glazed surface is made of acrylic material which allows a two-sided visibility and can be adjusted aesthetically by color, coverage design and texture, an added feature considered by the author. However, recent research conducted by companies using a tubular system cultivation using glass pipes has proven using glass material more effective in both illumination, and long-life span but higher in cost (Elrayies, 2018; Kim, 2013; Wallis, 2013). This applies that the flat panel system may be implemented using glass sheets as productive, bio secure, durable, resistant from chemical and scratches, low maintenance and mostly food safe.

3.2.4.2.5 System Flow and performance

The algae are able to thrive within the inch-wide cavity of water and algae solution by a system of carbon, water and air that is pumped in the cavity while another draining pipe is designed to drain the cultivated algae towards a separator/ filtration tank ultimately separating dry biomass matter and liquid content that is subsequently pumped back into the system. “Agitation is provided either by bubbling air from its one side through perforated tube to keep the algae from settling ”(Singh & Sharma, 2012).

The selected condition of the system input mainly confined in the level of (temprature, agetation, Carbon dioxide feed, growth factor, and nutrients) input of the system as controlled variables or constants. Thermal numerical specifications were not applied based on system process specifications literature which involve bubbling system in addition to thermal exposure surface which is conditional and can be regulated through the speed of flow and surface design considerations to adjust target thermal condition of temperature between (20-25 ℃) never exceeding 40 ℃.

Specific performance aspects were calculated based on IRA analysis where synergy areas with measurable benefits were detected as key performance features of the façade system relevant to the end use, effective role in urban aspect and that can deliver measurable optimization results, these are stated below and are further applied in the study case (Table 5).

Table 5 Photo-bioreactor Flat Panel Unit Information

Panel Description	Height (H)	Width (W)	Depth (D)
From BIQ and GSA study	3.6576 m	1.524 m	0.0254 m
Production cost	3.4 euro/kg (Ruiz et al., 2016).		
Productivity	(0.0026525-0.026525) Kg/panel/day		
Volume (V)	= 0.14 m^3		
Grey water – in	(70%) of waste water outflow (consumed water)		
Water-Flow-rate *f*	$f = \mu_A * V$	$\mu_A =$ range between $0.5 - 1$	
Carbon sequestartion m^3/panel/Day	0.108 Co2 /m3/day		
Grey water treatment	The current used volume of (0.14 m3) per façade photo bioreactor unit with a flow rate of [$f = \mu_A * V$] is able to deliver an equal amount of treated effluent flowrate per day in leters = 141.85L treated water per panel		
Bio fule produced KG/panel/Day	(0.00150156- 0.005255 Kg/panel/day of lipids equal to same amount biofuel		

Energy per unit produced from bio fuel KWh/panel/day	(20.115 - 199.48) KWh/panel/day (Murphy et al., 2015).	
Bio gas (Methane) L/Unit/Day	R1-low range = $0.085m^3$*3.9kw/hr =0.332kw/hr/panel R2- high range =0.169*3.9 =0.662 kw/hr/panel R1-low range 85.11L bio gas/panel/day R2- high range 169.89L bio gas/panel/day	0.6-1.2 L of gas /L of treated water. Also Methanol has the ratio of 3.4:1 volume of methanol to dry weight of algae biomass Means every kg of bimass can produce 3.4 times its weight in methanol volume. Conversion is used according to biomass total production. (Murphy et al., 2015).
Energy per unit produced from bio gas KWh/panel/day	R1=0.332 kw/hr/panel = 7.9kw / panel/ day	KWh/panel/day Each cubic meter (m^3) of **biogas** contains the equivalent of 6 kWh of calorific energy. However, when we convert **biogas** to **electricity**, ina **biogas** powered **electric** gen erator, we get about 2 kWh of useable **electricity**, the rest turns into heat which **can** also be used for heating applications (web 4)

		(Murphy et al., 2015).
Fertalizer Carbon sink	The average CO2 emission factors for NPK are as follows: 2.792 kg CO2 equivalents / kg N 0.738 kg CO2 equivalents / kg P2O5 0.352 kg CO2 equivalents / kg K2O CO2 sink is calculated according to these equivalents = 0.108 Co2 L /m3/day	Sink is calculated based on the equivalency factors providing amount of fertilizer used annually in Qatar.
Treated water Carbon sink	6.23 m^3 carbon dioxide / every cubic meter water treated.	Sink is calculated according to study area water treated calculations in relation to the water demand from desalination and related emissions in Qatar.
Energy related Carbon sink	Emissions sink = kw/hr produced * emission factor (0.596345388)	Emissions from electricity consumption are calculated by applying an “emission factor” to the quantity of electricity consumed. Qatar electricity specific co2 factor is

	0.596345388 co2kg/kwhr (Brander, Sood, Wylie, Haughton, & Lovell, 2011)
Energy per façade produced KWh/Unit/day	By using an equivalency calculating tool, the energy produced from algae can be compared to source use values.

3.2.4.2.6 System definition

Urban aspects are subsequently translated into a set of primary morphological data together with the algae performance data and indicators. The combined units of the flat panel bioreactor connected to building flows and physical structure are called (SEEDS) Algae facade system in regards to the optimized social, environmental, economic, demand and supply it aspires towards.

(SEEDS) is an integrated FWE resources system in one robust algae production system model that encompasses biological and economic aspects and considers social and physical encounters for productive urban agriculture solutions. It is based on urban fabric facades which requires it to be developed with aesthetical and functional real estate considerations that integrate within the exposed urban infrastructure. It is guided by MFA and IRA methodology and an intervention logic which will be translated as supply-urban waste, demand-urban food, water and energy of the system and their overall effect on ecological, social and economic factors.

3.2.4.2.7 *The intervention logic*

While the eco related supply and demand are majorly numerical understanding of how much and for how long nature can supply, the author considers it is most suitable to describe theses implication through a geometric reflection of a conics. The central vertex represents the sensitivity of earth system balances as well as the criticality of the approach when dealing with eco system resource services.

The four-identified supply, demand and social and economic generators of the cycle of city system are established based on the literature review which highlighted them as main streams of ecological human interaction that are guided by political and technological streams. The extended cone downwards represents the level of intervention needed from each category resembling the balance required through this approach (Figure 42).

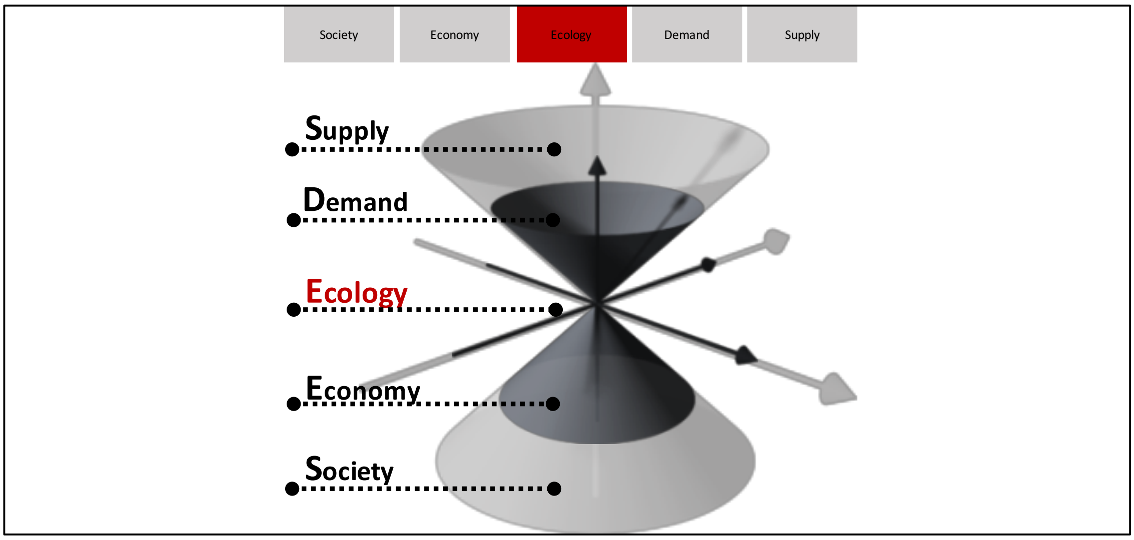


Figure 42. *The intervention logic of SEEDS represented in a conics shape that reflects the side view of the micro, meso and macro scales.*

3.2.5 Evaluation approach

Considering the relatively new application technology and experience with the proposed facade system, the plan to develop a functional algae façade system on larger city scales must take the form of a bottom up approach which not only allows the time to evaluate also simulate the effect of it on the extended latent and manifest considerations of the city, also financial feasible growth based on physical results in what can be considered a living lab scenario (André, Estevens, & Gabriel, 2017).

3.2.5.1 Evaluation scales

There are two major milestones of the research, the first aims to build data and knowledge needed about the nexus subject from the broad global sense towards the smaller localized product application sense. The harvest of this milestone transfers into a nexus framework evaluation context analysis of three scales (Figure 43) elaborated in chapter 5 findings.

First the macro scale which involves the regional profile of the nexus hotspot where geographic, climate and food production and provision is discussed. This level displays a discussion on nations relations as discussed in chapter 1 as the SDGs.

Second is the meso scale which discusses the local scale of Qatar as it relates to the associated risks considering a group of five sustainability principles (Social, economic, environmental and technology and politics as enabling factors) which behave differently in relation to resource stress.

Third, the micro scale which includes the numerical algae system performance evaluation that takes shape in the study analysis area, Qatar University. This level presents the smallest level of interactions analysis of the research which involves the shift towards an integration of both algae and urban systems answered by a set of micro inquiry aspects of how this integration can take shape.

Moreover, the Nano level is added as a major enabler for informing current and future possibilities in algae organism taxonomy, cultivation and processing characteristics.

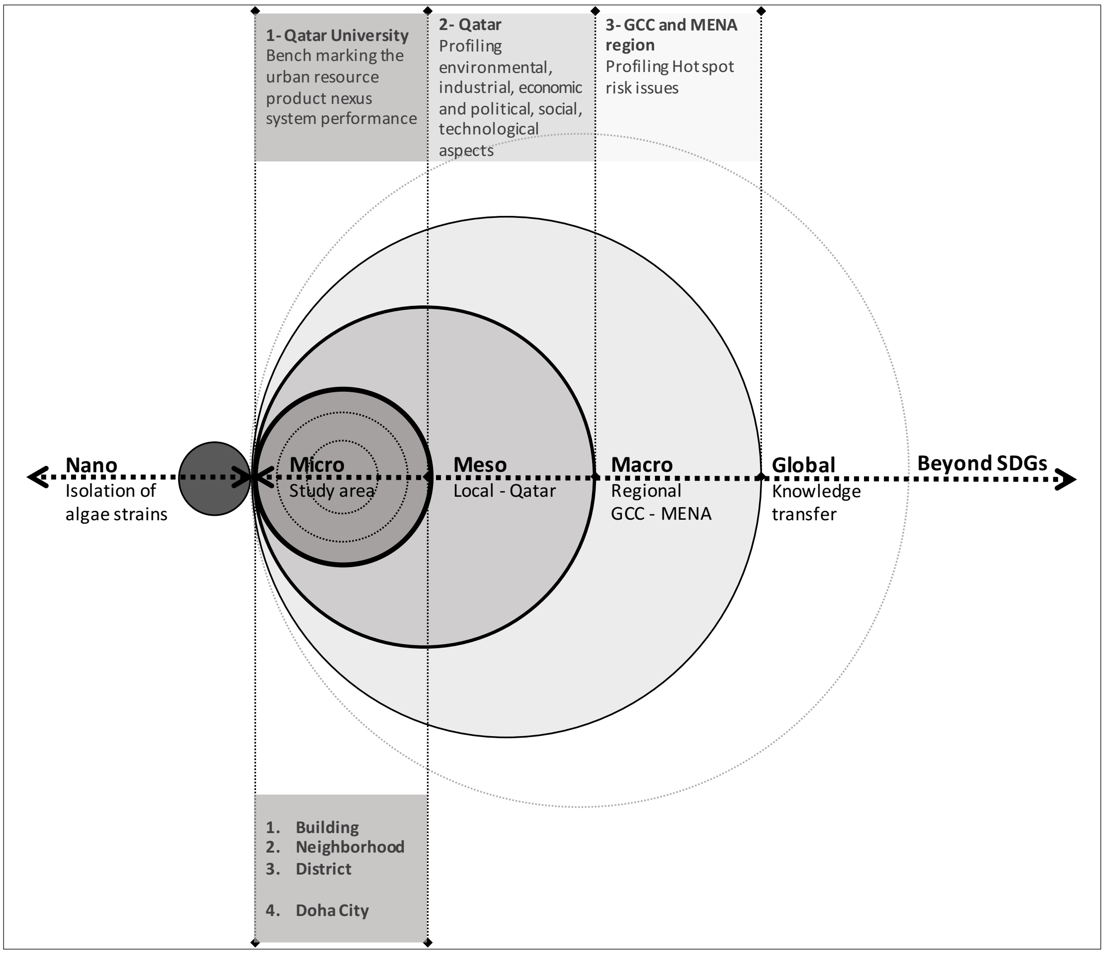


Figure 43. *Evaluation and analysis scales, top view of the intervention logic applied.*

The study area selection also plays a major role in result accuracy. The site selection is based on the following factors in significance order.

1. Data availability, urban systems, population census
2. Relation to ongoing initiatives in regards to sustainability and algae cultivation.
3. Controlled environment

4. A clear governance
5. A clear economic understanding
6. Reflects socio economy of the city

3.2.5.2 Evaluation variables

Three main variable types are distinguished:

1. Independent variables which the system has full control over and can be easily manipulated. These are the photo algae flat panel bioreactor performance which includes measurable variables about the productivity and circular metabolism performance in relation FEW resource. Specific quantity and size of the algae system where growth rate and flow rate of growth medium material is predicted.
2. Dependent variables, these are the ones a nexus system intervention aims to have effect over by controlling the independent variables to measure the effect of algae process and production related functions when combined with the urban fabric. In this context, defining the measurable indicators by revealing a set of common flows such as water, energy, heat transfer, food production, biomass production. The productivity of the algae system in relation to these components is used to make further connection to the nexus framework components indicators more specifically towards the environmental to reach a holistic evaluation of urban algae nexus and is achieved by expanding the relation between the direct carbon sequestrations and secondary carbon sequestration achieved by energy saving, water reuse, biomass production etc. that alter the performance of the production of the latter.

3. Control variables, these are constants which need to remain the same to deliver accurate measurable result used as part of the algae system performance

Due to the limitation of the research scope, the evaluation of sustainability factors identified in the research as social, economic, and their political and technological enablers are only theoretically discussed. The main actively and numerically discussed evaluation component in the research is the environmental (Figure 44), more specifically the ecological foot print influence of the system based on carbon emission indicators. Its indicators are, the competing demands on productive surfaces by land type these are:

1. **Cropland**, the relation lies in the hectare of algae crop produce from the vertical proposed system with no physical occupation of arable land and a high productivity rate.
2. **Forest land**, referring to the literature, forest lands are essential measures of a countries carbon sequestration active land area. while algae vertical system has no physical land occupation value also portrayed qualitatively and imperially as a high carbon sequestration space, Although forest land cannot be effectively compared to cultivated land in UN eco-footprint measure(Ewing et al., 2012), a comparison can be measured as an active forest land by the vertical hectares it occupies.
3. **Carbon demand,** algae during cultivation emits oxygen and sequesters carbon in high levels compared to other plant species. For that reason, the research considers its role during cultivation as part of the extended ecological footprint

reduction benefit. Calculating the benefit follows the SEEDS system performance which is ultimately compared to the larger context carbon emitted.

4. **Grazing land,** algae biomass dry weight is equivalent feed for animal feed, by that it plays a major role in the grazing need of meat production. Comparing the hectares of biomass produced as animal feed can then be compared to existing grazing land hectares ultimately influencing the overall ecological footprint value.

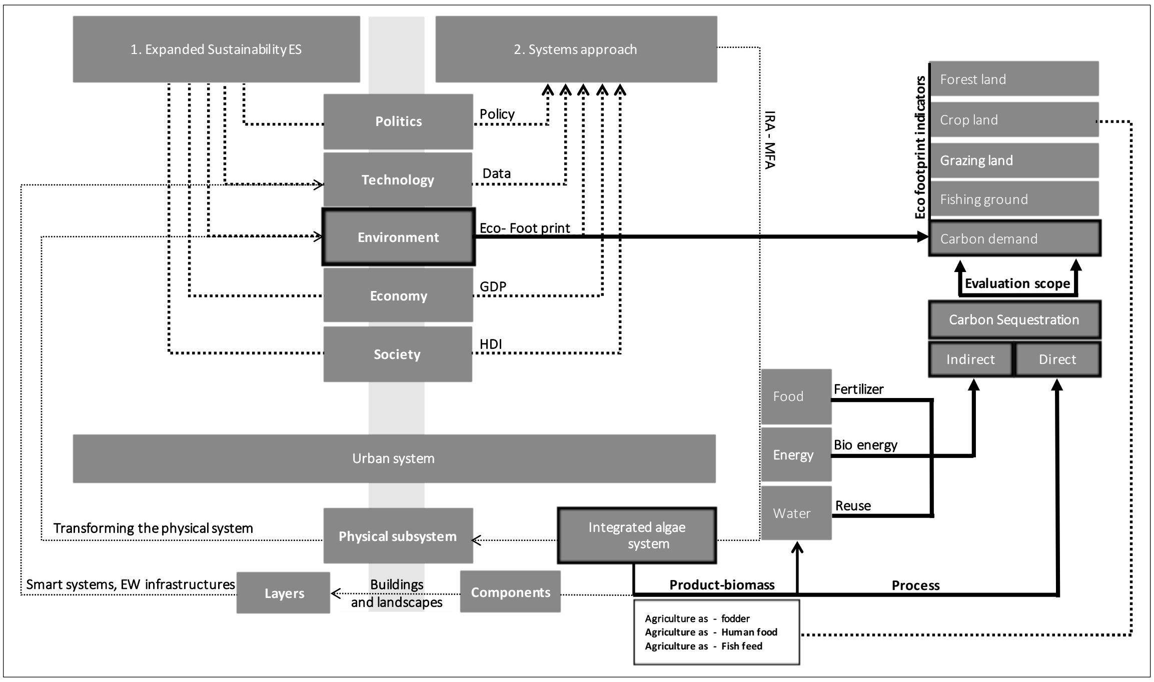


Figure 44. *Evaluation environmental scope, ecological footprint variables and indicators included.*

3.2.5.3 Evaluation phases

There are two phases in a comprehensive experimental evaluation that need to be considered.

1. The evaluation of the case scenario that merely seeks to numerically evaluate the system performance. This includes the system dynamic modeling based on specific input and output data. This phase concludes two results for system performance, the eco-efficiency and eco-productivity in the context of Qatar. The way the algae system influences social and economic patterns is limited only to a theoretical discussion.
2. The verification of the result which takes a practical approach through the built design and evaluation of a virtual pilot study which for temporal results which are subsequently compared to the latter simulation results. This stage is not included in the scale of this research.

3.3 Research Instruments

3.3.1 Qualitative instruments

These include instruments based on theoretical data analysis that are used to scale and direct the quantitative analysis instruments.

3.3.1.1 Nexus

The main instrument used in this research is the nexus tool. The scale of the nexus focuses on three main resources, food and its connected energy and water. The nexus relevant assessment tool helps deliver recommendations for urban planning policy and practice. While the nexus tool is used as a theoretical basis to strategically approach the research problem by a clear framework, it extends the level of integration considerations beyond the main sustainability pillars, the environmental, social, and economic towards political and technological players.

3.3.2 Quantitative instruments

3.3.2.1 Analysis strategic instruments

The identification of the interconnectivity is achieved using two main analysis tools, the MFA and IRA strictly in regards to the resource flows which will subsequently determine their effect on the economic and social sector.

3.3.2.1.1 Material flow analysis (MFA)

MFA procedure in this research applies it qualitatively limited to a (1) Systems Definition which targets primary objectives, (2) Spatial, temporal, functional Scope of the procedure and (3) system Boundary which defines the start and end of flows to limit the numerical data and confine it through the identification of the structure of flows(Musango et al., 2017; Pincetl et al., 2012). The flow analysis is limited to synergy areas between algae, food and urban system.

3.3.2.1.2 Integrated resource assessment (IRA)

IRA is applied by overlaying the different MFA analysis of urban, algae and food systems in order to identify best integration areas that will lead to a specific set of synergy areas and specify the numerical data needed for the case analysis study purpose and a discussion on the economic and social implications of the established overlay of the new system.

3.3.2.2 Evaluation strategic instruments

3.3.2.2.1 *Bench marking*

Bench marking is used to provide a performance evaluation comparison basis, (figure 45) shows the sequential steps taken to run the evaluation. Phase 1-2 are discussed in chapter 4 where the initial situation of the macro, meso, micro scale of the study is described. The micro scale is essential for the bench mark as it will deliver the numerical resource flow, consumption specific to the study area which will enable measurable results when integrated with the algae façade system. The specific data collected is stated in the following data definition section.

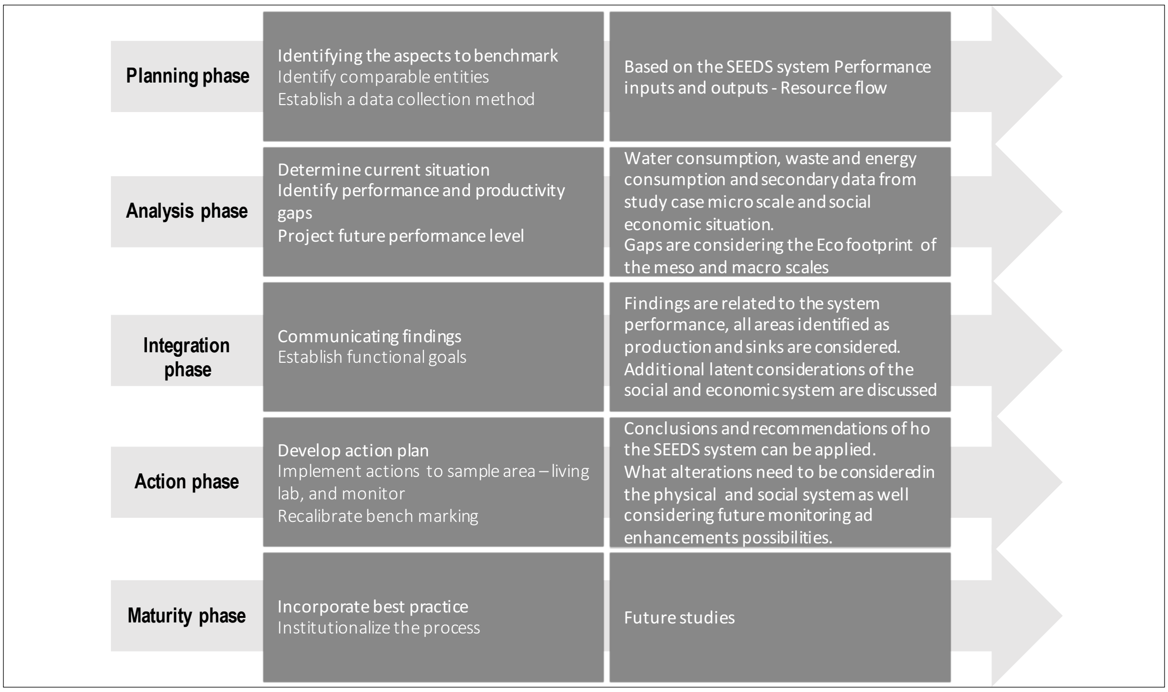


Figure 45. *Bench marking sequential steps.*

3.1.1.1 Modeling strategic instruments

3.1.1.1.1 System dynamic modeling

Nexus problems are commonly reflected in a series of simulation, a concept of examining solutions in practical practice and planning circumstances. By doing so, system applications can take a more effective and interactive role in generating real life numerical and behavioral aspects of the proposed solutions, thus allowing a more secure risk assessment of new innovation in a controlled margin or scope.

Important things to consider with simulation is data collection, the data sampling needs to be directly related to the actual case. In the case of this research, an excel sheet with context study urban physical subsystem data is translated into a production rate simulated using (Any logic software). The results of the simulation are then discussed within the extended nexus framework in relation to the context of the study area.

The data generated by these modeling scenarios can also be used to enhance design tools by the use of computational design.

3.1.1.1.2 Computational design

The computational design discussed aims to enhance the planning connectivity between algae system performance and the urban systems which cause diverse FEW flow behaviors and their related externalities of ecological stress and emissions depending on the design decisions and process. The latter is established by encoding design decisions using a computer language that translates algae façade system productivity and efficiency into scores.

3.4 Data Definition

Two types of data are at the forefront, qualitative and quantitative data. Qualitative data involves theoretical basis of the research which aims to collect incremental upward stream information about the research subject starting from the global towards the local and production-based information which will identify important factors to consider in the intervention approach towards proving the hypothesis. It consists of two sections:

1. Data that consists of nominal variables that are used to direct the discussion on nexus, these include the theoretical aspects of

sustainability principals (social, economic and environmental including the political and technological enablers)

2. The data which consists the variables which make up the nexus framework and are analyzed in an ordinal manner to achieve a consistent discussion flow. This is reflected in the stages of applying the framework in the findings.

3.4.1 Data analysis

The qualitative data is analyzed in a deductive manner, which involves the practice disciplines of a nexus framework and system efficiency discussion. Quantitative data is majorly used at the productivity evaluation stage of the micro scale. The two main sets of numerical data used are the resource flow data in the algae and urban system and the urban physical data which include building parameters, infrastructure readings and algae system parameters. Evaluation approach is based on the knowledge of the product metabolic cycle, and how this correlates to the larger FEW systems considered. To achieve this kind of system flow knowledge and data, the algae cultivation system is analyzed independently to identify system flow qualities from the biological function of the species to allow measurable effects on the larger carbon emissions and foot print accounts. In regards to the urban flows data, the availability of conventional metering system enabled the collection of input, consumption and outflow of urban water and energy.

The information obtained is subsequently used to apply:

1. computational calculation of the algae photo bioreactor system in relation to its material flow properties in terms of mainly productivity, sinks and sequestration.

2. The urban infrastructure and physical computational calculations which can translate the connection between the algae parameters and urban façade parameters.

In the case analysis, the application is considered on the east façade of case area existing building based on solar and direction/ East. Referring to the urban layers and scales identified, the number of units is ultimately translated into productive area per building, per block, per neighborhood and per district to illustrate the phasing of unit application in the study area. the scenario may be illustrated differently depending on the application density, units assigned to each building and the overall growth rate of the system.

1. Phase one. Building/block scale 10-20 buildings
2. Phase two. Neighborhood larger scale
3. Phase three. Whole District
4. Phase four. City

Balancing productivity and density of the system depends on the optimum level of productivity an area aims for. Also, the level of available application areas for the system product such as agriculture fertilizer, human consumers, water system to be recycled and more.

3.4.2 Data classification

Two main data types are identified in this research based on the level of reference, the primary and secondary data.

Theoretically, the literature of leading edge FEW intervention initiatives is explored alongside nexus system tools and method to collect data on how urban systems interact in terms of resource, and the interconnectivity of the three pillars of sustainable development, this point involves secondary data from research papers, scientific books and journals ultimately setting the background of the research. By using the UN initiatives during the secondary data exploration, several variables and indicators are assigned to the nexus framework.

The UN approach definition of sustainability and integrated system thinking deals with multiple aspects which the author explores in order to establish how each indicating variable, dependent, independent or constant is related to the holistic picture of the system. The three pillars of sustainable development are central in establishing the connections between all resource related urban consideration.

However, due to limitation reasons, the author focuses primary data on the environment pillar while generically discussing the other two pillars, the economic and social using census data available by government entities.

Moreover, the algae product system is analyzed by its urban related food, water and energy flows. This involves secondary data from the (QU study area's) water and energy meter readings to be collected from a secondary source then analyzed into evaluation information. Additionally, the urban subsystems data more specifically the physical system (layers and components) are collected and analyzed to present high interconnectivity, low interconnectivity urban issues to consider when integrating algae product holistically.

3.4.2.1 Primary data

3.4.2.1.1 Morphological data

Derived data or Morphological data is the creation of new data based on existing data points from different sources.

There are two sections where morphological data was applied:

1. The calculations of the SEEDS system performance per panel according to biomass production, bioenergy production and grey water treatment considering the synergy areas in the whole system.
2. Calculation of integration performance according to the study area (Qatar University) which include the direct and indirect carbon sequestration by the water and energy benefits gained and their effect on the larger ecological footprint of an urban development

3.4.2.2 Secondary data

The latent and manifest nexus present the embedded and extended social and economic considerations of the product. Latent reflects the unintended consequence caused by technological and economic development specifically ones that are resource related. Manifest on the other hand are intended and calculated but could present latent dysfunctions when implemented on the longer timeframe.

3.4.2.2.1 Latent data

This involves data needed to profile the research context in terms of ecological stressors, global trends and the latent social and economic factors which influence the design and operation of the system (Table 6). This data is also essential in the measurement of eco-efficiency of the system and will only be discussed qualitatively.

Table 6 Latent Data

Variables	Indicator	Measure unit	Source	Data type
Population	Population number	No.	Census data, Government	Secondary

Urbanization	Density and morphology	KM^2 occupied land	GIS data, MME	Secondary
Social	Human development index HDI	NA	Census data, Government	Secondary
Economic	Gross domestic product GDP	NA	Census data, Government	Secondary
Ecological footprint EF	Cropland, grazing land, fishing grounds, built-up land, forest area, and carbon demand on land	Global hectares	UN global standards	Secondary
Agriculture food industry	Crop land Fodder land	hectares	MME	Secondary

3.4.2.2.2 Manifest data

This involves the study area QU urban subsystem categories which present information needed for benchmarking the direct related factors in the physical integration of the algae faced system (Table 7). These were established according to the algae system (operation needs and application context). This data is also essential in the measurement of eco-productivity of the system and will be discussed quantitatively.

Table 7 Manifest Data

Variables	Indicator	Measure unit	Source	Data type
Climate	Solar direction	NA	Google Earth	Secondary
	Thermal average	Degrees Celsius	MME	
Density	Sloid and Void	m^2	QU master plan analysis	Primary
	Population	Capita/ m^2		
Land use-building use	Type and Function	Units or lots per type	QU master plan analysis	Secondary
Landscape	As empty lots	m^2	QU master plan analysis	Primary
	As fifth facade	m^2		
	As sixth facade	m^2		
Water tie in	Municipal water	Number of tie in points	Kahramaa-QU-FM department	Secondary

		m^3/day supply/ point		
	TSE	Number of tie in points m^3/day supply/ point	Kahramaa- QU- FM department	Secondary
Water consumption	NA	m^3/day	Kahramaa- QU- FM department	Secondary
Grey water	NA	m^3/day	Kahramaa-QU- FM department	Secondary
Electrical tie in	Number of connection points – Voltage	Voltage/Units	Kahramaa-QU- FM department	Secondary
Electrical consumption	NA	KW/hr/day	Kahramaa-QU- FM department	Secondary
Smart systems	Water Metering	Units / building	Kahramaa-QU- FM department	Primary
	Electrical Metering	Units / building	Kahramaa-QU- FM department	Primary
	BMS	Units / building	Kahramaa-QU- FM department	Primary

3.4.2.3 Data collection tools

3.4.2.3.1 Case studies

In the process of exploring algae advancements in urban entities, the research looks at 3 case studies for the purpose of understanding interconnections between urban systems and algae product system and more specifically the quantification of the inputs and output requirements of the algae system. Algae as a product is central to the integration and optimization aim of the proposed system. Additionally, the design of the algae system is based on a photo bioreactor study where specific dimensions, related sinks and productivity are measured accordingly.

3.4.2.3.2 Interviews

In this research, involvement in relation to the product system application is pursued in a number of ways. First the in-depth interviews with knowledgeable members of academic and professional development directly towards the design and application of an algae integrated urban system, food security and agriculture in Qatar. Members interviewed are:

1. Dr. Imen Saadaoui, College of Scince and technology at QU
2. Kira Schipper, Research Associate at Center of Sustainable Development at QU, interviewed for ongoing algae related research and pilot study in Qatar, Alkhor.
3. Dr. Vikram M Pattarkine, PhD, BCEEM, CEO, PEACE USA – Specialized Renewables and Environment, Mechanicsburg, Pennsylvania, interviewed on algae performance calculations.
4. Sara Almalki, Msc, MME, Food Security Specialist, interviewed on food security strategy in Qatar.
5. Eng. Mahmoud Husni Alsaeed, Msc, Engineering consultancy office,

interviewed for information related to the building sector and infrastructure water and energy grids in Qatar.

6. Potential stakeholders from the farming community, Mr. Ali Alkaabi-farm owner and Mr. Fawaz Aquarian-Global Farms Qatar consultant.

Second, the general public interviews which targeted three social groups. Residents of residential buildings area, professionals in commercial buildings areas and the student social group of an educational facility campus. All members were chosen on the basis of gathering opinionated answers towards the design and interaction aspects of the algae system within urban environments to inform the physical and aesthetic design aspects and economic and consumption expectation of the system product.

3.5 Chapter Summery

The methodology chapter plays a vital role in specifying the next transitional steps in the context discussion. The focus on scales is used as a guiding tool to deliver a deductive discussion of the context starting from the regional resource risk and downward towards a more local context. The discussion includes urbanization and population concerns in line with the specific local social, economic, environmental, political and technological features as they relate to food security and resource risks. These latent aspects present the embedded and extended social and economic considerations of the algae system integration nexus whereas Manifest nexus aspects are intended and calculated in the microscale study area QU. Data which is critical to the environmental evaluation of the study area is collected and analyzed according to the bench marking approach which will facilitate the evaluation ground between the performance of the system before and after the integration. Accordingly, below is a list of recommended discussion points which follow the defined scales are essential in the context chapter:

1. Macro

The population and urbanization risks associated with food, energy and water

2. Meso – Qatar Doha city

- Urbanization
- Population census
- Industry and economy of Qatar
- Socio economy of Qatar
- The food production supply, water and energy demand
- Energy and water production, supply, delivery and return system

3. Micro – study area QU general description which will be elaborated in the following chapter 5 findings. The main areas needed for the analysis are

- Human sub system – behavior and attitude towards resource
- Activity subsystem – includes FEW energy and water supply and demand
- Physical subsystem – included analyses of components and layers

CHAPTER 4: RESEARCH CONTEXT

4.1 Introduction

Because nexus analysis seeks customized solutions for resource driven problems, there are two main considerations in the context which build up towards the findings. First, the chapter plays a significant role in profiling Qatar regionally and locally and uses the study location in Doha-Qatar University as a case analysis to achieve a top down approach, from regional to local highlighting the nexus hot spot scenario to deliver customized solutions and discussions that fit the context urban and resource profile. The chapter aligns the discussion with chapter three methodology established scales and the predetermined nexus components which include environmental, social, economic technological and political aspects. After a comprehensive understanding of the hotspot factors involved in profiling urbanization and population trends as they relate to climate and resource stress, the chapter zooms the context into the applied study area/case (Qatar University Campus, QU) where a brief description of the data needed to analyze the productivity and efficiency of SEEDS in the campus is discussed. The site analysis and results of the algae optimization system will be sampled and discussed in the findings chapter (Figure 46).

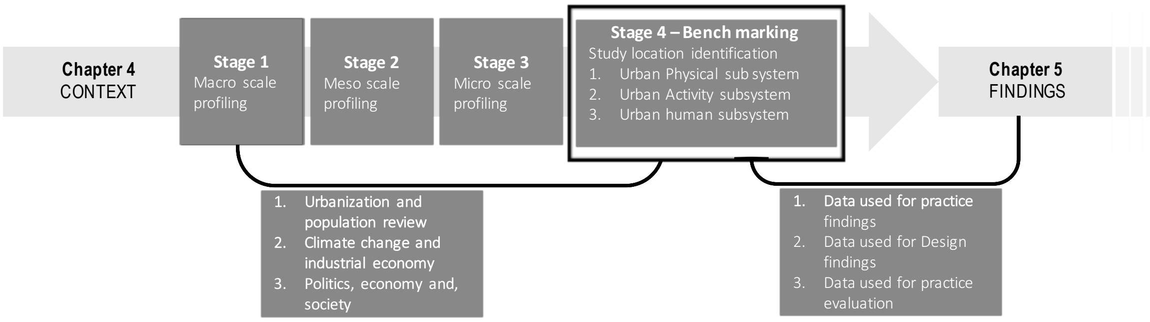


Figure 46. *Context chapter subsequent stages.*

4.2 Context Scaling and Profiling

Resource nexus creates environmental, economic and social effects that are felt prominently in risk hotspot countries and the extended effect on regional aspects. This section of the research is dedicated to discuss and identify the scale of the context, in order to emphasize the scale of the research. For that extend the description of the context respects a top down approach based on literature described sustainability initiatives that entail a think global act local point of view.

4.2.1 Macro scale - regional context

This section of the research is dedicated to describe, identify and review the characteristics of the region, where reginal is the Cooperation Council for the Arab States of the Gulf known as the Gulf Cooperation Council (GCC), GCC comprises six gulf state countries, Qatar, Kuwait, Bahrain Oman, United Arab Emirates and Saudi Arabia under a unified intergovernmental, political and economic since 25 May 1981 (Figure 47).

Figure 47. *Map of Gulf Cooperation Council (GCC), comprises six gulf state countries.*

4.2.1.1 Regional urbanization review and population morphology

It is indicated that there is a positive relationship between developed infrastructures, population and urbanization (Asif, Sharma, & Adow, 2015). In GCC countries, urbanization is generally rapid as is the population growth merely linked to high GDP which triggers international migration (M. A. Darwish, Abdulrahim, & Mohieldeen, 2015; Lowe & Altrairi, 2013; Ramady, 2012; Reiche, 2010) and extended life rate according to latest HDI statistics in the region. The speed in the development process and mostly in the infrastructure and services area is a reflection of the rapid shift in government and social entities towards higher level construction, industries, businesses as well as households leading to higher level of food, energy and water demand which in fact is the main climate concern aspect after the energy industry in the region. GCC countries are one of the highest contributors to climate change ranking from the top 25 countries emissions per capita (Ramady, 2012).

4.2.1.2 Climate change and industrial economy

The two highest ranking industries which have flagged the region as high emission factor are the energy fossil fuel industry and the water desalination industry (Mohammed & Darwish, 2017; Network, 2010). However, economically, the energy sector in the GCC is the main economic revenue which has labeled the region as major contributor to global climate change and resource risk(Munawwar & Ghedira, 2014) because of its high electricity demand and carbon intense processes.

According to UN Food and Agriculture Organization of the United Nation, the physical effects of climate change are likely to hit the Gulf states and the rest of the Middle East and North Africa hardest. "Worsening dust- and sandstorms cause significant agricultural losses in countries such as Saudi Arabia, and Yemen, which are near the bottom of the rankings in terms of historical susceptibility to storm damage" (Almanza & Nesmith, 2004). Hence, based on self-sustained and resilient food system in the region, it is labeled by UN measures as insecure (Andy Spiess, 2012).

4.2.1.3 Politics, economy and society

The food insecurity categorization encourages strategies to boost domestic agriculture in the region. This was on cost of increased capacity of energy intense desalination (Figure 48) as the region lacks fresh water resource which brings the issue back to oil and gas-energy reliance that sustains water security (Shah, 2010).

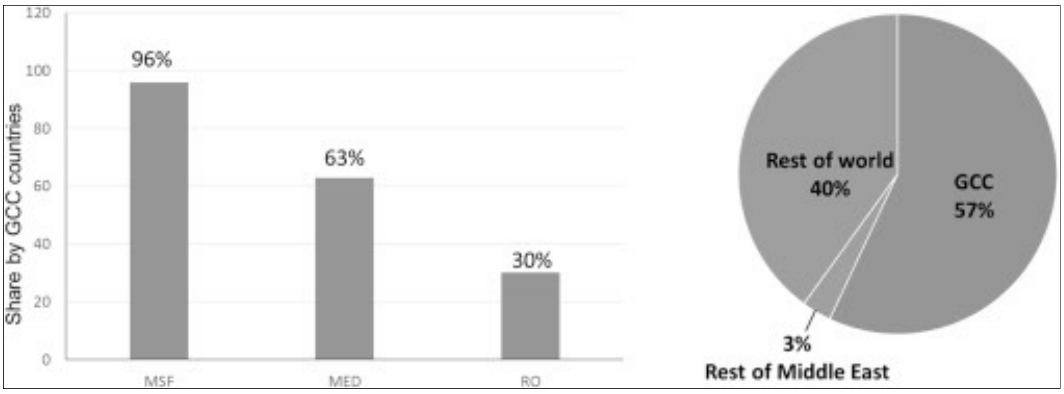


Figure 48. *GCC countries desalination water share from global total, Source: World resource institute 2018.*

One major issue is the GCC regional policy is described as blocking international climate change negotiations (Reiche, 2010) due to an inevitable situation where the region is almost fully dependent on oil and gas revenue and fundamental international share, mainly US oil share agreements which further complicates attempts to move towards intense green economies in the region (Hammoudeh & Choi, 2006; Mohanty, Nandha, Turkistani, & Alaitani, 2011). The region has limited alternatives in case of future prospect of post oil era (Ulrichsen, 2014). For now, GDP prospects and the HDI reflected by it are positive an on the rise in the region which explains the last decades general society unhurried attitude towards climate change risk threats (Dunlap & McCright, 2011). However, GCC countries remain conditional to the geopolitical security which could limit confidence of foreign investment in the region (Al-Khouri, 2010).

Hence, food security in the gulf quickly slips from its essential role as an economic stimulus into a political response (Khalifa, Alsarhan, & Bertuccelli, 2017). With the recent dynamics of geopolitical instability in the region which has presented new externalities that threaten food security and the ability to trade or import food stuffs (Ramady, 2012) (A Spiess, 2011), it is important to evaluate food security in the Gulf monarchies not only by "the access for all people at all times to enough food for a healthy, active life" (FAO, 1996), but also to be specific about self-sufficiency, "defined as being able to meet basic consumption needs (particularly for staple food crops) from own production rather than by buying or importing"(A Spiess, 2011; Ulrichsen, 2014).

4.2.1.4 Food, energy and water resource

Food and agricultural in the gulf region present a more challenging ground for resource management. The rapid development population growth and harsh weather conditions have escalated domestic challenges. Combined with the uncertainties of changing climate and environmental uncertainties that threaten domestic agricultural efficiency, the gulf countries are obligated to readdress their development models.

The conventional model has been low in agriculture and food production markets, grounded on oil resource wealth that prefers of state over markets, and import over industry and disconnection between food distribution and production cycles at the consumers level(Breisinger et al., 2010). Hence, GCC countries are noticeably food secure rather than food sufficient, meaning they can buy their way out of the problem(A Spiess, 2011)(World Bank 2004a)(Bruinsma, 2017).

The GCC countries with limited farming community, fertile land, freshwater, and abundant capital, geographical and cultural proximity made SAARC countries a natural trade ally. The South Asian Association for Regional Cooperation is the regional intergovernmental organization and geopolitical union of nations in South Asia (SAARC) countries rich with fertile soil, fresh water”(Mohammed & Darwish, 2017). Additionally, GCC countries have perused a new strategy of purchasing farmland across region boundaries. Almost 2% estimated land is categorized under this agreement type. Still, the production of crop based goods in that sense remains subject to externalities amongst the bought lands which also run under a different set of governance and product still needs to be transported into the region.

This has caused the domestic consumption of energy in the region to increase at an astonishing rate, weather fossil fuels or food stuffs transportation and management related which resulted in high ecological and carbon foot prints labeling the region as one of the highest per-capita. The energy demand has also taken its toll on water security in the region. Although underground water reservoirs are available and are commonly used for agricultural activities (figure 49), due to excessive saline, brakish or treated sewage effluent (TSE) water injection into earth crust during oil and gas pressure balancing action known to the industry the underground is exceedingly suffering from increased salinity and possible contaminants.

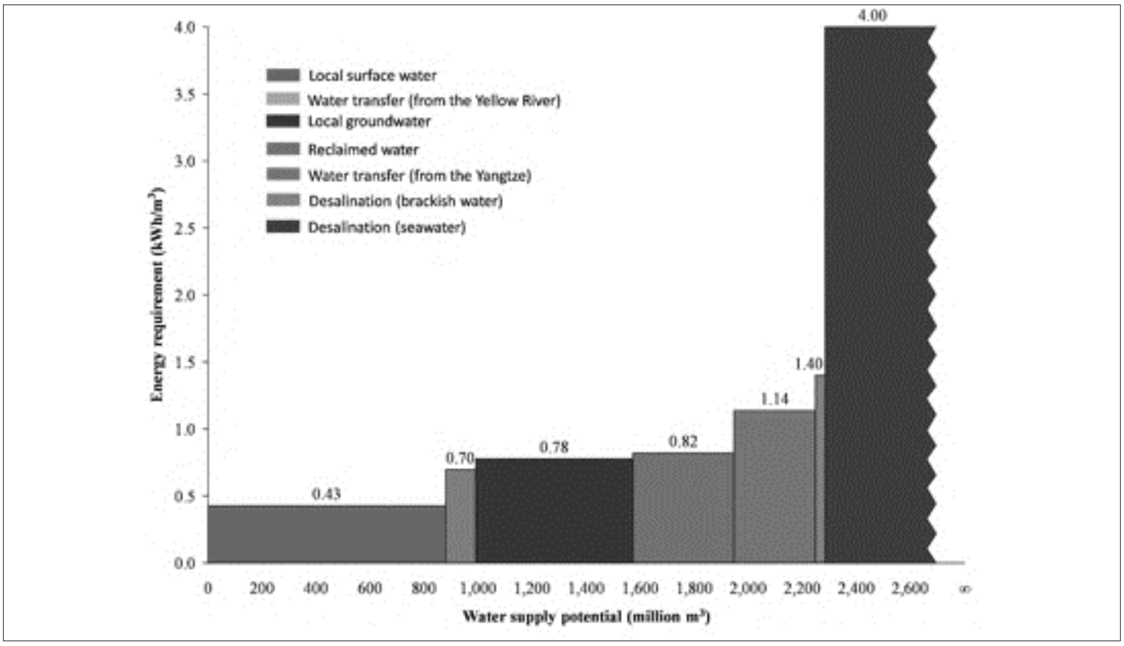


Figure 49. *Middle east water desalination source (Li, Siddiqi, Anadon, & Narayanamurti, 2018)*

Natural reserves are also subject to sudden shocks such as nuclear contamination in the regions water.

Currently TSE where range of 10-50% is currently being adapted back in the system for nonagricultural uses. Also, trends of increasing municipal water price to accommodate the stress all which still remain relatively insecure. As a result, research on high salinity tolerant crops, alternatives such as algae cultivation are progressing as are technical agricultural advancements as vertical farming.

4.2.2 Meso scale - Qatar context

Qatar peninsula located in the western part of the Arabian Gulf is described as a hot desert climate country surrounded with a 1000km coastline and extends northwards in the region covering approximately an area of 11600 km^2 (Figure 50). It is majorly 11437 km2 of flat topography. The latter has stimulated the regional trade markets through land and open sea which has played a major role in formulating international agreements, relations and diversifying imports.

Climate wise, the high luminosity and solar energy during the day-(3422 sunlight hours per year) is an advantage in the context of algae development. Temperatures are an average of 34 °C escalating to 45+ during summer months, a humidity of 59%, with very low precipitation (75 mm per annum) (Saadaoui, Bounnit, Al Ghazal, & Al Jabri, 2016) ultimately aggregating the challenges of securing FEW resource in the country. The fresh water resource is 100% reliant on desalination - an energy and ecologically intense process which was only been made possible by the abundant oil and gas revenue. Hence, the country is able to manage its harsh geographic and climatic challenges and buy its way out of the threat.

Figure 50. *State of Qatar geographical location, global, regional and local.*

4.2.2.1 Urbanization and population review.

In a comprehensive context, the State of Qatar is divided into eight administrative municipalities: Doha, Al Rayyan, Al Wakra, Umm Slal, Al Dayyan, Al Shahnia, Al Khor and Al Shamal (MDPS, 2018; Qatar, 2008), which are further divided into 98 different zones (Figure 50), Generally, urban development in Qatar is led by two main factors, the coastal line where first settlement occurs, and the oil and gas industry which facilitated action to rapid growth and urban development. Most of Qatar’s cities suffer from fast planning and construction misconceptions and disconnection from its ecological performance. Population increases radically in well developed areas of Doha city specifically where proximity to main roads and costal lines is high (Figure 51).

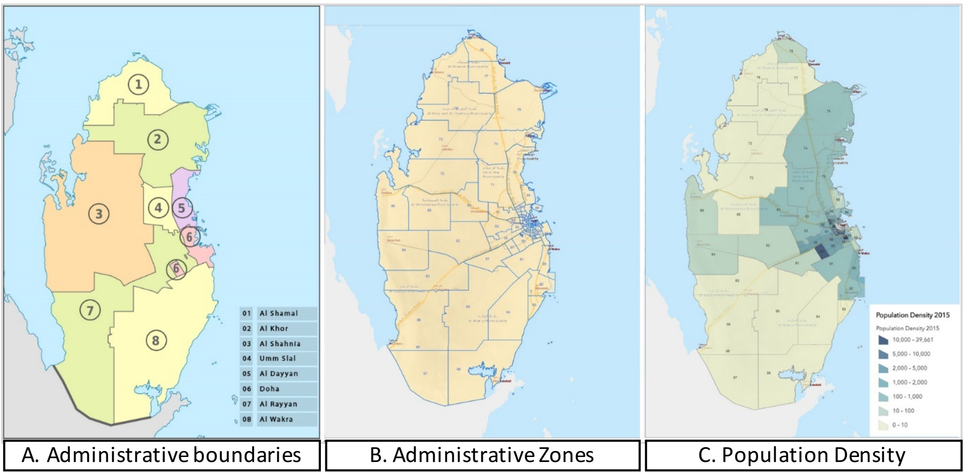


Figure 51. *State of Qatar, A. Administrative boundaries, B. Administrative zones, C. Population density, (Source; Qatar, GIS portal, 2017).*

Although Qatar’s urban development is a relatively new sinse1940s(Omran, 1980), 99 % of Qatar’s population currently live in cities which is expected to increase 53.2% to reach 3.7 million from 2015to 2030 due to the a fertile ground for construction and the country's reliance on mainly male foreign workers(Cohen, 2003) (figure 52). This corresponds to a population growth rate of 10% per year and 7% GDP (figure 53-54). Population trends are mainly migration and annual foreign employment related

(Cordesman, 2018) . Population morphologies beyond 2030 remain unpredictable considering the number of construction expat workers in the country exceeding 60% of its population.

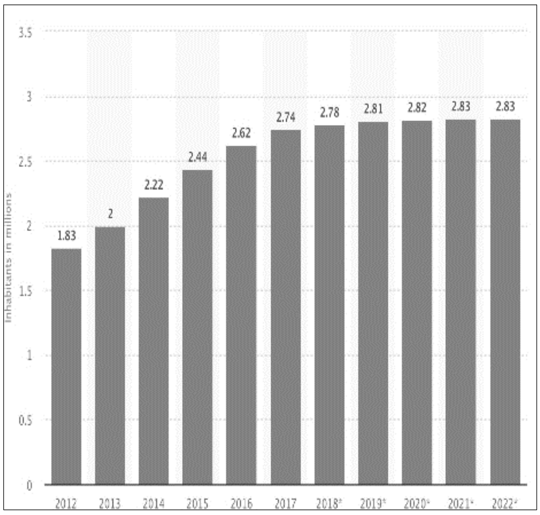


Figure 52. *Qatar population data, migration rates 2015- 2022. Source: World Bank 2018.*

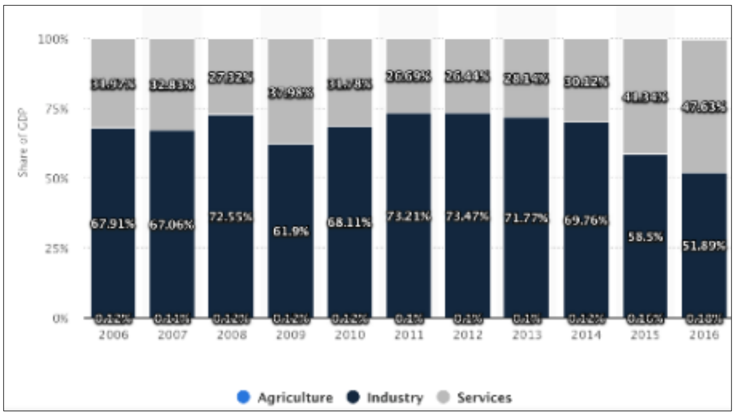


Figure 53. *"Distribution of the gross domestic product (GDP) across economic sectors in Qatar from 2006 to 2016". Source: World Bank 2018.*

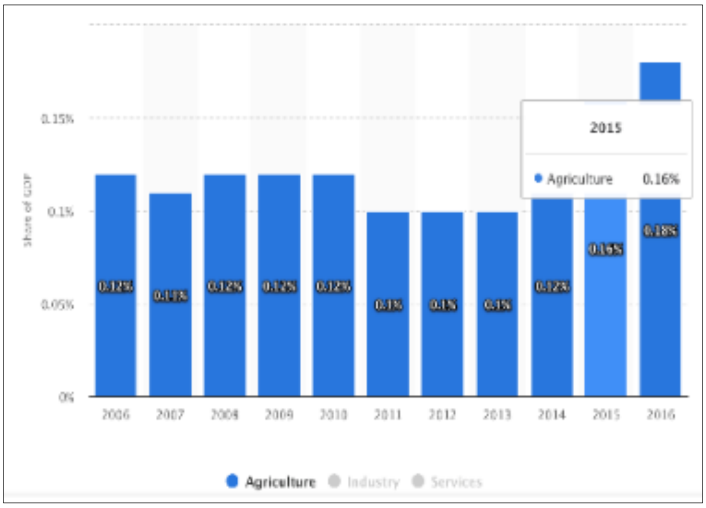


Figure 54. *Distribution of the gross domestic product (GDP) from agriculture in Qatar from 2006 to 2016. Source: World Bank 2018.*

Doha municipality as the capital city involves major municipal buildings and quires the largest 80 % of total population in Qatar, infrastructure, density and business developments which puts it at a higher level of urbanization activity(Cordesman, 2018).

Four urbanization sequential trends have been identified (Figure 55) as a result of a growing oil and gas revenue as well as political state. By exploring these planning principals, the knowledge can be used to guide future system and structure adaptation methods that consider the scale and pattern of the existing master plan.

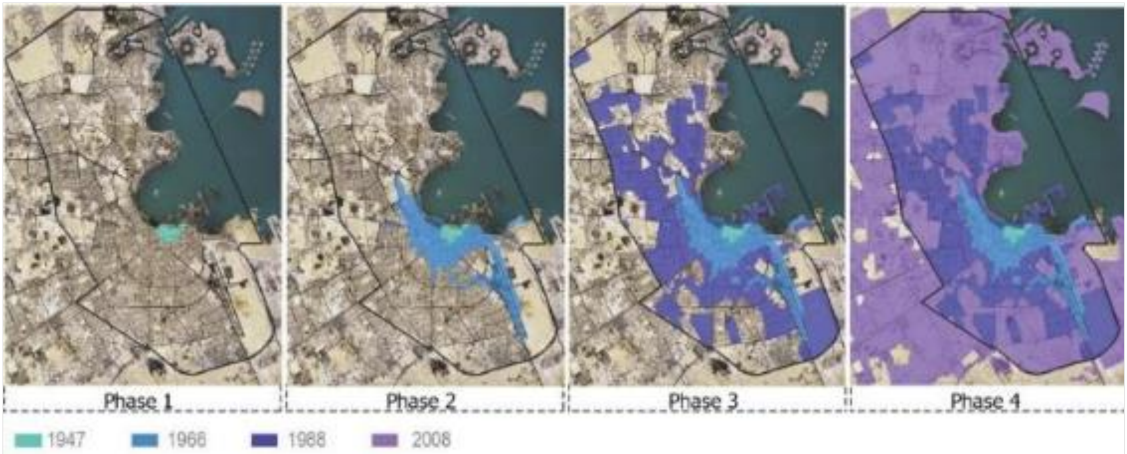


Figure 55. *development of Doha urbanity, (Source; MMUP, 2014).*

First the development between (1972–1984), urbanity of modernization. This trend was established by Qatari government invitation to Llewellyn-Davies-British planning firm. The agreement to develop Qatar's first master plan formulated a physical decentralization of the development and road infrastructure expanding the size of the urban development (Adham, 2008; Nagy, 2000)(Alsaeed.M,2018).

Second was the petro-urbanism between (1980–1990) stage. At this stage, economic inflation due to the industry intensified urban development aspiration facilitated the consultancy services of several international planning entities to restructure the initial master plan. The high light of this stage was the establishment of the first government data base in the country (Qatar Area Referencing System) that communicated through a systematic information archive (Adham, 2008; Al-Buainain, 1999; Riad, 1981) (Alsaeed.M,2018)..

The third trend was a transitional period through the instability caused by the Gulf War. During approximately ten year span (1990–1998), the internationally consulted developed plans failed to be executed though todays master plan has been chiefly guided by them(Adham, 2008; Rizzo, 2014) (Alsaeed.M,2018).

The fourth trend is one that has put Qatar at the high of its current development as well as a controversial ecological position under the media light. The mega-project trend is a result of a globalized mindset in the development needs of the country stimulated by its high economic empowerment and lately the FIFIA world cup awardee which has put the country in a direction of intensified reformation of transport, tourism and business development. While the new developments are generally sustainability oriented and smart system based by which GIS demographic, social and country wide consumption patterns have been incorporated in infrastructure planning decision making (Henderson, 2014; Shamsi, 2005), still, the rapidity of the development and vulnerability to temporal errors between projects execution and infrastructure reformation has triggered the country to further questioning about its ecological foot print contribution and to climate change dilemma globally. The trends highlight the power of economic revenue and the ability to transform rapidly, but on what ecological cost?

4.2.2.2 Climate changes and industrial economy.

Today, Qatar’s ecological footprint is 8.5 gha/pers which has fallen since 2013 from 12.5 gha/pers is ranked second behind United Arab Emirates amongst the highest GCC ecological footprints as per UN indicators (Figure 56).

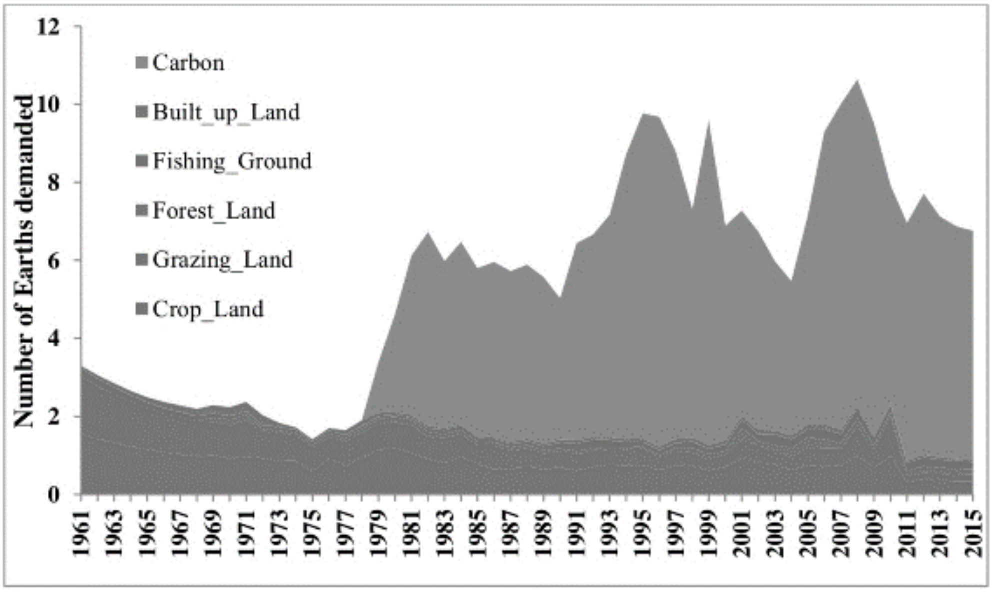


Figure 56. *Qatar ecological footprint by indicating components. Source, Global footprint UN 2018.*

It is still significantly high and shifting to rise with population and urban development increases including metro rail and infrastructure in preparation for the world cup 2020. Although this situation is considered temporary, the future still needs to recover the accumulated land and resource losses since the industrial era. An eco-debt study which examined how much countries put back in the environment also highlighted Qatar as the second highest consumer at 11.6 Global Hectares without regenerative acts. It is for that reason that even if current practices are mitigated, there needs to be a shift towards a return factor to ecological reserves.

Although the country is producing most of the worlds clean liquid Nitrogen gas (LNG) (figure 57), public media focus and UN measuring of global ecological foot prints have discredited Qatar's green energy industry.

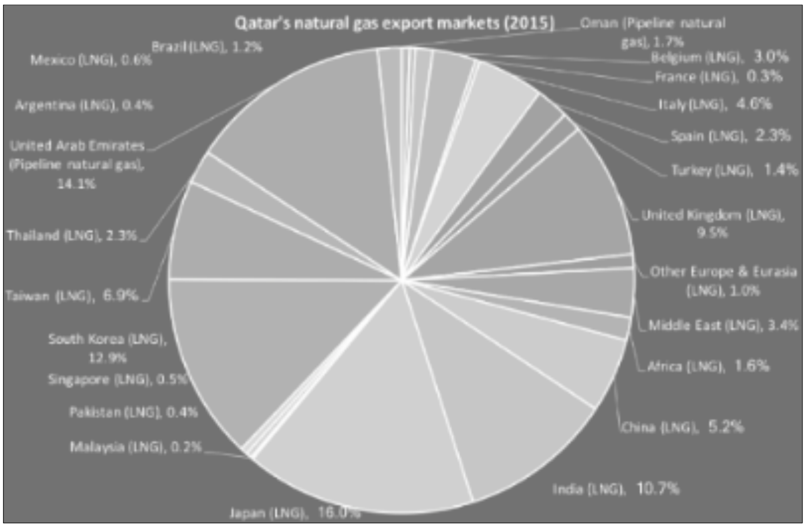


Figure 57. *Qatar natural gas export numbers, figure 4.x. Source: World Bank 2018.*

Qatar is majorly burning Gas to sustain the energy industry demand, it takes a lot of energy to liquefy natural gas, transport and manage in Qatar, thus increasing the carbon footprint and contributing heavily to climate change (figure 58).

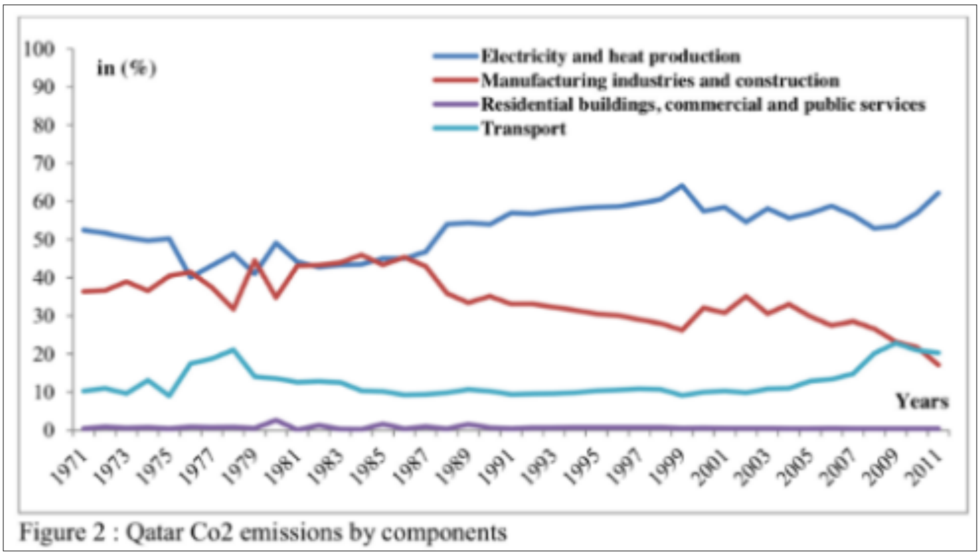


Figure 58. *Carbon footprint levels Qatar. Source, World Bank 2011.*

According to World Wildlife Fund's Living Planet Report 2014 Consumption per capita is also one of the highest in the world merely due to high living standards and free electricity and water for local community and high subsidy for non-locals. The study by living planet report compared amount of production per land hectare that needs to be balanced with hectares of land to offset its resource consumption and to account for its waste. Comparing the countries production and land size, this is also causing extreme contrast. Also, the countries dry land, lack of forestry is considered a dominant factor for these numbers compared to countries with similar consumption but rather high sink and regenerative natural ecosystems.

The problem with the latter scenarios was discussed in the past years as unjust to the country since the results were based on first, population compared to resource consumed. In the case of Qatar, this might result in figures that do not reflect the true number of its local consumption since most of its production is exported (Posner & Sunstein, 2009).

However, this issue does not change the fact that there is a resource and footprint stress caused by local industry. For Qatar to become resilient to this, it needs to find ways to counter balance the resource stress which at this point can be considered a mandatory state of economy to succeed.

The Qatari Government is aware of the problem and has initiated agreements such as the Paris agreement in 2014, aiming towards tackling climate change. The focus since then was to deliver more finance to agricultural production in order to enhance regenerative land use and tackle food security simultaneously whilst also many technology related inventions were taking action in the energy industry process related emissions (Piggot, Erickson, Lazarus, & van Asselt, 2017).

4.2.2.3 Politics, economy and society

4.2.2.3.1 Policy

These targets were made official when the country reacted by aligning its national goals with SDG's in the established Qatar National Vision (QNV). Qatar National Development framework (QNDF) and Qatar National Masterplan (QNM) (Rizzo, 2014; Tan, Al-Khalaqi, & Al-Khulaifi, 2014).

A main aim is to increase the competitive and innovative approach between industries which also secure a higher number of jobs which require professional considerations of resource management. The QNV Roadmap provides a framework which translates sustainable resource considerations and low carbon economy aspiration into actionable practice, design, implementation and policy transformation in raw material extraction, energy, transport, agriculture, water and food industries

According to the UN Habitat in accordance with SDG's, Qatar's urban development needs a cohesive cross-sectoral engagement strategy by comprehensively engaging and coordinating stake holder, together with a public awareness and engagement plan. This means coordination between high authorities, government and municipal planning sectors with private sector partners and the public institutions at an early planning stage. the gap between government, the private sector and individual members of the community must be bridged" UN.

Although these initiatives are currently scarce in Qatar, there are some leading organizations and local initiatives that promote sustainability awareness which are making a big change in consumer mindset, Tarsheed, (Gray, 2013; Richer, 2015) and Qatar Green Building Council.

Additionally, the country is confronting a number of notable converging trends that are shaping the geopolitics within the region(Francis, 2013). "The recent blockade crisis has spurred Qatari government to refocus on policies and investments to improve food security, self-sufficiency and better link food security to national development strategies and plans"(Bruinsma, 2017).

Clearly this creates a problem, if Qatar proceeds in food sufficiency processes, gaps between the trajectories will occur, especially in water supply. efforts towards a more sustainable urban metabolism will require significantly more effort than purchase of green energy alone(Kenway et al., 2011; Shomar, Darwish, & Rowell, 2014).

National food security policies are currently taking new shape, the main policy related to securing a food production and are at immediate implementation by the Urban Planning department at Ministry of Municipality and Environment MME, Public Works Authority (PWA) Ashghal, Qatar Tourism Authority QTA and Qatar General Electricity & Water Corporation (KAHRAMAA) is environmental policy (EP6)- National food security which identifies its policy actions in protecting natural arable land in line with sprawling city planning. It also includes fishing grounds, livestock, aquaculture and supplying the correct infrastructure at an early stage for future hydroponic and other mechanized agriculture or food systems. Also, the preservation and utilization of the green belt around Doha city and other key locations for environmental and food security reasons. The second policy is EP5 which concerns local rural industries including fishing, agriculture, herding and livestock activities. The policy stresses the immediate maintenance of existing facilities from the above categories, also, facilitating new industries by adequate infrastructure both hard and soft as explained in the current local agricultural financial support and training to ensure the continuation and growth of rural production. Action plans are presented at two levels, immediate and Short-Med.

Immediate include the infrastructure development for rural areas based on environmentally aware GIS data, water and land quality as well as adequate housing to ensure a wellbeing incentive of rural industry personal. Also, the immediate action in increased aquaculture which protects local fish stock and facilitate and promote livestock and fodder for direct feed and market storage and distribution.

Short Med are the use of TSE in all irrigation possible areas for farming and livestock, together with the coastal zone management plan, establishing fish habitat mapping to protect a sustainable fish industry, develop existing fishing ports to stimulate tourism, local traditional industry and fish related industry and related mechanics market.

Last year's financing strategies and insurance policies encourage and support local farmers to expand their produce which range from 25 - 75 % of the of the cost depending on the farms productivity and technological advancements. Also, a local share platform where locals can apply for agricultural land on specified legislations which mandate the land to be used only for agricultural production related fields has allowed many local farmers to initiate private farming businesses as well as boosted local agriculture in initiatives that offered high-level platform of integration since 2017.

4.2.2.3.2 Economy

Sustainable food industry and agriculture is becoming of significance in Qatar's future vision and several clean technology initiatives have been launched in the past few years ("<Qatar_National_Vision_2030.pdf>," ; Rosenthal, 2009), some which as stated above included algal studies and initiatives towards greening water systems Qatar is still exceedingly vulnerable from a food security stand point. The risk of aggregate discontinuities which will worsen present situation 1severe water stress, 2degraded land and 3high carbon footprint and GHG emissions from increasing energy consumption and reliance on sea water desalination as a main fresh water resource(Ulrichsen, 2014).

A supply of more sink and regenerative factors needs to be balanced by the demand for energy industry, upcoming food industry and water consideration(Gray, 2013; "<Qatar_National_Vision_2030.pdf>,").

While “Agriculture is not the primary source of the economy with only (0.1% of GDP) and employment (1.6% of total labor force)”(Mohammed & Darwish, 2017), with an increase of 70% as per Qatar food security plan, the GDP is expected to double. In 2016, agriculture contributed “0.18 percent to the GDP of Qatar, 51.89 percent came from the industry and 47.63 percent from the services sector” World Bank Report (figure 59).

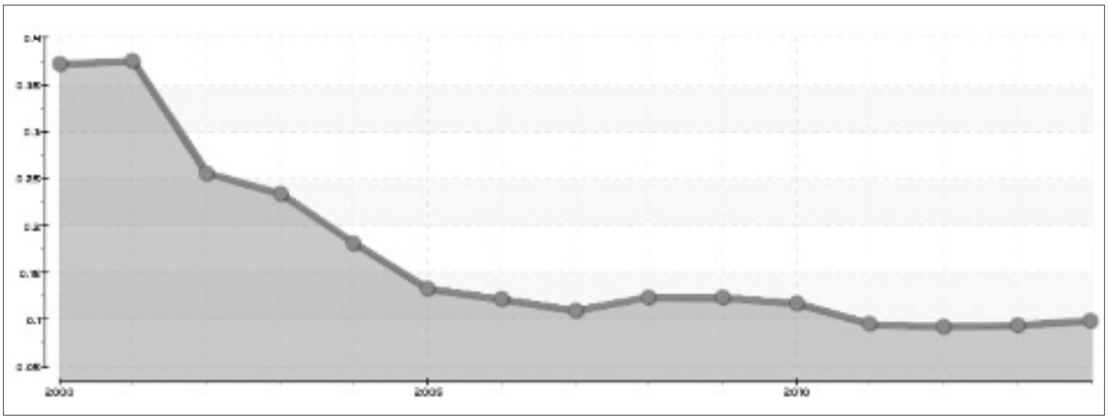


Figure 59. *Agricultural related GDP and employment before self-sufficiency development in Qatar. Source: World Bank 2018.*

4.2.2.3.3 Society

This is amplified by the social aspect of socio economic behavior towards food stuffs which can be described as import driven, dietary preferences towards meat consumption and a disconnection_between consumer and product system and between community and the local agriculture which could have a disproportionate impact on the low-income social strata majorly in construction field who are currently more than 54% of the population (Ramady, 2012).

The latter is a reflection of well-being, an HDI and GDP index which both are a mirror of the social and economic aspects of a country or city. As per the United Nations Sustainable Development Program (UNDP) report 2017, Qatar's HDI value for 2017 is 0.856, this is a very high value making it one of the highest at 37th place between countries worldwide. Accordingly, life expectancy, birthrate and educational level have increased more specifically because of the governments financing of public services from health, education mostly. An increase in the educational facility infrastructure has also improved the social wellbeing condition and a number of universities and schools private and public are forming the new social intellectual level and reshaping the way the ecological footprint is perceived locally. It may also reshape the approach to new food security advancements that are ecologically sound and community driven.

4.2.2.4 Food, energy and water resource

Qatar is food secure, but food sufficiency is not reached in the country (Saadaoui, Bounnit, et al., 2016) (Table 13). Currently there is a total Agricultural Land 11,216 hectares in 2015 to 11,339 Hectares in 2018 out of the 6% arable land in the country. These consist of 2.5% greenhouses and 0.2% hydroponics and a water usage for vegetables: approx. 19,000,000 m3/year from ground water mostly for irrigation. still the country has not reached a self-sufficiency point. For the current 24% vegetable production which has seen the most growth in local farming produce, it is expected to increase to 70% by 2023, this is in line with a local food security strategy which is currently being recalculated and adjusted by the MME.

Another important produce is the fodder, green fodder is a main source for animal feed which is currently consumed at 215,000 tons/year and a Water usage of approx. 125,000,000 m3/year. The current Local Production 115,000 tons fodder which is 54% sufficient and expected to increase to around 63% by 2023 occupies Land used for green fodder approximately 4,500 hectares. The current production does not fulfil the need, 110,000 tons more are currently imported. Previously fodder was imported mostly from Saudi Arabia, with the blockade, the problem of transporting the goods has seen new external emission and resource stressors which emphasizes the need to deliver a local sufficiency of fodder as well. Concentrated fodder consumption is 58,000 tons/ year, concentrated fodder production is 117,000 tons, self-sufficiency for concentrated fodder is 50%.

As a result of the above, chemical fertilizer production and consumption amongst other petre-chemicals and basic iron and steel domestic products mostly during the last decade is seen shooting up especially during the initial start of self-sufficiency between 2009 and 2011. While the data for the current increase in fertilizers was not obtained, the expectation of the emissions and usage growth is determined higher than peak usage 2011(Figure 59). World Bank data stated that in peak year 2010 methane emissions reached 0.31% of total, this is expected to exceed with the current growth (Figure 60-61).

Main manufacturing products

Product	2014	2015	2016
Petre-chemicals (MT 000)			
Ethylene	1 083.0	1 219.0	829.7
Methanol	839.9	871.0	903.7
Chemical fertilizers (MT 000)			
Ammonia	3 623.6	3 685.5	3 424.1
Urea	5 431.7	5 527.6	5 619.5
Basic iron and steel (TN 000)			
Basic iron and steel	6 500.6	6 037.4	6 919.7

Figure 60. *Main manufactured products in Qatar, Source: Qatar in figures 2018.*

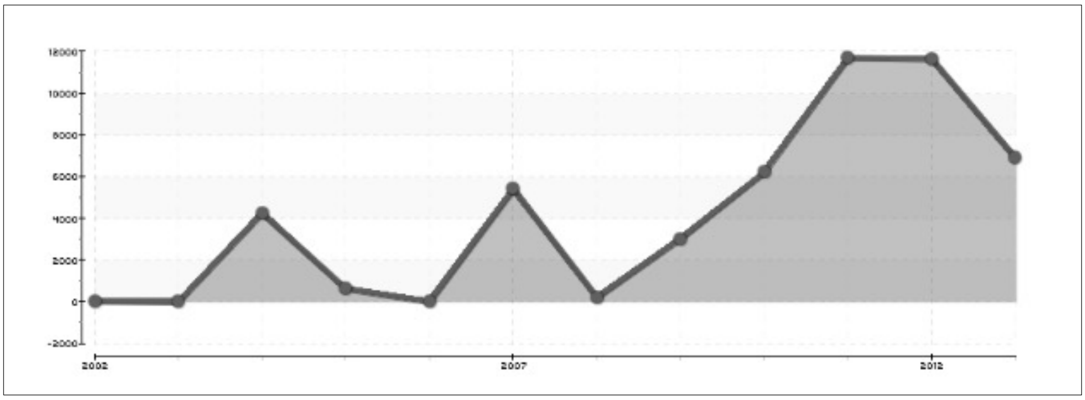


Figure 61. *Methane emissions from fertilizer use. Source: The World Bank 2012.*

Dairy, meat and vegetable local large scale market did not exist before 2009 when Qatar government urged the need to diversify its food resource. Spurred by the recent blockade, New farms such as Baladna Dairy Farm and The Global Farm are currently exploring mass production using hydroponics, low water footprint agriculture and supplementary fodder through algae.

The current agricultural and farms practice is fully centralized. This is due to the rural allocation of agriculture activities influenced by natural resource of ground water, and soil appropriate arable land (figure 62).

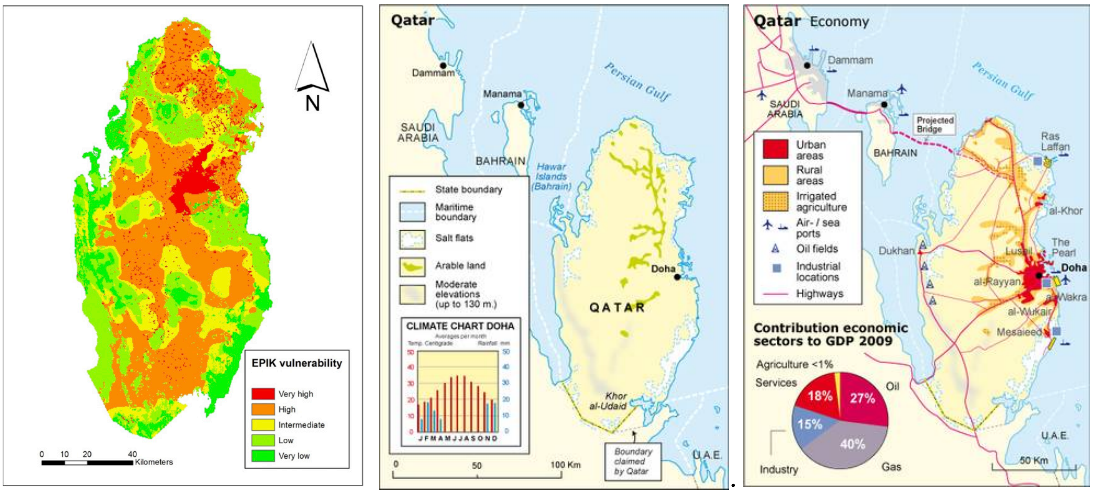


Figure 62. *Left. Ground water situation in Qatar. Middle. Arable land map Qatar 2015. Right. Urban areas, Rural irrigated areas by ground water. Source: Ministry and Municipality of Environment Qatar 2018.*

Due to the urgency of the water situation in Qatar, water reuse systems have already taken shape 10-15% (Figure 63) by treated sewage effluent (TSE) – (considerably low compared with Kuwait and Saudi Arabia 50%). However, the use of water is restricted to non-food products as per short-medium Environmental policy which has also yet to be accepted culturally (Ringbeck, Majdalani, & Ismail, 2006).

Since relying on desalination for conventional irrigation agro-systems is not feasible and comes with limited produce due to exposure to the local environment, Qatar is currently exploring new farming technologies such as centralizing hydroponics 200 hectares today, and vertical farming structures around rural area being tested. By that, security is diversified together with self-sufficient smaller municipalities in the country that can accommodate the growing demand more efficiently (Mohammed & Darwish, 2017).

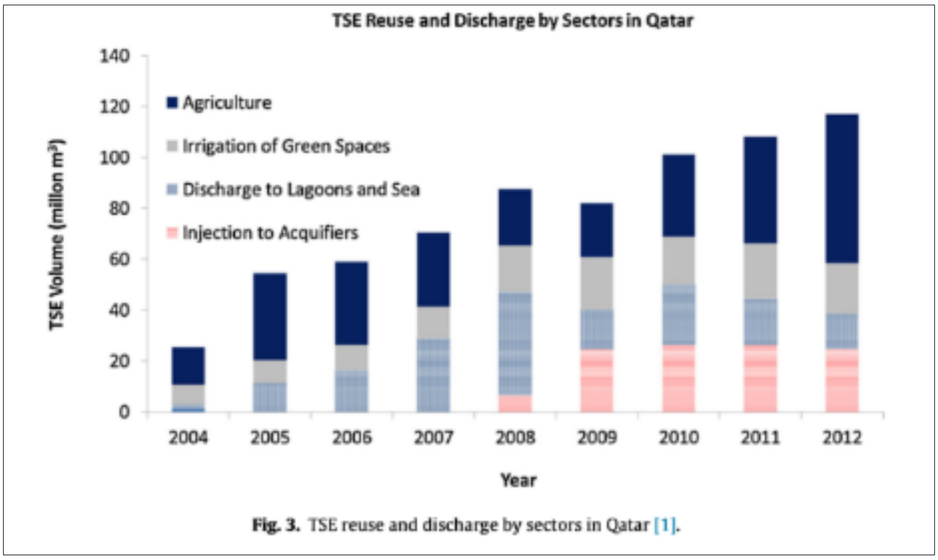


Figure 63 . TSE reuse discharge by sector in Qatar (2004-2012). Source: (Ringbeck et al., 2006).

4.2.3 Nano scale - Algae technology advancement

Algae in Qatar is recognized as an indigenous species which has the ability to thrive despite the unique and harsh climate of the region. Algal Technologies Program (ATP) at QU in Qatar has identified algae as a promising future resource in water treatment and balancing aquatic life specifically in issues dealing with sea water contamination (Dragone, Fernandes, Vicente, & Teixeira, 2010; Saadaoui, Al Emadi, et al., 2016; Schipper et al., 2018; Schipper et al., 2013).

Since 2011-2014, algae samples were systematically sourced from across Qatar coastal areas (Figure 64). Fifty-three strains of algae were isolated according to potential uses within the climate profile of Qatar (Saadaoui, Bounnit, et al., 2016). The heterogeneity of the collected samples has proven Qatar to be diverse with algae strains which went through a long evolutionary line leading to proliferation, high tolerance and unique growth speeds under extreme conditions(Saadaoui, Bounnit, et al., 2016). Consequently "Qatar University Culture Collection of Cyanobacteria and Microalgae (QUCCCM)was established in 2011, located at QU college of arts and sciences, center of Sustainable development, Algal Technologies Program (ATP).

13 different known genera and several novel strains 8 fresh and 8 marine strains were identified for co2 capture, growth rate, lipid production, water treatments and productivity which revealed Chlorella as the most abundant fresh- water known genus (22.64%), followed by Chlorocystis (13.21%)(Saadaoui, Bounnit, et al., 2016). Mixotrophic growth condition was identified with great potential in water treatment, and urban systems integration.

"Other promising strains were identified, for biodiesel production such as Nannochloris sp. (strain QUCCCM31) which also produced nervonic acid, a C24:1 straight chain fatty acid of high pharmaceutical potential"(Saadaoui, Bounnit, et al., 2016).

Other strains were catagorized as higher potential for animal feed and fertalizers due to their fatty acids and nutrienal values (Al Muraikhi et al., 2016) which can also be utilized as mineral and primary and secondary metabolites based pharmaceuticals.

An Outdoor testing facilities in Alkhor, 150.000-25,000 liters of micro algae biomass of selected strains in an open pond centralized facility are being cultivated and tested with a result 50% higher productivity than Europe was proven.

The above situation has put a large focus on saline water strains that delivered exceptional biomass productivity, doubling time and high lipid content. Delivering more research on fresh water or waste water is currently taking the spotlight, especially with the water scarce environment of the region (Dragone et al., 2010; Saadaoui, Al Emadi, et al., 2016; Schipper et al., 2018; Schipper et al., 2013) (Saadaoui, Al Emadi, et al., 2016; Saadaoui, Al Ghazal, et al., 2016).

Figure 64. *Locations of algae samples collected by the algae research organization QUCCCM at QU. Source: (Saadaoui, Bounnit, et al., 2016.*

According to research personal at QU-sustainable development center conclude that 100 acres of land are needed to begin commercialized national scale production of algae which in case of future surplus may become a new revenue to export to near GCC neighboring countries and possibly internationally if the demand is high. It is also suitable considering the lack of arable land giving it more flexibility in the region. Conditions and location of best place to practice commercial cultivation is however yet to be determined.

Currently, saline water algae cultivation is allocated at Alkhor coastal line to be near the main water source and take advantage of desalination plants co2 emission. However, this does not apply to fresh water growth medium. It was originally intended to cultivate algae for aviation fuel for Qatar Airways-a partnering stake holder in the living lab, current testing on biomass products has seen more potential in animal and fish feed for economic market demand and current food security initiatives.

The main success driver of the algae research in Alkhor was collaboration from the ministry Municipality of Environment and the stake holder's involvement and financial support which delivered real tailored results for Qatar and its community needs.

As fertilizer, A study involving growing palm trees, as high fruit indigenous plant species concluded that compared to conventional chemical fertilizers, despite their positive effect on crop yield, Algae based fertilizer offer a high performance organic fertilizer, their research concluded; "(1) can be cultivated in arid areas (2) produce the majority of micro and macro nutrients necessary for plant growth, (3) increase nutrient transfer, (4) increase beneficial microorganisms in the soil), (5) stabilize soil aggregates, and (6) fix CO2 via photosynthesis leading to decrease the release of CO2 into the atmosphere and, ultimately, attenuate the trend toward global warming"(Saadaoui et al., 2018). Also, the research reflected on the positive feed of algae fertilizer on rise and cereals, also as bio stimulant spray on tomatoes (Saadaoui et al., 2018).

4.2.4 Micro scale - Qatar university study location

It's critical to this research to engage in close study and analysis at specific geographical location within Doha city. Referring to chapter 3 methodology on site selection, selection indicators including Qatar university as a leading organization of algae research played a main role in allocating the study in the area. While QU has selected coastal areas for previous studies in Alkhor, the approach of this algae research is different, it relies on close relation between water and nutrient source for the algae system. It brings an urban agriculture approach and high level public involvement in this new paradigm.

4.2.4.1 Urbanization review

Aldoha municipality is considered central in terms of government and municipality building locations. It is also the home of the highest number of schools, universities and public health services, and the most populated amongst all Qatar University, a public and first national university in Qatar since 1973. QU has a planning history that started from urbanity of modernization and passed through the three identified trends in Qatar up until today where it is still expanding and strategizing in line with the transit development and colleges expansions. It is located on the northern outskirts of the capital Doha. located 7km North less populated outskirts of Doha and 2km from the Gulf shore on an elevated site in Aldoha municipality, zone 68, district no.110. The district area is 6,417,880.09 m2 out of the total 219,655,039 m2.

4.2.4.2 Population review

Qatar university is populated by a large sector of a variety of community members, the unique factor in the university is the diversity in educational levels, professional background, income and country of origin. This is because as an educational facility campus, workers maintaining the campus, students of multiple age groups between 18-35, faculty and staff from different genders share the community of the campus. The general stigma of the place is culturally oriented highly influenced and run by government local authorities who target increasing local's professional development to balance the high contrast between local 13 % and expats from total population number.

4.2.4.3 Policies and future vision

According to Qatar University Strategy (2018-2022) QUS, "the leading government educational institute has declared a 2020 strategy to be recognized as a benchmark for organizational and operational quality and sustainability and ecological aware development on and off campus". The university is changing its organization and operation system towards a sustainable structured one where pillars such as diversity, resource sustainability, participation and sustainable and resilient governance is a key player to enhance an overall sense of stewardship in the country and campus community.

4.3 Site Identification – Qatar University

Referring to chapter 3 on evaluation instruments, this section is dedicated to the bench marking of the study area. The bench marking will analyze the study area (Qatar University QU) tangible and intangible urban system. The tangible physical system is primarily related to the numerical analysis of the intervention system and will be discussed in the findings chapter 5 whereas the intangible activity and human sub-systems are limited to a brief theoretical review.

4.3.1 The intangible systems

The intangible system includes (the none- physical components) human and activity related aspects of the study area where aspects includes the inhabitant (users) behavior, consumption patterns and inhabitant general description.

4.3.1.1 Inhabitant descriptions

Since the study location is a public educational institution that host several types of activities such as education, research, and public activity (sports, festivals, conferences and so on), it's important for this research to identify the type of users and create a systematic classification according to the purpose of visiting Qatar University campus, where below (table 8).

Table 8 Qatar University User Profile.

Main Category	Sub categories	Percentage total population	Visiting hours
Educational	Staff member (academic and administration)	16 %	8-hours average
	Students (Resident and none- resident)	60%	8- hours average
	Visiting student (training and special purposes)	1%	4- hour
Support staff	Services staff	5%	24- hour
	Security and control	3%	24-hour
	Maintenance and construction	1%	24-hour
Research centers	University researchers	5%	8- hours average
	Collaborate researchers	3%	8- hours average

	Independent researchers	1%	Variable
Public activity	Sport facilities users	3%	6 hours
	Special visitors (festivals and public activity)	Variable	Variable
	Library visitors	2%	Variable
Others	Special visitors	Variable	Variable

Users display behavior and attitude towards resource and resource crisis as do they respond to intervention and physical aspects of the built environment.

4.3.1.2 Behavioral and users' attitude.

Qatar university society addresses resource crisis concerns in a large research and learning platform that aims to enhance student awareness on food security, biodiversity and resource industry sustainability under the current climatic stressors. They can study, test and implement in the university environment. University play a major role in generating highly skilled personnel to meet the current economic decoupled from environmental and ecological wellbeing. The role is conveyed as social and cultural values which take action towards FEW security (Grichting, 2017).

Agroecology projects are used as tools to communicate the idea and the importance of the food security and sufficiency specific to the country and region characteristics. It offers a high level of interactive and social involvement as highlighted by the UN Global compact initiative and restressed by the SDG which aim to put the citizens in the heart of the data and early stages of the problem or project as such offering a different scale perspective from a local community sense. "The example presented as the Edible Boulevard, as an interdisciplinary project, has included staff, faculty, students, schools and international experts, as well as research centers at the University"(Grichting, 2017)

Also, the behavior of the campus community in sense of consumption and sustainable awareness is critical to expectations, design decisions and the associated FM management behavior accordingly. A research conducted on the FM at QU concluded Qatar general socio economic behavior towards consumed goods, production and food stuffs is also import driven, dietary preferences towards meat consumption and a disconnection_between consumer and product system and between community and the local agriculture (Epstein, 2018; Ramady, 2012). "The interaction effects and feedback loops between different resources mean that securing resources will require environmental and community stewardship"(Lee & Lambert, 2018). The research also included that the Ministry of municipality and environment MME in addition to Ashgahl Public Work Authority as major role-players in urban decisions also as Planning Authorities and services provider entities with significant role in university led research.

4.3.2 The tangible systems

Following literature on urban physical system, the research has identified two different categories as (campus components and campus layers) which must be considered in a holistic algae integration opportunity discussion.

4.3.2.1 Components

Because the designed system is applied on a building scale level which expands into larger block to neighborhood to district and city scale. the components of the built environment are studied at the scale of plots/buildings. The analysis of existing buildings is required where a grouping methodology is applied on the building component scale to facilitate the process to establish a temporal growth and trajectory analysis in the following chapter 3 phasing. Specific focus on the food related buildings will guide the selection of phases preference.

5.4.1.1.1 Buildings

Building function is identified for the purpose of selecting core production areas. Campus building were selected according to (1) proximity to main food hub, (2) vacancy for permaculture land, (3) future expansion option, (4) current accessibility to the area and to food hub. High, medium and low state will determine the best phase for first phase scenario, second and third follow. Building such as storage, security small rooms, cooling towers were not considered as they do not apply to the façade system needs. Biomass as fertilizer and system water filtration offer possible permaculture activities. Close proximity was evaluated based on plot, block area and a walkable distance of 500 m suitable for possible agricultural activities and hands on maintenance of filtration units. The table below (Table 9), lists and identifies each building according to the zone, activity and assigned code.

Table 9 Evaluation of Building, Group Selection for Phasing Aspects

	Buildings Within the 500m radius	Buildings outside the 500m radius	Ongoing construction and residential zone

Selection of phasing	C01 C04 C05 C06 C07 C08 C09 C11 D01 D02 D03 D04 D05 D06 D07	A01 A02 A03 A04 A05 A06 B01 B02 B03 B04 B05 B06 B07 B08 B09 B10 B11 B12 B13 BCR C02 & C03 C12 F01 H08 H09 H10 H11 H12 I01 I02 I03 I04 I05	F05(M) F16(F) F19 F20 H15 + Existing future building lots estimate

Evaluation points	Group 1	Group 2	Group 3
By proximity to food hub	High suitability	Low suitability	Undefined food related project
By available permaculture possible land	Medium suitability	High suitability	High suitability

By future expansion and design flexibility	Low suitability	Low suitability	High suitability
By current accessibility	High suitability	Medium suitability	Low suitability

Based on the above results whilst considering the general site orientation and charateristics, the best suitable group to begin the application study for is group-one as such it is considered phase 1. Following (phase 2) are the remaining buildings within the campus. Group-three however demonstrates higher potential in future development based on the proposed system which makes infrastructural adjustments and design more flexible (Figure 65, 66).

Landscapes and layers are further discussed in chapter 5 as they relate to the application of and algae product intervention in the context of QU campus and Doha city characteristics.

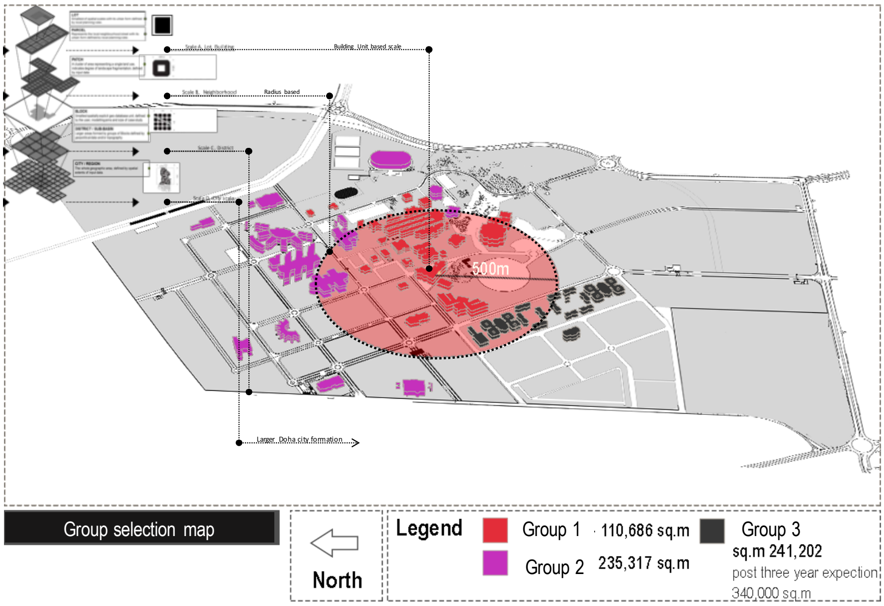


Figure 65. *Group selection map and reference radius 500m.*

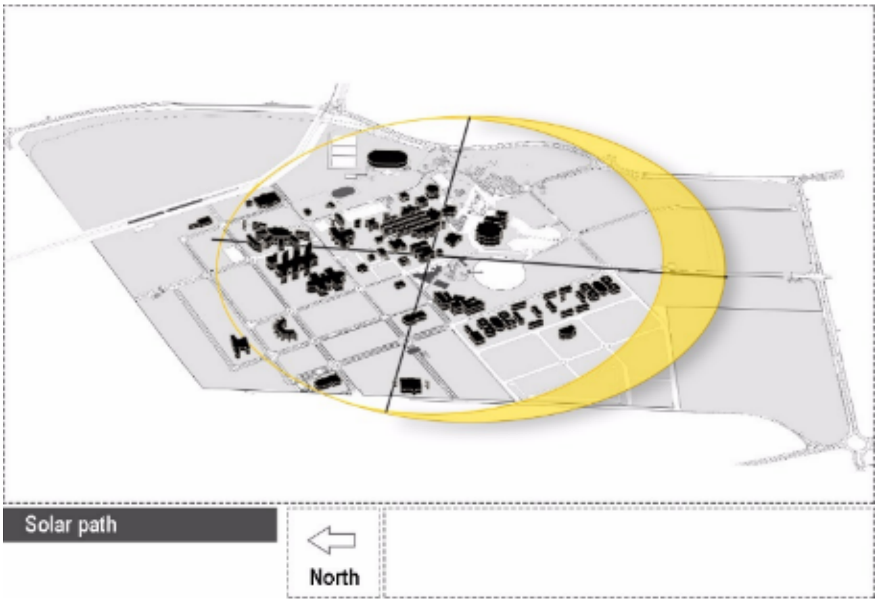


Figure 66. *Solar path map 500m. Source Author 2018.*

4.4 Chapter Conclusion

4.4.1 Qatar towards an algae nexus practice

A strong opportunity is recognized for algae system integration on multiple scales of the country and city systems, more specifically in addressing foot print from carbon emission catastrophe. Promising results in ongoing algae production and research in conjunction with agricultural, oil and gas industry.

With the rate algae research is taking place, Qatar may soon become a leading global force in biomass research and medical drug discovery path for a greener future which can put the country on a new media focus arena. “The described collection microalgae isolates from Qatar is a unique resource, and the first of its kind in the Gulf Cooperation Council (GCC) region” (Saadaoui, Bounnit, et al., 2016).

There is a need to follow a well-defined framework which can guide a specific intervention model that informs means of algae production within the urban physical context based on nexus rational and one that participatory based and gives valid evaluation prospects to determine efficiency and productivity of it.

4.4.2 Qatar towards an algae nexus design

Considering the already substantial knowledge and research level of a centralized algae application system in the country and region, the research steps up the knowledge into challenging a decentralization of the system by merging it with the urban city fabric which aims to deliver benefits on both urban and food security-algae production performance as per the hypothesis aim.

4.4.3 Qatar towards an algae nexus Evaluation

In regards to evaluation, estimating the environmental benefit gained by the system design is a top priority considering the high footprint stigma which has been the soul of all Qatar's sustainability initiatives. This can be achieved through system dynamic model using flow data provided by the context study area in (water and energy supply and demand) and how these can be transformed into a new calculated system result of economic, social and mostly environmental benefits. Also, the social behavioral change through participation and economic benefits associated with implementing these technologies must be considered as they are key to the continuity of this intervention plan.

CHAPTER 5: RESEARCH FINDINGS

5.1 Introduction

This chapter is fourfold (Figure 67). First a comprehensive discussion on the establishment process of the nexus practice framework for hot spot risk scenarios. Second is the design based findings which includes a theoretical based MFA and IRA of the urban FEW and the algae system and will guide the measurement aspects of the study location based on the provided synergy aspects. Third is the evaluation and discussion based findings, an applied algae production system discussion performance based on Qatar university urban system baseline scenario as part of the larger Doha city context. Last is the generated data that will define the next steps for an algae intervention based model with respect to the nexus formwork steps considered in urban and product aspects.

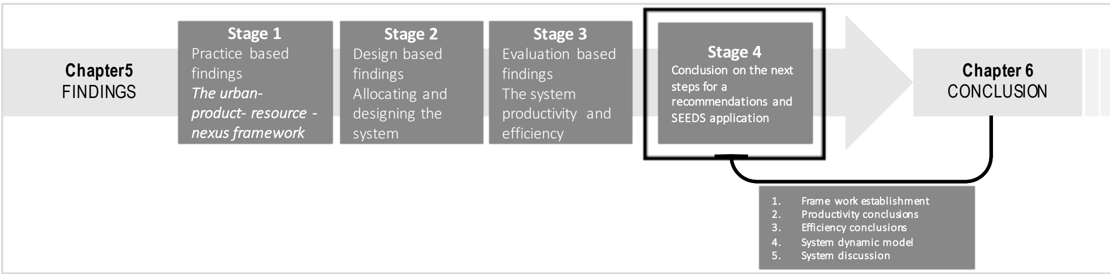


Figure 67. *Findings chapter 5 -subsequent stages.*

5.2 Practice Based Findings

It is established that high system based integration and participatory approach are key elements towards new planning decisions. An urgent need to decouple resource consumption from economic and urban development in addition to the need to shift industrial production away from its current contribution to global emissions and climate change stresses the necessity to deliver a guiding roadmap for planning future paradigms which will ultimately require connecting local nexus concerns (the horizontal perspective) to a broader regional and global scope (the vertical perspective) (Figure 6).

The nexus framework aims to deliver a structured approach to practice that makes it possible to visualize connectivity between an industry, product or planning decision and the broader resource system behavior considerations. The level of complexity in each of the roadmap elements depends on the entry point to the nexus, in this case is the food resource.

5.2.1 Scaling the nexus

The nexus consists of three main resources, these are the food, energy and water in the urban system. It also functions on diverse special scales. These can be global, national or local each with a different level of complexity and focus. The global perspective of the nexus is important in linking international externalities with main resource food energy and water cycles. By this, local decisions are aimed towards a chain of related externalities and benefits of food, energy and water market which help planning decisions for a more sustainable future.

The inclusion or exclusion of considered drivers is based on the literature identified megatrends that drive climate change effect on resource. These are (1) urbanization and the and its positive relation with growing industry and urban economic development, (2) population displacement or morphology considering climate change and common resource industries (figure 68).

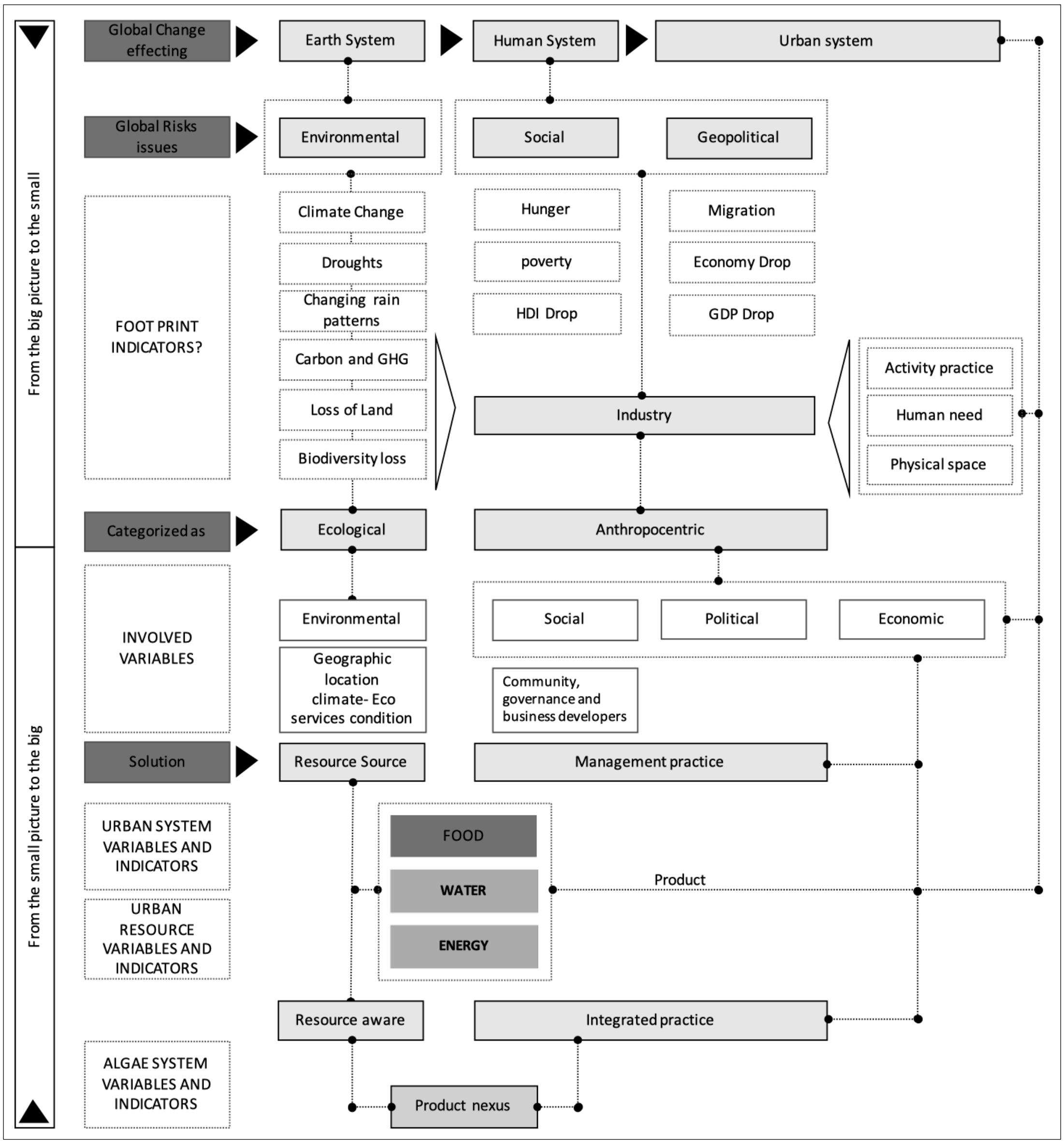


Figure 68. *The global risks and motivating factors associated with the food-water-energy nexus down to the local product development scale.*

The nexus takes a supply and demand risk based approach while focusing on a bottom up approach through the algae product system and collectively considering sustainable goals in social and economic areas.

5.2.2 Establishing a nexus framework

Referring to chapter 3 practice approach built on agro, ergo and industry ecology, it is clear that in all three disciplines, ecology is central to the discussion (Figure 69). Industrial ecology focuses on the product based ecological considerations approach, it promotes ecological services and employs technological advancements to mimic nature in ways that reduce natural resource stress and increase urban resource and is considered the first step of intervention.

Agro-ecology, which focuses on the local farming industry and community and stresses the need to diversify and decentralize agricultural systems within urban environments using local farmers knowledge transfer to local community is considered a step forward in food industry resource sustainability as it promotes merging FEW systems flows with the urban environment to enhance productivity, increase revenue to decouple economic growth from natural resource.

Ergo-ecology which proceeds in an urban physical scale is amore holistic way of looking into ecological interactions with the physical environment of the urban area guided by policy and governance that regulate the way a city develops by means of physical structures and infrastructures that animate functions socially, and physically by its facilities, services, FEW and waste flows.

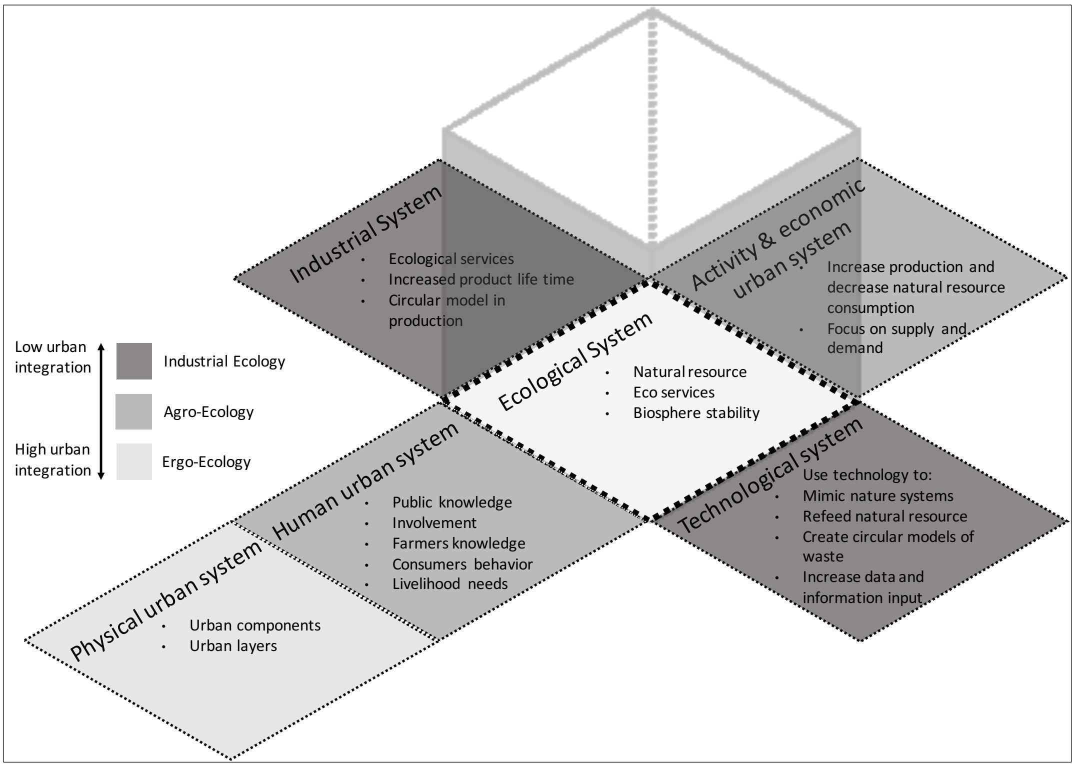


Figure 69. *Sustainability approaches in different practice disciplines explored to inform the adopted nexus framework of this research.*

All three concepts are information and technology based by which decisions and alterations in the system can be distinguished in seeking an ecological equilibrium through a systematic increase in information input and a decrease in material input which corresponds directly or indirectly to natural resource consumption (Figure 70).

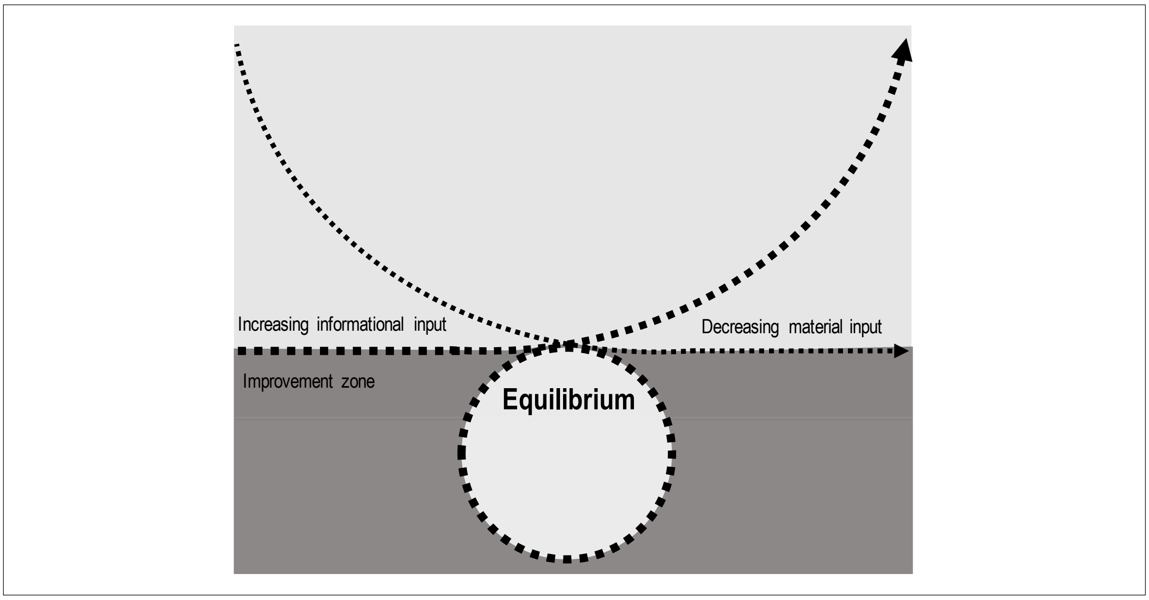


Figure 70. *Common to industrial ecology, agro and ergo ecology reliance on increasing information input and decreasing material input towards resource equilibrium.*

The intervention applications of all three concepts enabled the formation of the final resource nexus framework as it relates to hotspot scenarios. The profiling process is recognized as the first stage of approaching a nexus.

Two main resource nexus principals are identified in stage 2 of the framework, these create the intervention framework to achieve a good understanding of the way human systems and ecological systems interact. (1) The sustainable pillars focus expanded (ES), which represents the sustainable urban block within nature in a series of scale hierarchy system principle areas. (2) The FEW resource systems (dynamic and holistic) approach (figure 71).

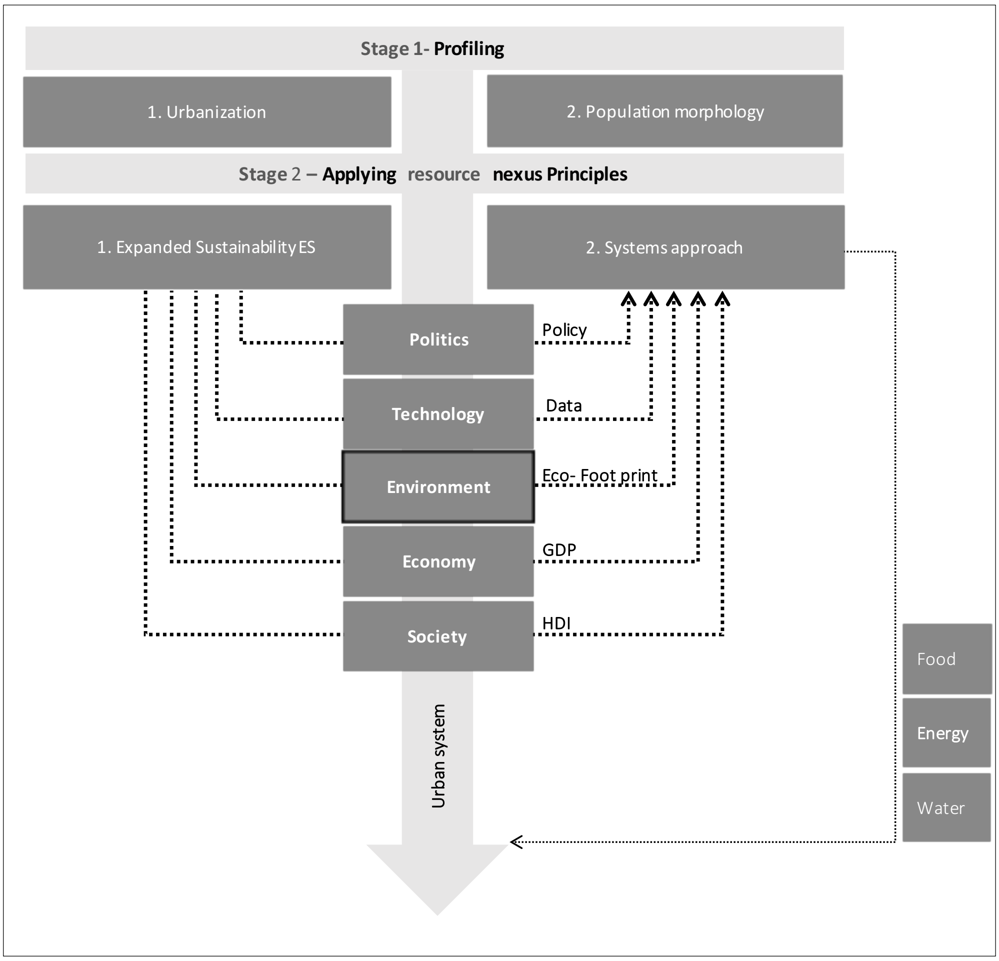


Figure 71. *Stage 1 - 2 of a resource nexus approach, the framework is based on five sustainability pillars which make up an urban system scenario.*

5.2.2.1 Stage 1-Profiling process

Urbanization is a reaction of population increase. This will stimulate the development of infrastructures for increased food, water and energy resource flows and need for sanitation, transport and other public services. All which will require more energy, material and industry to construct and provide. The main enabling factors of urbanization are the technological advancements, political stability and economic prosperity of a country which determines the general character of the development.

Population increases the demand on resource. By 2050, estimates conclude that the food production must increase 60% more in animal feed product and 70% in crop than current to achieve food security for all. Demographic trends identified in the literature are in positive relation with urbanization. The knowledge of census data, population morphology and development index calculations are key in delivering impact assessment to either increased resource stress or the related sinks of applied systems per capita use. Additionally, demographic data is basis of ecological footprint UN calculations considered in this research as a guiding point for ecological stress.

5.2.2.2 Stage 2- Nexus principles

5.2.2.2.1 Principle 1-System thinking

Food water and energy systems are embedded within the urban system supply and demand cycle. The entry area to this research to understand FEW resource systems is through food resource system. This is based on the nature of algae as an agricultural resource and its uses as animal and aquaculture feed and agricultural fertilizer for human consumption products and other pharmaceuticals.

Referring to the literature on circular metabolism that works on expanding a life time of a resource cycle while also circulating it back into the original feed system or as new revenue system with a new set of resource metabolic opportunities and considerable social and economic connections. Also, the Fast replacement system vs slow replacement industrial system towards a full self-replenishing system perspective, achieving improvement in risks associated with energy and water industry and excessive agriculture in a metabolic oriented approach through the use of algae requires identification of the hot spots of the problem within agriculture food production, water and energy systems.

MFA and IRA as part of the nexus analysis is applied to highlight the product, industry and system scale hotspots as well as synergy areas comparison basis which focus on resource flows that are extended in length, reduced in waste or output and increased in efficiency between once separate systems. The detailed connections established by the algae and resource system is further discussed in the design based findings.

5.2.2.2.2 Principle 2-Sustainability

An absolute focus on sustainable goals. The diagram presents the different stages that contributed to the development of the framework elements and the comprehension of the urban circular resource flow of the new aspired city system which ultimately proceeds towards sustainable development and achievement of SDGs (figure 72).

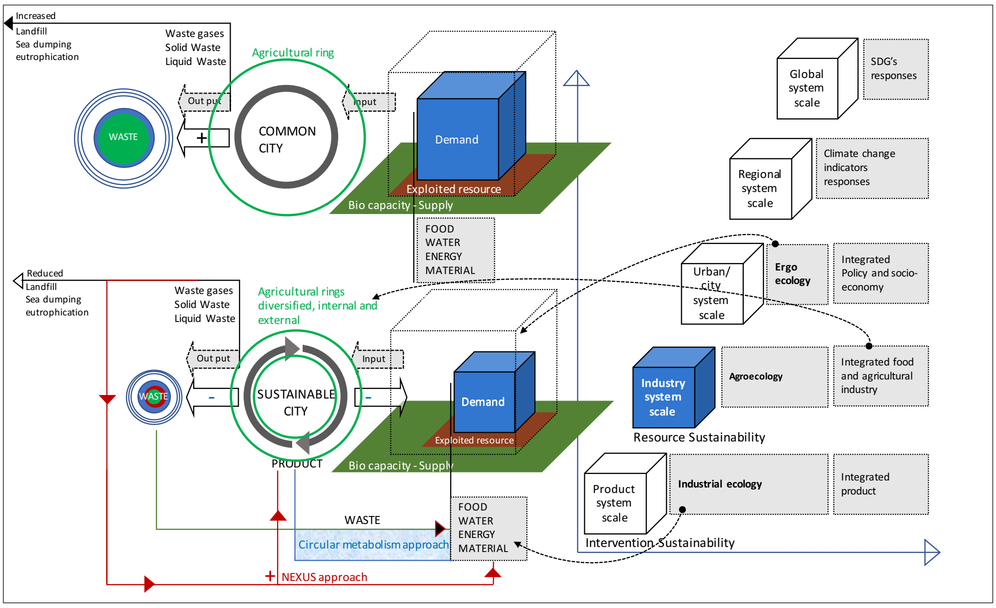


Figure 72. *Expanded sustainability fields within a city model and Allocation of the product NEXUS between multiple city system circular metabolism and nexus factors.*

It is found that the three sustainability pillars, social, economic and environmental should always be connected with the technological and political factors which enable them. Meaning, an expanded sustainability ES concept is presented (Figure 73). This means the analysis of the system must consider the extended sustainability involving the social, economic, ecological, technological and political influencers also considered as intervening variables between different contexts.

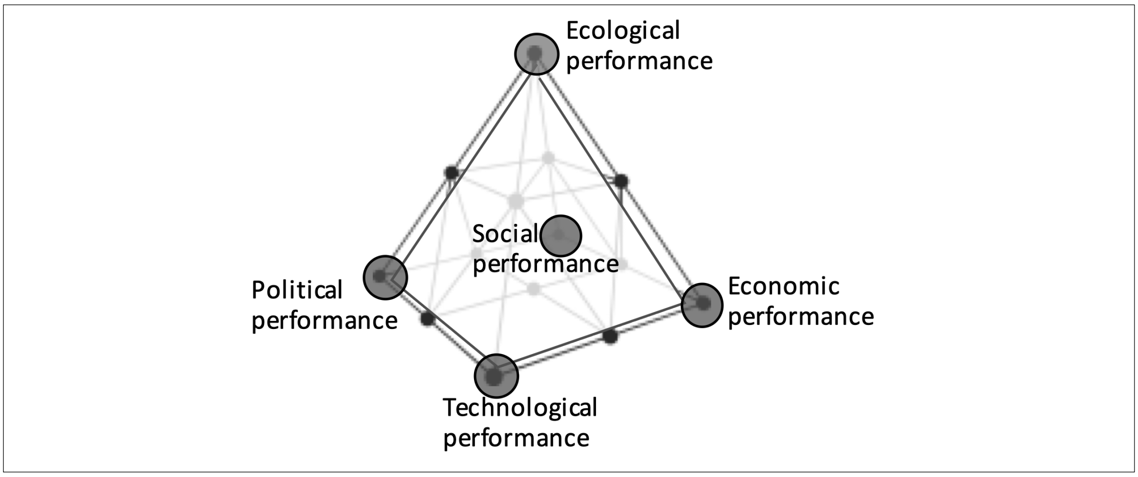


Figure 73. *Sustainable concept expanded to 5 pillars, environmental /ecological, social, economic, political and technological.*

The base of the pyramid shape represents the social, economic, political and technological factors all which lead to one dominant apex which entails ecological stability. The goal behind the new expanded nexus framework is to capture a higher level of integration and complexity in the algae façade system which will have long-term and short-term response. On the long term, it will high light future research areas needed to fully integrate algae in the future. Additionally, on the short term it provides base line for response in actionable policy making specifically in the planning and design phase of buildings and the resource cycle in relation to the larger resource flows and infrastructures.

ES1-Technology

"Concerns about the sustainability of the economy and climate change are spurring the development of technologies that can help reduce our fossil fuel consumption and CO2 emissions. However, the large-scale implementation of technologies for renewable energy and increased energy efficiency may also increase the demand for certain minerals and metals, for example those used in solar panels and wind turbines" (Pîrlogea, 2011).

Technologies must consier feasibility, affordability and manufacturing cost as well as the compatibility and adaptability of their use in the social and environmental context. The development of technology needs to be closely designed to the needs and situation of the local community. In this regard, learning from Agri and Industrial ecology, technology needs to reflect the lead causes of resource stress from industries, release dependence of economies by acknowledging local production and consumption patterns to ensure a culturally and financially appropriate solution based on social involved decisions (Pîrlogea, 2011).

Referring to the literature on algae photo bioreactor technology. Two main types of algae production system, the open-pond and photo-bioreactors. Based on in-depth interviews on algae studies in the Algal Technologies Program Center for Sustainable Development, closed system offer a better controlled environment for algae by which any system fails or complications are contained. Also, the product and treatment cycle from algae using closed systems can cultivate a single algae species given accurate control of temperature and nutrients, this leads to a higher concertation of biomass, a far better-quality produce and specific traits of product ultimately a better chance in the market. Although energy demand and capital cost of a closed system is significantly higher than an open pond, the outcome is potentially of high value quality specific to the use for consumption rather than biofuels market. Photo-bioreactor products today reach (>$10,000 per ton) where professional concluded that it will not be cost efficient to use this type of cultivation method for fuel production on the scale of commercial use. However, they are feasible in production of high density and specific market line biomass.

Photo bioreactors are more expensive than open pond system at all levels, the design, construction and application. However, the running of the system once installed requires minimal maintenance and monitoring. It can be monitored by a smart system requiring less operational man power. Also, with the integration between algae technology system and the urban system, extended benefits can arise from the indirect technological advancements. This is seen in the collection of carbon outflow for reuse, technologies of bio oil and gas production which can redefine the energy infrastructure, technologies in water treatment and infrastructures which can redefine the infrastructure of water systems that will holistically redefine the long-term cost and process of resource flows. Hence, when applying the physical calculations of the integrated system, the cost factor is discussed in terms of long term social and local capital.

ES2-Policy

Political stability of countries is also considered and enabling factor which manages economic social and environmental resource stability. Referring to the UN measure, a foot print of a country is a reflection of its ecological assets which ensure a secure economic resource for future generations wellbeing.

The environmental and financial profitability of the system is considered a major aspect which will define the way governance reacts to the system proposal. Considering the limited analysis on QU site, which focuses primarily on the environmental advantage of the system, the financial consideration is also discussed briefly. The aspired result of an optimization algae cultivation system is to redefine policy and regulations and the way industries work. A higher level of nexus means less damage to the biosphere, which will only be effectively operated with full engagement from government and private sectors. In that sense, mitigation of emissions and water waste of the system can become a regulatory aspect that changes the way planning and building constructions connect with the resource infrastructures.

ES3-Economy

Highlighting the main economic source and industrial type of activity with more input in the footprint level of a country or city is significant to the allocation of sustainable efforts as well as the sequential steps governance take to induce research and funding.

Particular matter and emissions from industries is a cumulative influencing factor which collectively effects human beings globally. Treating a single source of industry related activities or more based on the nexus strategy must be well informed of the source and its quantity to bring beneficial outcomes (Gliessman, 2006). How these relate to the consumer level are essential to determine action areas.

Referring to the literature on rising class food consumers in 2050, 80% of the global population will become part of the GDP pattern. This means higher consumer class that demand luxury lifestyles, equipment, materials, amount of goods consumed, transport methods and more. Mostly, issues of higher dietary changes towards meat and dairy and imported materials are a concern where a 37 kilogram of dairy and meat product per capita is expected by 2050. This means higher amounts of fodder, energy and water almost 7 times more.

ES4-Society

The resource nexus empowers its outcomes by integrating the single human action in a sense of involvement and awareness which is ultimately ingathered on the large-scale behavior of the social system. Actions of humans are the ultimate reflection of a need or knowledge of how urban development and resource relate. Like many other sustainability initiatives, focus on informing citizens of the impact they have on ecological resource throughout the resource system, consumption and production is essential.

The way built environments interact with the user and natural environment delivers a set of common expectation and behavior towards resource which puts sustainability exposure by design and management at a high influence level on the general public. Considering the possible interaction areas between humans and the resource built system can change accordingly which is examined by the urban system analysis layers and components.

ES5-Environmental

Ecological foot print indicators established by the UN definition of what is considered a measurable aspect towards sustainable development performance are used to discuss the effect of algae optimization system on eco-footprint accounts. These are further explored in the following evaluation variables section for QU.

5.2.2.3 Stage 3- "Urban" resource nexus

In the case of urban planning intervention approach to a resource nexus, the framework expands to a set of three urban subsystems identified as physical, activity and human which enable, formulate and animate the urban development process. Specific focus is given to the physical system by the fact that it is the entity where resource flows are supplied by infrastructures which carry them and the buildings that animate them in relation to human occupants who interact with and consume them.

Looking at the relationships demonstrated (figure 74), urban systems interconnect within a cycle of supply and demand, production and consumption considerations which make the development and improved life quality possible. With ecological stress identified, this cycle demonstrates that product industry transformation is needed by which technology and innovation, finance and governance are critical enabling factors.

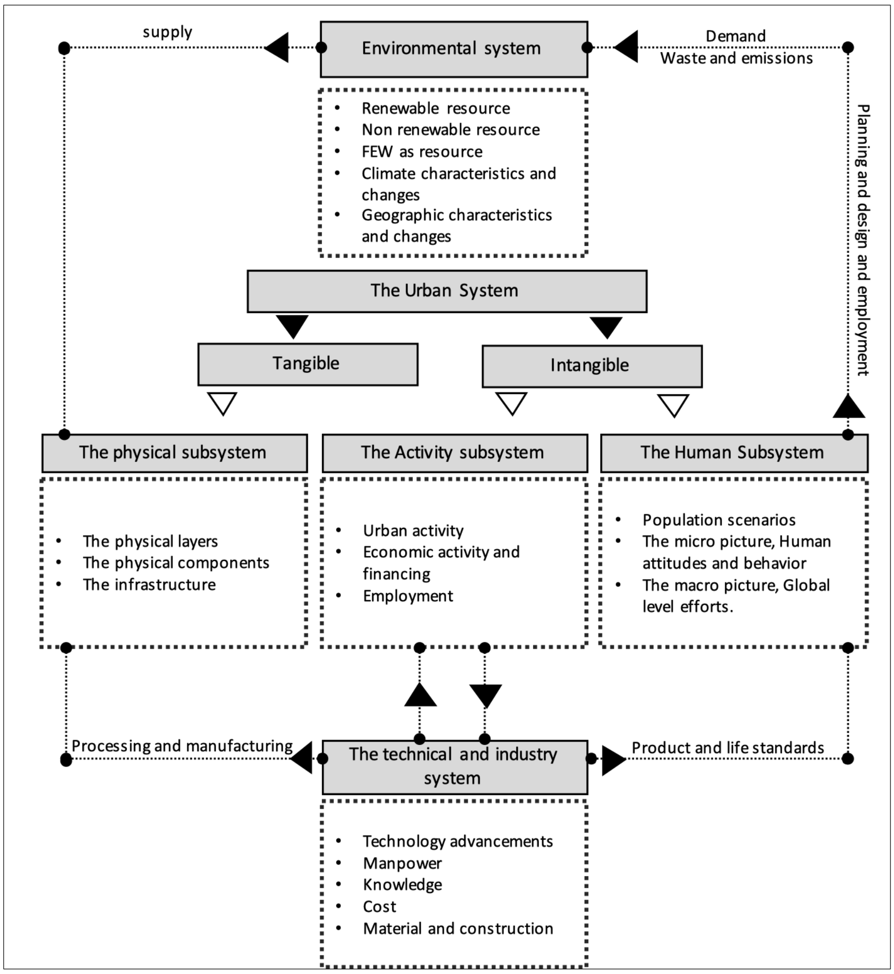


Figure 74. *Urban systems interconnect within a cycle of supply and demand, production and consumption considerations.*

5.2.2.4 Stage 4- “Urban-Product” Resource nexus

The focus of this research is product based, meaning the way a large resource nexus frame work addresses the production scale must be systematically configured with the relation production has with urban system physical, human and activity needs.

An algae product nexus approach towards urban system involved cross links between the physical engineered infrastructure system which supplies water, energy and food indirectly, and the natural ecological system. For that reason, the nexus must consider all involved scales where infrastructures run from the smallest building and lot towards the larger city grid scale which all present different actions that the nexus must consider systematically to avoid conflict and consider the different scales as an entire system holistically together with highlighting the long-term impacts that may arise from main resource flow patterns.

There needs to be connections between the resource flows from the tangible and intangible design aspects. The tangible urban physical components and layers are considered a main road map to allocate the areas where higher integration and circular metabolism can be achieved. However, these interventions must be in a positive relationship with the social and economic aspects of the city.

5.3 Design Based Findings

There needs to be connections between the resource flows from the tangible and intangible design aspects. The tangible urban physical components and layers are considered a main road map to allocate the areas where higher integration and circular metabolism can be achieved. However, these interventions must be in a positive relationship with the social and economic aspects of the city.

5.3.1 Allocating SEEDS integration

Referring to the methodology, for integrating the SEEDS system at the QU case area study scale, three systems are considered in the MFA study, the urban system, the food resource system, and the algae system.

The MFA will be limited to a conventional system definition and boundary identification which defines the start and end of flows. And a description of the Spatial, temporal, functional Scope of the procedure.

5.3.1.1 Urban system MFA

5.3.1.1.1 Systems Definition

To understand how to reduce the resource intensity requires an understanding of the urban system's primary acting supply and demand fields which are a reflection on local urban policies which influence natural resource depletion intensity. The MFA analysis in a typical urban resource system is distinguished by three primary actors, the supply of food, energy and water in a linier metabolism shown in the central area of the diagram that ends in a set of main outputs or waste categories mainly as carbon, solid and liquid waste including water and additional loss of natural land that is converted into urban or industrial production space. Carbon is specifically discussed as it relates to the urban cycle.

5.3.1.1.2 System Boundary

Start and end of flows and the specific consideration of the system are recognized. Majorly, the system is confined to the three resources, food, energy and water. Climate change induced by rapid development, industry, social and geopolitical economy is indicated by GHG emissions. The FEW resource dilapidation association made with GHG and water demand are countless, worth mentioning factors are the associated level of foot print and externalities from industries, the research focused on the discussion of three major industries.

1. Food-Agricultural industry
2. Energy industry
3. Water industry

These are further discussed in the evaluation context related findings and discussion.

Water is a critical factor in food production. Conventional wastewater treatment processes are being currently substituted with the use of algae which conclude that in the case of grey water, algae could remove all SBOD from grey wastewater which can be reused back into domestic use. Energy embedded in all food supply chains in the process of irrigating crop, transport, storage, production of fertilizers, processing seeds, tractor fuels, and disposal of organic and inorganic waste. Energy is also main player in water system by which it enables extraction, desalination, storing, pumping, cooling in cooling towers. Even in consideration of crop turned into bio fuel, water is a main aspect considering the high-water demand in open fields of corn, canola, sugar and palm oil.

Waste from energy and agricultural industries are also a concern of contamination through the inorganic and organic waste disposal by which water sea surfaces are considered a main sink effecting the hydrological cycle (figure 75).

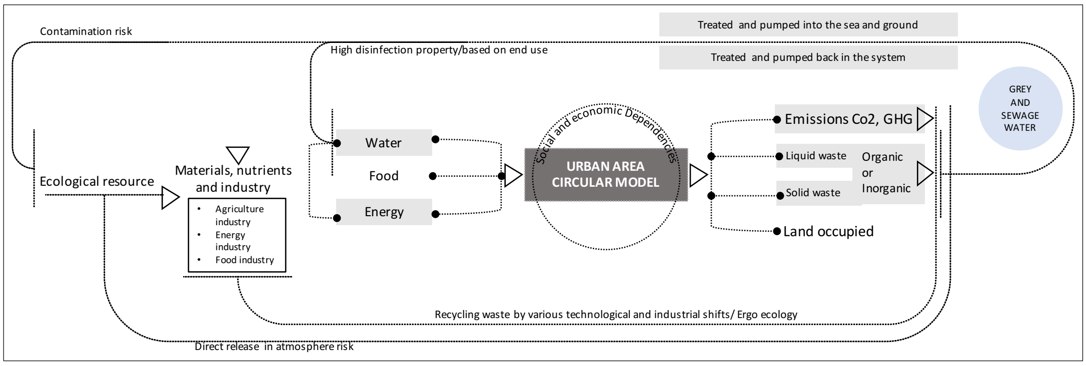


Figure 75. *qualitative MFA analysis of the urban resource system.*

5.3.1.2 Food system MFA

In addition to the GHG emissions, agriculture for food production pressures the ecological resource and environment by the water and land demand increasing meat and dairy food products are also cause of extended agriculture for fodder an increased water demand (Figure 76) in addition to the manufacturing, transportation, packaging and storing (Figure 77-78).

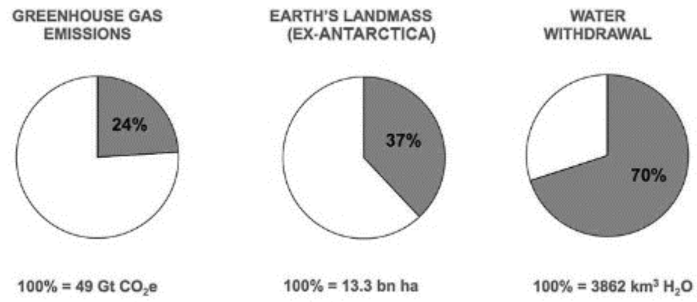


Figure 76. *Embedded water, GHG and landuse footprint from food agriculture, dairy and meat produced. Source: International Master on Sustainable Development EOI collective blog.*

The MFA diagram (Figure 76) displays the nexus factors between energy and water industry in a conventional food system cycle also typical for Qatar. Inputs other than the WE critical to the system is the arable land. The quality of soil determines the efficiency of the land, in most cases, rapid industrial mass production of food crops and animal feed crops require nutrient replacement in soil.

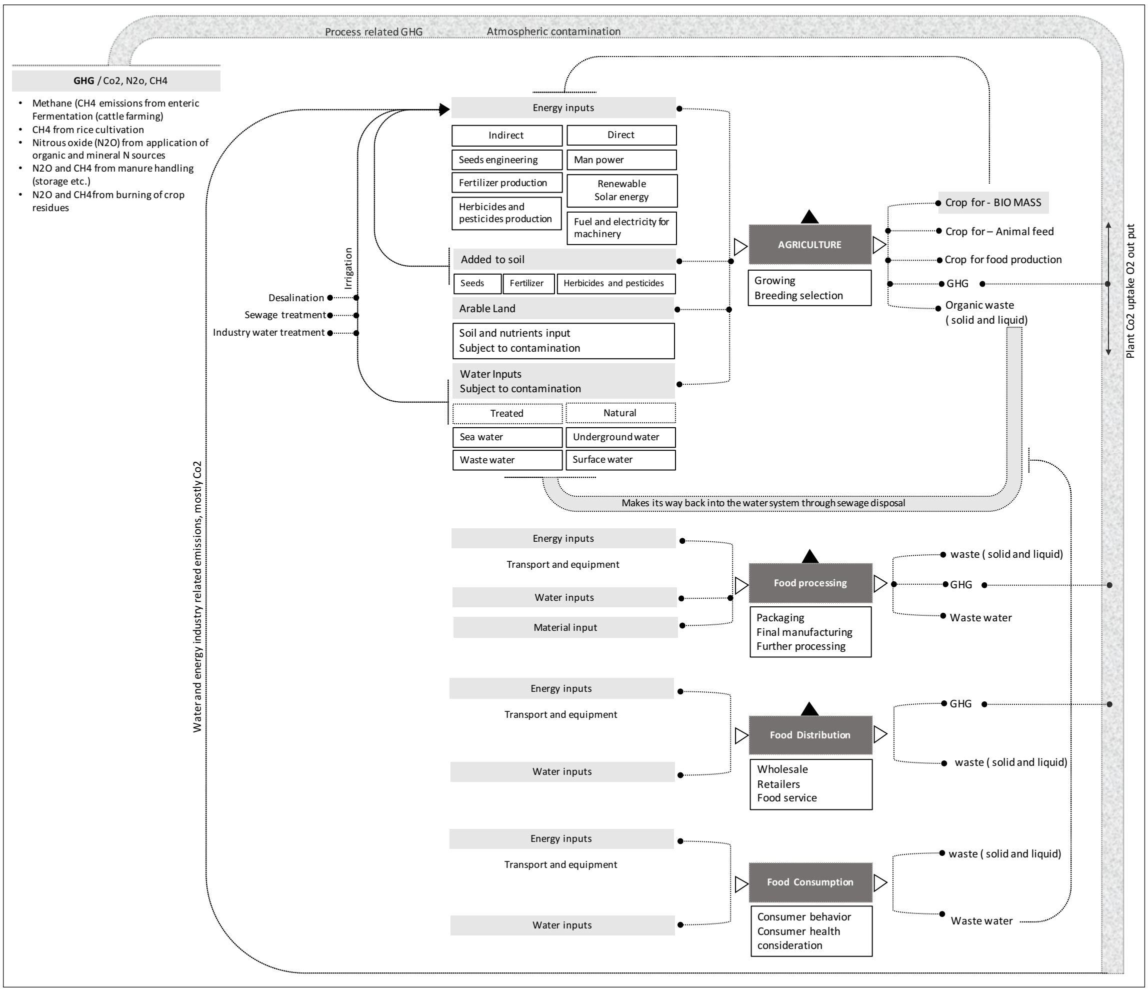


Figure 77. *A qualitative MFA analysis of the food-agriculture urban system.*

This is achieved by adding fertilizer which can by either organic or inorganic in matter. The use of mineral fertilizer as one source of plant nutrients is an essential component of sustainable mass agriculture to achieve desired food industry yield. Three main nutrients necessary for crop are Nitrogen (N), Phosphorus (P), and Potassium (K) which are currently added in fertilizers to sustain soil management for the growing industry demand. Also, improved productivity through intensification helps to defuse the increasing competition for the scarce resource “land” between agriculture, urbanization, and nature preservation in addition, it controls the sprawling of agricultural lands into forest lands with high soil qualities by which carbon stress is associated. (Figure 78) displays 6% - 17% GHG related to agricultural land (Signor & Cerri, 2013).

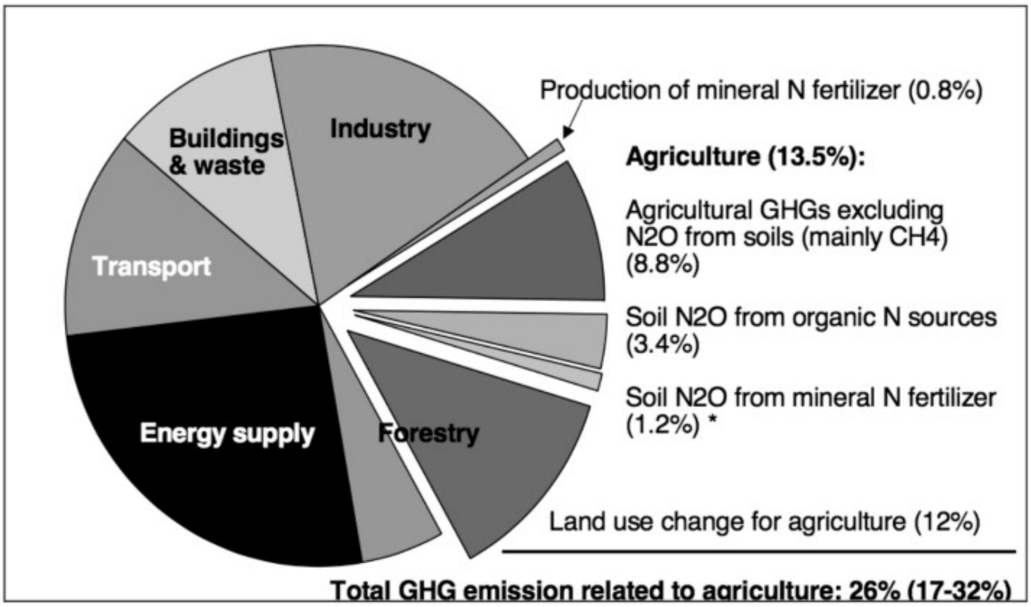


Figure 78. *Contribution of all activities related to agricultural industry to the global GHG emissions (Gustavsson, Börjesson, Johansson, & Svenningsson, 1995; Hati et al., 2008; Wilson & Al-Kaisi, 2008).*

5.3.1.3 Algae system MFA

The potential of algae in becoming a major ecological service lies in the simultaneous decoupling of disproportionate algae growth and urban waste from the natural system presented in new industrial chain (Figure 79).

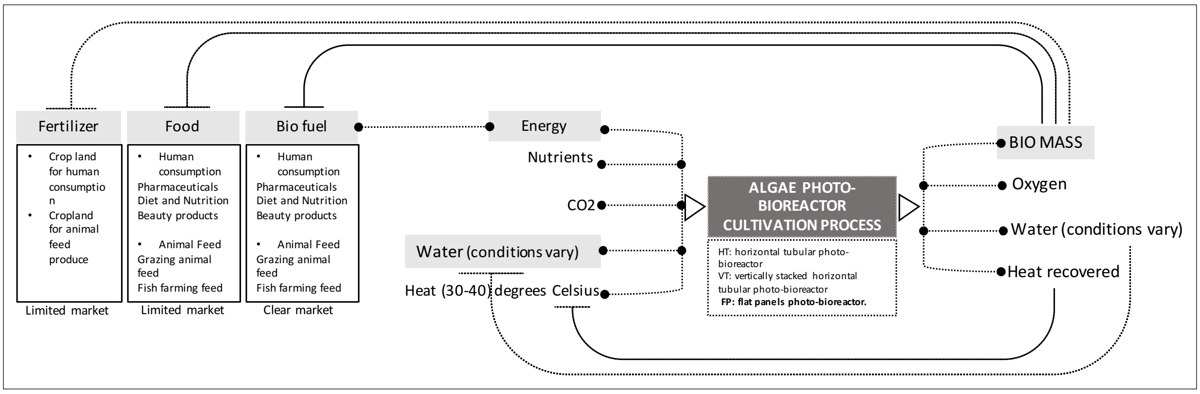


Figure 79. *Algae system inputs outputs during cultivation and harvest.*

5.3.1.3.1 Energy demand

In the extended energy demand of conventional land grown crops, three main areas are highlighted, the transportation of material and goods, the packaging and preparation, the cultivation machine related energy and the seed preparation stage. Algae is different from the conventional agriculture of crops by the process of both cultivation and harvesting (Figure 3.x). During cultivation, algae energy demand is relatively low for the pumping system which delivers water nutrient mix and the bubbling system for agitation. In both cases the energy can be recycled in the form of heat accumulated from the system or in the form of biogas produced afterwards which can be utilized to generate energy for the same machine cycle. The second harvesting stage of algae is higher in terms of energy demand, this is due to the high-level pressure needed to separate water from the dry mass biomass called centrifuging. There are two considerations in this matter, first, transporting the algae after the separation stage and the condition of algae during transport which in both cases relates to transport energy considerations. If algae are harvested on the same building scale location it is cultivated in, this means that dry matter is transported from several buildings into the larger retail areas for packaging and distributing. In this case, the system is decentralized by production, but centralized in packaging which is not feasibly done on the block scale level. If the condition of algae being transported for further refinements is liquid, not filtered, a specialized piping infrastructure can deliver the algae water mix into a larger vicinity which collects algae cultivated from multiple building. This means on the building, block the system is significantly decentralized, this decentralization shifts as the urban scale grows towards the neighborhood or district scale which can be considered the infrastructural boundary. This is depending on the intended use of the product. For urban farming for example, the product may be collected and filtered on the neighborhood or building scale. For larger scale contribution of the biomass, the system can extend its centralization to the district level by which the product can be transformed to the desired industry line. The above depends on the context the urban algae are grown in. Furthermore, the energy demand of algae if transformed into biofuel and gas includes a fourth stage after filtration, digester units used to convert biomass into energy product require high energy which can also be replace by the produced bio product to achieve a closed energy loop(Murphy et al., 2015; Prajapati et al., 2014).

5.3.1.3.2 Water and carbon demand

Water is the main medium for algae growth and is considered abundant in urban environment in terms of waste water, a factor that makes the integration unique.

During the cultivation, algae is capable of absorbing high concentrations of carbon which makes it specifically interesting in terms of carbon level risk. Although the algae are able to absorb carbon out of the surface contact with air, it is not enough for industry scale cultivation. Co2 must be pumped in specific amounts in the water medium to enhance absorption and growth rate while keeping algae moving - avoiding it sticking to the surface of the glass or early settling. The amount of carbon sequestered by mixotrophic algae is based on the condition of the algae type in terms of its chemical composition and the physical conditions which effect the process. These include, bubbling system speed and amount of solar and nutrients available.

Carbon can be sourced, ideally from a neighboring industry emitter. Choices vary depending on the context of the algae treatment system facility and location.

5.3.1.4 Integrated resource assessment IRA

An assessment which involves overlaying the latter MFA system diagrams to reveal nexus interdependencies to elevate the level of integration choices (figure 80).

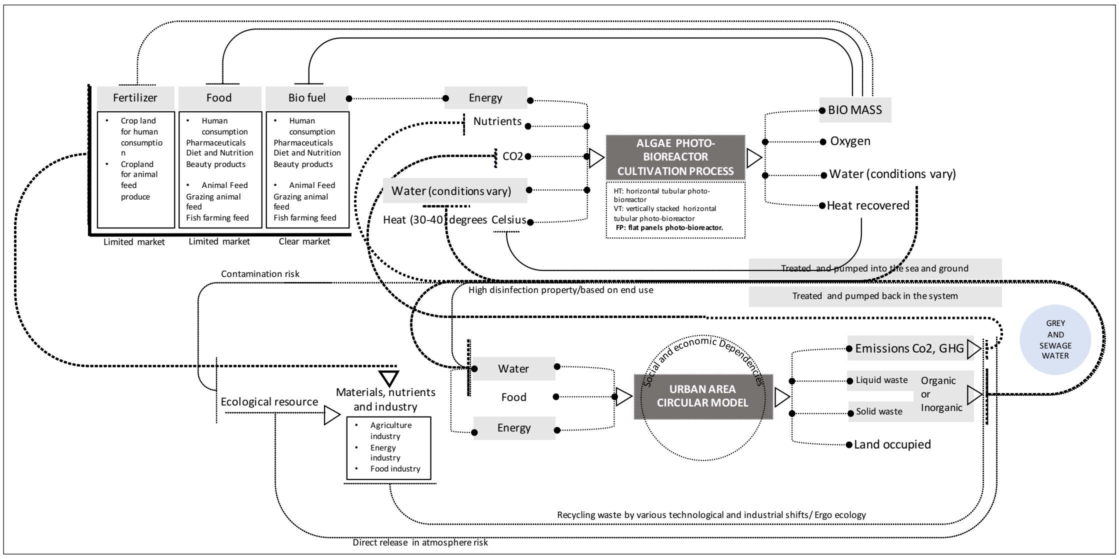


Figure 80. *Integrated resource assessment between algae and urban MFA.*

First, the overlay between urban system and algae system. The diagram reveals synergy areas at the water as a growth medium for algae. Nutrients in urban waste water which could be potentially consumed by algae. Another factor is the carbon dioxide, co2 is plenty in urban industry outputs and so are other GHG. Finally, the biomass opportunities in reentering the urban resource cycle as food, fertilizers and bio energy (figure 81).

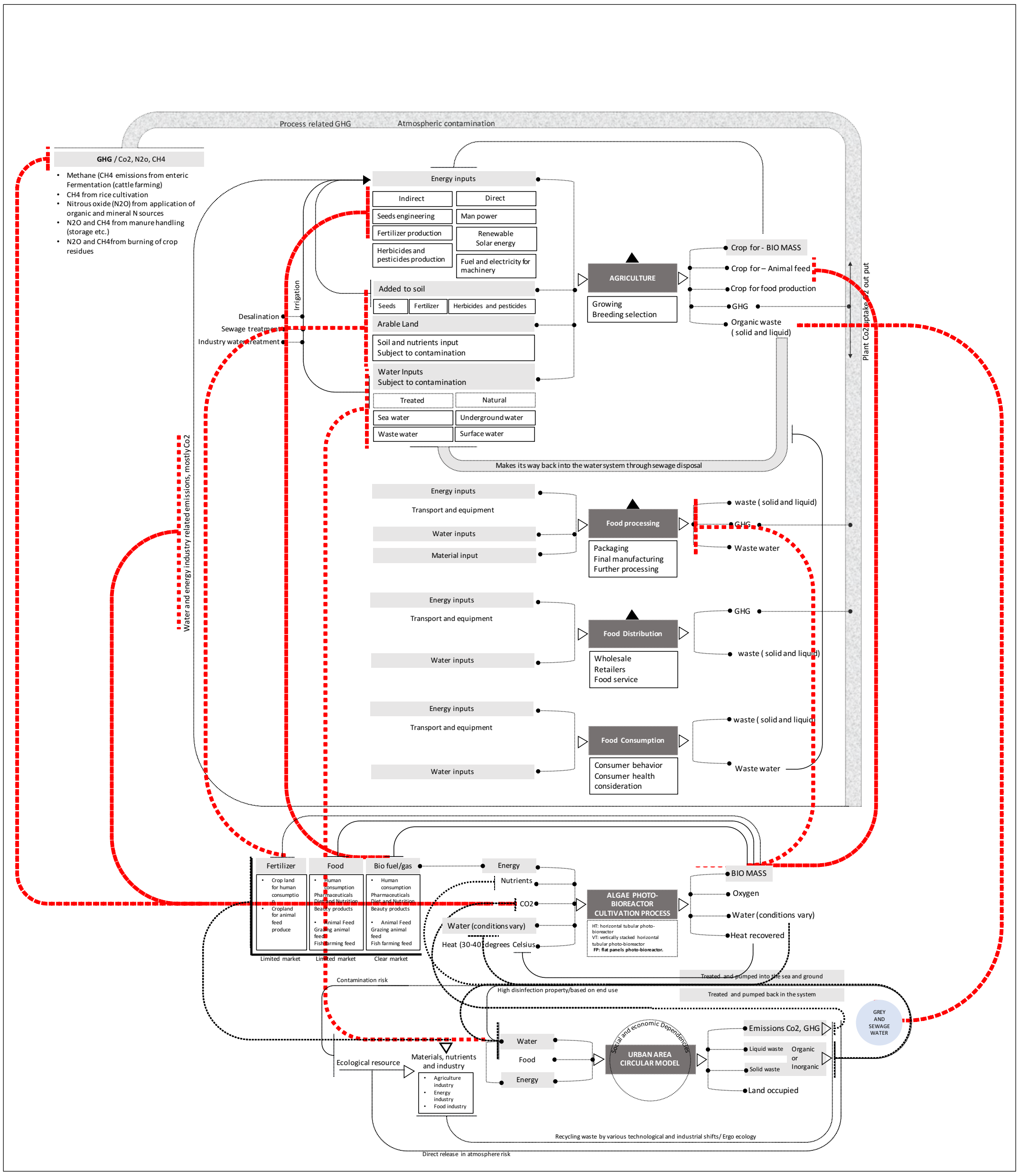


Figure 81. *IRA between Food, Urban and Algae MFA.*

Second, an overlay between food, urban and algae MFA. Communicating these synergy areas in the design and planning and future management of cities means expanded lifecycle, reduced waste and emission and water footprint sinks. Production of agricultural crop or in this case algae biomass presents multiple opportunities in the urban system (in and out) flows by which a physical application of the system may be applied from the building level towards the extended infrastructural feed of the city.

The biomass productivity is the main factor in truing algae into a productive industry with mutual benefits for climate and resource along the line of its production chain. Based on the literature, the cultivation process of algae is the primary area where exchange factors take place. By exchange we mean, waste into biomass. Synergy areas in the resource diagram concluded that urban output in relation to algae metabolic cycle is categorized as:

1. GHG/Carbon sequestration, direct sequestration is by the algae cultivation process, indirect sequestration is in relation to water treatment and energy reentering the urban system in different form, also the indirect reduction of carbon during conventional fertilizer production and chain.
2. Waste water, grey and sewage reuse. Grey water which ranges between 50-80% o total water outflow is considered a leading approach in the current decade especially in countries with extereme climatic, geographic and natural water shortage such as Qatar.
3. Biomass into food system directly as animal feed, human mineral products and pharmaceuticals or indirectly as fertilizer for largescale agriculture.

The energy and water needed and recycled by the cultivation process can reenter the urban system in different forms such as transportation, electricity powering etc. For that reason, when approaching the analysis on a specific context, the existing water and energy grid will guide the benefits.

5.4 Evaluation Based Findings

In a series of numerical calculations on a local district (Qatar University Campus), the research will evaluate the effect of the manifest system based on the environmental considerations of the nexus framework, which will also highlight the compatibility between the surrounding tangible components and layers and latent city's urban socioeconomic needs and the overall footprint crisis.

The first stage includes a comprehensive discussion on QU campus as an applied study area considering its physical system description in relation to Doha city. Following, numerical manifest system performance calculations for productivity and efficiency are discussed where.

A phasing is then used based on chapter 4 grouping to demonstrate a more realistic productivity growth of the system considering the previously discussed physical installation requirements that require temporal considerations of construction and planning. The phasing of the selected context micro scale study location is as follows:

Phase 1 – Year one = (Group 1)

Phase 2 – Year two = (Group 1) + (group 2)

Phase 3 – Year three = (Group 1) + (group 2) + (group 3)

5.4.1 Tangible system components

Components include buildings and landscapes discussion as they relate to QU as part of Doha city context.

5.4.1.1 QU- Qatar Buildings evaluation

5.4.1.1.1 Buildings density

Compared to zones of Doha municipality (Figure 82), QU campus zone 68, building density is low, 0.9km2 compared to the void spaces-street scape and parking is considered, it would mean 60% of the district is occupied (Figure 83), however, 80% increase is expected between 2017- 2022, more specifically with the development of the rail station and upcoming new projects.

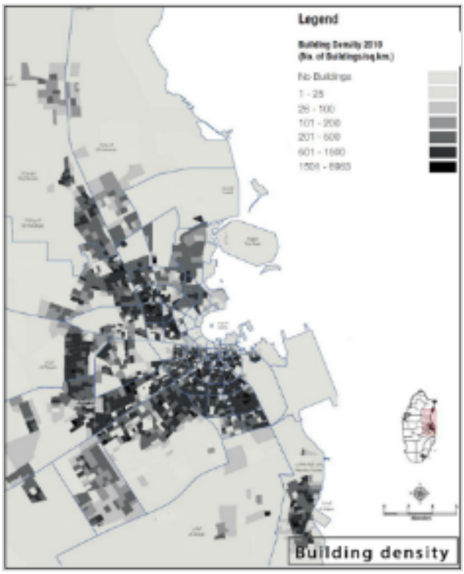


Figure 82. *Doha land use and building density, (Source; Qatar atlas, 2014).*

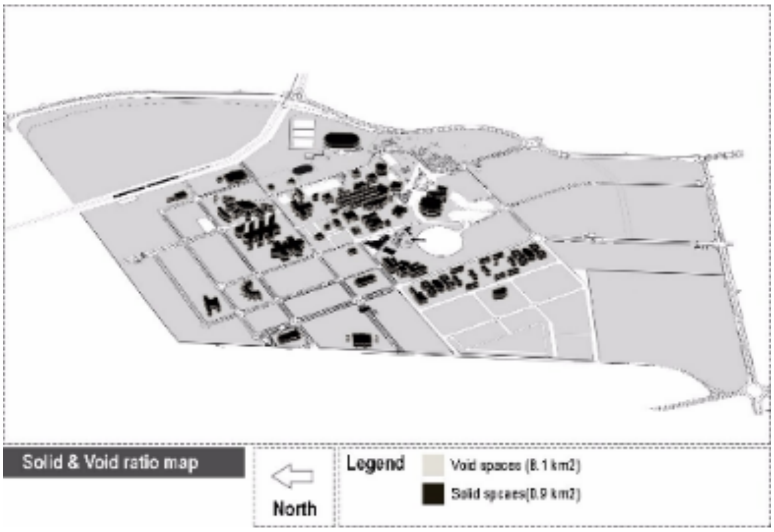


Figure 83. *QU district density map.*

The figure below (Figure 84) showcases condition of most of QU low-rise buildings, some exceptional cases as seen in the BCR modular style building, one of the oldest constructions does not have flexible roof area which makes future occupation of the space difficult. Openings on the façade are considered as 30% of total façade area as per Qatar building regulation, so are the HVAC units which are calculated as 30% of roof space area with 70% of roof tops allowance for construction.

Figure 84. *Qatar university buildings layout.*

5.4.1.2 QU- Qatar landscape evaluation and discussion

Landscape in this research is identified as any space not occupied for a specific purpose of the related buildings functions, including roof top fifth façade and the vertical space 6^{th} façade.

Qatar in general lacks a landscape concept due to the harsh climate which suppresses the design, maintenance and occupation of those places. In regards to Doha cities fifth façade, the flat surface buildings which are common to the gulf region offer a large roof vacancy generally occupied by HVAC systems. Government regulations allow 70 % of roof space to be built. Although there is a great opportunity for developing green roofs, it is not a common practice nor it is preferred in terms of maintenance, irrigation and more.

In new Musheireb district project in central Doha, the success of this application was due to early identification of the green roof concept during the planning phase, a luxury most Doha districts lack due to the high density and already systematized infrastructure which bares high installment cost and disruption of systems if redesigned. In the sixth façade concept, Qatari building styles are commonly flat surfaces with a minimum 30% large window openings from the total surface by regulation and glass cladding with double façade in high rise buildings. Although this is not aligned with climatic considerations specifically temperature, the abundance of electricity in Qatar supports this flexibility in design choices and no policy has yet been established in that sense.

In terms of green scape, a large number of parks, open spaces and green scape are forming in the last decade, this is a reflection on the QNV and QNDS which urged the need to deliver green areas that sink the environmental deterioration caused by the oil and gas industry.

A green belt project and large-scale parks are surfacing. While these are considerably positive in terms of carbon and pollution, they also cause added water and energy stress due to externalities related to the water provision and maintenance. By that the country is also engaged in maximizing its water efficiency and reuse structure further discussed in the infrastructure section. The map showing proportion of land used under the category of green areas to the total land under use at the Zone level as per the Census 2015 (Figure 85). The green area category includes Farms, Nursery plant Farms, Poultry Farms, Animal farms (camel, sheep, goats, cows, etc.). Out of the total land so far under use in the country overall 25 % falls in this category. Variations between 0 to about 85 % in Zone 76 and Zone 77. In Zones 71, 72, 74, 75 and Zone 97 this proportion is more than 50 %.

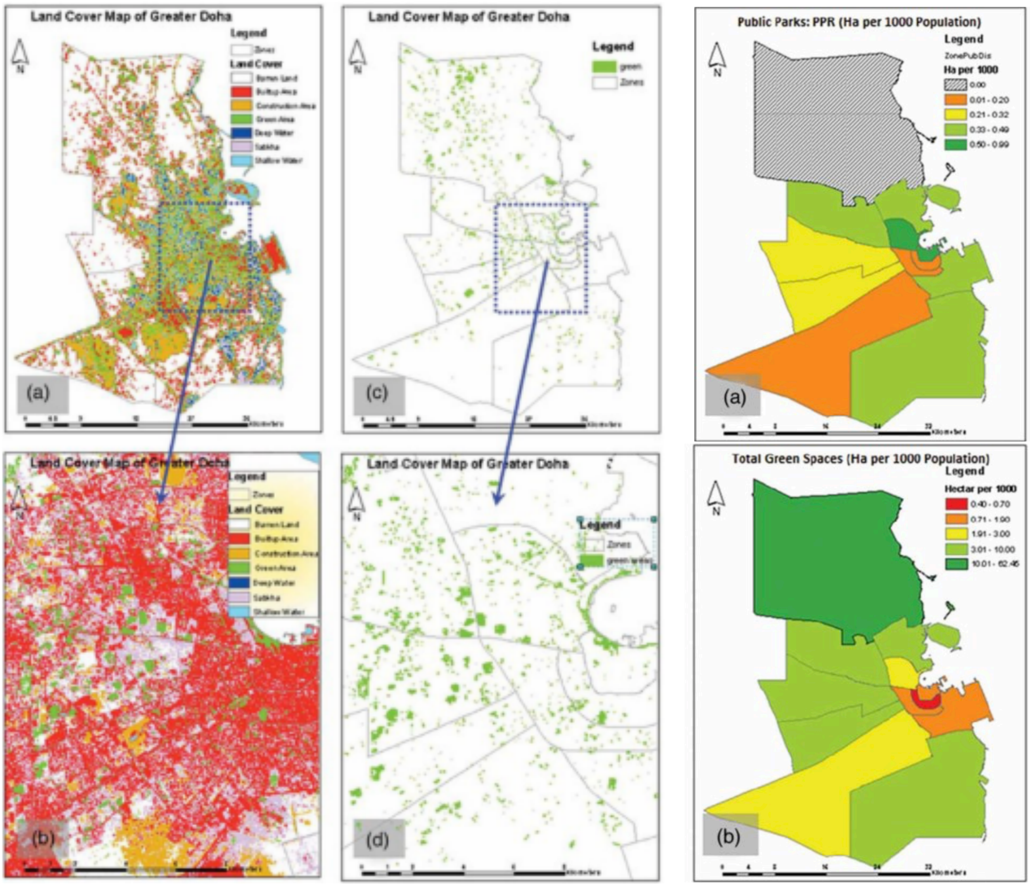


Figure 85. *Land cover map of greater Doha, total green space and public parks per population. Source: (Hashem, 2015).*

Narrowing down to QU district level located in zone 68, based on census identified categories 2015, there is 1.5km green areas in the QU zone. However, the zone is suitable for assuming new approaches to urban agriculture given the vacant land identified in density map (figure 84, 86). Most of the existing open spaces in the campus have been developed without consideration of climate characteristics leading to a low usage of them. Reassigning these spaces to cultivate produce may deliver a better outcome for promoting usage and occupation. For that reason, while also referring to the methodology of maximizing nexus opportunities, the research links the empty space lots to possible cultivation ground/ urban farming to the proposed algae system.

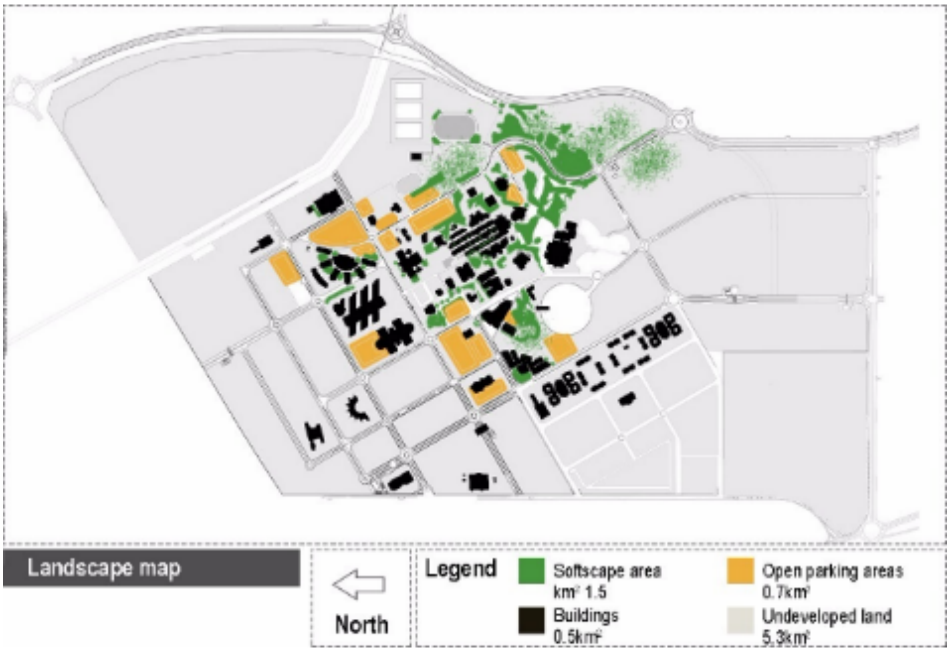


Figure 86. *Qatar University landscape analysis map.*

The systems approach is not a first for the QU campus area, the university has launched multiple small scale agro ecological projects as well as research where permaculture and urban farming site trials and planning took place (Grichting, 2017; Grichting & Awwaad, 2015). Currently, living labs scenarios of vertical planting and climate control, roof top agriculture, in campus green houses are being operated and evaluated on small scale scenarios.

Permaculture in the campus is an agro ecological practice based initiative by which the systems thinking included was to minimize resource use through increased recycling of (organic waste, water); also creating healthier production with hands on engagement of the campus community more specifically the students. By that, contributing to food security by research and design. "It brings together academics and practitioners, and also involves the Campus facilities engineers and gardeners, the expatriate workers and students at Qatar University, looking at ecological, social and economic values of integrated and holistic landscape practices and systems" (Grichting & Awwaad, 2015). The UNI (Habitat Partner University Initiative) which promotes cooperation between UN-Habitat and institutions of higher education, identified QU as an initiative towards the sustainable development goal 11 by 2030. Actual living scenario measures are required to reflect the actual impact of the initiative on the larger sustainable development system and goals.

The below (Table 10) demonstrates area calculated as agro ecological practice available lots based on the three categories of landscape/ Group.

Table 10 Calculated Landscape Types Based on Phases

Landscape type	Group 1	Group 2	Group 3	Measuring unit
Empty lots	311.6909	293.1585	586.317	Area m^2
Fifth façade/ roof tops/ 70% area available for filtration unit	311.6909	293.1585	586.317	Area m^2
Sixth façade/ vertical façade area	502.5251	143.586.373	872.011	Area m^2
Number of buildings	15	33	5	Units numbers

In regards to the building heights calculated as a fifth façade, Qatar university and Qatar in general is common to the oversized buildings and increased height, a questioner conducted in 2017 at QU concluded 60% of QU occupants think that QU buildings are unnecessarily increased in both height and size (Kyrö et al., 2010). The argument is climate issues which lead to the maximization of interior spaces, however, the HVAC related externalities in both cost and emissions is alarming. This augments the need to deliver the same space preference together with external façade treatments which influence the thermal performance of the space.

The same QU study also concluded that FM personal concerned sustainability in buildings is presented is the following sequence, top concern to low, "energy efficiency, water efficiency, waste management, indoor environment, material management, cultural aspects, site quality" (Kassem et al., 2015). Compared to personal in building design field, "waste management, water efficiency, indoor Environment quality, energy efficiency, site quality, cultural aspects, material management"(Kassem et al., 2015). The listing displays a need to align sustainability concerns between the two most effective personal domains in the campus.

5.4.2 Layers

5.4.2.1 QU- Qatar infrastructure evaluation and discussion

In this section, the author has discussed and explored the current infrastructure network within Qatar university to comprehend the scale of electrical and water grids.

5.4.2.1 Electricity grids

As its part of Doha city, Qatar university obtains its electricity by the conventional method fully depending on the local service provided (Kahramaa), where the electric delivered to the campus follow several phases that start by the generating phase and ends with the users. within the State of Qatar, MME and Qatar General Electricity & Water Cooperation (Kahramaa) are the main responsible sectors for management and provision of both water and electricity, however similar to urban zoning structure the services systems (energy and water) are divided into main electrical zones supplied by Extra High Voltage (EHV) substations, in turn the main zones are divided into several sub-zones, where, each zone is supplied by Medium Voltage (MV) and Low Voltage (LV) substations (Figure 87). Similar to electrical infrastructure, the water zones are served by main and secondary storage tanks (Figure 86), where the capacity of substations and tanks are determined by existing and predicted inhabitant density and facilities typology (Corporation, 2016a, 2016b) .

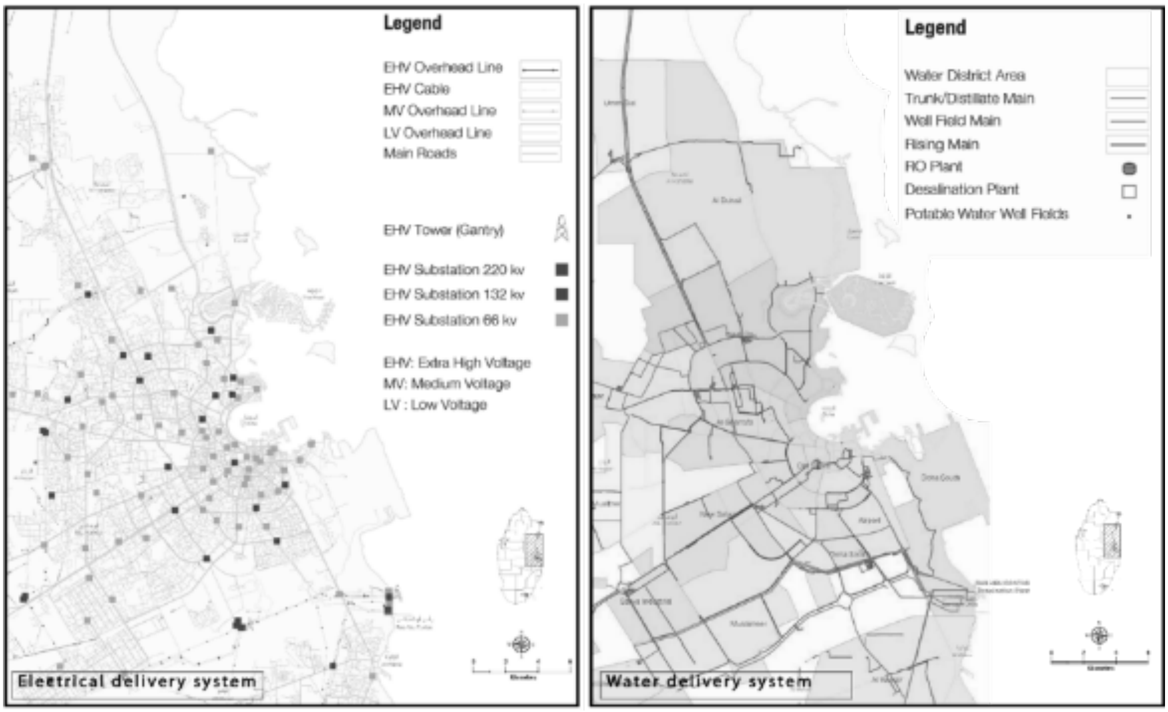


Figure 87 . *Electrical and water delivery system structure.*

Referring to the literature, the general distribution system in Doha consists of five phases. (1)- Generating phase, (2)- transmission phase, (3)- step down phase (4)- distribution through cables and secondary substations. (5)- End-users connection tie- in points and in-home substations(Corporation, 2016a) (Figure 86).

Municipal load calculations by KAHRAMAA are done in accordance to predefined building design data. These are standardized measuring units which include measuring the load a building requires in relation to its (1) building area, (2) number of equipment, (3) frequency data of each of these installations. Maximum loads for specific land use repartition are also predefined and calculated through the plot size and building used type. However, these are not considered as part of the study as the integration is concerned with direct to building home feed connection loads. Other considerations and restriction may apply specifically when buildings apply a green building g rating system such as Leadership in Energy and Environmental Design (LEED) certification (Council, 2001).

Furthermore, the Qatar university electric grids use a central substation within the heart of the campus (Figure 88) that feeds all buildings inside the campus operated by the service provided (Kahramaa), An annual consumption is provided in (Figure 89). The university is an educational governmental institution and therefore, the cost of operation is sponsored by the Qatari government.

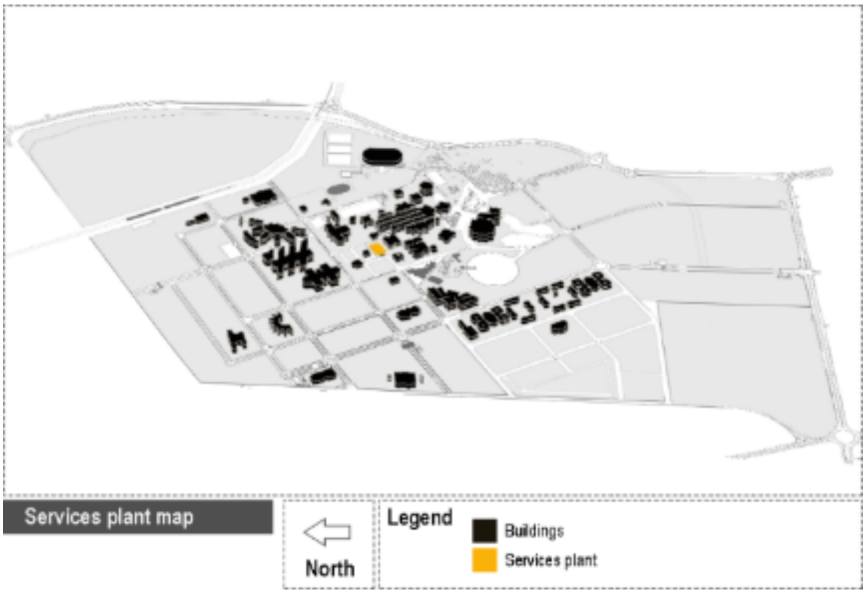


Figure 88. *Services plant location in QU campus.*

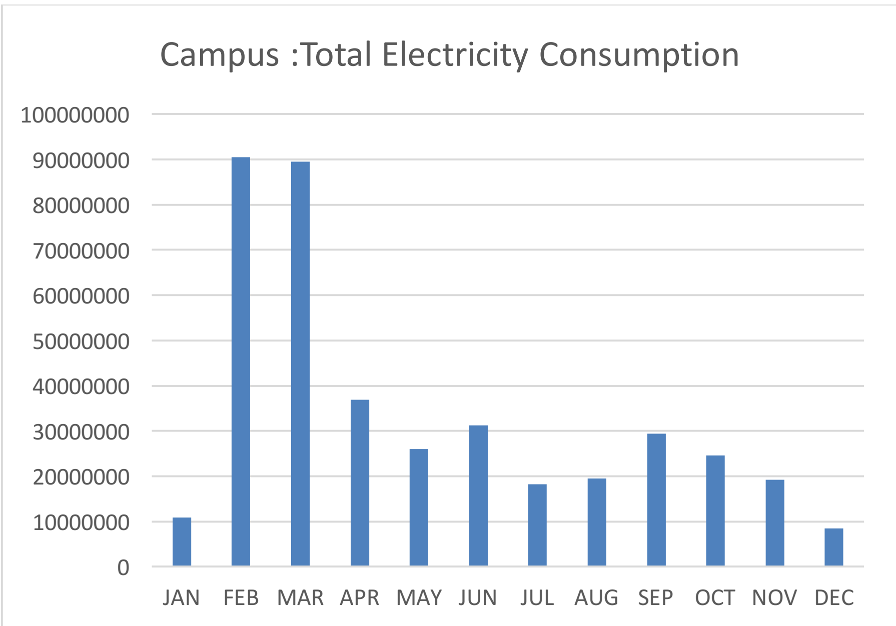


Figure 89. *Qatar University Annual Electricity consumption- year (2018).*

5.4.2.1 Water grids

Mainly, drinking water comes from desalination plants governed and managed by Qatar General Water and Electricity Corporation. KAHRAMAA is responsible of providing 99.6% of water where ASHGHAL continues to reconstruct the water infrastructure network to encompass the growing demand of desalination. “There are three Reverse Osmosis (RO) desalination plants, two with small capacity of <1000 cubic meters per day and are used to desalinate brackish water wells and one a seawater plant with a capacity of 35,000 cubic meters per day (still under commissioning stage)” KAHRAMAA.

The process of extracting water and deliver it to end-users is divided into five stages (1) Water Extraction and Desalination phase. (2) Strategic storage (3) Transmitting (4) Secondary Storage Tanks (5) In city distribution grids

Municipal water load calculations by KAHRAMAA are done in accordance to predefined building design data. These are standardized measuring units which include measuring the load a building requires in relation to its (1) number of users, (2) number of plumbing fixtures, (3) flowrate data of each of these fixtures(Council, 2001).

The price of water is 4.4QAR/m^3 for residential buildings and 5.2QAR/m3 for commercial while considering that residential, (water is free for local community). Maximum loads for specific land use repartition are also predefined and calculated through the plot size and building function. However, these are not considered as part of the study as the integration is concerned with direct to building tie-in loads. Other considerations and restriction may apply specifically when buildings apply a green building rating system such as LEED certification which comes with specific recommendations and requirements in regards to the type and design of the fixtures and building size.

The water sources in Qatar has been classified according to their origin into three main classes that includes (desalination and abstraction of groundwater and the re-use of treated sewage water treated sewage effluent TSE)(Abdel-Kader, 2013). The extracting and producing water is a rapidly growing sector in the State of Qatar (Figure 90) and water uses is coupled with GDP and HDI, the total water production in 2012 was estimate around 437 million cubic meters/ year which increased in 2016 to reach 560 million cubic meter/ year

Electricity

Particulars	2014	2015	2016
Electricity generated (GWH)	38 593	41 489	42 307
Electricity generated, yearly change	11.6%	7.3%	1.9%
No. of customers	310 107	329 310	344 446
Electricity consumption (GWH)	22 216	24 491	25 107
Yearly change	10.4%	10.2%	2.5%
Per capita consumption (KWH)	15 113	16 025	14 477

Water

Particulars	2014	2015	2016
Water production (Ml.Cu.Mt.)	494.0	533.0	560.0
Water production, yearly change	6.2%	8.0%	5.1%
No. of customers	262 018	277 483	296 846
Percentage of customers served by tankers	0.25%	0.16%	0.14%
Annual per capita consumption of water (Cu.Mt.)	221	220	231
Annual change rate in per capita consumption of water	-2.6%	-0.5%	5.0%

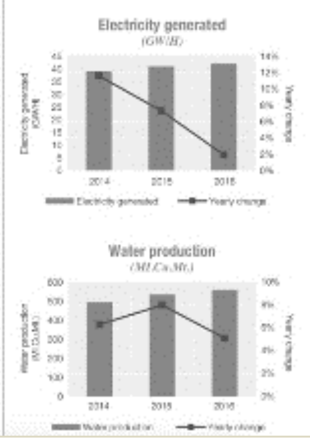


Figure 90. *Water and electricity total production. Source: (Kahramaa, 2017)*

Listing the source of water includes the following:

(1)- **Desalination**: From the total water consumption, (267m^3 is from desalinated sea water) and 293 from underground and treated water source with (Kahramaa, 2017) a high consumption 557 L/day/inhabitant(Lee & Lambert, 2018). The cost of desalinating, transporting, and retreating water represents an unnecessarily large financial burden for the state(Lee & Lambert, 2018). The aim of Qatar national development strategy (QNDS) and QNV 2030 to reduce the total consumption of water leads to decrease the consumption per capita from 238 cubic meter/ year in 2012 to reach 216 cubic meter/ year in 2016 (Kahramaa, 2016). Qatar follows high regulation international water quality standards.

Ras Abu Fintas desalination plant is located in the coastal area near Doha city with a capacity of 10% from Qatar's fresh water demand 160.000m3 per day. It requires 597MW to equip brine heaters, evaporators, heat exchangers and tubing. Currently the desalination industry is constructing additional 183km-long and 2.5m-wide pipeline infrastructure to connect it to a network of reservoirs. The current carbon emissions related to this plant are 14000 tons/Co2/year (M. Darwish, Mohtar, Elgendy, & Chmeissani, 2012)

(2)- Ground water: From the total water consumption, (293m^3 from underground and treated water source) (Kahramaa, 2017). The aim of Qatar national development strategy (QNDS) and QNV 2030 to reduce the total consumption of ground water. A 47.5/year use of ground water mainly for agricultural uses means that aquifers are lowered and salinity is increased which can cause ground instability and loss of fresh water source.

Currently, there is an artificial recharge of these aquifers which includes injection of TSE water into the ground.

Artificial recharge of groundwater aquifers by TSE injection, recharge wells and recharge from irrigation have become the dominating source for the national groundwater stocks

(3)- **Treated waste water:** Ashghal has planned and constructed multiple waste water treatment plants based on using chemical and biological bacteria process (figure

3), Doha west treatment plant is the largest 135,000 m3/d operating system. In 2010, the plant was expanded to 175,500 m3/d, in addition to previous plants, Doha West is currently treating more than 245,500 m3/d. The water is 100% reused, 55% for agriculture, 42% is pumped to Doha city irrigation of green areas and market gardens and 3% is injected to recharge aquifers. Also, in addition to the Doha North plant, sludge secondary treatment is currently harvesting fertilizers yet to be permitted for larger use in the country. The process shows a high systems approach to the waste management and agriculture industry.

Qatar university campus is supplied by desalinated municipality water from main supply tie in point provided by kahramaa, two holding tanks are currently on site and the FM is planning for a third in 2019.

Phase calculated waste water measured grey water as 70% of total output estimated, group (1, 5349715 m^3/day), group 2, (133547 m^3/day), group 3, (190782 m^3/day). Additional irrigation use is 30003 m^3/day (Figure 91).

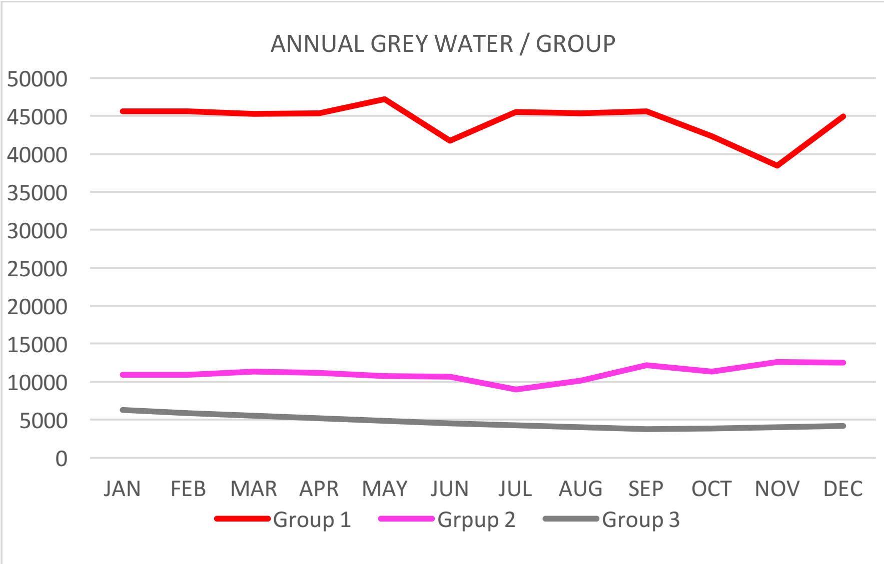


Figure 91. *QU-Kahramaa supplied water meter readings translated into grey water readings/assigned groups*

Additionally, two Treated sewage effluent (TSE) are pumped through Doha North Water treatment plant with a connection point at gate 1 and gate 2 (figure 86), this water is strictly used only for irrigation. In some locations of the campus highlighted, the water irrigation system is not connected which the university is currently using truck tanks to support the annual need. Also, water overflow of the TSE holding tanks requires transfer to truck tanks. Newly applied chillers are supplied with TSE water in three main district cooling towers at three different locations (figure 92-93).

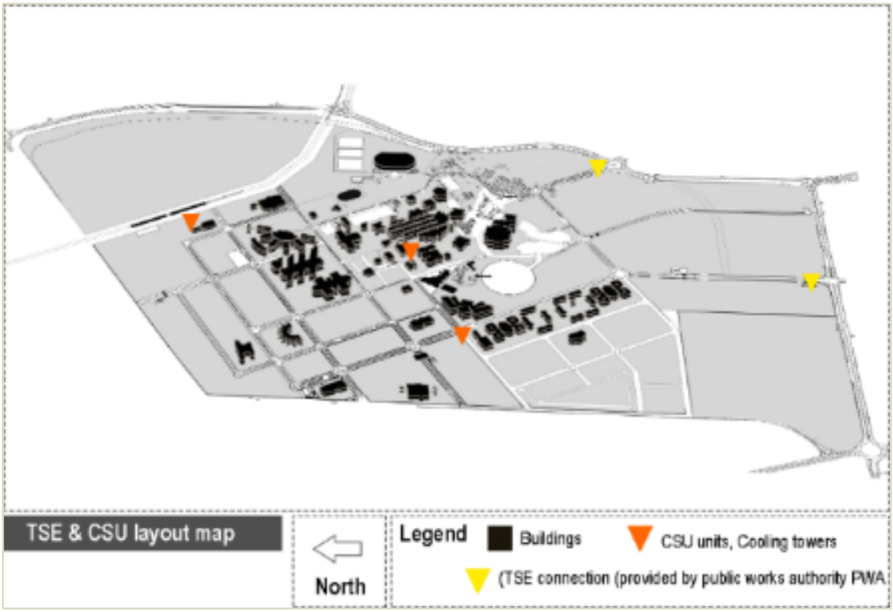


Figure 92. *TSE and CSU input location on QU campus map.*

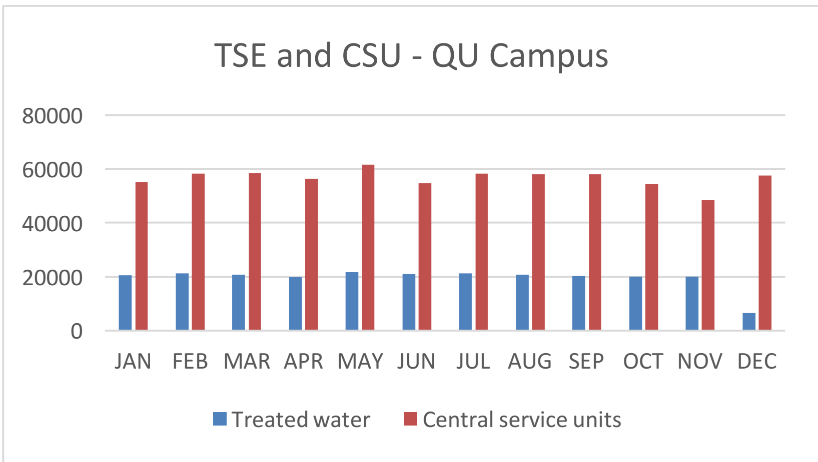


Figure 93. *TSE meter readings and district cooling meter readings for year (2018), indicated as smart meter system which sends data to Kahramaa and Ashghal for monitoring.*

Infrastructure of water, energy in addition to the above collected building fabric data are the main input for the SEEDS Algae façade system. The University campus readings are obtained to deliver an annual monthly consumption of both electrical and water readings which are used to run the system as well as measure performance by the output range.

The university FM has yet to deliver smart metering connected to the larger municipal monitoring system in all building. However, the university still remains connected to the centralized system of the city and does not do any water and energy production within the district zone. Qatar University calculated water readings/per group where based on 70% of total waste water.

5.4.2.2 QU- Qatar repartition evaluation and discussion

The current method of distributing land use has led to concentrated single function (lack of diversity), which prevent the launch of several development projects. Land use within the zone, where Doha city considered the most populated area and the high density of residential buildings that form almost 75% of the total area is clearly noticed (Figure 94).

Zone 68 contains two major land use types (Figure 95), residential and educational QU campus section. Qatar university land use data is generalized under educational land type, it displays a variety of building function types, commercial, academic, services, research and residential (showcased in the housing section of the campus as well as the surrounding 126.6938 m^2 residential neighborhood around the campus), also a transit development station which is designed to deliver commercial functions in addition to its transport use.

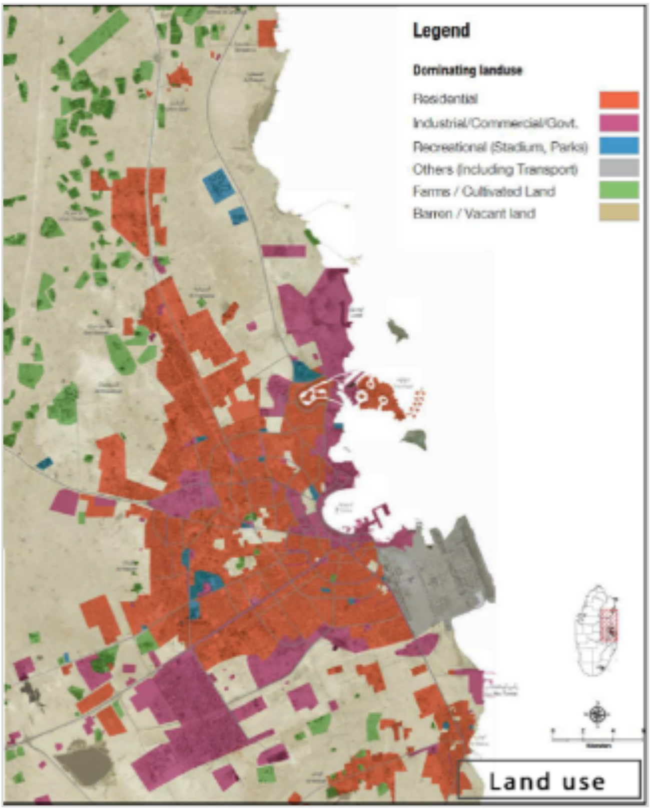


Figure 94. *Doha land use. Source: MME 2018*

Figure 95. *Zone 68 Qatar university district land used 68% of total area, plot and building use map.*

4.3.2.2.3 Smart Layer

Referring to the literature, smart layer in urban development is a lead aspect enabling innovation and sustainable achievement guided by research, governance and economic prosperity. As such, enabling QNV and QNDS towards a more sustainable smart application of infrastructure, buildings, energy, mobility and utilities, among other.

Doha city smart component:

The city of Doha has launched a generic aim adapted through the QNV2030, to promote technology at all levels of (1) - design technology: and refers to the system and method used in the process of designing the requirement of establishment, the design technology in Doha still at its early stage and it only include the computerized system with conventional data collection and dialog. (2)- planning technology: working as the backbone of the city, the palming technology has evolved rapidly in the last view years where the government data base of information uses and deploy several methods of tracking and planning the city such as GIS and City Map. (3)- monitoring technology: its considered as the most advanced technology among the three parts, where the government has obtained the capacity and required infrastructure to use the methods of rea-time tracking such as (smart meter adapted in several location, advanced monitoring and sensory system, and real-time data collection platforms) (Alsaeed.M,2018).

Current local smart systems alongside innovative technologies specific to food resource systems including infrastructure attributes and its associated water and energy are explored as facilities management FM, a basis for integrating the technology based SEEDS algae façade system.

Qatar university Smart component:

Several enhancements have been applied to the campus aiming to develop better environment and operation results, however the current method of water and energy management and operation inside the campus can be described as conventional, where all the electricity and water consumed are free of charge and delivered through conventional methods of centralized services station. The operation of the campus obtains a very limited capacity of real-time monitoring technology where conventional metering system are used, and the process of data collection uses the conventional dialog without direct possibility for real-time data collection, all in all, the current system within the campus that operate and maintain the campus are conventional and require steps to apply more advanced technology if algae SEEDS system is connected and monitored.

The current data provided and urban system analysis is a fundamental milestone for planning new enhancements to the campus performance in sense of environmental as well resource system efficiencies and can be used to deliver the critical analysis of a new intervention and integrated enhancement initiatives on all scales considering the current centralized nature of the campus resource dependencies.

5.4.3 Eco-productivity

Productivity is based on a quantified analysis of algae during its cultivation process and harvested biomass. The discussion on three conversion factors for algae as water treatment, biomass and energy and its related sinks by which a model is established.

5.4.3.1 Water treated

As a primarily inflow in the SEEDS system, the water condition from the system outflow is significant. The unique aspect of the design is the ability for it to alter the flow of water waste treated by which it becomes a denominator for the extended water demand for the area and also diversifies the supply module with a new source of fresh water that ultimately has its advantage on the holistic water system performance.

According to the grouping applied at the QU study area. An initial consumption of water was established at baseline (group 1)- 5349715 m^3/day, (group 2)-133547.4 m^3/day, (group 3)-3190782 m^3/day. Additional irrigation use is 30003 m^3/day

Water Treated by SEEDS system per groups is based on the flowrate needed for the system, as a result (715421.975M^3) system treatment capacity of water is able to be treated (Figure 95) exceeding the demand of the campus.

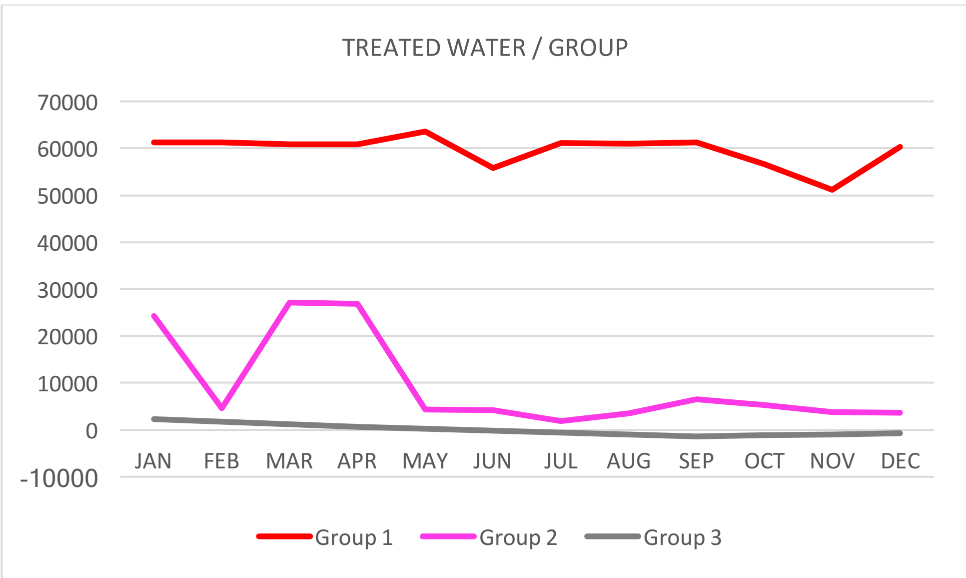


Figure 96. *system treatment capacity.*

By calculating the grey water treatment capacity of the SEEDS demand and supply system aspects it is concluded that in (group 1) (Figure 97) and (group 2) (Figure 98), the capacity of the system to treat water exceeded the amount of grey water inflow which concludes that an additional inflow must be supplied into the cultivation system to keep it running (Figure 99).

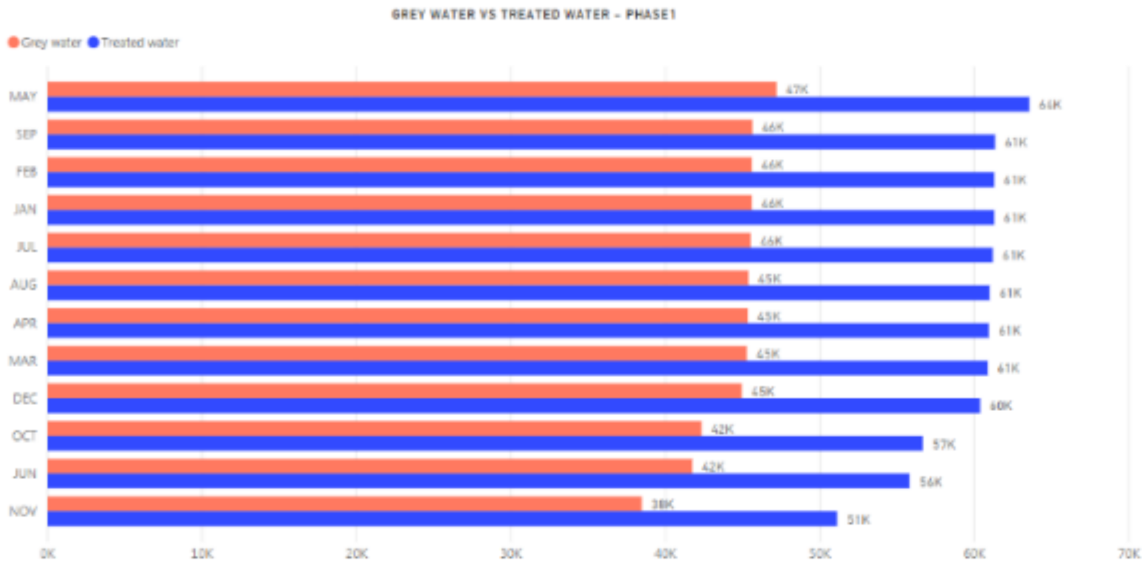


Figure 97. *Treatment capacity of the SEEDS system compared to the annual grey water inflow per month (group 1).*

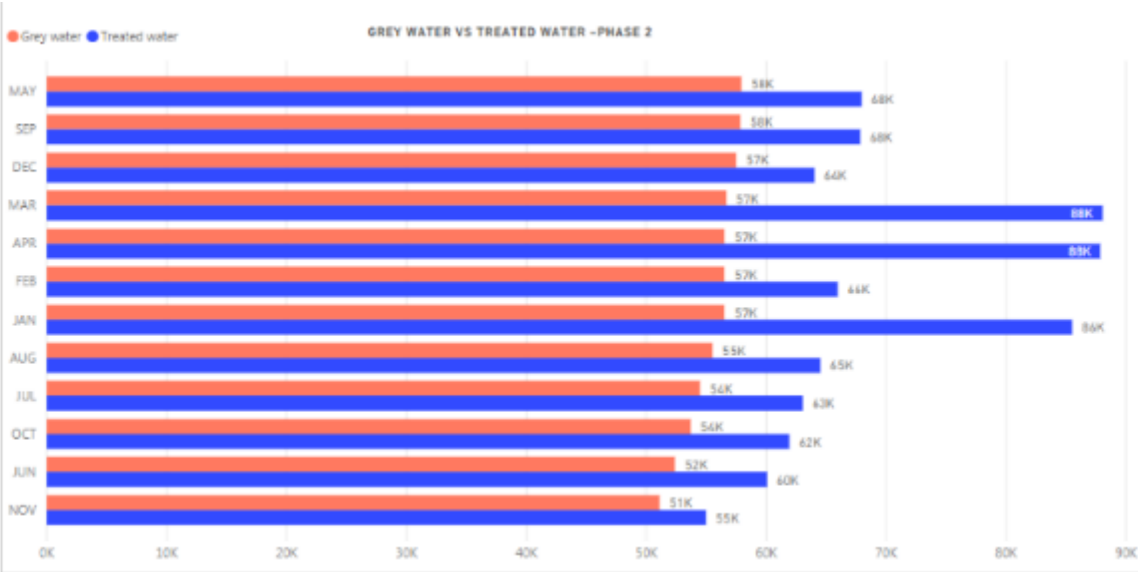
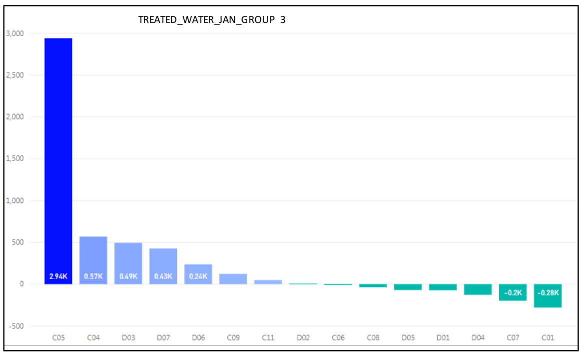
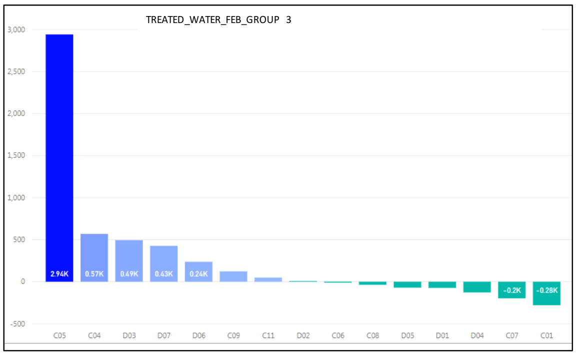


Figure 98. *Treatment capacity of the SEEDS system compared to the annual grey water inflow per month (group 2).*

However, in (group 3), the results show a lower capacity of the system compared to the amount of inflow of grey water (figure 101).





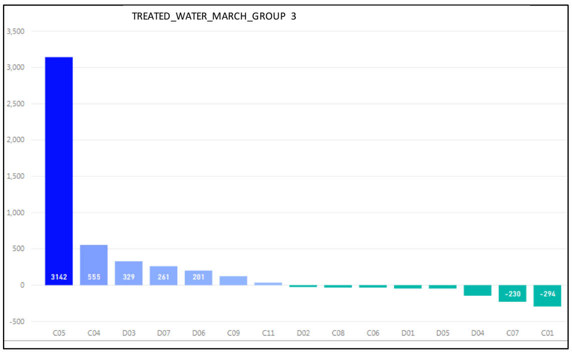


Figure 99. *water treated by SEEDS system results for the months Jan-Feb-March in – (group 3).*

An additional inflow could be provided by 3 optional cases, (1) TSE influent available on the campus utility which however requires more nutrient added considering that TSE water contains none. (2) Supply of grey water from the neighboring residential block which can also benefit from this system. (3) Adjusting the system into full capacity sewage treatment which would require if proper pre-filtrations are done.

The exceeding capacity of the system is compensated in the phasing where excess capacity in groups (1) and (2) may be used to compensate the shortage (Figure 100). This is due to the number of panels in relation to initial inflow of grey water which is highly dependent on the building activity and façade size.

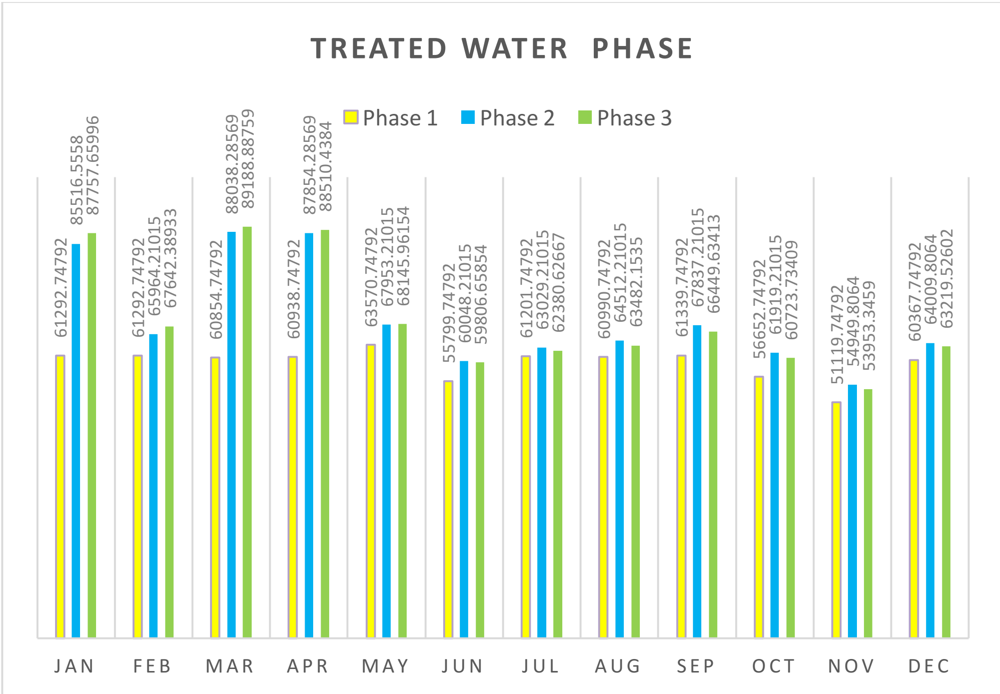


Figure 100. *Grew water treatment capacity of the SEEDS system compared to the annual grey water inflow (all phases).*

The amount per phasing exceeds the inflow of grey water. The production under a three-year phasing shows that the QU site is able to treat an approximate total (34%) more water than its current sewage effluent in (phase 1), (10%) more in (phase 2) and (5%) more in (phase 3). Hence, the productivity is highly efficient with exceeding 5% (figure 101).

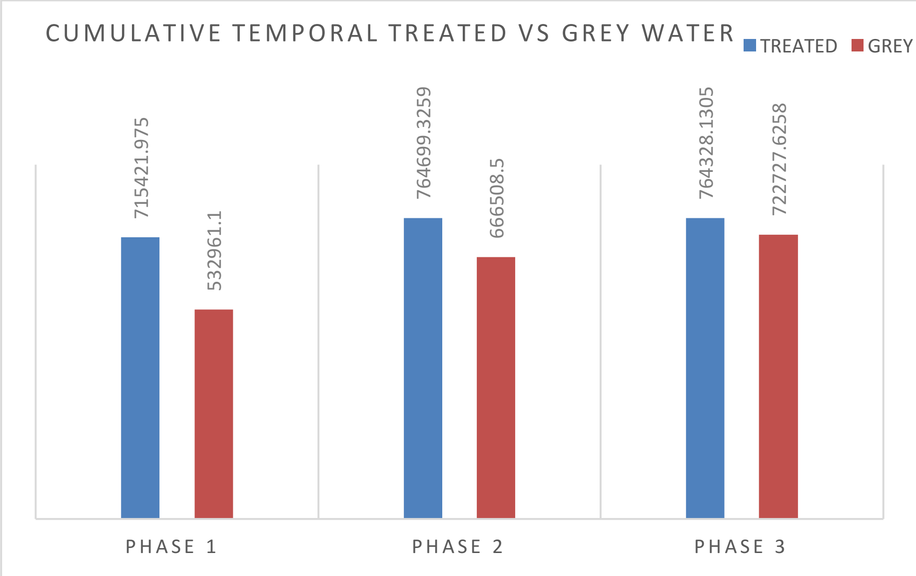


Figure 101. *A total cumulative temporal by phase treated water annually versus grey inflow annually graph.*

5.4.3.2 Biomass produced

The biomass production is the most influencing factor on the system performance evaluation. It transfers its effect on secondary sequestration through productivity of alternate (1)- energy source, (2)-food source, (3)-fertilizer source and other uncalculated benefits in pharmaceutical industry for human consumption. It is for that reason the performance of the system is calculated first by the biomass produced as per the study area-QU. An accumulative display of the system production by group shows that there is a positive relationship between biomass productivity and the water treatment.

The below graph (figure 102) demonstrates a production region which can deliver secondary benefits and their indirect influence on the sequestration of Co^2. As per the QU campus study, (Table 11) shows the production range of biomass per group-per day.

Table 11 Biomass Production min –max range Kg/panel/day.

Phase	Biomass min Pro	Biomass Max Pro
Group 1	5.98	59.78
Group 2	17.08	170.82
Group 3	10.50	104.97

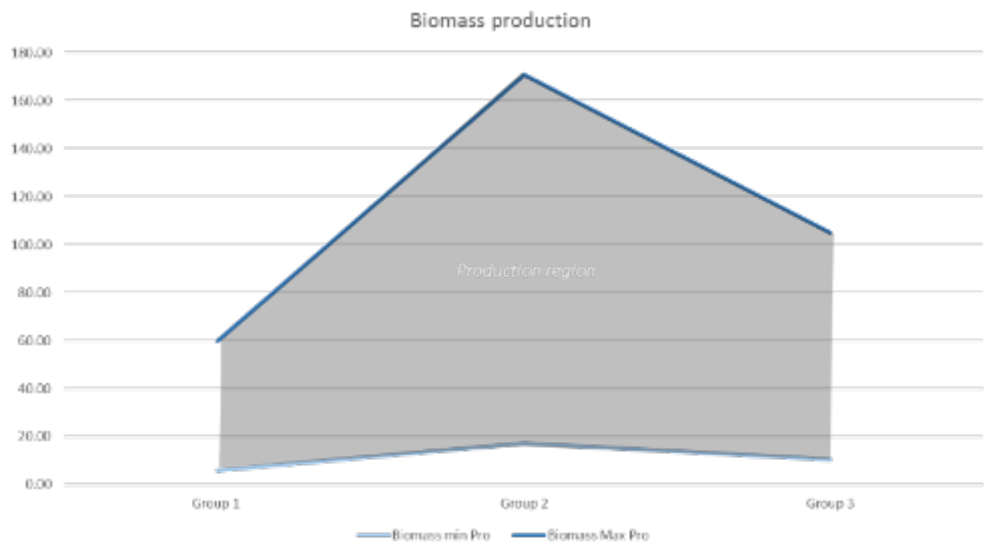


Figure 102. *Biomass production min –max range Kg/ group/day.*

The calculation of QU campus production in relation to the density presents a maximum (122487.55 kg in phase 3) from area of 8.094 km²- Density 4.854km^2

The annual phase production displays (21821.22) phase 1, (84172.23 phase 2) and (122487.55 phase 3) showcasing a growth of six times according to the established growth plan of the university campus buildings.

The initial biomass productivity in the QU campus was 0%, hens there is a positive growth of production versus consumption which can transfer into other revenue chains. With a phased application of the system, there is a sequential growth in a three-year time frame which also directs practical planning based on a small-scale production group1 area. Accordingly, the decision on product endues is established (Figure 103). The production of biomass is the base line for calculating the bio energy and secondary sequestration aspects in the following section.

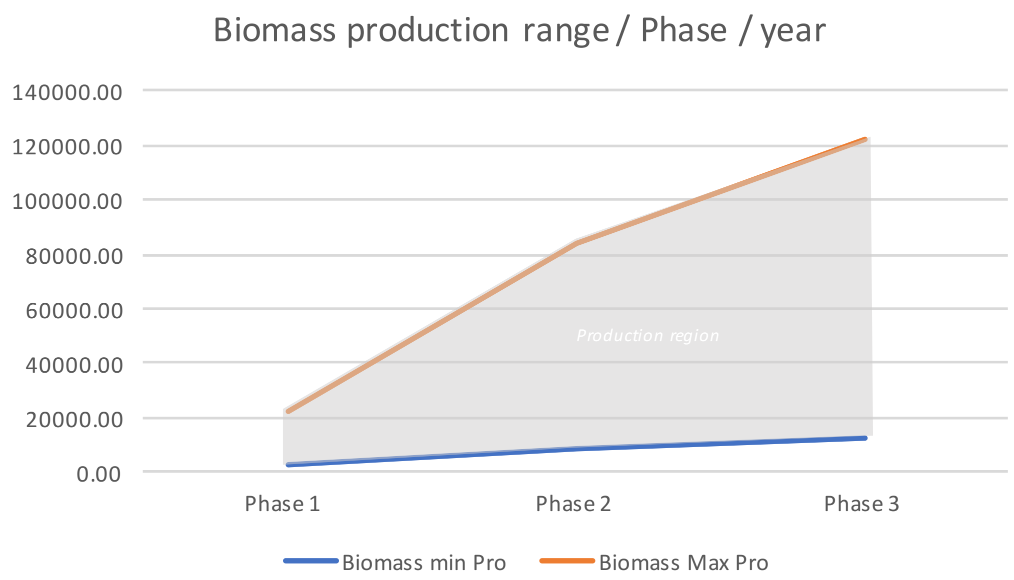


Figure 103. *The biomass production min –max Kg/phase/year - range per-per phase.*

5.4.3.3 Sequestration

There are two sets of sequestration considered as essential to the overall effect of the system on the ecological-carbon footprint. These are the direct sequestration which are a result of cultivation process and indirect which are calculated in relation to fertilizer, bio oil and gas replacements in the industry. Referring to the methodology of system performance calculations, the sequestration results are displayed by group and phase scenario that showcases a positive relation according to panel application and performance (Table 12) (Figure 104-105). The total sequestration as per the three-year phasing is 498724m^3

5.4.1.3.1 Direct sequestration

Table 12 Sequestration per group

Phase	**Sequestration m^3**
Group 1	243.42
Group 2	695.5349623
Group 3	427.4132939

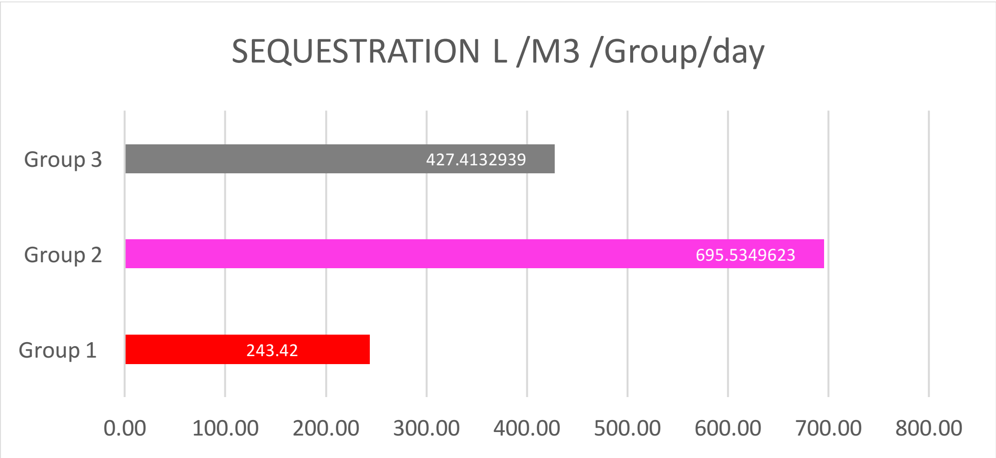


Figure 104. *Direct carbon Sequestration-per group-per day.*

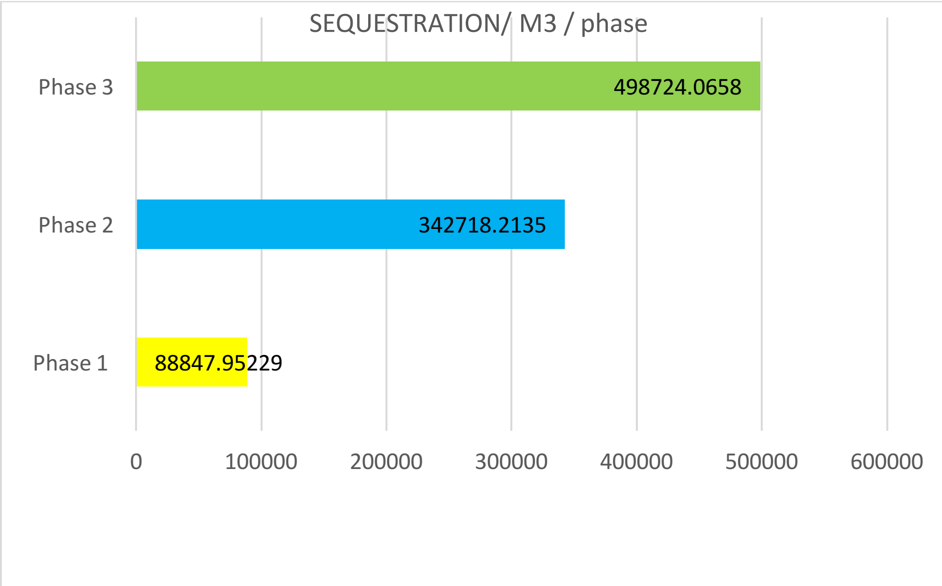


Figure 105. *Direct carbon Sequestration-per phase*

5.4.1.3.2 Indirect sequestration

1. From water treated

Table 13 Indirect Carbon Sequestration From Methane Produced

Group	**Sequestration KG CO2/KW/h from energy produced min**	**Sequestration KG CO2/KW/h from energy produced max**
Group 1	445.98	889.27
Group 2	1274.32	2540.97
Group 3	783.08	1561.45

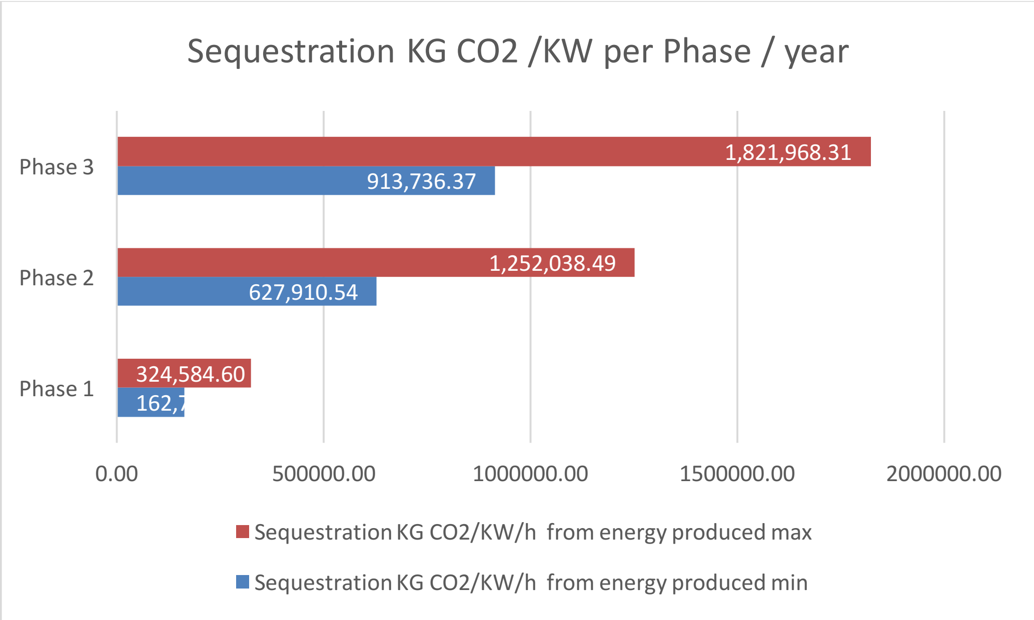


Figure 106. *Total sequestration from methane energy produced.*

5.4.1.4 Bio-fuel and bio-gas production

In an anaerobic digestion process, methane gas and bio fuel can be harvested from the SEEDS system.

Table 14 Biofuel produced per group-per day

Group	Biofuel production min	Biofuel production max
Group 1	3.38	59.78
Group 2	9.67	170.82
Group 3	5.94	104.97

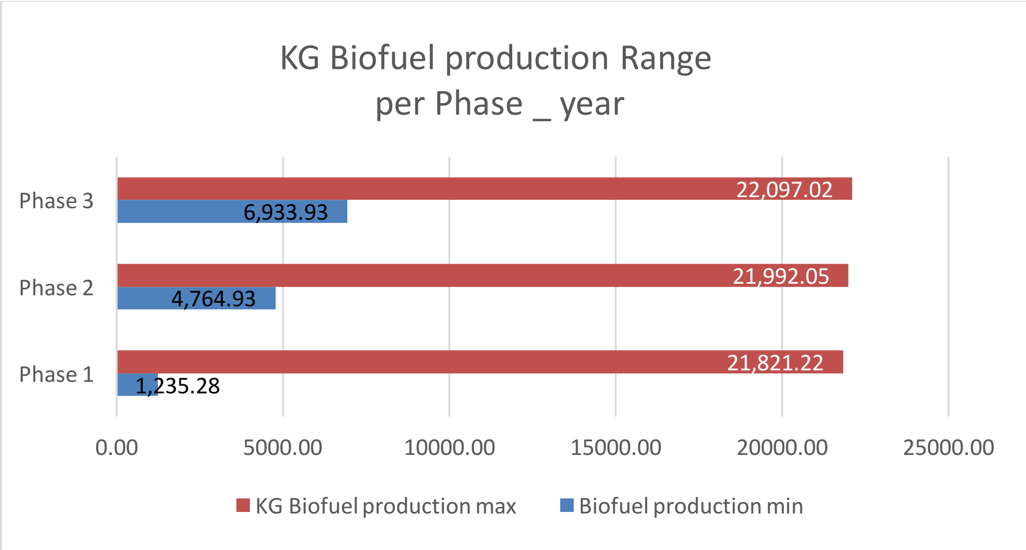


Figure 107. *Biofuel min and max range produced per phase.*

Table 15 Methane Produced Per Group-Per Day

Group	Methane production min (m3)	Methane production max (m3)
Group 1	191.58	380.91
Group 2	547.41	1088.38
Group 3	336.39	668.82

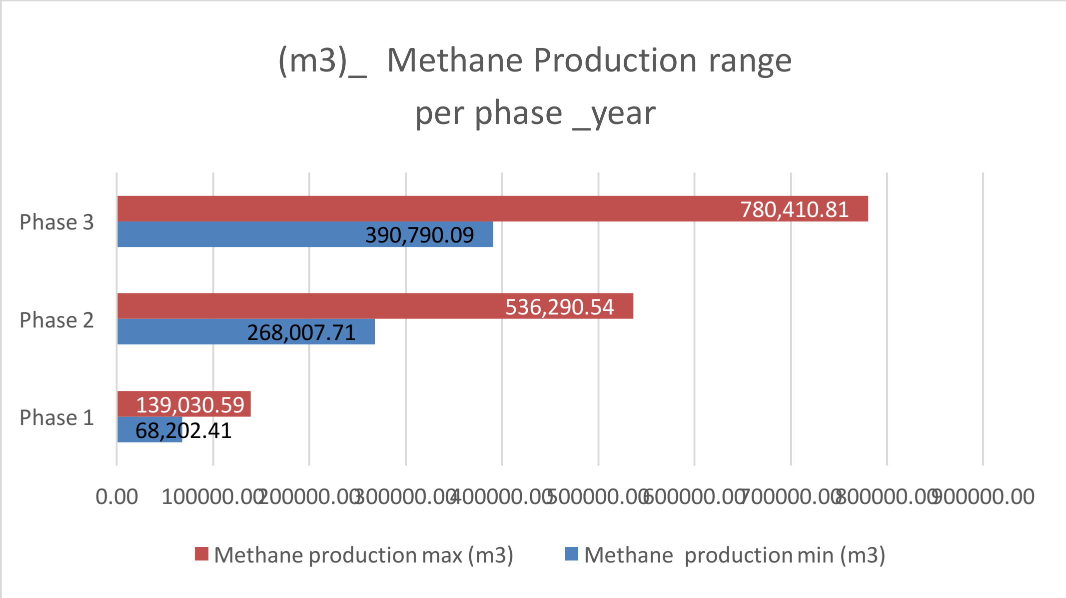


Figure 108. *Methan production.*

5.4.1.5 Power generation from methane

Table 16 Power Generation From Methane Per Group-Per Day

Group	Power generation (KW/h) min	Power generation (KW/h) max
Group 1	748.29	1492.07
Group 2	2138.13	4263.37
Group 3	1313.90	2619.89

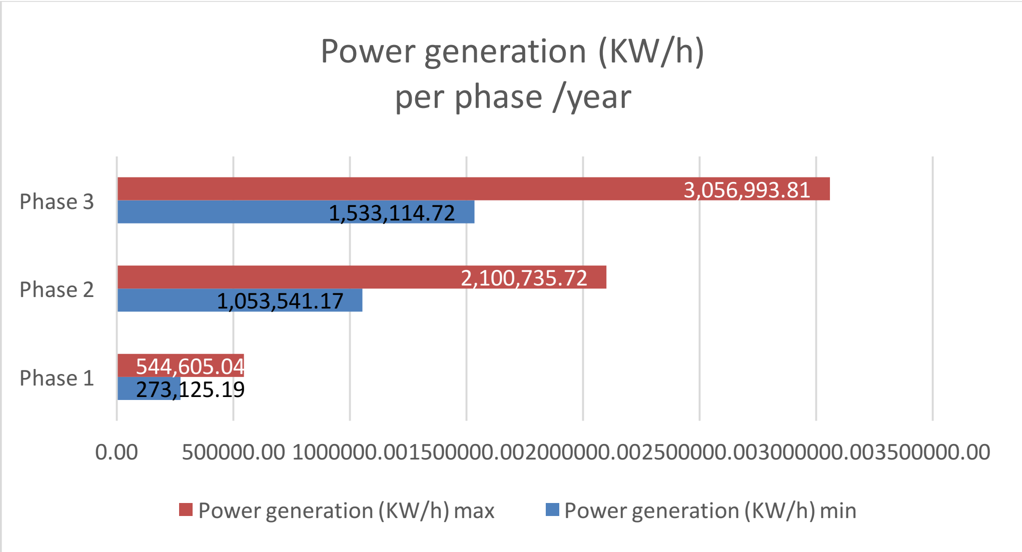


Figure 109. *Power generation from methane per phase.*

5.4 Chapter Conclusion

The first stage includes numerical manifest system performance calculations on the microscale followed by the discussion on latent influences by the system on the larger meso and macro scales. These are discussed under the two subtitles eco-efficiency and eco-productivity.

5.4.1 SEEDS productivity and carbon footprint performance

After the production of the system is explored, related sinks are used to evaluate ecological benefit inherited by the system which will demonstrate the level of SEEDS to produce with minimal negative impacts on the environment. Referring to chapter 3, the methodology evaluation variables, four indicators are used to evaluate the environmental pillar of the nexus framework. These are indicated by land type as Carbon, Forest land, Grazing land, Cropland Fishing grounds and built up land (figure 48)._

5.4.1.1 The cropland and grazing land

Qatar is scares in terms of meat production related grazing land. It is for that reason fodder agriculture is a crucial agricultural industry which enables a sufficiency in the meat production market and is currently on the rise. Referring to the context in chapter 4, the environmental protection policies have restricted open land grazing to protect natural fauna and biodiversity in most of the countries lands which has put more pressure on the fodder production. As per the results of algae biomass dry weight considered as equivalent feed for animal feed. It can add to the annual agricultural production of fodder 45 tons. In the case when biomass is converted into animal feed, this means that the fodder increases in production by (0,039%) from (27.84 hectares vertical area) in QU campus. If biomass production becomes a practice in the initial infrastructures of new projects in the region and Doha city, there will be a significant growth in the stability of fodder sufficiency.

The current production of fodder is 115,000 tons/year - 54% and is planned to increase to 63% by 2023. The biomass transferred benefits into the fodder industry is an asset that can allow the country to meet its demand (Table 17).

Table 17 Added Value In Hectares Of Fodder Production

Item	Baseline scenario	SEEDS integration scenario	Added value
Biomass as animal feed	Qatar production - 115,000 tons/year - 54% of population need	45 tons/year	0.039%

Crop land-fodder	4,500 hectares	27.84 hectares	vertical	0.6% cropland	added

The effect of the agricultural cropland SEEDS system presents is also beneficial as it has 0% land occupation versus the conventional farming which is highly land intense and poses inherent discontinuities of natural fauna and biodiversity. The later further reveals the extent of SEEDS ecological interconnections in the country profile.

5.4.1.2 Forest land

While a direct comparison between the sequestration of forest land SEEDS system cannot be established based on area and sequestration only, it is still a considerable aspect to discuss the effect of sequestration the system has. Considering the lack of forest land in the country. The system can simulate sequestration results similar to ones calculated from forest values. The process is based on the same photosynthesis and sequestration component. Furthermore, sequestration is continuing during algae cultivation despite natural light availability increasing its performance timeframe. Algae has a similar sequestration of forests between 1.78 – 2 kg/year/kg dry biomass compared to forests and higher yields 127–250 t/ha/year compared to forests 2.6–3.9 t/ha/year.

5.4.1.3 Carbon demand

Indirect sequestration (Figure 110) (Table 18) is calculated by the use of bio methane and water treatment sinks in the industry conventional system demand. Hens they offer a reduction in the production or a revenue for export.

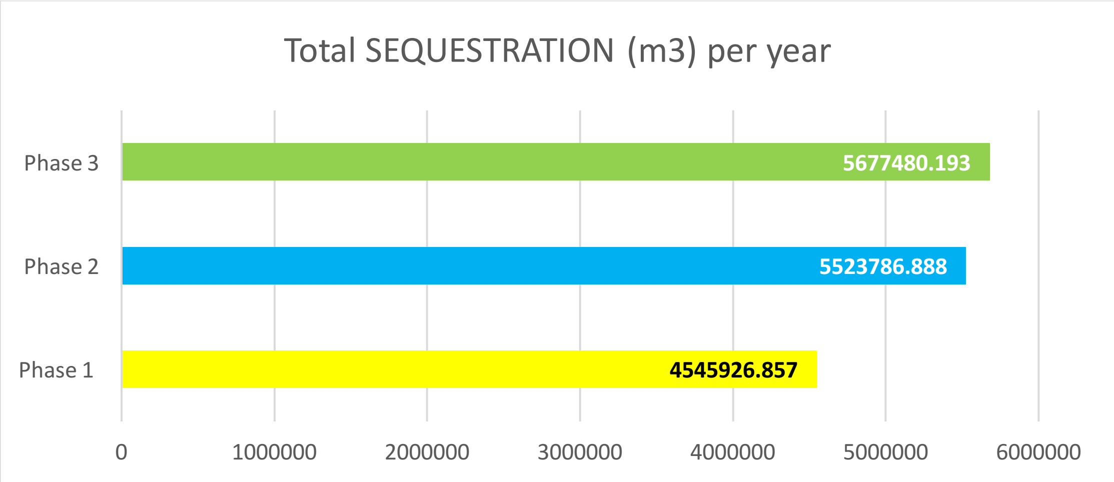


Figure 110. *Total sequestration (direct and indirect) per phase.*

Table 18 The Cumulative Sequestration FromD Direct Sequestration and indirect Sequestration From energy (methane) use and (water treatment)

Type	SEEDS integration scenario
Direct sequestration	498,724.06
Indirect sequestration	From water treatment From Bio-methane
Total sequestration	567,7480

5.4.2 Eco-efficiency

Eco-efficiency which is the balanced management of socio economic and natural resources. While the research focus is majorly on the manifest effects of the system, the latent social and economic effect of its application are generally discussed to display the connections through the nexus framework lens. Main latent and manifest connections are illustrated (Figure 111).

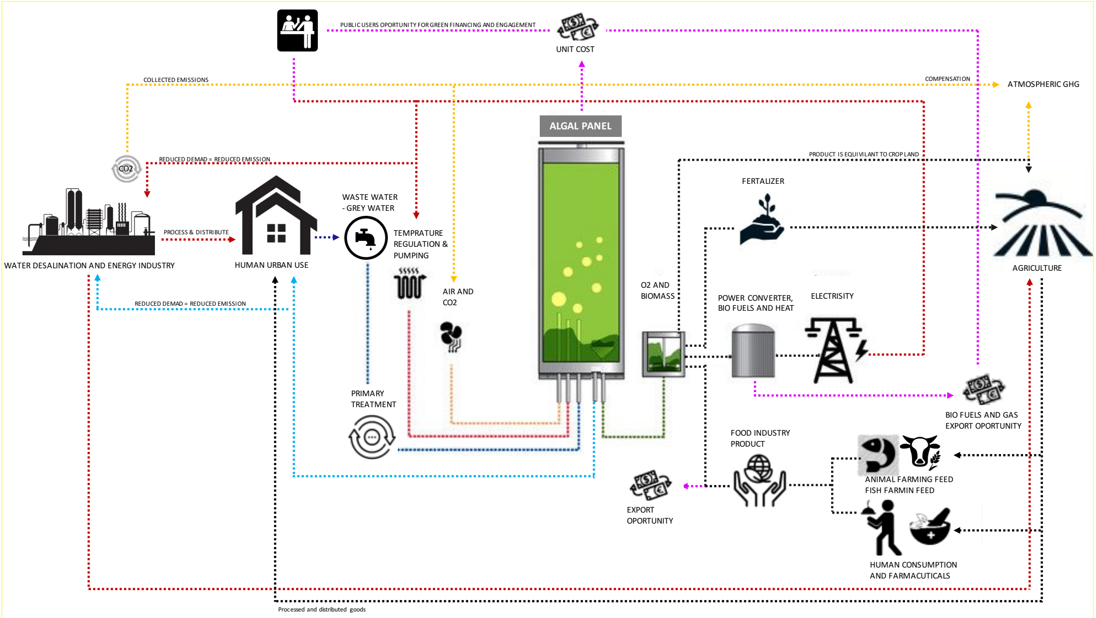


Figure 111. *SEEDS integration cycle with manifest urban environment, resource production and with latent socioeconomic aspects.*

Three areas are highlighted as central to intervention, the power of purchase, the planning authority and policy, the socio-economic collaboration. The question is, how these can be used to expand the stages of the nexus frame work which sets the course to specific variables, dependent, independent or constant and analytical tools that define them considering context related attributes of the city.

The power of purchase is a result of economic empowerment due to industry progression. The way the industry works is central to intervention within production, delivering and waste management.

Intervention in industry shifts and integrating resource flows is a government issue mainly, the allocation of integration is an urban planning aspect which remains dependent on the physical characteristics specific to the city. In the case of FEW resource, these are highly dependent on the infrastructural layer alongside other layers identified as critical to decision making.

This means, financing design interventions which require raising awareness amongst decision and policy makers and social awareness in consumption patterns.

Achieving the latter becomes a more applied practice research area by which the evaluation and analysis considerations for the nexus application are expected to take positive role when followed systematically with less margin for errors.

Based on the productivity results, a system dynamic model is established and discussed in the following chapter, although the model is not run at this point of the research, it is based on the synergy areas between physical urban components and the façade system all together SEEDS. The purpose of the model is then to deliver a tool that can be used to generate data of specific building or neighborhood. Hens, the data input is based on the system physical and productivity aspects which include the grey water treatment, the sequestration, the biomass production and energy by biofuel or gas. The direct and indirect sequestration is the base scenario for scoring the carbon footprint sink presented as a carbon footprint score in the model.

CHAPTER 6: RESEARCH CONCLUSIONS

6.1 Introduction

The chapter is four-fold, after a discussion on resource risk towards the main urban algae product application, through a body of literature and previous nexus-based initiatives, a nexus framework is identified and expanded upon to guide the research discussion toward developing high-level integration between existing urban systems and algae as an agriculture production system. This section discusses the practice - established nexus framework principals and how these are the steps that facilitate urban nexus prospect. Second is the design based findings - physical urban system design highlights. Third is the evaluation based findings, this section showcases the system dynamic model established based on the system performance findings. Fourth are the future outlooks and opportunities (figure 112).

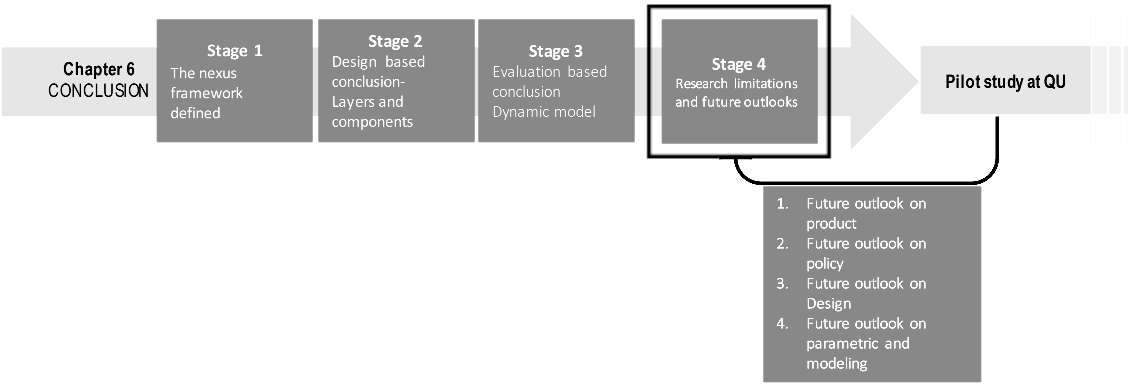


Figure 112. *Findings chapter 5 -subsequent stages*

6.2 A Macro-Micro Resource Risk Prospect

Earth is experiencing irreversible damage both environmentally and socio economically given the fact that all consumption is socioeconomically driven. This puts pressure on consumption and production rates of food, with considerable disruptions in energy and water flows that lead to unpredictable migration and conflict over natural resources. Coupled with economic disturbance, it poses inherent inequality amongst developed and developing countries, specifically referring to the devastation of developing countries' natural resources and socio-economic systems to fulfill requirements of developed countries' basic needs.

From the global perspective, the influence of urban resource flows is not restricted to one biological region, in fact, because of the unique interconnectivity of earths systems, any local damage to earths biological fabric, or excessive consumption of its resources that alters the natural and energy balance of its surface is considered a global threat.

Rapid urbanization is causing unprecedented demands on food, energy and water systems which all play vital roles in supporting life services. A coordination between the inter-sectorial connections between these systems is required.

Currently, the interconnectivity between urban resource systems is nascent in planning practice and is critical to the future of resource availability and operational efficiency for urban resilience. Resilience at this point is effected by the footprint measure of cities and countries.

Largely, carbon footprint problem is a major concern of sustainability. Emissions related to agricultural production are a common source of GHG, in addition to the solid waste and indirect emissions from related activities such as transport, storage, services and products or goods produced elsewhere, all which sustain resource damage.

Both cities with high or lower ecological footprint need to mutually address their current practices in all resource sectors in order to find ways to mitigate significant threats and shift back to a Holocene balance.

This will require new paradigms, ones where urban planning and development of flow models reflect more sustainably on all three scopes, local, regional and global. The importance between the three scopes will vary depending on the production system target, type, level of development and economic activities between cities which determine the effect that system flows have on both resource and environment.

The planning, design and operation of urban food and its related energy and water systems requires an integrated system analysis vs an isolated one which can deliver better building, infrastructure, land use and decision making especially under extreme events and hazards.

Qatar is currently presenting a higher level of risk from the political security sense which has aggregated an already high climate change risk and contribution .While Qatar is yet to commit to a firm greenhouse gas emissions reduction target, the political stressors pressured a sudden spike of local food production presented in a shortage in synergies between existing urban infrastructures and new food industries structures which presented a new set of risks; increasing resource depletion and risking an increase in GHG and carbon footprint. Because of the lack of underlying understanding of the inherent interconnections between overlapping pressures, Qatar is considered a ‘FEW Nexus hotspot (figure 113).

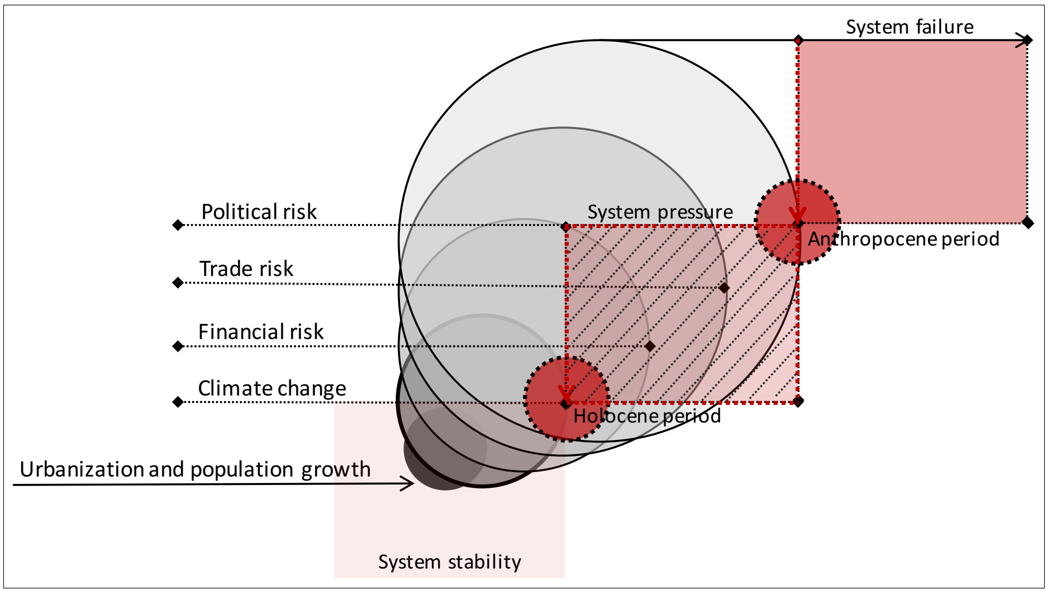


Figure 113. *Position of Qatar as a hotspot scenario in the system pressure area at the peak of political disruptions.*

A broad food security strategy in the Qatar must first address the issue of sufficiency for demand growth , evaluate spatial and cultural patterns of life in the city as an inseparable part of the nexus and develop a robust research in integrated product systems that realize economic, social and environmental issues through the 1;estimation of resource fluxes (energy, nutrients, water and emissions) inputs and outputs which circulate between city flows, 2;examining antagonisms or synergies resulting from algal product system integration, estimating the economic benefits by the use of innovative technology.

While the research begins with a broad discussion on resource risk and climate uncertainties, it migrates down to the production scale level which has been identified as the core element where city industry based solutions can evolve from.

An assessment of an urban algae nexus approach is at the core of this research where an instructional framework is developed to deliver a comprehensive system based understanding. A system design and evaluation method is applied on the scale of Qatar university campus which reflects a local development aspects and also offers future opportunity for a second stage verification area based on the current research and pilot study aspirations. Hens, the case analysis of the University is a step forward towards an active pilot study analysis that can bring real life numerical application of the system performance.

6.3 Practice Based Conclusion

There isn't a unified solution to the nexus issues. However, an effective approach is place based and one that considers the physical characteristics of the urban area and the city's (economic, social, natural and social capitals and geography). Hens a framework is developed to guide a nexus approach of the algae product system application. The framework is also applicable on all scales and can be used for a top down approach or opposite. It is designed to confine any planning decision within a clear scope of considerations when FEW resource aspects are involved. It is used to identify key points to design new intervention plans that can redirect policies and practice towards achieving SDG's.

6.3.1 Nexus framework

The established result is a basic yet comprehensive schematic overview of the resource nexus (Figure 114) which serves as a conceptual framework, and as a tool to facilitate analysis of resource challenges. It integrates:

- Global megatrends which influence supply and demand of resources for the benefit of urban and human development (urbanization through industrial economic growth and population morphologies) which are essential in profiling a city hotspot situation and offer opportunities to improve resource systems generated by these risks.
- Sustainability expanded with an anthropocentric focus on politics and governance, technology, in addition to social, economic and ecological factors.
- System approach of three basic resource systems (food, energy and water) and the industry which enables them.
- An urban system – subsystems dependency on the expanded sustainability principals and supply and demand medium for FEW resource.

The goal of an expanded conceptualization of the resource nexus framework is to represent its complexity within consideration of the of urban planning and policy making practice.

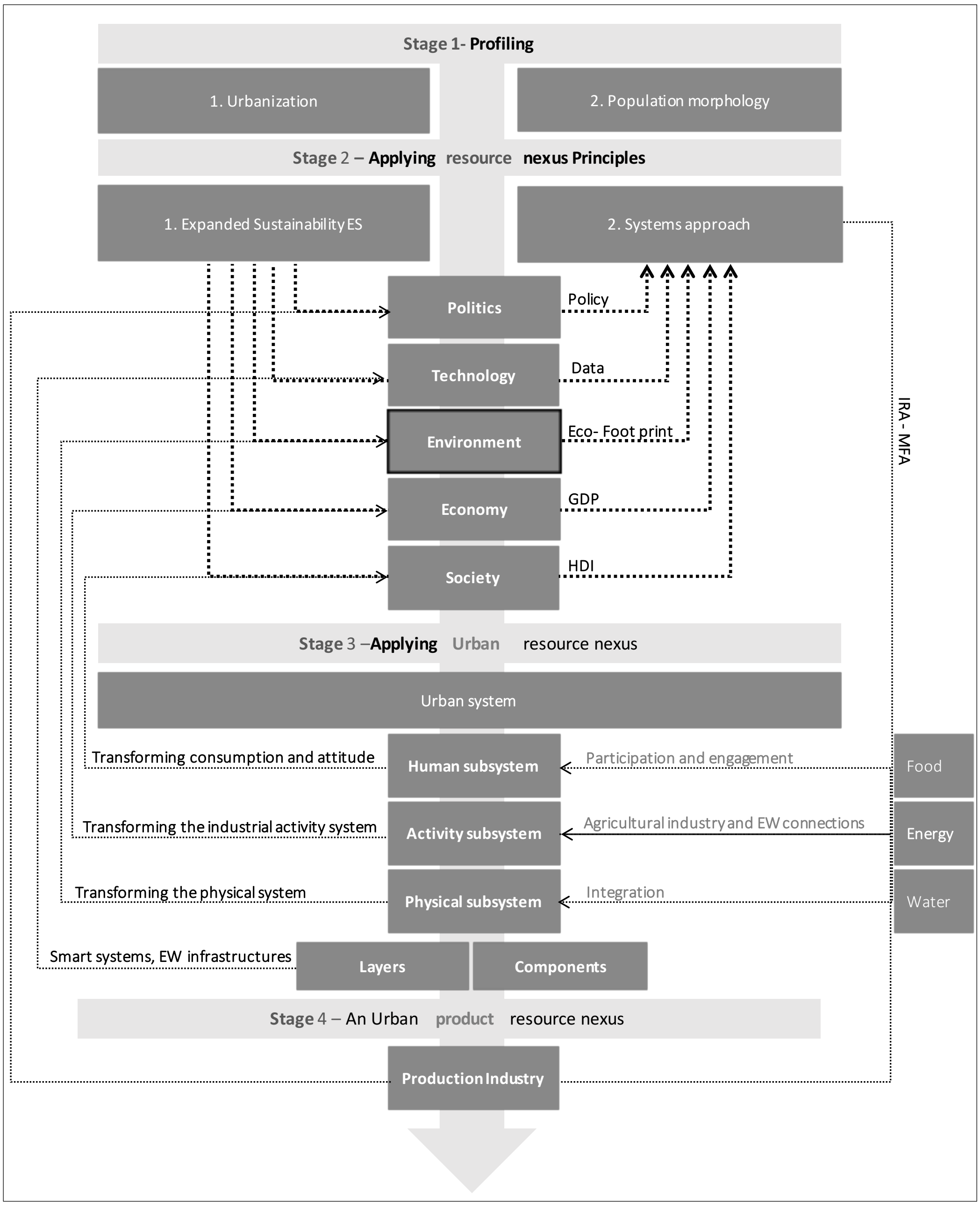


Figure 114. *The research nexus framework and stages.*

The framework adopted stages and principals are theoretically and practically discussed in relation to the urban algae product system. After numerical integration results are established, the design of the urban algae system must address each section of the framework systematically following three scale levels, macro, meso and micro from the regional to Qatar – Doha city QU case analysis to achieve a holistic understanding and predict the way the integrated system influences direct and more specifically indirect externalities which are a main reason why many unpredicted resource problems are taking shape today.

6.3.2 Applying the nexus

6.3.2.1 Stage 1- Macro Scale-Profiling brief

By revisiting chapter 4, context profiling, the macro scale reagional; population and urbanization trends, the following factors are concluded in relation to SEEDS system application.

The region is currently marked as a main carbon footprint source by the nature of the GCC energy industry based economic model. The problem is recognized by the GCC leadership which has sprung them into a new direction towards greening economies. The region is currently undergoing an urbanization shift which aims to diversify its economies leading to massive cultural, transport, business, tourism and entertainment projects which have also pressured the already high footprint. This was established by the global footprint which grew 1.5% per year while a 3.4% was witnessed in the region. Hens, there is a shift towards production entities which aim to achieve a higher level of intervention which lead to the current buzz of alternate eco-industrial models. Population morphologies in the region are also shifting rapidly as more opportunities arise from the new business models ultimately increasing the FEW resource demands. This is a result of high HDI which exceeds 0.7 as defined by the UN development program as the threshold for high level of development.

6.3.2.2 *Stage 2- Meso scale- Resource nexus principles in Qatar brief*

Similarly, Qatar is facing industry and population shifts and a significantly high role in the GCC footprint as well as the country scale footprint which has caused great controversy on the current urbanization trend. By revisiting chapter 4, context profiling, the meso scale, Qatar local characteristics in terms of urbanization and politics, the following factors are concluded in relation to SEEDS system application.

1. SEEDS system is compatible with the geographic layer characteristic of Qatar. The high temperature climate and lack of arable land showcase an opportunity to peruse the mass production of algae in the region.
2. The high urbanization in Qatar is currently shifting towards more sustainable development with the new QNV environmental sustainability pillar while also being challenged by the FIFA infrastructure and mega project phase. Considering the large construction, SEEDS system can integrate with current development models as part of the FEW infrastructural transformations.
3. The current high GDP and economic revenue from oil and gas industry enables a high technological transformation of urban and industry systems which can accommodate the initial cost of the system application on a large scale.
4. A high dependence on oil and gas is considered in terms of global climate a short-term ecological plan. While currently the dependence is inevitable, diversifying energy sources can reduce pressure and offer new production trends in the energy industry.
5. The up-to-date dependence on food imports is subject to crisis risk. Under the current political instabilities which resulted in a food industry spike, SEEDS system demonstrates a new direction for food security agricultural production

in line with the Qatar food security and sufficiency progression. It also offers a trade option between the GCC neighboring countries which have similar industrial system behavior.

6. Socially, there is a high level of disconnection and centralization between consumer and producer which has resulted in an absence of stewardship and awareness towards FEW interdependencies with the ecological and urban system.

7. This is amplified by the local energy and water subsidies which have further disconnected consumers from production process externalities and the associated global risk with them. SEEDS is highly integrated in the urban physical system and decentralized at the infrastructural level which exhibits a higher level of product to human and machine to human interaction as considered by ergo-ecological systems.

6.3.2.3 *Stage 3 – urban considerations*

The multiple urban layers and the internal components are critical to understanding their interaction level with the environment, enabling best physical development decisions of infrastructure, land use and taking advantage of existing components of the city.

Environmental considerations are always a reflection of a sustainable protocol in urban development. The more cities expand, the less likely they are to positively interact with natural environment due to a larger impact on land occupation, resource depletion and above-mentioned emissions and waste externalities associated with industries and construction.

A main driver of the urban integration is a sustainable urban metabolism driven food supply approach. The movement had a significant buzz the last decade by making use of urban spaces and buildings for agricultural activity. These could vary from roof tops to empty lots also identified as urban landscapes for the purpose of improving food supply as well as reducing environmental stress due to rural agriculture activity as well as becoming social an d economic small hubs.

The level of alterations in urban design in favor of food resource and ecological improvement is encompassed in all stages of urban planning from policy to planning to design and implementation. With the information and technological advancements in today's construction materials and systems, complex connections can be made on the multiple physical levels of urban space which allow the flow of resource in synergy with environmental, human and economic needs. Being able to adjust means being able to intervene.

6.3.2.3.1 *Design based discussion - components*

Buildings and landscapes as identified by the research are evaluated by a facilities management professional practice framework. Like UN sustainable development identified by wellbeing and foot print, FM is the internal reflection of the operation systems that achieve or cause the latter. Satterthwaite (1997) identified sustainability FM as responsibility to "provide a healthy living and working environment for residents and furnish them with clean air, clean water and provide the essential infrastructure for economic growth" (Mallory-Hill, Preiser, & Watson, 2012) all within the scope of ecological bio-capacity of the local and global ecosystem.

Between commercial and residential buildings, agricultural industry and services, water and energy infrastructures are increasingly adapting to the need for reduction of demand and consumption. Building solutions are currently in practice and include changing equipment and utility designs. The purpose of the alteration is to reduce energy requirements from treatment systems and waste management as does the algae façade system considering the generated water treatment results.

Improved water and energy efficiency can also lower emissions related to fossil fuel industry electricity generation. These relationships are often identified by analyzing urban metabolic flows referred to above as the water-energy nexus and their benefits reflect strongly on ecological wellbeing consequently the well-being of humans. They are also identified by the FM as hard and soft factors in direct relationship with the occupation and operation of the building presented in a set of supply, demand and waste flows.

Components of buildings which directly connect to the SEEDS system are, exterior vertical surfaces, ones that are exposed to solar energy and are structurally considered in terms of system loadbearing.

SEEDS system merges two environmental benefits external to its intended purpose in biomass produce. Urban areas are characterized and defined socially by the animation and images they present. A unique aspect about the system is that it can be considered as a double façade system. This is ideal for the hot weather climate. It also means that such a design will not only present an aesthetic function to the area, it will also have its indirect positive resource chain of embodied heat exchange for the purpose of cooling building interiors. The construction of the double façade envelope systems common to the gulf regions. The high sun angle of the region makes it easy to incorporate shading devices as the required length of projection is minimized (Figure 115).

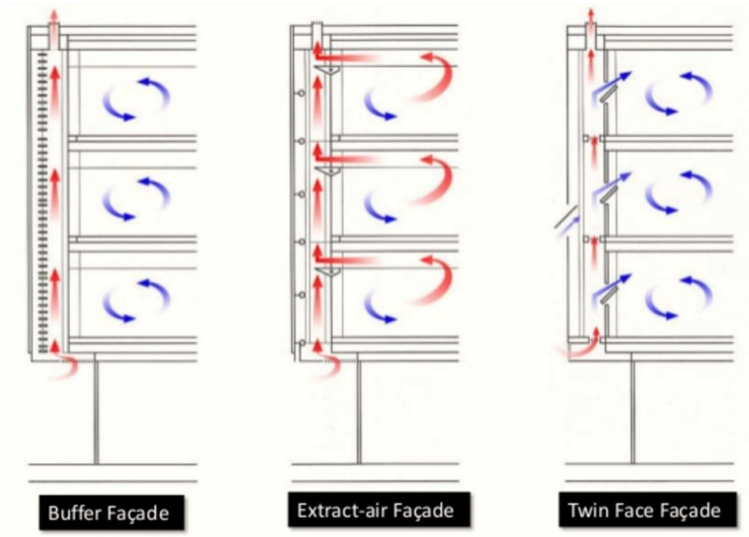


Figure 115. Double façade system, an opportunity for algae application for thermal control.

It is also important to note the solar exposure of the system. Taller towers tend to have minimum sun exposure at lower levels of the façade especially in dense areas like Doha city which needs to be considered in terms of façade system placement and orientation (Figure 116)

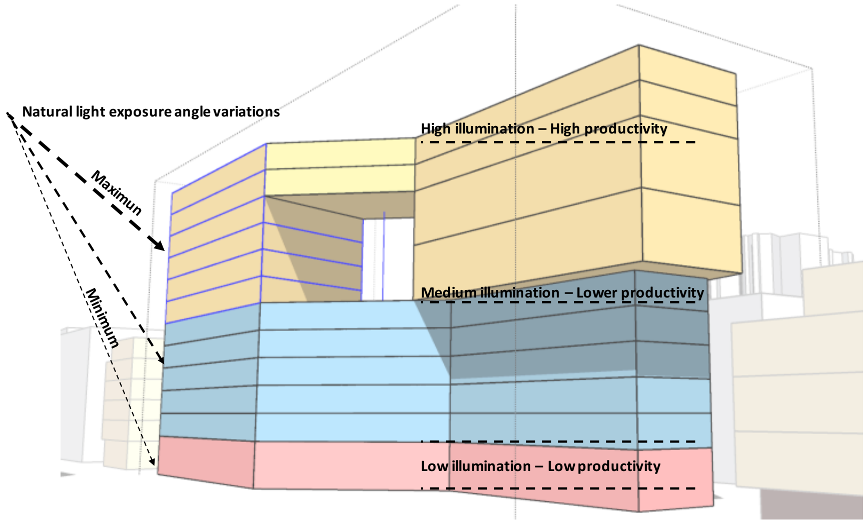


Figure 116. Surface exposure to natural light in relation to building height and solar angle.

6.4 Design based discussion - layers

6.4.1 Infrastructure and repartition

Infrastructure feed into to urban areas differently based on their function. Typically, infrastructures that service the urban areas are centralized towards a city scale, this could vary depending on the land use, complexity and size of the area. For example, industrial areas requiring larger energy feed may be subject to isolation from the main city grid to balance load.

On district or neighborhood scales, efficiency progressions are witnessed in areas of locating land use where most suitable for both its functionality as well as its interaction with surrounding ecosystem, for example, allocating industrial zones further from residential activity which allows natural purification of the atmosphere before reaching areas of maximum human encounters.

In a closed system approaches towards greening urban areas, these emissions can transform into benefit by feeding into SEEDS system, reducing water and energy demand as well as other utility pressure on the city scale ultimately avoiding extra costs of services and infrastructure.

From a food perspective, repartition layer, land use allocation plays a significant role in allocating production land around the city, usually in periphery considering agricultural land are identified as threat to environmental wellbeing by the land they occupy as well as significant amount of GHG during the production, harvesting, processing and transporting.

Considering that all lots are powered and water fed by municipal entities, SEEDS operation is decoupled from the repartition layer- planning. The system has a flexibility to integrate with any building type taking the form of a parasitic addition which feeds off of the building or area flows.

The model of algae intervention is characterized by the complexity and morphology of its system processes and the physical layers and components which animate them.

At the infrastructure level, the system is connected with the flow of the city water and energy resource. the connection is established based on production of the units, the water treatment which can be reused in the system and the possibility of bio energy production which can also enter back into the system (figure 117). This is an application of partial decentralization of the resource flow as shown in case B. Specifically to the biomass production which is considered a food source, the food system is also decentralized partially**.**

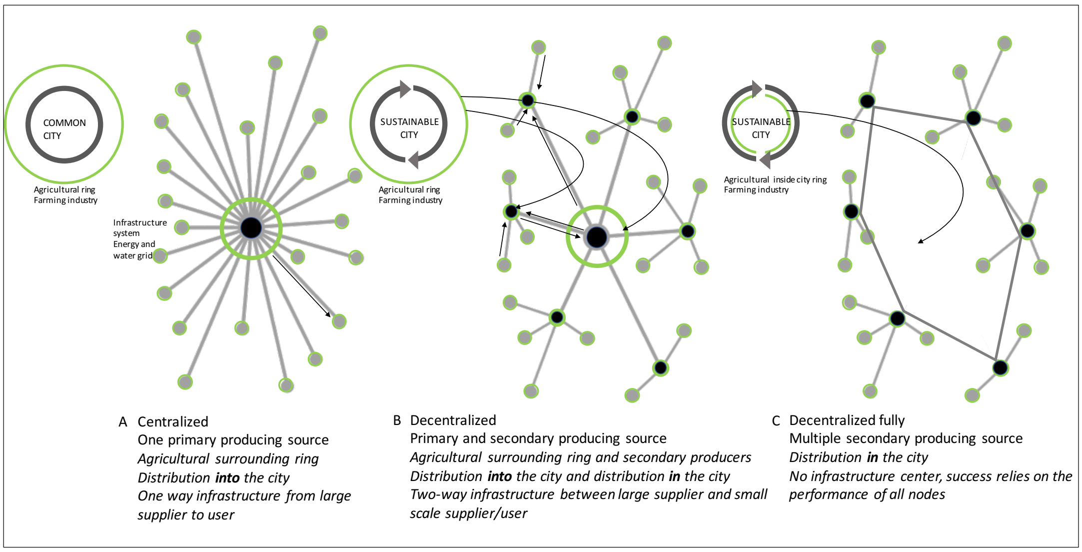


Figure 117. *Centralization, partial decentralization and full decentralization of agricultural systems.*

Case B, the centralized system exists in addition to decentralized smaller systems, these can vary depending on the performing urban components considered as suppliers. For example, Urban farming means productions comes from both around the neighborhoods as well as the larger agricultural industry, this releases the stress on the industry by produce as well as the recycled water and possibly energy.

The physical consideration of the system includes a separation line between grey and sewage water which isn't yet available in QU site. However, these alterations can be managed well in new development projects where the infrastructure is not yet established.

6.4.2 Smart system layer

Second is the need for a smart system application that involves a physical change in the smart layer. Low carbon technologies infrastructural system has a substantial effect on the delivery of resource solutions by the information technology infrastructure comprised of (smart grids, sensors and smart-aaps) which generate data that can be used to better understand the integration level needed in the systems and to:

1. Monitor system flowrates, temperature and production which can-for example transfer climate data (temperature, humidity, solar radiation) to predict system behavior. For example, if the luminosity of a day exceeds capacity of the algae to perform photosynthesis, the façade can either be hydraulically redirected away from the solar direction. Furthermore, in a high temperature environment condition the system can automatically increase the bubbling speed inside the panels.
2. Collect data for the purpose of monitoring productivity for future research, planning and design. Deliver information to user groups (citizens and businesses), service providers and regulators within the district.
3. Information system will be used to monitor resource flows (and emissions) and used to change behavior amongst users, to improve service efficiency.

6.5 Evaluation based conclusion

The integration between algae and urban system relies on physical applicability with urban components and urban system flow infrastructure. A virtual prototyping of the algae physical features and modeling resource flows facilitated the system performance evaluation at QU urban fabric.

6.5.1 System dynamic model

Onsite generation of energy using renewable solar or wind energy, storing mechanisms which allow longer spans of resilience from shortage as well as building efficiency protocols such as legislative leadership in energy environmental design LEED which gives buildings scores on operation time and loads as well as construction generally emphasizes on building performance efficiency towards environmental impact. The same concept can be applied at the scale of SEEDS system through a dynamic model that communicated its performance

The established dynamic model (Figure 118) also helps the design by the architectural sense where the building lifecycle can be considered as part of the decision making specifically in allocation of the façade system, structural considerations, weight baring, exploring new structural systems that can be integrated with this self-replenishing façade.

Also, considerations of smart plumbing systems and electrical design which will minimize maintenance and overall long-term documentation, monitoring and design improvement basis of the system.

This dynamic information is used by urban planners to find synergy areas between the system performance and the obtained information of the city. In this case, the understanding is used to examine urban algae as an urban agricultural fodder case.

There are two ways of entering the proposed model. First is from an early planning phase which can generate data to how much SEEDS system is needed to balance the carbon footprint of the production. This means that a step of obtaining carbon foot print without SEEDS is needed and compared accordingly to desired product endues path.

The second is when a scoring is done on an existing building scenario such as one applied on QU campus study where the existing urban fabric and more specifically water and energy flows are translated into production patterns.

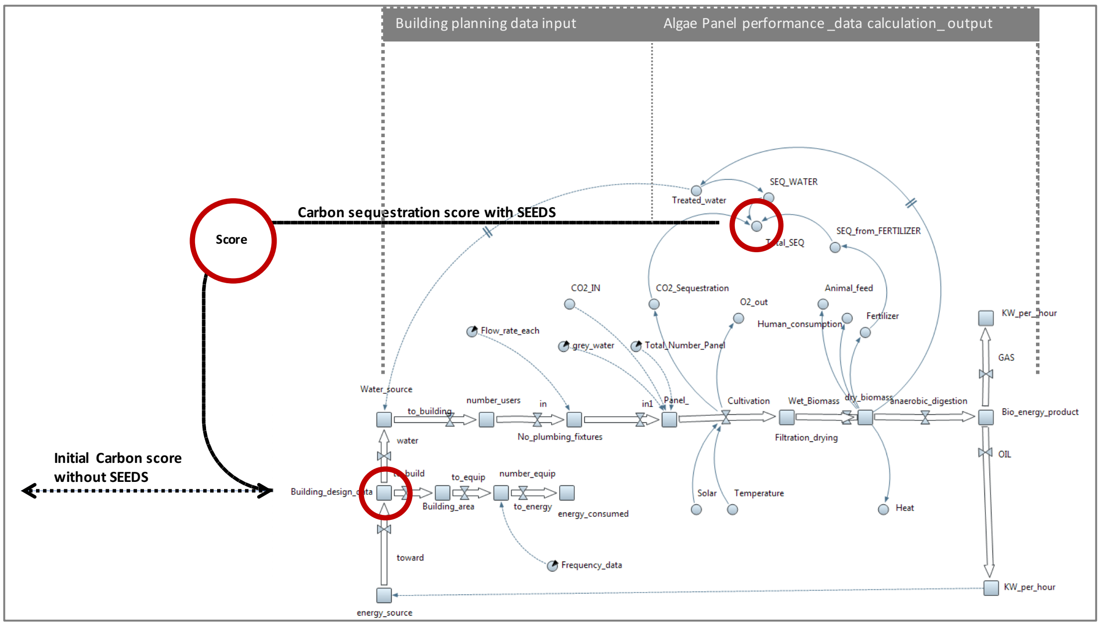


Figure 118. *System dynamic modeling of a typical SEEDS applied panel-to building which can generate design based data.*

6.5.2 Verification

By revisiting the methodology chapter 3, the evaluation phases of the system require two stages, (system evaluation and system verification). System evaluation, which is partially applied in this research is based on developing the dynamic model based on simulated data _ (computed using excel data sheets). At the current stage of the research, the data used to simulate the system performance based on a specific Control variables of (photo-bioreactor type), (parameters), (growth medium restrictions), (flowrate), (productivity). Also, independent variables are considered at the design stage of the system considering a full control over how many panels and where these panels are applied in the study location QU case. Dependent variables are recognized at the HDI and GDP indirect effects on the urban system. These are a result of economic value of the system.

In order to verify the data. The application and evaluation must be based on actual field pilot study area as a second stage of the research. The established data set on system productivity and efficiency can bae used and accordingly challenged.

The benefit of using simulation data is the flexibility of this data to be transferred into cognitive maps possibly in a GIS format ultimately extending the simulation process on different scales. It can also help generate graphics which can illustrate the benefit of the system to the local planners, governance policy makers, steak holders, or users involved in financing the system. Also, simulated system tools can be expanded to fulfil agriculture connections with the system on a land use vs production basis and improving cross learning between framing, industry, community, research and design.

6.5.3 Computational design and evaluation

The idea is to allow the planner to view options of when the total productivity of the system is directed to agriculture produce or energy or other pharmaceutical products which can be an added point to the model but are not considered in the research (Figure 119). Accordingly, a score of the planned area can be given by which the design and level of SEEDS integration needed is presented. This is translated into a set of façade area options that will eventually influence the design of buildings and is also influenced by solar direction and building orientation.

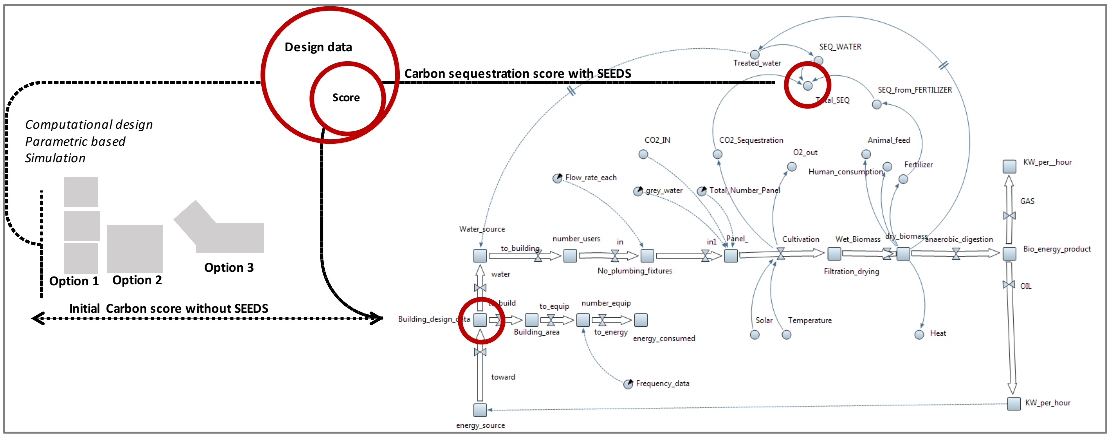


Figure 119 Computational design based on system dynamic model of the SEEDS system.

In relation to food security, the tool can provide MME and Kahramaa with data needed for food sufficiency. This can be done according for example by specifying the local fodder demand which can be translated into the system as number of panels needed to apply. Ultimately this data can be used as a design basis for planning entities that deliver asset of recommendation scenarios for urban planning.

6.5.3.1 Parametric design

Based on the score target, different option of design based on photo bioreactor type and size can be established. An example to demonstrate this is at the QU scale which compares a flat panel photo-bioreactor to a tubular model. Tubular systems offer a dynamic aesthetic value as per interview with public and offer a circular application method which can be developed on a curved facade surface design more efficiently than the flat panel system.

The figure below compares the QU production if translated into vertical tower.

To help visualize the comparison, the 46 floors, 238 m high (Doha Tower _Jean Nouvel) located in central Doha city, building parameters are used to complete the calculations. To reach the same productivity of the existing building scenario at QU, 2.3 times Doha tower need to be constructed (figure 120).

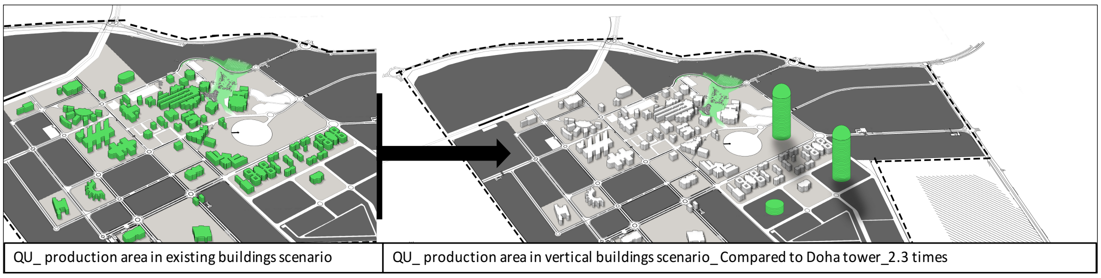


Figure 120. *An illustrated example on parametric calculations using SEEDS system dynamic modeling.*

While the physical model is not developed for this research, the data, parameters, inputs and considerations of the design of the system in relation to its performance is a ground base for computational application. The building information is then merged with the computational design of the algae units.

The unit's parametric quality is succeeded by the ability to determine the effect of one unit of façade multiplied on a specific area of building façade. The repetitive nature of the algae unit system which is based on specific parameters and relation with the physical urban fabric can be identified as "definition of a family of initial parameters and the design of the formal relations they keep with each other, more specifically the which can be developed into parametric applied smart design system to explore the whole range of possible solutions from a single façade or algae system towers given calculated infrastructural input data.

This requires input data which a preprogramed intelligent system can generate. The input data includes the unit dimension, orientation and function specifications in relation to the architectural considerations of a façade system such as regulations regarding open window to solid surface ratio, wall baring, overall size.

Density of the algae system is then possibly parametrically designed by communicating building information such as height, number of floors, surface area which is converted into total units per façade. Because the study includes an urban scale to it.

6.6 Future outlooks

6.6.1 Future outlook on Parametric based Simulation

Based on the dynamic model, design simulation can be established to deliver future application of the research findings. Parametric rely on mathematical equations to reproduce design conditions of a specific scenario as it relates to the scoring data.

A parametric specification of the added algae system is defined accordingly. The simulation is used for optimization performance evaluation or in an opposite setting where inputs of new development plan data input in the model to simulate possible options with a specific Eco footprint score. Testing and verifying the tool for accuracy and reliability is primarily based on the developed dynamic model and data accuracy.

6.6.2 Future outlook on system productivity

1. Biomass

The production effectiveness of biomass earliest on the productivity and the collection method. Collection of biomass can be effectively transported to processing centers if left in its liquid or sludge form. The idea is to facilitate the transportation of the material to larger more centralized processing centers which are considered to be more effective in transforming the algae water mix into a transportable state while also avoiding unnecessary transport automobile from entering the urban area if the harvest is left on site. Hens the recommendation is to decentralize the process of cultivation whereas centralize the process of obtaining “dry biomass” and further secondary products (Figure 121).

Biodiesel can be distributed through the existing network of liquid fuel in the city currently petroleum and gas based. Also, engine can be redirected for the use of these fuels without change in the original structure of manufacturing.

Methane is also a product that can be redirected into the infrastructural system to be used in domestic appliances. However, this is not applicable in the current type of domestic piping in the country and needs to be adjusted accordingly.

Bio-methane can also be used as transportation fuel when compressed, however, this means higher energy demand that needs to be considered where it can replace LNG in the current industry (Nanou, 2013).

The computational modeling strategy is essential in this case as it will allow transferring the data and information patterns into a system dynamic model which can predict multiple design sequence optimization performance which can be developed into a proto type pilot run of urban algae façade systems through the use of parametric design tools.

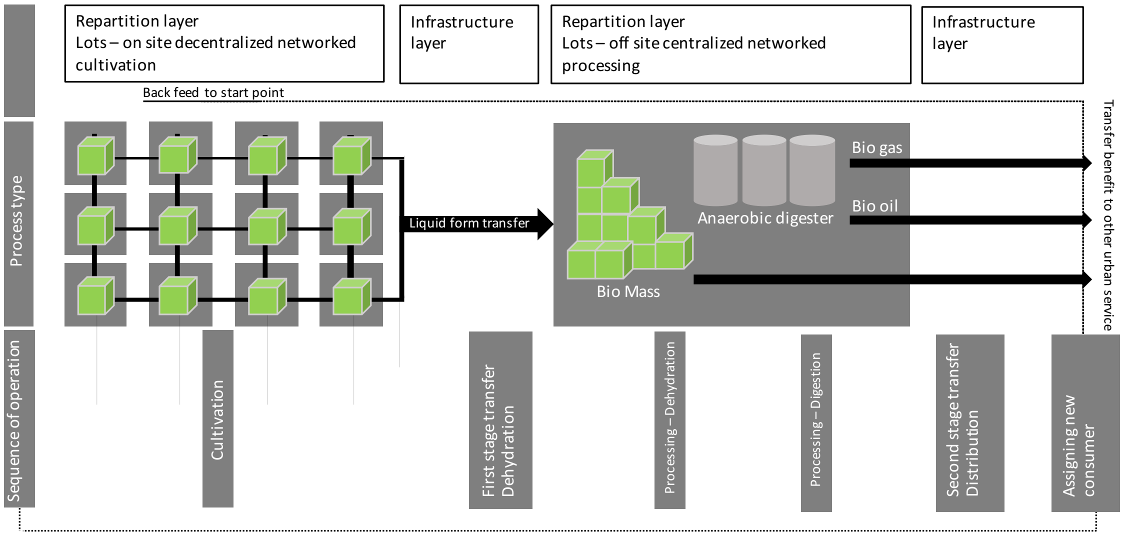


Figure 121. *The recommended centralized and decentralized behavior of the system.*

2. **Bio gas** and Bio fuel

The distribution of biodiesel can be applied through the existing petrol infrastructure.

Methane is already used in heating and home appliances, it can be compressed and used as automobile fuel.

It is important to note that the combustion of methane and biogas in general is also a GHG contributor, by that, converted methane through the algae photo bioreactor may be used to generate energy for the same urban area or building it is implemented in while a GHG capture system can redirect the gasses back into the algae system.

However, this is overestimated and needs to be considered based on analytical lab studies to determine the effect of these gasses on the overall algae biomass quality which may be transferred into other consumption product and most likely as fertilizing nutrient (Salerno et al., 2009).

Also, During the process of generating - combustion, heat is produced in much higher levels than conventional fueles which can be harvested to regenerate energy using water systems or by simply applying the heat generation towards domestic or building heatig systems.

A heat exchange system can be constructed to harvest the thermal energy.

6.6.3 Future outlook on economic value

Referring to the findings on system performance, an optimistic outlook considers that at the current productivity rates will turn into a valued economic profit that can bring benefit to the community and government economy from:

1. Water transmitting distance reduction and water desalination reduction, ultimately reducing water costs.
2. Biomass products chain into bio energy which can be used on site as reduced energy cost or diversifying the current energy export model
3. Biomass food products chain which can offer production of high quality minerals and pharmaceuticals. Or as a bio fertilizer that reduces cost of current NPK fertilizer production or diversifying fertilizer export market.

Despite the positive outlook on the system productivity which may seem profitable considering only the production, realistic results of the economic value of the system require two factors that need to be considered and calculated into the total cost and profit relation.

1. The initial cost of the system construction which include the panel and the installation
2. The operation cost of the system which includes the energy and equipment cost needed in the process. The digester for example is a costly and high energy

demand feature in the process as is the technology behind the design and application of the system.

3. The product market value, productivity, processing and transport.

6.4.4 Future outlook on system design aesthetics

The Mashrabiya is also a culturally accepted screen which makes the development of modular units' compatible with the algae screens. These may well become a façade design and urban treatment system. Variations of the design opening will also determine the level of sun light and temperature exposure of the algae. This can be further investigated by researchers to find optimum design quantified measures between the local climate, its changing conditions in relation to solar and temperature exposure compatible with the algae photo-bioreactors. An example of the Qatar's Doha tower (Figure 122) shows a double facade system used as an aesthetic culturally derived design element and shading screen. When coupled with the algae system results will show higher level of aesthetic acceptance specifically in commercial buildings as per interview results.

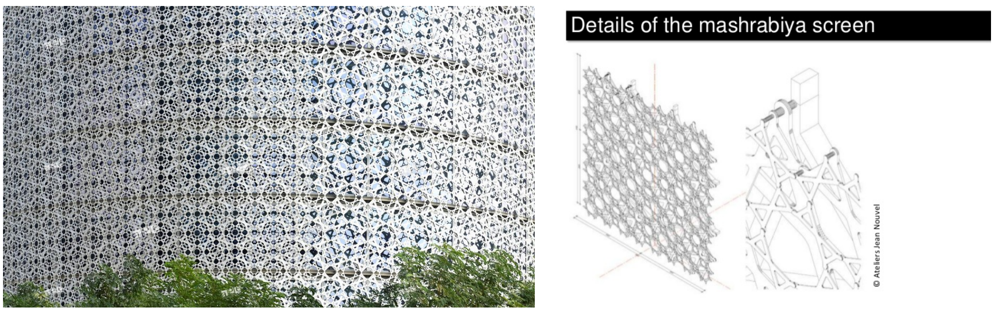


Figure 122. Example on Doha tower that used double façade Mashrabiah style system.

The color of the algae facade due to the previously discussed daylighting spectrum quality is variable by the type and color of algae in the system. Certain preference for specific visual tastes or function of an area may present another opportunity of aesthetic value of the system. Studies of different color luminance and human physiological and physiological wellbeing have also been explored by scientists in the area of color therapy

6.6.5 Future outlook on changing policy and socioeconomic engagement

The design of new algal product system of food urban infrastructure must be founded on integrated, intelligent and inhabited infrastructural water and energy systems or ‘flow architectures’ of urban metabolisms that consider the physical interaction of these systems with product systems and the given natural characteristics, spatial and cultural patterns of the city while also taking effect in new business models and investment decisions, assessments, planning and policy processes.

The research identified four regimes towards the challenges for cities more specifically when agriculture industry and food security are a stake. All four regimes are guided by a system approach and are central to policy changes.

1. The initiatives which involve the use of renewable resource that requires a deliberate intervention from humans to transform and maximize existing resource systems or services. In agricultural activity, this is applied on a wide range from mimicking natural resource to regulate growing conditions of crop to altering behavior of a species. The main trigger of this regime is the need to sustain the nonagricultural population. The multiple forms of renewable energy and resource transformation altered the way urban dwellers involve with the food production or agricultural industry, this is displayed in urban rain water collection points from

building to larger scales, also the internal application of energy colleting structures that range from windmills to solar panels and more, which collectively balance the resource stress from a growing food industry and agricultural demand. Also, introducing agriculture into the urban environment throughout a decentralized manner which will change the way food and resource in managed and transported around the city.

2. Second is the industrial based regime, this is specifically important for countries with high fossil fuel industry guided by technology and mechanics which facilitate the production process. These are established by a high urbanization and transport patterns. When compared to agriculture, the process of mechanizing the food production industry is dependent on energy availability in many ways. The mechanisms used to deliver mass production crops also the related meat and dairy industries are motivated by the high level of urbanization and the resource disconnected demand urban areas present.
3. The ecological aware regime, which utilizes the given level of urbanization and technological advancements to reestablish a connection between the renewable sustainable resource advancements, the urban infrastructures, population demand by looking at the resource in as s closed system loop and tries to find synergies between each supply, demand and waste process. The two-important feature of this regime is the organic level awareness which attempts to deliver non-ecologically toxic systems specifically when food production is the case, and the technological advancements used at all stages of planning, design and operation.
4. The inclusion regime, this regime builds on finding sustainability and resource responsible supply and demand systems through the high level of society involvement in different layers of governance and private sector industrial, urban

development and legislation decisions. By doing so, development decisions are based on a higher level of awareness extended from professionals and scientists who deliver technology and innovation. A remaining challenge will be to consider the multiple special and temporal scales in design methods for linking various inputs and actions from stakeholders of algal product systems in multiple sectors of the FEW which will ultimately shift policies and industries.

A production of drinkable treated water as well as irrigating and fertilizing crop research and pilot study analysis will become a key player in changing policies of TSE use for agricultural crop. Also, considering the level of exposure and engagement at the campus educational and community ground, cultural resistance to the possibility of reused water may diminish. This also opens doors for nutritional and contaminants research ground extending the learning, engagement and influence of the research.

Referring to the Environmental policies established throughout the blockade which deliver a high subsidy and farmers community support, the government granted arable land can be transferred into virtual vertical meters which will expand the type of community members involved in the national food security plan and enhance a sense of stewardship and engagement.

Concerning components of the urban system, the integration takes place at the building level which requires a physical alteration to facades. This needs to consider the social acceptance and aesthetic value. An urban integrated system means the system is in high level contact with social factors such as the sensory aspects, smell, vison and noise. Involving society in system based thinking includes having social members knowledgeable about the system, involved in the design of the system and benefit from it. Interviews with public in regards to the social acceptance were conducted. The purpose was to define the general design aspects involving social/user interface feedback about the system.

The discussion revealed that the application of the façade system while challenging to comprehend is generally excepted. However, the majority of the interviewed had a preference to apply the SEEDS system on commercial buildings considering the common preference of household design.

Also, the public is more susceptible to accept the design aspect of SEEDS if a direct economic value is at hand. For that reason, the system is considered an extended layer of the government agricultural subsidies which can be communicated with the public as a virtual ownership of agricultural land. The flat panel design facilitates such a concept by considering a per-panel purchase which also contributes to the community engagement factor.

6.7 Limitations and future opportunities

Considering the large set of data and literature which was not fully utilized in the numerical analysis of the research, it is important to note that the data and discussion is considered part of an ongoing design led research (Movable Nexus M-NEX) which this research has aligned its goals with. While this confined data analysis to the QU campus site, the study managed to align goals strategically considering the M-NEX main focus that targets a FEW urban living labs scenarios at QU campus between 2018-2020, an important factor to consider is the Qatar University Strategy (2018-2022) which declared QU district and campus area to be recognized as a benchmark for organizational and operational excellence and sustainability.

Because of the educational and large research community on the QU campus, the university campus presents a fertile ground to apply the research and future pilot study on. This will also bring a stronger research community and internal agreements with local government authorities such as Ashghal public works authority, Ministry and municipality of environment to the project which ultimately increases the nexus system integration level and shared goals between the algae system and other projects involving science research on fertilizers, water treatment systems etc. To that extent, this research has identified QU aligned with the process of applied urban algae system.

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