Enhancing Environmental Sustainability of Healthcare Facilities:

A System Dynamics Analysis Approach

A thesis submitted for the degree of Doctor of Philosophy

By

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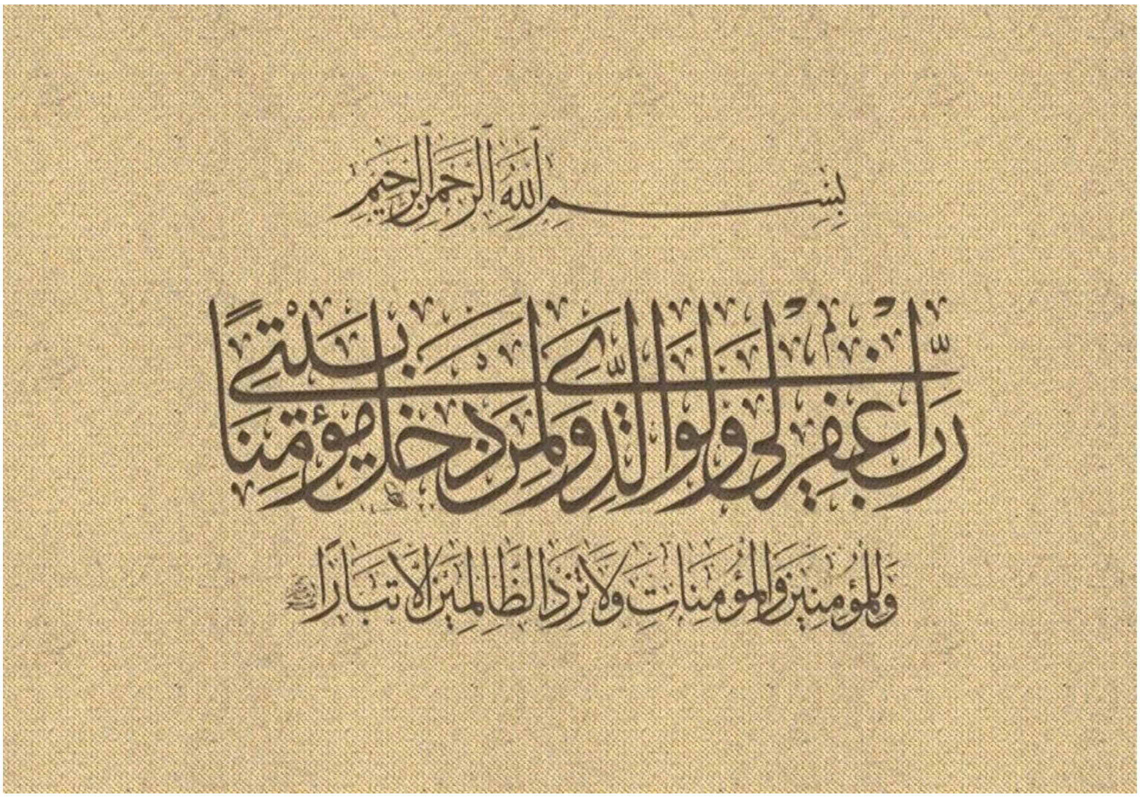

“In the name of Allah the merciful the compassionate”

“My Lord, forgive me and my parents and whoever enters my house a believer and the believing men and believing women. And do not increase the wrongdoers except in destruction”. (Holy Quran 71:28)

Abstract

Due to the limited studies related to healthcare services future expanding demand, required resources and utilities, and related environmental and economic challenges; this research is carried out to complement other researchers in other economic sectors to identify the gaps, highlight good potentials of sustainability achievements and recommend necessary actions.

This research investigates the future expanding demand of healthcare services; the environmental and economic challenges related to this expand and its environmental and economic impacts and the opportunities to overcome these impacts in order to improve healthcare services sustainability and performance.

The research follows a SLR to discover earlier works related to environmental sustainability in buildings and healthcare facilities. The environmental challenges related to expanding in healthcare facilities found in the literature are increase in energy consumption and waste generation. The environmental impacts related to these challenges are excessive CO2 and GHG emissions. The economic impacts are escalations of project expenditures, operating expenditures and utilities expenditures.

The research uses SD Analysis, as a methodological approach, to framework and understands different healthcare system elements and to develop models that are representing the dynamic relations between these elements. Bahrain healthcare system is selected as a research context due to the availability of good quality healthcare secondary data, the small size of the country that makes it a good model to implement and test new concepts, the limited country resources, and the country keenness to implement sustainability plans to meet sustainability objectives.

This research numerically tests and subsequently, supports the implication of stated environmental and economic challenges. It also develops a number of important technical parameters and indicators such as energy and water benchmarks for different healthcare facilities.

The research also determines another two sources of environmental challenges related to expanding in healthcare facilities. The first challenge is excessive water consumption. Availability of enough treated water for healthcare applications, especially in countries with limited fresh water resources and depending on 90% of its water need on desalination like Bahrain, a tangible environmental challenge needs to be addressed. The second one is a group of environmental challenges related to the practicing of healthcare services that can expose personnel and environment to high risks. These challenges need to be efficiently managed to improve the environmental sustainability and the social sustainability of healthcare facilities.

The research also investigates the effectiveness of a number of mitigation measures used to overcome the environmental and economic negative impacts, such as using energy efficiency technologies, renewable-based energy resources and waste energy recovery. In this regard, the research numerically tests and subsequently supports the implication of stated environmental and economic impacts and the effectiveness of tested measures in mitigating the undesirable results on healthcare facilities.

The developed SD Model, as one of the main contributions of this research, is considered as a strategic planning and decision-making administrative tools to forecast future healthcare facilities demand and required resources. It is also considered as a risk assessment tool to assess environmental challenges related to utilities and its environmental and economic impacts in order to improve healthcare facilities sustainability and performance.

The potential of utilities saving and utilities expenditures saving in healthcare buildings are high and it is recommended to work toward energy efficiency and renewable energy deployment to achieve sustainable healthcare buildings. Recovery of energy from Medical Waste incineration to be kept under consideration as it is offsetting double the quantity of CO2e emissions resulting from the incineration process. Safe recycling of wastewater of some healthcare processes is highly recommended as it can reduce water consumption and contributes to the reduction of healthcare facilities CO2e emissions. Sources of gray water and gray water applications must be carefully selected to avoid any contradiction with Infection Control regulations or other healthcare regulations. It is recommended to conduct utilities assessment studies on wide sample of healthcare facilities to avoid low peaks and odd operation periods.

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It is just the beginning…

Thank You Very Much…

Achievements:

Some of this research works have been published in symposia and National and International Conferences as part of academic activities, knowledge sharing and Social Corporation.

PhD Symposia:

1. Participated and presented a paper in the 5th PhD Symposium, 18-19 May 2014, Manama, Bahrain. The paper published as chapter-9 of a book,

   Shehab, S. (2015a) 'Review of energy management policies in healthcare buildings', in Al-Hawaj, A. and Twezill, E (eds.) High education in Twenty-First Century II. London: CRC Press, pp. 99-104.

2. Participated and presented a paper in the 6th PhD Symposium, 24-25 February 2015, Manama, Bahrain.

   Shehab, S. (2015b) Enhancing environmental sustainability of healthcare system: a systematic literature review, Ahlia University 6th PhD Symposium, Manama, Bahrain.

3. Participated and presented a paper in the 7th PhD Symposium, 7-8 February 2016, Manama, Bahrain.

   Shehab, S. (2016a) Enhancing environmental sustainability of healthcare facilities: a System Dynamics Analysis approach, Ahlia University 7th PhD Symposium, Manama, Bahrain.

4. Awarded "The Best Paper Award" in the 7th PhD Symposium, 7-8 February 2016, Bahrain (https://youtu.be/VsSM3G2u00U & https://youtu.be/J5tdHjJkn94).

5. Participated and presented a paper in Ahlia University 4th Research Forum, 28-29 March 2016, Manama, Bahrain.

   Shehab, S. (2016b) Enhancing environmental sustainability of healthcare facilities: a System Dynamics Analysis approach, Ahlia University 4th Research Forum, Manama, Bahrain.

National and International Conferences and Activities:

1. Participated and Presented a paper in POMS 2015, 8-11 May 2015, Washington DC, USA.

   Shehab, S. (2015c) Enhancing environmental sustainability of healthcare system: A System Dynamics Analysis approach, POMS Conference, Washington D.C., USA.

2. Participated and Presented a paper in OR 2015,1- 4 September 2015, Vienna, Austria.

   Shehab, S. (2015d) Enhancing environmental sustainability of healthcare system: A System Dynamics Analysis approach, Operation Research Conference, Vienna, Austria.

3. Invited to participate in GCC Electricity & Water Conservation Workshop, 23-24 Nov. 2015, Manama, Bahrain.

4. Participated and presented a paper in 2nd Energy Management Conference, 6-8 December 2015, Manama, Bahrain.

   Shehab, S. (2016c) Enhancing environmental sustainability of healthcare facilities: energy recovery from Medical Waste, 2nd Energy Management Conference, Manama, Bahrain.

5. Represented (Brunel University London – UK Side) and presented a paper in UK-Bahrain Science Collaboration Symposium arranged by British Council, 21-22 February 2016, Manama, Bahrain.

   Shehab, S. (2016d) Bahrain healthcare sector water demand: future perspective, UK-Bahrain Science Collaboration Symposium, Manama, Bahrain.

6. An interview with Radio Bahrain (102.3 FM) on 27/08/2016 to present this PhD research work to public (http://d.top4top.net/m_237ayim2.mp3).

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Glossary

ARRM	Administrative Rules & Regulation Management
BAU	Business As Usual
BDF	Bahrain Defence Force
BEV	Bahrain Economic Vision
BF	Bed Factor
CLD	Casual Loop Diagram
DECC	UK Dep. Of Energy & Climate Change
E	Energy
EBM	Energy Benchmark
EDB	Economic Development Board
EEA	European Environment Agency
EEF	Energy Efficiency Factor
EEm	Energy CO2 Emissions
EER	Energy Emission Reduction
EExp	Energy Expenditures
EExpS	Energy Expenditures Saving
EF	Emission Factor
EGR	Economic Growth Rate
EIA	US Energy Information Administrative
ES	Energy Saving
ET	Energy Tariff
EWA	Electricity & Water Authority
FGR	Facilities Growth Rate
GF	Government Fund
GWhr	Giga Watt Hour
HEPA	High Efficiency Particular Air
IEA	International Energy Agency
IT	Incineration Tariff
Kg	Kilogram
KHUH	King Hamad University Hospital
KWh	Kilo Watt Hour
LCP	Low Calorific Power
M2	Square Meter
M3	Cubic Meter
MENA	Middle East and North Africa
MOH	Ministry of Health
MW	Medical Waste
MWE	Medical Waste Energy
MWEF	Medical Waste Emission Factor
MWEm	Medical Waste Emissions
MWEmR	Medical Waste Emission Reduction
MWER	Medical Waste Energy Recovery
MWExpS	Medical Waste Expenditures Saving
MWF	Medical Waste Factor
MWIExp	Medical Waste Incineration
NEB	National Energy Board of Canada
NHS	The National Health Services
OB	Office Building
OExp	Operating Expenditures
OF	Operating Factor
PExp	Project Expenditures
PF	Project Factor
PHC	Primary Healthcare
PHF	Public Health Facilities
PI	Primary Healthcare Indicator
PPP	Public Private Partnership
PTF	Patient Factor
SD	System Dynamics
SHC	Secondary Healthcare
SI	Secondary Healthcare Indicator
SLR.	Systematic Literature Review
SMC	Salmaniya Medical Complex
TM	Time management
TMTP	Time management and Technical progress
TP	Technical Progress
UN	United Nations
UNEP	United Nations Environment
UNFCCC	The United Nations Framework Convention on Climate Change
W	Water
WBM	Water Benchmark
WCED	The World Commission on Environment and Development
WExp	Water Expenditures
WExpS	Water Expenditures Saving
WPE	Water Production Energy
WPEm	Water Production Emissions
WPER	Water Production Energy
WS	Water Saving
WSF	Water Saving Factor
WT	Water Tariff

Chapter 1: Introduction to the Research Area

This chapter is covering Sustainability and Environmental Sustainability in buildings and healthcare facilities that are the main concepts motivating this research.

1.1. Introduction to Sustainability or Sustainable Development

Critical resources of earth are subjected to depletion due to excessive use. Sustainability or sustainable development approach is trying to rationalise the use of these resources and highlight the importance of protecting the earth and its natural resources as an important step to good well-being development.

The world Commission on Environment and Development (WCED) report or what is known as Brundtland Report (1987, p.16) defined sustainability or sustainable development as: “Development that meets the need of the present without compromising the ability of future generation to meet their own needs”.

The concept became one of the most successful approaches that helped to shape the international agenda and the international community’s attitude towards economic, social and environmental development. The report gained great momentum when it is approved in 1992 by the world leaders in United Nation Conference on Environment and Development conducted in Rio de Janeiro with motivated commitment to ensure sustainable development in many areas and on all levels of society (UNECE, 2004/5).

As a continual effort in the same direction, and on 25th September 2015, UN approved a number of goals to end poverty, fight inequality, protect the earth and tackle climate change among other goals of new sustainable development agenda. On 1st January 2016, the 17 Sustainable Development Goals (SDG’s) of the 2030 Agenda for Sustainable Development officially came into force (UN, 2016). These goals are shown in Figure 1.1.

Figure 1.1 - The 17 Sustainable Development Goals (SDG’s) of the 2030 Agenda

This research is concerned with some of the goals related to environment and natural resources such as:

- **Goal 6 - Clean Water and Sanitation:** Emphasises on ensuring access to fresh and clean water for all essential parts of the world to avoid people death due to diseases associated with inadequate water supply, sanitation and hygiene. Water scarcity, poor water quality and inadequate sanitation is directly impacting living standard.
- **Goal 7 - Clean and Affordable energy:** Emphasises on ensuring access to affordable, reliable, sustainable and modern energy for all. Year 2030 targets are increasing the contribution of renewables in global energy and double the rate of improvement in global energy efficiency. It is also targeting enhancing the International cooperation in clean energy researches and technology including renewable energy, energy efficiency and clean fossil fuel technology.
- **Goal 12 - Responsible consumption and production:** emphasises on ensuring sustainable consumption and production patterns including resources and energy efficiency. Year 2030 targets are achieving sustainable management and efficient use of natural resources, reducing the food waste to half, achieving environmental sound management of chemicals and all wastes and significantly reducing their impact on human health and environment and reducing waste generation.
- **Goal 13 - climate action:** calls to take action to fight climate change and its impacts through the United Nations Framework Convention on Climate Change (UNFCCC), the primary international forum for negotiating the global response to climate change.

The world is concerned in the next fourteen years to reach these goals targets. This can be achieved through a number of action plans taking into consideration the nature of economic sectors classified by energy agencies (IEA, 2012; EIA, 2013; NEB, 2013; DECC, 2013a: DECC, 2013b; EEA, 2013a), that are industry, transportation, and buildings (residential or domestic, commercial, services and Healthcare Facilities) and summarised by researcher in Figure 1.2.

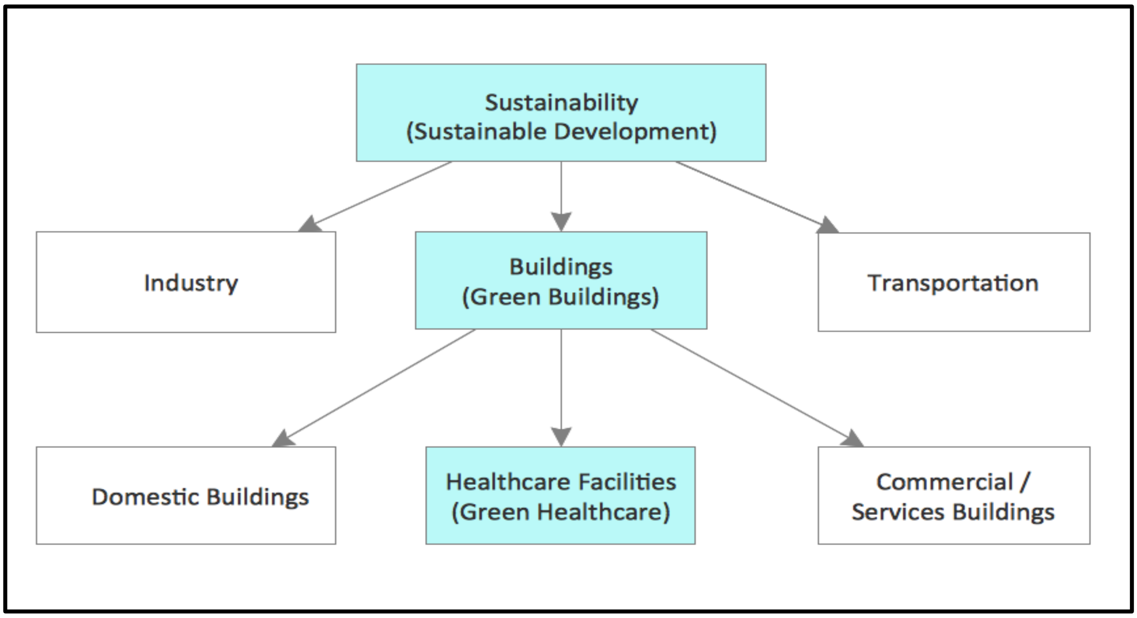


Figure 1.2 – Sustainability Action Plans as per Economic Sectors

1.2. Environmentally Sustainability in Buildings (Green Buildings)

There is a continuous increase in the construction of buildings to meet the demand of urbanization. It is predicted by the International Energy Agency that the commercial buildings and institutional buildings will grow two times by 2050 (WBCSD, 2010). The substantial negative impacts of buildings on the environment, as driven by Ghaffarian Hoseini et. al. (2013), are claimed to be energy use and atmospheric emissions, water use and water effluents, row materials use and solid waste in addition to land use. Building block accounts for 40% of total energy consumption and produce Greenhouse Gases emission (GHG) that is responsible for global worming as per the World Business council for Sustainable Development (WBCSD, 2007).

In order to achieve environmental sustainability, green buildings concept is been introduced to mitigate the negative impacts of the building stock on environment, society and economy (Zuo et. al., 2014). Green building is defined as:

> "… Healthy facilities designed and built in a resource-efficient manner, using ecologically based principles" (p.9, Kibert, 2008)

Green buildings, compared with conventional buildings, generally provide higher performance due to energy efficiency, water efficiency and carbon emission reduction (Zuo et. al., 2014).

The contribution from buildings towards energy consumption, both residential and commercial, has increased reaching figures between 20% and 40% in developed countries, and has exceeded the other major sectors; industrial and transportation.

Energy efficiency in buildings is a prime objective for energy policy makers at regional, national and international levels (Perez-Lombard et al., 2008)

Global warming has large impact on many aspects of environment and human activities in buildings. One area directly affected by climate change is the energy consumption for heating and cooling (Radhi, H., 2009). International Energy Agency (2008) report recommends to move toward environmentally sustainability in buildings through three actions that should be used in the following order; reduce the heating, cooling and lighting load to minimum; use the energy of renewable and waste energy sources as effectively as possible and make fossil fuel use as effective and clean as possible. International Energy Agency, IEA (2012) recognized energy efficiency as a key option in the hands of policy makers but the current efforts fall short of tapping its full economic potential, as Four-fifths of the potential in the building sector still remains untapped.

As a result of energy consumption, buildings produce Greenhouse Gas emissions (GHG) that responsible for global warming. The carbon emission of buildings across the world will reach 42.4 billion tonnes in 2035, adding 43% on the level of 2007 (International Energy Outlook, 2010).

Domestic water use in buildings is covered in the literature with a focus on domestic hot water use in conjunction with energy consumption of buildings to investigate the bridge between the two sources of consumption in buildings (Jeong et. al., 2014). There is a shortage of numerical studies about the general water use in buildings.

1.3. Environmentally Sustainability in Healthcare (Green Healthcare)

The “sustainable healthcare” concept first defined in 2006 as:

> ” A complex system of interacting approaches to the restoration, management and optimisation of human health that have an ecological base, that are environmentally, economically and socially viable indefinitely, that work harmoniously both with the human body and the non-human environment, and which do not result in unfair or disproportionate impact on any significant contributory element of the healthcare system” (p.10, Alliance for Natural Health, 2010).

Any sustainable healthcare system must be friendly with the local environment within which it exists. Healthcare buildings have large impact on environment. The impact is generated from two sources; energy consumed and waste generated. In order to protect the environment, hospitals and healthcare facilities must have an efficient management and operational strategies of these resources (Gunther et. al., 2008).

Hospitals and healthcare buildings are classified by energy agencies under different subsectors within the buildings sector as shown in Table 1.1. In UK and EU, it is classified under the Public services buildings (DECC, 2013a, DECC, 2013b and EEA, 2013a) while in USA and Canada; it is classified under the commercial buildings (EIA, 2013 and NEB, 2013).

Table 1.1- Energy consumption by sectors as classified by energy agencies

Country	Energy Agency & Ref.	Energy sectors				
		Transportation	Industrial	Building		Others
				Residential / Domestic	Commercial / Pub. Services	
OECD	International Energy Agency (IEA, 2012a)	28%	27%	34%		11%
EU	European Environment Agency (EEA, 2013a)	33%	24%	27%	13%	3%
UK	UK Dep. Of Energy & Climate Change (DECC, 2013a & DECC, 2013b)	28%	22%	32%	18% (NHS 6%)	-
USA	US Energy Information Administrative (EIA, 2013)	19%	30%	29%	22% (Hospitals 9%)	-
CANADA	National Energy Board (NEB, 2013)	25%	48%	14%	13%	-

A study of U.S. healthcare sector found that hospitals are responsible for 9% of the total energy consumption of buildings as per Perez-Lombard et al. (2008) and 7% of CO2 emission as per Chung et al. (2009). The National Health Services (NHS) in UK is responsible for 6% of the total energy consumption of buildings as per Perez-Lombard et al. (2008), 3% of UK carbon dioxide emission and 30% of all public sector emissions as per Gatenby (2011). As per Ascione et. al. (2013) Hospitals and other healthcare facilities are considered as major energy-intensive buildings. Rabanimotlagh et. al. (2014) believes that hospitals and healthcare buildings are energy intensive units due to the specific requirements to maintain patient comfort, meet standards for a bacteria and virus free environment, and deliver patient services. The high-energy consumption is due to high utilisation and high demand of the buildings. It has high level of energy demand due to high Efficiency Particular Air (HEPA) filtrations required to prevent spread of diseases, stringent regulated indoor air quality and special HVAC pressurisation requirements especially in operation theatres, intensive care units and laboratories; some low temperature climate control areas such as orthopaedics rooms; sterilisation, laundry and kitchen operations as listed in TAC white paper (2006). Brown et. al. (2012) believes that understanding the energy consumption and emissions associated with health services is important for minimising their environmental impacts. The healthcare sector energy demand is expected to grow significantly in the forthcoming years to meet the increase in healthcare demands due to demographical growth, demographical shifting and new healthcare regulations and legislations.

There are earlier researches recognise the importance of studying energy management in healthcare sector. The fourth Energy Efficiency Indicator Survey outcomes summarised by Smith (2011) focused on energy management opportunities and challenges for healthcare industry, particularly energy efficiency and financial benefits. Murray et. al. (2008) worked on benchmarking the National Health Services of Scotland smaller health buildings and found that it constitutes 29% of the total treated floor areas of NHS-Scotland Buildings. Garcia-Sanz-Calcido et. al. (2014) determined the optimal sizing of health centres in Spain based on health services provided by optimising energy consumption and minimising greenhouse gas emissions and found that the potential saving from energy management of health centres have not yet been systematically and thoroughly studied

Carbon management is an increasingly important issue for all organisations and taking sustainability and Carbon emissions seriously is an integral part of a high quality health service as per National Health Services (NHS, 2009).

From discussions in sections 1.2 and 1.3, the key gaps defined in the literature are:

- The non-human environment, i.e. healthcare facilities operating environment is an important element of healthcare system (Alliance for Natural Health, 2010).
- Energy consumptions, medical waste generation and CO2e emissions are the main Healthcare building's impact on environment. In order to protect the environment, hospitals and healthcare facilities must have an efficient management and operational strategies of these resources (Gunther et. al., 2008).
- Energy and Carbon management strategies in hospitals and healthcare facilities need to be reviewed and developed under guidance of international energy agencies (IEA, 2008; IEA, 2012) to cover diversified range of activities such as energy generation and consumption, energy saving, clean fossil fuel applications and renewable-based energy generation and use including energy recovery from medical waste.
- Green buildings strategies need to be implemented in hospitals and healthcare facilities to get higher performance buildings due to energy efficiency, water efficiency and carbon emission reduction (Zuo et. al., 2014).
- Numerical studies related to general domestic water use in buildings and healthcare facilities are limited compared to studies investigating hot water use in conjunction with energy consumption of buildings (Jeong et. al., 2014) that needs to be addressed.

1.4. Problem Statement

From previous discussions it is clear that the expanding in healthcare services is increasing the healthcare facilities impact on environmental that is generated from energy consumption and waste generation and in order to protect the environment, as per Gunther et. al. (2008), hospitals and healthcare facilities must have an efficient management and operational strategies of these resources. These strategies, in addition to Carbon management strategy, need to be developed under guidance of international energy agencies (IEA, 2008; IEA, 2012) to achieve high quality and sustainable healthcare services.

It is also clear that there is a need for of strategic planning and decision-making administrative tool to connection healthcare services expanding plans with required resources and utilities. There is also a need for assessment strategy / tool to assess environmental and economic impacts of these healthcare facilities.

Green building strategy need to be developed and implemented in healthcare facilities to mitigate significant impact of the building stock on environment, society and economy and to get higher performance buildings in term of energy efficiency, water efficiency and carbon emission reduction in order to achieve Green or sustainable healthcare (Zuo et. al., 2014).

This research is trying to answer the following questions:

- In addition to what is stated in literature what are the healthcare facilities impact on environment?
- What are the suitable strategies (in term of academic methodology / tools) to be developed to connect healthcare services expanding plans with required resources and utilities?
- What are the suitable strategic planning and decision-making administrative tools to assess environmental and economic impacts of healthcare facilities?

1.5. Research Aim and Objectives

The aim of this research is to develop a strategic planning and decision-making administrative tool to forecast future healthcare facilities expanding demand, essential resources and required utilities. The developed tool shall work as an assessment tool to assess environmental and economic impacts related to the facilities in order to improve healthcare facilities sustainability without compromising healthcare services provision. This can be achieved through a number of objectives:

1) Conduct literature review by following a Systematic Literature Review (SLR) to review healthcare facilities environmental and economic challenges, environmental and economic sustainability opportunities.
2) Design and Develop System Dynamics Analysis methodology to study and analyse healthcare facilities environmental and economic challenges and its negative impacts.
3) Follow standard methodology to implement and demonstrate the developed SD Model by conducting a research on healthcare System in Kingdom of Bahrain as a research context.
4) Demonstrate theoretical and technical findings and limitations related to environmental sustainability of healthcare facilities to contribute to better understanding and enhance implementation of research aspect.
5) Propose recommendations for researchers and practitioners to overcome the negative impacts related to healthcare facilities environmental and economic challenges.

1.6. Research Challenges

The majority of healthcare facilities energy management programs are designed to achieve economic goals as a response to interim consequences, such as financial difficulties. It is also designed to achieve environmental goals as a response to interim objectives such as building energy audit, meeting legislations regarding carbon mitigations, meeting community expectations regarding sustainability, etc. This trend is supported by many national, regional and international organisations that produce white papers, reports and roadmap plans. It is also highly supported by consultancy firms offering consultancy services. The energy management programs are heavily driven by the industrial sector that provides technical solutions supported by successful case studies. Although most of these documents are available and can be accessed through web search, unfortunately most of them are lacking the scientific research approach, which make it less accredited by academic institutions. From other hand there is a good intention from academia toward this important research area but the outcomes are still limited. This research is seeking academic contributions in improving healthcare facilities sustainability by providing scientific persuasive information.

1.7. Chapter Summary

The purpose of this chapter is to covering Sustainability and Environmental Sustainability in buildings and healthcare facilities that are the main concepts motivating this research. Sustainability of buildings is considered due to the high potential of energy saving and subsequently economic saving achievable in the building sector. Healthcare buildings are selected as a research area due to high utilisation of this type of buildings, high reliance of the community on its services and the nature of energy-intensive use of these facilities.

The research problem found worth attention is that the expanding in healthcare services will increase healthcare buildings notable environmental impact that is generated from energy consumption and waste generation. In order to protect the environment, healthcare facilities must have an efficient management and operational strategies of these resources. The aim of this research is to develop a strategic planning and decision-making administrative tool to forecast future healthcare facilities expanding demand, essential resources and required utilities as well as develop an assessment tool to assess environmental and economic impacts related to the facilities in order to improve healthcare facilities sustainability without compromising healthcare services.

Chapter 2: Systematic Literature Review (SLR)

The purpose of this chapter is to satisfy the first objective set of this research by conducting a systematic literature review (SLR) to cover preceding efforts and works related to healthcare facilities environmental and economic challenges and its negative impacts and environmental and economic opportunities to enhance hospitals and healthcare facilities sustainability and performance.

Tranfield et. al. (2003) defined the literature review process in management research as a key tool used to manage the diversity of knowledge for a specific academic inquiry and specify the aims behind conducting a literature review are often to enable the researcher both to map and to assess the existing intellectual territory, and to specify a research question to develop the existing body of knowledge further. Kitchenham et. al. (2007) identify systematic literature review (SLR) as a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest.

Conducting a Systematic Literature Review (SLR)

Before starting the review, a review team is formed from the researcher, the principled supervisor and the local supervisor. Systematic review is conducted in three stages through ten phases as described and practiced by Tranfield et. al. (2003); Kitchenham et. al. (2007); Afzal et. al. (2009) and Nedhra et. al. (2013).

2.1 Stage I- Planning the review

This stage of SLR is consist of three phases as follows**:**

2.1.1. Phase 0- Identification for the need for a review

Due to diversified knowledge and massive volume of available information related to sustainability, Environmental sustainability, Sustainable buildings, sustainable healthcare (green healthcare) and energy issues, generally in buildings and specifically in hospitals and healthcare facilities, there is a real need for summarising all the available information and conducting this review. The main objective of the review is to provide adequate answers for the following questions:

- **Q1: What are the current environmental and economic challenges related to healthcare facilities?**
- **Q2: What are the available opportunities to enhance environmental and economic sustainability of healthcare facilities as an outcome of this SLR?**

- **Q3: What are the lessons learned and the recommendations for researchers and practitioners as an outcome of this exercise?**
- **Q4: What are the most appropriate model development and analysis tools to study environmental and economic issues in healthcare facilities?**

2.1.2. Phase 1-Preparation of a proposal for a review

To prepare a proposal for this review, the latest published papers in journals listed in bibliographic databases and conference proceedings are identified for review. Global and regional energy reports, outlooks, surveys, models, publications, industrial studies and reliable Internet resources are examined for relative information.

2.1.3. Phase 2-Development of a review protocol

The main objective of the review protocol is to protect the objectivity of this research by explicitly identifying the research road map.

Conceptually, the sustainability and utilities management in buildings are very important research fields. Environmental sustainability and utilities saving in hospitals and healthcare facilities are very significant and vital subjects worth research focus. One route of conduct this study is exploring the potentials of progressive researches through good quality academic studies and publications. The other route is exploring reliable data available through national and international organisations, global and regional energy reports and industrial studies.

Studies meeting the following criteria will be included in the review:

- Written in English language,
- Available in full text, and
- Covering Articles related to ‘sustainable healthcare’, ‘sustainability’ ‘environmental sustainability’, ‘energy management’, ‘energy strategy’, ‘energy saving’ and ‘system dynamics’ in ‘buildings’, ‘hospitals’ and ‘healthcare buildings’.

Studies not meeting these criteria will be excluded. i.e. that

- Not written in English language,
- Not available in full text, and
- Not related to research subjects.

2.2 Stage II-Conducting the review

This stage of SLR is consist of five phases as follows**:**

2.2.1. Phase 3-Identification of research

Conducting a systematic review for this research started by identification of research terms and keywords as an outcome of first literature reading. These terms and keywords are used to map relevant studies from different bibliographic databases. To consider both USA & UK English dictionaries the question mark (?) will be used instead of the characters (z & s). List of terms and keywords are shown in Table 2.1.

Table 2.1- Terms and keywords used in Systematic Literature Review (SLR)

Term	**Keywords**
Sustainable Healthcare, Environmental Sustainability	Energy policy, energy strategy, energy management, energy saving, energy efficiency, energy conservation, energy recovery, energy optimi?ation, energy minimi?ation, energy reduction, energy payback, rebound effect, carbon footprint, carbon dioxide emission, CO2 emission, greenhouse gases emissions, GHG emission.
Healthcare	Healthcare building, healthcare facility, healthcare services, hospital, health center, clinic, center, department, ward, operation theater, recovery, accident, emergency, Intensive Care, Cardiac Care, laboratory, pharmacy, physiotherapy, occupational therapy, maternity, geriatric, pediatric, psychiatric, kidney dialysis, cancer, cardiology, gynecology, hematology.
Outcomes:	Challenges, barriers, obstacles, shortcomings, techniques, strategies, solutions, mitigation, objectives, motivators, promoter, economic sustainable goals, environmental sustainable goals, social sustainable goals, system dynamics model, SD,

In such studies it is suitable to use “PICOC” Criteria to structure research question as suggested by Petticrew et. al. (2005). “PICOC” stands for five steps of the research, i.e. Population, Intervention, Comparison, Outcome and Context.

The population in this research is the environmental sustainability and its synonyms, the intervention is the application of the environmental sustainability in the healthcare buildings and its synonyms and the outcomes of the exercise are the strategies, challenges, motivators and barriers. Comparison and context are not applicable in this case.

The search strings are constructed by joining the terms “environmental sustainability” and “healthcare” with one of the outcomes with an AND operator. The synonyms words or related terms were joined using an OR operator. The wild card operator (*) is used where required. Related and good outcomes search databases are selected among the available databases list. Search databases and strings for Systematic Literature Review are shown in Table 2.2.

Table 2.2 - Databases and search strings for Systematic Literature Review (SLR)

Databases	Strings
Science Direct, Elsevier / Scopus, ABI / Inform Global Google Scholar, etc.	“Energy policy” OR “energy strategy” OR “Energy management” OR “energy saving” OR “energy efficiency” OR “energy conservation” OR “energy recovery” OR “energy optimi?ation” OR “energy minimi?ation” OR “energy reduction” OR “energy payback” OR “rebound effect” OR “carbon footprint” OR “carbon dioxide emission” OR “CO2 emission” OR “greenhouse gases emissions” OR “GHG emission” **AND** “Healthcare building” OR “healthcare facility” OR “healthcare service” OR “hospital” OR “health center” OR “clinic” OR “center” OR “department” OR “operation theater” OR “recovery” OR “accident” OR “emergency” OR “Intensive Care” OR “Cardiac Care” OR “ward” OR “laboratory” OR “pharmacy” OR “physiotherapy” OR “occupational therapy” OR “maternity” OR “geriatric” OR “pediatric” OR “psychiatric” OR “kidney dialysis” OR “cancer” OR “cardiology” OR “gynecology” OR “hematology” **AND** “Challenges” OR “barriers” OR “obstacles” OR “shortcomings” OR “techniques” OR “strategies” OR “solutions” OR “mitigation” OR “objectives” OR “motivators” OR “promoter” OR “economic sustainable goals” OR “environmental sustainable goals” OR “social sustainable goals”, “system dynamics model”, “SD”

2.2.2. Phase 4-Selection of studies

After searching four databases, that give good and adequate response to research key words and terms, a set of 5147 studies was found. After applying the full text & English language criteria a set of 4739 studies was left. The number is reduced to 1429 studies after journal review. This step was very important to eliminate health sciences journals that research in particular subjects related to healthcare practices and procedures and hospital management issues. The number reduced again from 1429 to 210 studies after title review and to 39 studies after abstract and conclusion review. Reading the full text of the papers and applying inclusion / exclusion criteria fixed the selected papers to 37. Monitoring progress (2017) increases the number to 40 papers. Summary of the same is shown in Table 2.3.

Zotero (2014), free citation and bibliography processor, was used to document search results and to remove duplicates.

Table 2.3 - Selection of Systematic Literature Review (SLR) Studies

#	Databases	Paper Found	Full Text in English Language	Journal Review	Title Review	Abstract & Conclusion Review	Reading Full Text & Applying incl./ Excl. Criteria
1	Science Direct	334	334	19	19	8	8
2	Scopus	3319	3115	726	148	3	3
3	ABI / Inform Global	884	680	74	20	5	5
4	Google Scholar	610	610	610	20	8	8
5	Manual Search					15	13
6	Monitoring Progress					4 + 6	4 + 6
	Total	5147	4739	1429	210	49	47

2.2.3. Phase 5-Study quality assessment

The main objective of quality assessment is to evaluate the overall quality of selected papers. Following Nedhra et. al. (2013) quality assessment criteria were developed to evaluate selected papers:

- Is the paper published? (1 marks)
- Is the topic of the paper relevant to SLR questions? (2 mark),
- Is the paper having standard methodology? (2 mark)
- Are the outcomes of the paper relevant to SLR questions? (1 mark).

Papers are marked based on the following criteria:

- If the paper satisfied a criterion it will be given a full mark,
- If the paper partially-satisfied a criterion it will be given 50% of full mark,
- If the paper doesn’t satisfy a criterion it will be given a mark of 0,

The papers quality is considered base on the accumulated marks of all criteria:

- If the paper mark is between > 5 – 6, it will be classified as “Good”,
- If the paper mark is between > 3 – 4, it will be classified as “Fair”,
- If the paper mark is between 0 – 2, it will be classified as “Poor”,

Applying quality assessment criteria on the primary studies, as shown in Table 2.4, shows that 63.8% (30 studies) are good and 36.2% (17 studies) are fair. The same is summerised in Figure 2.1.

Table 2.4 - Systematic Literature Review (SLR) Papers quality assessment criteria

Paper	QC-1	QC-2	QC-3	QC-4	Total	Quality
P1	1	1	1	1	4	Fair
P2	1	2	2	1	6	Good
P3	0	2	0	1	3	Fair
P4	1	1	2	1	5	Good
P5	1	1	2	1	5	Good
P6	1	2	2	1	6	Good
P7	1	2	0	1	4	Fair
P8	1	2	2	0	5	Good
P9	1	2	1	1	5	Good
P10	1	2	2	0	5	Good
P11	1	1	1	1	4	Fair
P12	1	1	2	0	4	Fair
P13	1	1	1	1	4	Fair
P14	1	2	2	1	6	Good
P15	1	2	2	1	6	Good
P16	1	2	2	1	6	Good
P17	1	2	1	1	5	Good
P18	1	2	1	1	5	Good
P19	1	2	1	1	5	Good
P20	1	1	1	1	4	Fair
P21	0	1	1	1	3	Fair
P22	1	1	1	1	4	Fair
P23	1	2	2	1	5	Good
P24	1	2	2	0	5	Good
P25	1	2	2	1	6	Good
P26	1	1	2	1	6	Good
P27	1	1	1	1	4	Fair
P28	1	2	2	1	6	Good
P29	1	2	2	1	6	Good
P30	1	2	2	1	6	Good
P31	1	2	2	1	6	Good
P32	1	2	1	0	4	Fair
P33	1	1	1	1	4	Fair
P34	1	2	2	1	6	Good
P35	1	2	2	0	5	Good
P36	1	2	2	1	6	Good
P37	1	2	1	1	5	Good
P38	1	1	1	1	4	Fair
P39	1	2	2	0	5	Good
P40	1	2	2	0	5	Good
P41	1	2	2	1	6	Good
P42	1	1	1	1	4	Fair
P43	1	2	1	1	5	Good
P44	1	2	2	1	6	Good
P45	1	1	0	1	3	Fair
P46	1	1	1	1	4	Fair
P47	1	1	1	1	4	Fair

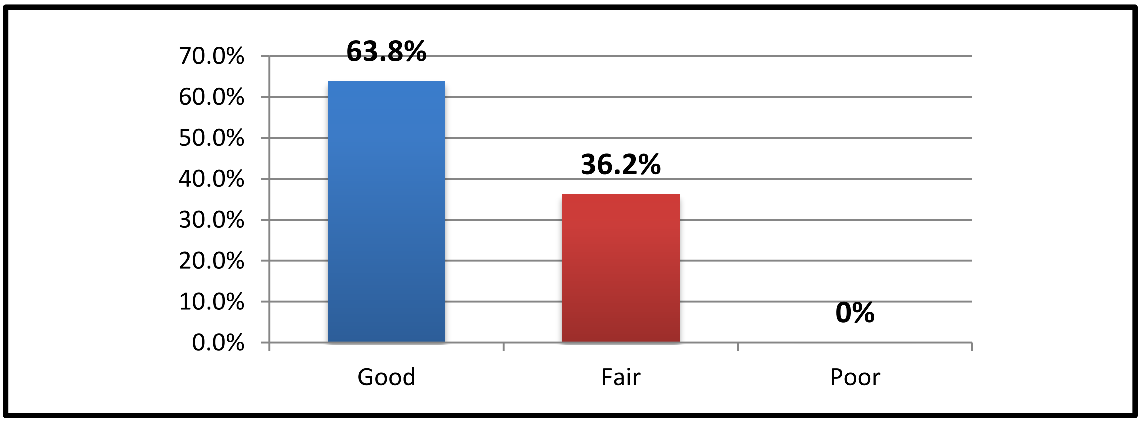


Figure 2.1 - Summary of SLR Papers quality assessment

2.2.4. Phase 6-Data extracting and monitoring progress

After comprehensive reading of selected papers, the data extracted from the literature are summarised in Table 2.5.

Table 2.5 - Summary of Systematic Literature Review (SLR) Papers

	Authors & Year	Aim & Objectives	Type of Data	Methodology	Key Findings
P1	Ahn et. al. (2014)	To study the heating properties of LED lighting and establish a management strategy to exploit these properties to reduce the energy used for heating and cooling of buildings.	Secondary (Existing Building Data)	Control strategy & Simulation of virtual building	The total building energy consumption can be reduced by the installation of LED lighting with a control strategy that releases convective heat either outdoors or indoors as required.
P2	Allcott et. al. (2012)	To study the investment in energy efficiency programs.	Secondary (USA Energy Data & Policies)	Mathematical Model (Economics of Energy)	Further research required to estimate the impacts of energy efficiency programs on consumers.
P3	ANHI (2010)	Review of the existing body of knowledge of researches related to sustainable healthcare.	N/A	Narrative	Encouraging paradigm shifting of healthcare to principles of sustainability.
P4	Atkinson et. al. (2015)	A systematic search conducted to identify articles published that described applications of system dynamics modeling to support health policy at any level of government.	N/A	Literature Review	Six papers were identified, comprising eight case studies of the application of system dynamics modeling to support health policy. No analytic studies were found that examined the effectiveness of this type of modeling. Only three examples engaged multidisciplinary stakeholders in collective model building. Advances in software are allowing the participatory model building approach to be extended to more sophisticated multi-method modeling that provides policy makers with more powerful tools to support the design of targeted, effective and equitable policy responses for complex health problems.
P5	Brailsford et. al. (2001)	To discuss two different approaches to simulation widely used in healthcare domain, i.e. discrete event simulation and system dynamics.	N/A	Case Studies	More communication and discourse between the communities of SD and DES modelers would have great benefit, particularly in the field of healthcare.
P6	Brailsford et. al. (2009)	The article describes a multi-dimensional approach to the classification of the research literature on simulation and modeling in health care. The aim of the study was to analyse the relative frequency of use of a range of operational research modeling approaches in health care, along with the specific domains of application and the level of implementation.	Secondary (Publications Data)	Systematic Literature Review	The results provide new insights into the level of activity across many areas of application, highlighting important relationships and pointing to key areas of omission and neglect in the literature. In addition, the approach presented in this article provides a systematic and generic methodology that can be extended to other application domains as well as other types of information source in health-care modeling.
P7	Brennan (2013)	Review of the existing body of knowledge of researches related to energy efficiency policy.	N/A	Content Analysis	Energy efficiency become an important and infrastructure policy

	Authors & Year	Aim & Objectives	Type of Data	Methodology	Key Findings
P8	Chaeruk et. al. (2007)	Presenting the Healthcare and public health impacts on environment and risks from healthcare waste perspective.	Secondary (Indonesia Population & Health data & statistics)	System Dynamics Analysis with simulation	The hospital waste generation is affected by various factors including the number of beds in the hospitals. To minimise the risk to public health, It is found that waste segregation, infectious waste treatment prior to disposal, has to be conducted properly by hospital.
P9	Chang et. al. (2009)	Despite heightened worldwide interest in sustainable health care, the carbon footprint of the US health care sector has not yet been estimated. Quantifying the environmental impact of health care is important to determine the potential value of mitigation efforts and to reduce harm associated with health care delivery.	Secondary (USA healthcare expenditures)	The Environmental Input- Output Life-Cycle Assessment (EIOLCA) model developed by the Carnegie Mellon University Green Design Institute	The carbon footprint of the US health care sector, defined as total greenhouse gas (GHG) emissions attributable to the production of health care goods and services, is estimated. In 2007, the health care sector accounted for 16% of US gross domestic product; total effects of health care activities contributed 8% of total US GHG and 7% of total carbon dioxide emissions.
P10	Ciplak et. al. (2012)	Presenting the Healthcare and public health impacts on environment and risks from healthcare waste perspective.	Secondary (Istanbul Population & Health data & statistics)	System Dynamics Analysis with simulation	The best healthcare waste management practice for healthcare institutions is to prevent and minimize the generation of waste. However the potential for waste prevention at the point of generation is limited because of the infectious Characteristics of the waste stream and the increased use of single-use-only disposable items.
P11	EDB (2008)	Present the Economic Vision 2030 for Bahrain. The vision focuses on shaping the vision of the government, society and the economy, based around three guiding principle; sustainability, fairness and competitiveness.	N/A	Narrative	Economic growth must never come at the expenses of environment and long-term well being of people.
P12	Eleyan et. al. (2013)	Presenting the Healthcare and public health impacts on environment and risks from healthcare waste perspective.	Secondary (Jenin District Hospitals in Palestine health data & statistics)	System Dynamics Analysis with simulation	Most of developing countries are experiencing increases in quantity and variety of the generation of medical waste. The management of waste is of major concern to reduce potential high risks to human health and the environment.
P13	Faezipour et. al. (2013)	This paper discusses the importance and definition of sustainability in healthcare systems. The focus of this paper is on patient satisfaction in the context of the social pillar. Patients are the main focus in healthcare	N/A	System thinking & System Dynamics Analysis	System thinking offers a holistic view of a system and facilitates the understanding of complex systems. This method is used to address sustainability challenges in healthcare. System dynamics helps to explore the complex relationships between the various factors in a system. A causal model is presented that provides a graphical illustration of the factor relationships associated with patient satisfaction in the social pillar. Next steps include the validation of the causal model that ensures that the factors and factor relationships are correct and the development of a simulator.

	Authors & Year	Aim & Objectives	Type of Data	Methodology	Key Findings
P14	Fone et. al. (2003)	The objective of the review is to evaluate the extent, quality and value of computer simulation modeling in population health and health care delivery.	Secondary (Publications Data)	A narrative systematic review	Simulation modeling used in a wide range of health care topic areas, including hospital scheduling and organization, communicable disease, screening, costs of illness and economic evaluation. SM is a powerful method for modeling both small and large populations to inform policy makers in the provision of healthcare. Although the number of modeling papers has grown substantially over recent years, further research is required to assess the value of modeling.
P15	GDPMREW (2008)	Presenting Bahrain's Initial Communications to the United Nations Framework Convention on Climate Change	Secondary (Bahrain resources & environmental Data)	Statistical Analysis & Data Reduction	Bahrain extremely impacted by climate change. High health costs is pushing to take appropriate measures to alleviate negative impacts, implement adaptation policies, and lower emissions.
P16	GDPMREW (2012)	Presenting Bahrain's Second Communications to the United Nations Framework Convention on Climate Change	Secondary (Bahrain resources & environmental Data)	Statistical Analysis & Data Reduction	At present, the National Economic Strategy (2009-2014) identifies energy efficiency and renewable energy as two strategic options to achieve a reduction in GHG emissions. While a clear action plan is not yet in place.
P17	Ghaffarian-hoseini et. al. (2013)	The study targets to elucidate the essence of sustainability in green building design implementations.	Secondary (Environmental & Applied Energy Data)	Statistical Analysis & Comparative Analysis	Versatile parameters for improving the energy performances of green buildings. These parameters are derived from interdisciplinary studies with view to the design, construction, maintenance and user studies.
P18	Greening et. al. (2000)	Review of some of the relevant literature related to rebound effect.	Secondary (Empirical Evidence of Recent Studies)	Quantitative (Survey)	The rebound is not high enough to mitigate the importance of energy efficiency as a way of reducing carbon emission.
P19	Herring (2008)	The paper challenges the view that improving the efficiency of energy use will lead to a reduction in national energy consumption, and hence is an effective policy for reducing national CO_2 emissions.	Secondary (Lighting in GB)	Literary Analysis	-Energy efficiency is a valuable tool to save money and stimulate economic productivity. - it should still be promoted irrespective its impact on energy consumption
P20	Heartwich et. al. (2009)	Quantify greenhouse gas emissions associated with the final consumption of goods and services for 73 nations and 14 aggregate regions	Secondary (GTAP Database for 57 Sector & 87 Region)	Multiregional input-output model	Carbon footprint is strongly correlated with per capita consumption expenditure. CO2 and GHG emissions are increasing with increase in consumption expenditure.
P21	IEC et. al. (2010)	To present best environmental practices in healthcare sector.	Secondary (Data for Public & Private Hospital in Jordan)	Case Studies	Cleaner Product potentials in healthcare Facilities will bring economic saving, environmental benefits as well as increase safety for staff and patients.
P22	Kaufman et. al. (2012)	Analyse the evaluations of California energy efficiency programs to assess the effectiveness of these evaluations in (1) improving understanding of their performance and (2) Providing a check on incentives to energy savings.	Secondary (California Energy Efficiency Data)	Statistical Analysis & Mathematical Modeling	Energy efficiency programs did not meet their energy savings projections.
P23	Kolokotsa et. al. (2012)	To review the state of the art technologies for the energy efficiency in the hospitals' sector.	Secondary (Energy Consumption in Public Hospitals)	Literary Analysis & Case Study	The cost of high tech. devices represents a barrier for wide scale applications. Implementing simple energy conservation tech. (for which no special budget should be needed) can save up to 10% of primary energy consumption.

	Authors & Year	**Aim & Objectives**	**Type of Data**	**Methodology**	**Key Findings**
P24	Kunc et. al (2014)	A modeling project involved system dynamics simulation of chronic cardiac disease in Bulgaria, examining the cardiac behaviour of drug molecule in the market.	Secondary data of market from the Bulgarian National Healthcare Fund.	Case Study	The main result of the study showed that the timing access to market was a critical driver in reducing the prices and providing wider access for patients to medical therapy.
P25	LCB (2011)	To disseminate the initial findings of the LCB-HEALTHCARE project. To share experience and information on best practice procurement, lead market innovation methodologies and case studies related to the design, construction and refurbishment of LCB in the healthcare sector.	Primary (Survey) & Secondary (Case Studies of EU)	Quantitative (Survey)	Overview of the EU healthcare infrastructure, which highlights the complexity and diversity across Europe and provides an indicator of the sector's carbon footprint. It then highlights the regulatory pressures that will be applied on EU Members States over the coming decade to improve the energy performance of buildings and reduce CO2 emissions.
P26	MENA (2013)	To provide a comprehensive and timely overview of developments in renewable energy markets, industries, policies, and investments in the MENA region, drawing on the most recent data available, provided by a network of more than 50 researchers from the region.	Secondary (Renewable energy data 2008-2011)	Statistical Analysis	- Installed Bahrain Renewable Energy Capacity is 5.5 MW. 5 MW is generated from Solar PV and 0.5 MW from Wind. - Capacity of Future Bio-mass Renewable Energy estimated at 25 MW.
P27	MOH (2012)	Present Bahrain Health Strategy (2011-2014)	N/A	Narrative	Policy-makers are looking to see evidence-based decisions shape the future of healthcare and to ensure that funds are suitably allocated to develop a sustainable healthcare system.
P28	NHS (2009)	This carbon reduction strategy has been developed in response to the need to take action in climate change and in consultation with the NHS and other organizations.	Secondary (Survey Data)	Mix method. Quantitative (Survey) & Qualitative (Consultation)	Sixty-six per cent of all NHS organisations responded to the consultation. Of these responses, 95% strongly supported the NHS acting as a leading organisation in reducing carbon. Significantly, 65% felt that the measures proposed in the draft strategy were not ambitious enough. Seventy-eight per cent of respondents felt that carbon reduction should be measured and managed as part of core business in every NHS organisation.
P29	NHS (2010)	This Update is a supplement to the NHS Carbon Reduction Strategy for England 2009.	Secondary (Data of potentials of energy saving and GHG reduction)	Statistical Analysis	It provides essential new information and additional tools to help NHS organisations reduce its carbon emissions and become more sustainable.
P30	NHS (2014)	This strategy outlines a vision and three goals based on the challenges outlined to aim for by 2020. It describes the opportunities to reduce environmental impacts, improve natural environment, increase readiness for changing times and climates and strengthen social cohesion.	N/A	Modular approach	-A sustainable system protects and improves health within environmental and social resources now and for future generations. -Reducing carbon emissions, minimizing waste and pollution, building resilience to climate change and nurturing community strengths. -Communities and services are resilient to change in time and climates.
P31	Oikonomou et. al. (2009)	To identify the effects of parameters that determines energy saving behaviour with the use of the microeconomic theory.	Secondary (Empirical Evidence of Rebound Studies)	Mathematical Modeling	-Study differentiated between the concepts of energy efficiency and energy conservation, often used in parallel in literature. - Parameters affect end-users behaviour for both energy efficiency and energy savings. - There is a direct association between intention to conserve energy and psychological factors.

	Authors & Year	Aim & Objectives	Type of Data	Methodology	Key Findings
P32	Peterman et. al. (2012)	Using a mixed-method, both quantitative and qualitative approach, to find the barriers to energy efficiency that can interpret strategic drivers for the emergence of five forms of voluntary and mandated program forms.	Primary (Interview Data) & Secondary (DOE Survey Data)	Mixed methods quantitative and qualitative (Survey & Interviews)	To reduce energy consumption, sustainability, efficiency and effectiveness must be evaluated at the systemic and programmatic level In voluntary energy efficiency programs.
P33	Rabanimotlagh et. al. (2014	The energy consumption of a major healthcare facility in Wichita, KS is examined to understand the relationship between energy use and ambient air temperature, energy efficiency programs, and extreme temperatures.	Secondary (CDD & Electricity Data)	Statistical Analysis	A transformation of electricity use was developed so that the relationship between energy consumed and outdoor temperatures could be determined and used to forecast energy consumed over the next four decades.
P34	Rashwan et. al. (2015)	The problem of bed blocking in acute hospitals causes substantial cost burdens on hospitals. This study presents a system dynamics methodology to model the dynamic flow of elderly patients in the Irish healthcare system aimed at gaining a better understanding of the dynamic complexity caused by the system's various parameters.	Secondary data of elderly people in Ireland.	System Dynamics modeling.	The mounting demand for elderly healthcare services due to population aging is confronting Irish healthcare executives with critical capacity planning issues. Addressing these challenges requires advanced planning tools that can handle the complex interlinked service constraints on proposed interventions and operational strategies. This study has used conceptual modeling to illustrate different elderly patients' care pathways, and this qualitative model provided a better understanding of the resources required during their care journeys.
P35	Rohleder et. al (2007)	To discuss the role of discrete-event simulation and system dynamics modeling for redesigning and implementing patient service centers at a medical diagnostic laboratory to improve patient service, in particular to reduce average waiting times as well as their variability.	Secondary data of patients.	Discrete-event simulation and System Dynamics modeling	When redesigned facilities or operations result from a detailed modeling exercise similar to the one described herein, system dynamics may be a useful tool for exploring the possible side effects of the new system and creation of a causal loop diagram may provide valuable insight.
P36	Reddy (2013)	This taxonomy aims to synthesize ideas from three broad perspectives, viz., micro (project/end user), meso (organization), and macro (state, market, civil society).	Primary (List of Drivers & barriers to Energy Efficiency)	Casual Model – Actor oriented approach	The importance of the identification and classification of barriers as a precondition for the successful diffusion of energy efficient technologies.
P37	Saunder (2000)	To delineate a few key insights extracted from theoretical macroeconomic considerations of the rebound issue. The goal has been to reduce these thoughts to a clear set of assertions that, if true, would be useful points of reference in the ongoing discussion despite their non-empirical nature.	N/A	Theoretical Modeling	A number of recent empirical studies have begun to establish a very strong body of evidence that point to rebound effects being relatively small - on the order of 5-10%
P38	Short et. al. (2010)	Computer simulations have been carried out to predict the influence on thermal performance (overheating risk) and energy consumption of different options on the original design	Secondary (NHS Hospitals Energy Consumption)	Solar Modeling and Building Simulation	Energy consumed by equipment may decrease in time as more energy-efficient systems become available.

	Authors & Year	Aim & Objectives	Type of Data	Methodology	Key Findings
P39	Singer B. (2010a)	To present the results of a review of publicly available information on energy use in healthcare facilities in USA.	Secondary (energy-use in healthcare facilities)	Statistical Analysis	Healthcare buildings energy-use is intensive. -Hospitals and outpatient clinics end-use energy is intensive.
P40	Singer B. (2010b)	To presents a road map for improving the energy efficiency of hospitals and healthcare facilities.	Primary (Challenges to Energy Efficiency)	Qualitative (Interviews)	The barriers to improved energy efficiency in healthcare facilities include challenges that are common across commercial buildings as well as issues specific to healthcare industry.
P41	Smith M. (2012)	To present a literature review related to sustainable healthcare system.	N/A	Qualitative (Performance Measurement, opinions, etc.)	To find the level of saving conserving can contribute with.
P42	Smith R. (2011)	To present the fourth Annual Energy Efficiency Indicator (EEI) survey.	Primary (participants responses related to Energy)	Survey	Energy efficiency can be both rewarding and financially beneficial to any healthcare system.
P43	Take et. al. (2014)	Research papers and practical studies on energy efficiency and energy saving potentials on HVAC systems at the hospitals are presented.	Primary (System Equipment Energy Use)	System Simulation	Improving the efficiency of air conditioning systems is the main way for improving the use of energy.
P44	Tolba M. et. al. (2009)	Review of the finding of the Intergovernmental Panel on Climate Change (IPCC) and references quoted in the 2009 report of the Arab Forum for Environment and Development (AFED).	Primary (Survey Results) & Secondary (Weather Data)	Regional Climate Modeling and Survey	The Arab countries are among the most vulnerable in the world to the potential impacts of climate change, the most significant of which are increased average temperatures, less and more erratic perception, and sea level rise (SLR).
P45	Vernon et. al. (2009)	To present several practical and low cost approaches that healthcare organizations have taken.	N/A	Narrative	Although environmental regulations will raise the energy cost to discourage consumption and emission, they will present more opportunities for saving money and offer rewards for energy conservation and system efficiency.
P46	Wang et.al. (2016)	Maximizing energy efficiency within HHFs (hospitals and healthcare facilities) is a major challenge in the field of energy conservation. This paper studies the key barriers to the implementation of energy-efficient technologies in China's public HHFs.	Secondary (of 20 healthcare facilities)	Survey	The results show that the economic incentives, appropriate technology, as well as enforceable laws and regulations are insufficiently supported by the government, have become the most significant obstacles to the improvement of energy efficiency. To remedy this, policymakers should take a multipronged approach which addresses the hospitals, projects, and technical and operating procedures in order to encourage the full participation and support of all stakeholders involved.
P47	Zue et. al. (2014)	Critical review of the existing body of knowledge of researches related to green buildings.	Secondary (Performance of Green Buildings)	Literary Analysis	- Most of green building studies focus on environmental aspects of sustainability such as energy consumption, water efficiency and greenhouse gas emission together with the technical solutions. -The studies on social and economic aspects of sustainability are comparatively lean, despite a large number of literatures emphasising their importance.

2.2.5. Phase 7-Data syntheses

The objective of this section is to evaluate and assess the literature in relation to the research questions. The main trend of the primary studies is to provide a comprehensive overview of existing healthcare facilities energy and utilities consumption and waste generation using the available data of these facilities in statistical methods, simulation and system dynamics analysis.

The primary 47 studies were classified as per context in Table 2.6. It is found that 12 of the papers covered energy issues in buildings while 6 covered the same in healthcare buildings. Sustainability and Green building concepts are covered by 8 in buildings and 10 in healthcare buildings. Finally, 11 of the papers covered concepts related to using System Dynamics Analysis in strategic planning and management of healthcare sector as shown in Figure 2.2.

Table 2.6 - Distribution of Primary studies as per context

Context	Author(s)	Year
Energy Saving, Energy Efficiency, Energy Conservation, Energy Policies, Energy Programs, Rebound Effect in Buildings	Ahn et. al.	2014
	Allcott et. al.	2012
	Prennan	2013
	Greening et. al.	2000
	Herring	2006
	Heartwich et. al.	2009
	Kaufman et. al.	2012
	Oikonomou et. al.	2009
	Peterman et. al.	2012
	Reddy	2013
	Saunder	2000
	Take et. al.	2014
Energy Saving, Energy Efficiency, Energy Conservation, Energy Policies, Energy Programs, Rebound Effect in Healthcare Buildings	Kolokotsa et. al.	2012
	Rabanimotlagh et. al.	2014
	Short et. al.	2010
	Singer B.	2010-a
	Singer B.	2010-b
	Smith R.	2011
Sustainability & Green Concept in Buildings	EDB	2008
	GDPMREW	2005
	GDPMREW	2012
	MENA	2013
	Ghaffarianhoseini et.	2013
	Tolba et. al.	2009
	Vernon et. al.	2009
	Zue et. al.	2014
Sustainability & Green Concept in Healthcare Buildings	ANHI	2010
	Chang et. al.	2009
	IEC et. al.	2010
	LCB	2011
	MOH	2012
	NHS	2009
	NHS	2010
	NHS	2014
	Smith M.	2012
	Wang et. al.	2016

Context	Author(s)	Year
System Dynamics Analysis	Atkinson et. al.	2015
	Brailsford et. al.	2001
	Brailsford et. al.	2009
	Chaeruk et. al.	2007
	Ciplak et. al.	2012
	Eleyan et. al.	2013
	Faezipour et. al.	2015
	Fone et. al.	2003
	Kunc et. al	2014
	Rashwan et. al.	2015
	Rohleder et. al	2006

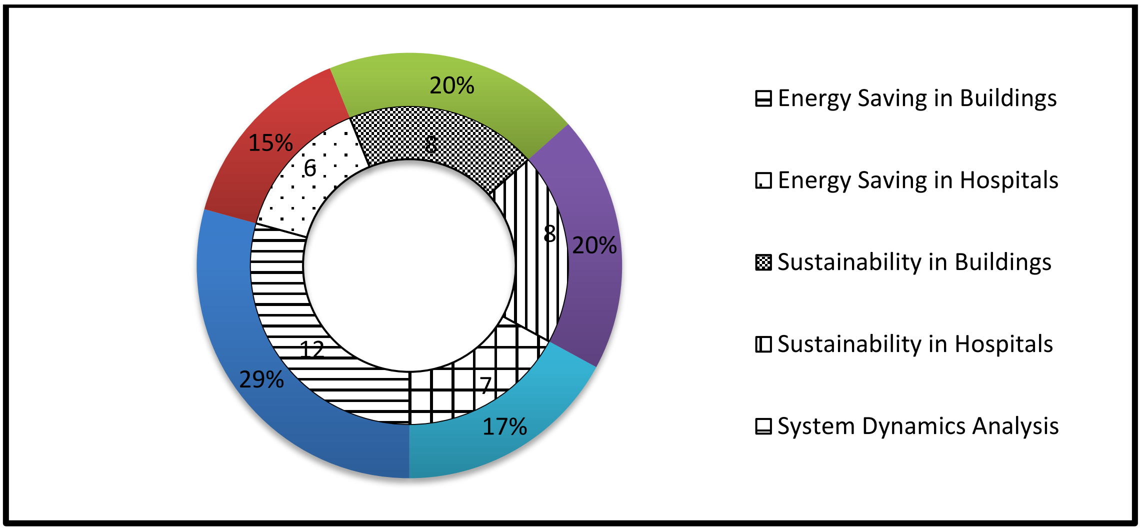


Fig. 2.2 - Distribution of Primary studies according to context

Table 2.5 shows that 66% of the papers (31 papers) are published between 2010 and 2016 while 34% (16 papers) are published between 2000 and 2009 as summarised in Figure 2.3. The time horizon for the bibliographic search is shown in Figure 2.4.

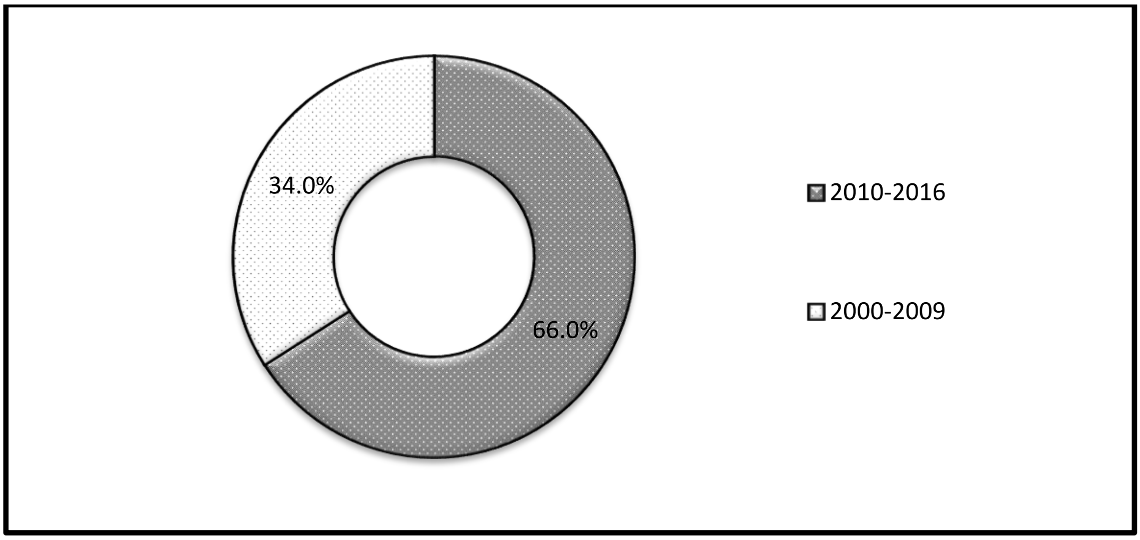


Fig. 2.3 - Distribution of Primary studies according to publishing year

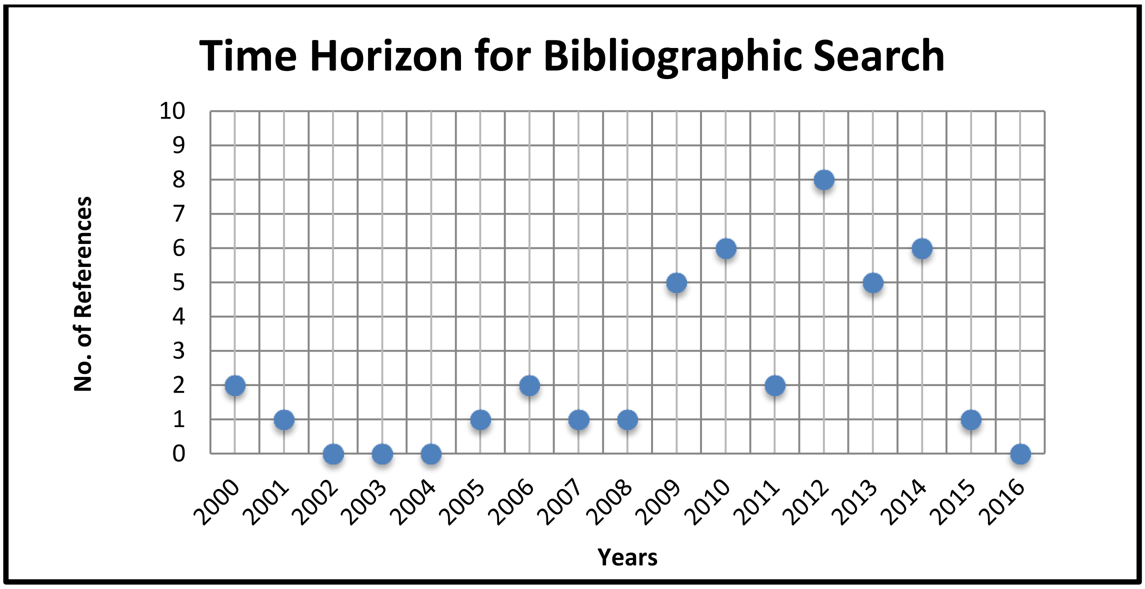


Fig. 2.4 - The time horizon for the bibliographic search

2.3 Stage III-Reporting and dissemination

2.3.1. Phase 8-The report and recommendations

In this section the main key gaps and findings related to the four questions raised earlier in chapter 2 is identified as per the following details:

- **The current status of environmental and economic challenges in healthcare facilities**

By reviewing the literature of healthcare buildings, it is found that it is facing environmental challenges in the form of increasing in energy use, waste generation and related CO2e emissions as illustrated by Gunther et. al. (2008). Healthcare buildings are also facing difficulties to meet healthcare sector commitments toward climate change. Carbon management is an increasingly important issue for all organisations and an integral part of a high quality health service as per National Health Services, NHS (2009).

Singer (2010b) organised energy efficiency challenges in hospitals and healthcare facilities in four groups. The first group related to the provision of medical services such as operating hours, operational needs, life-safety concerns, infection control, ventilation challenges, diversity of operational needs for spaces, system complexities, hi-powered medical imaging equipment. The second group related to the organisational and cultural constrains such as seeing medical needs more important than other considerations, energy is not a main concern for hospital administrators, cost cutting of non-medical provisions, limited budget, reluctance toward non-conventional and conventional approaches, highly stressful environment to experiment changes to operation of building system, low risk tolerance for experiments, disregarding energy as strategic issue, lack of strategic plans for energy. Third group is related to issues specifically related to the legacy of existing facilities such as old hospitals building stock and construction infection control challenges. Fourth group is related to multiple codes and standards hospitals are subjected to such as design guidelines, accreditation, HVAC, Electrical, standby power and uninterrupted power supply.

❖ **Opportunities to enhance environmental and economic sustainability in healthcare facilities**

Singer (2010b) organised energy efficiency opportunities to achieve energy saving and carbon reduction and enhancing environmental sustainability of hospitals and healthcare facilities around ten themes, i.e. challenges related to achieving understanding and benchmarking energy use, best practice and training, codes and standards, improve utilisation of existing HVAC designs and technology, innovation in HVAC design and technology, electrical system design, lighting, medical equipment and process loads, economic and organisational issues, and design of sustainable hospitals.

Oikonomou et.al. (2009) addresses the reduction of final energy consumption to energy efficiency improvement or behavioural change (energy conservation). To distinguish between the two techniques, i.e. energy efficiency and energy conservation, the former refers to adoption of a specific technology that reduces overall energy consumption without changing the relevant behavior, while the latter implies merely a change in consumers' behavior. Although the terms energy efficiency and energy conservation have often been used interchangeably in policy discussion but they do have very different meanings as per Herring (2006).

Energy efficiency, as per Oikonomou (2009), is the technical ratio between the quantity of the primary or final energy consumed and the maximum quantity of energy services obtainable (Heating, Lighting, cooling, mobility, and others). This is a very important factor can be empirically measured in energy saving process before and after implementing of specific preference technology.

Although various studies indicated the limited effect of energy efficiency on bridging the gap between growing demand and limited energy supply, Herring (2006) believed that energy efficiency is a valuable tool to save money and stimulate economic productivity and it should still be promoted irrespective its impact on energy consumption.

To improve energy efficiency in hospitals and healthcare facilities many building's Electro-Mechanical services need be optimised by incorporating energy efficiency technologies either at the initial stage or by retrofitting these systems. The fourth Energy Efficiency Indicator Survey results summarised by Smith (2011) show that improving Heating, Ventilation & Air Conditioning (HVAC) systems and lighting system accounts for approximately 60% of all energy used in traditional buildings. The same is recommended by IEA (2008) while Teke et. al. (2014) considering adoption and improvements of effective air-conditioning systems are the main way for improving the use of energy. Ahn et. al. (2014) recommends using Low Emitted Diode (LED) lighting to save energy. These improvements in HVAC and lighting, in addition to domestic hot water, can help healthcare facilities to move a long way toward energy efficiency and subsequently energy and energy expenditures saving.

The focus on HVAC system is due to the significant growth in energy used which reached 53% of building consumption in the USA, 68% of in EU, and 62% in UK. Lighting system is the second area of focus, where its energy consumption is found to be 30% in USA, 18% in EU, and 16% in UK of building consumption. Domestic Hot water is found to be another important area of energy consumption with 17% consumption in USA, 14% in EU, and 22% in UK of building consumption (Perez-Lombard et al., 2008).

Energy conservation concept refers to the reduction of energy consumption associated with frugal lifestyle that includes a form of regulation such as speed limitation; reduce domestic heating or spontaneous change in consumer preferences result in behaviour changes. This concept often implies more moral aspects than a strictly economic one (Oikonomou et. al., 2009). Nevertheless, energy conservation can be enhanced via changes in the context (including environmental concerns and feeling of moral obligation to reduce energy consumption). Kolokotas et.al. (2012) believes that implementing simple energy conservation techniques can save up to 10% of primary energy consumption. This is another important factor affecting the energy saving process. It can be measured before and after implementing regulatory changes or limitations of energy sources. It is also can represent, in a numerical form, the impact of the change in preferences, behavior and motivation of people on the energy saving process.

Herring (2006) highlights one more important factor affecting energy saving in hospitals and healthcare buildings that is some of saving from efficiency improvements will be taken in the form of higher energy consumption (~10-20%) the so-called take back or rebound effect. Saunders (2000) found that a number of recent empirical studies have begun to establish a very strong body of evidence that rebound effects being in the order of 5-10%. Greening (2000) believes that the rebound is not high enough to mitigate the importance of energy efficiency as a way of reducing carbon emission while Sounder (2000) emphasizes on great deal of empirical work needs to be done to develop a full understanding of the rebound issue. The rebound effect is mainly linked, as a negative behaviour, to the energy conservation that required incentive mechanism or motivation to balance it. Although the rebound effect has a limited effect, it is an important factor and disregarding it in energy saving strategy may lead to lose some effective efforts in energy saving process.

❖ Lessons learned and recommendations for researchers and practitioners

The literature shows that environmental challenges in healthcare facilities such as energy use, water use and waste generation are increasing due to expanding in healthcare services. In spite of status of countries, developed or developing, it is facing the same environmental challenges with different progression toward mitigation of these challenges. There is still needs to develop more comprehensive strategies and implement more stringent plans to achieve the targeted goals.

❖ Model development and analysis tools to study environmental and economic issues in healthcare facilities

Systematic Literature review (SLR) of the research subject shows a number of System Dynamics analysis studies conducted in healthcare sector that are covering healthcare strategic planning, diseases management, forecast healthcare expenditures, planning healthcare facilities and evaluation of future CO2 emissions in healthcare in addition to environmental issues such as medical waste management. Chaerul et. al. (2007) studied the factor influencing the hospital waste management system and how they are linked to each other. These factors required a comprehensive analysis to determine the role of each factor in the system. In this study, waste management SD model was presented to determine the interaction among factors in the system using Stella software and a case study of hospitals in city of Jakarta, Indonesia. Ciplak et. al. (2012) selected Istanbul, Turkey as a case study area to identify the factors affecting healthcare waste generation and developed a long-term system to support selection and planning of future medical waste treatment capacity using System Dynamics approach. Eleyan et. al. (2013) presented a new technique, using System Dynamics modelling, to predict generated medical solid waste in a developing urban area based on samples from Jenin District Hospital, Palestine.

This SD analysis study is an added value to other System Dynamics analysis studies conducted in healthcare sector and there is a high potential to achieve good outcomes by developing a SD model(s) to quantify the environmental impact of healthcare to determine the potential value of mitigation efforts and to reduce harms associated with healthcare delivery. Evaluation of future CO2e emissions in healthcare is an important step to achieve sustainable healthcare though the carbon footprint of the healthcare sector in many countries is not yet been estimated and need good efforts to move forward in this direction.

2.4 Chapter Summary

After providing a brief description of the research area and defining the research scope, the theses begins to review the preceding efforts and works related to healthcare facilities environmental and economic challenges and the available opportunities to enhance hospitals and healthcare facilities sustainability and performance by conducting a systematic literature review. The literature shows that in the presence of environmental and economic challenges in healthcare facilities there are high opportunities to attain environmental and economic sustainability by implementing a number of recommended measures to reduce the utilities consumptions and waste generation and achieve economic saving.

Chapter 3: Research Design and Methodology

In order to design and develop a strategic planning and decision-making administrative tool to help researchers, policy makers and health planners to forecast future healthcare facilities expanding demand, essential resources and required utilities as well as an assessment tool to assess environmental and economic impacts related to healthcare facilities; and to satisfy second objective of this research, an appropriate research design and methodology shall be selected and justified following standard research process. The proposed methodology, based on the brief of chapter 2, is System Dynamics Analysis modelling methodology that is conducted in qualitative-quantitative mixed method. Qualitative method is used to verify relations between factors influencing the healthcare sustainability. Quantitative method is used to implement and demonstrate the developed model using Primary and Secondary Data of healthcare system as per the forthcoming details.

3.1. Knowledge Framework

To underlay a theoretical and philosophical research approach, it will be very useful to follow Crotty (1998) four key elements in construction and process of research that are:

- Method proposed to use,
- Methodology governs the use of method,
- Theoretical perspective lies behind the methodology, and
- Epistemology informs the theoretical perspective.

Clear definition of the meanings of these elements is very helpful in understanding the hierarchical structure of the research process, that comprise of Method, Methodology, Theoretical perspective, Epistemology and Ontology. The hierarchical nature of the structure determines that the element inform each subsequent element. These four (or five) elements are showed in Figure 3.1.

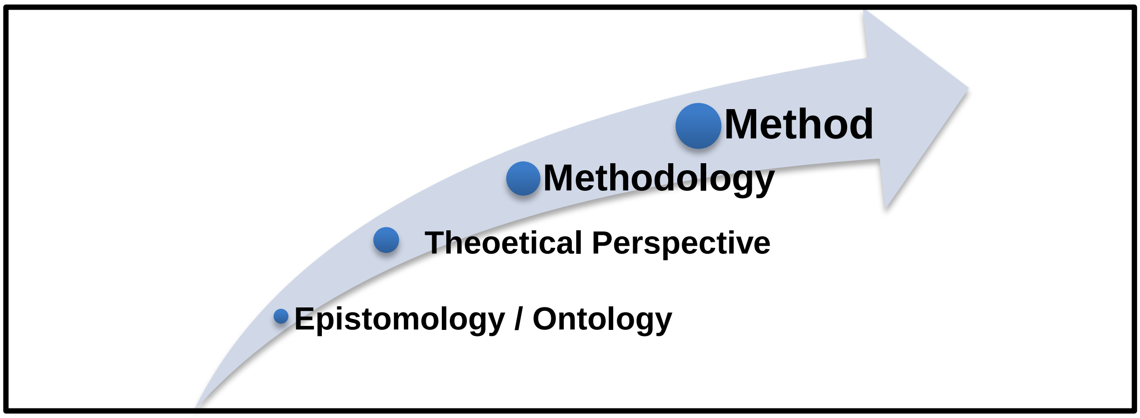


Figure 3.1 - General Research Process Key Elements (Crotty, 1998)

3.2. Research Philosophy

The philosophical foundation of the research process is under lied by ontology and epistemology and lead to theoretical perspective. For each theoretical perspective embodies a certain way of understanding ‘what is’ (ontology) as well as a certain way of understanding ‘what it means to know’ (epistemology). Ontological issues and epistemological issues tend to emerge together (Crotty, 1998)

Crotty (1998) defined three ontological positions: (1) Objectivism: an epistemological notion asserting that meaning exist in objects independently of any consciousness: (2) Constructionism or realism: an ontological notion asserting that realities exist outside the mind; and (3) Subjectivism: an epistemological notion asserting that meaning is created out of nothing. He also defined the theoretical perspective as a way of looking at the world and making sense of it. It is involving knowledge, therefore, and embodies a certain understanding of how we know what we know. He defined number of theoretical stance such as (1) Positivism; (2) post-positivism; (3) Interpretivism; (4) Post-modernism.

The ‘uncertainty principle’ articulated by Werner Heisenberg, positivist scientist and founder of ‘quantum theory’, questions the positivists science’s claims to certitude and objectivity. According to ‘quantum theory’ it is impossible to determine both the position and momentum of a subatomic particle, such as electron, with any real accuracy (Heisenberg, 1949). Heisenberg argument’s is epistemological; in pointing to science’s inability to determine subatomic with accuracy, he locates the limitation in the way in which we know what we know.

Since the researcher of this study believes that reality exist outside the mind and the meaning exists in objects independently of any consciousness or awareness of its presence, Realism is the ontological stance and objectivism is the epistemological stance adopted to develop the main research stage of this study. Positivism is the researcher perspective that believed that scientific research could attain that objective truth and meaning and offers assurance of unambiguous and accurate knowledge strongly. The researcher is fully aware of the scientific research limitations and uncertainty in understanding relations between things and defined their influence on each other, which are the motivator for further researches.

3.3. Research Methodology

This research is conducted using System Dynamics Analysis modelling methodology in qualitative-quantitative mixed method. Qualitative method is used to verify relations between factors influencing the healthcare sustainability. Quantitative method is used to implement and demonstrate the developed model using Primary and Secondary Data of healthcare system.

Casual Loop Diagram is developed to frame the relationships of main variables. It is validated using focus groups interview (qualitative method). System Dynamics Model is developed and implemented to analyse the healthcare system of kingdom of Bahrain as a research context (quantitative method). The same is discussed in details in section 3.4. The research process key elements are illustrated in Figure 3.2.

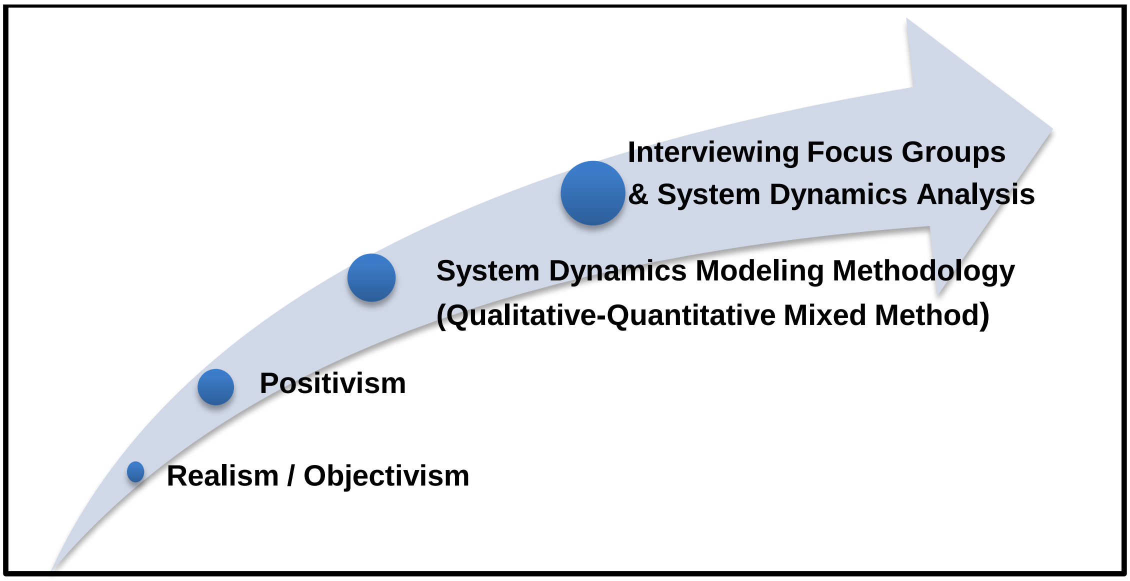


Figure 3.2 - Research Process Key Elements

3.4. System Dynamics Methodology

System Dynamics is a powerful methodology and computer simulation modelling technique for framing, understanding and discussing complex issues and problems. System Dynamics (SD) was introduced by Professor J. W. Forester of Massachusetts Institute of Technology’s Sloan School of Management during mid-1950’s to help corporate managers improve their understanding of industrial processes. SD currently used by public and private sectors for policy design and analysis (Michael et. al., 2008). Forester brought engineering feedback control principles and methods to management and social science situations, and then applied this approach to any complex system that exhibited dynamic behaviours over time. SD methodology attempts to simulate the system’s behaviour over time by representing the causal relationships between its key variables, and is particularly suited to cases of dynamic complexity. The approach supports decision-making processes that can drive system improvement, as well as being useful in improving learning in complex systems (Rashwan et. al, 2015)

By reviewing research methodologies of primary studies of SLR, it is found that the majourity of these studies are using statistical analysis to study and analyse secondary data. To study, understand, investigate and analyse the dynamic behaviour of complex systems such as healthcare and the environmental and economic complex challenges related to it; long-term effect and long-term consequences trigging system feedback; different internal and external variables, constraints and barriers influencing it; System Dynamics Analysis is found to be the most appropriate tool. This view is supported by Forrester (1961) whom defined SD as a modelling methodology for understanding and representing complex systems and analysing their dynamic behaviour, Bouloiz et. al. (2013) whom defined SD as It is dealing with the study of how the behaviour of complex system changes over time and Kunc, M. (2016) whom described SD as a behavioural simulation modelling method. It is also supported by the unique characteristics of the system that are interdependence, mutual interaction, information feedback and circular casualty. These characteristics cannot be fined in the other static analysis systems.

System Dynamics Analysis Methodology is design and developed through number of steps as summarised by researcher in Figure 3.3

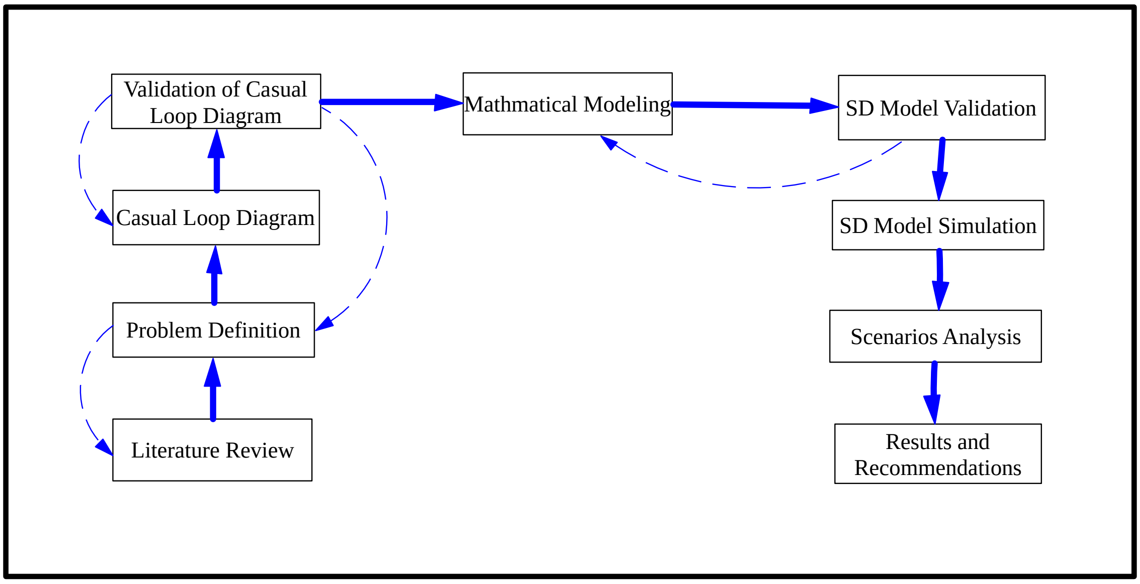


Figure 3.3 - System Dynamics Analysis Research Methodology

In chapter 2, the literature is reviewed in order to find the main effective variables affecting the environmental sustainability of healthcare facilities and the relations among them, next the main problem is articulated and the main variables are selected to proceed with the study. In the third step, the mechanisms and relations affecting the environmental sustainability of healthcare facilities need to be clarified through the formulation of Casual Loop Diagram (CLD) and then the validation of these mechanisms and relations through appropriate validation methods. The following step is to develop a mathematical model(s) to simulate the current and future trend of healthcare facilities operation. The developed model needs to be validated and tested before simulation to ensure the consistency of the model and its true behaviour. Finally, trend of healthcare facilities environmental and economic impacts need to be simulated and analysed under different scenarios using data of healthcare system in Kingdom of Bahrain to produce results and recommendations for researchers, policy makers, health planners and practitioners. The main four steps of the methodology are elaborately discussed as follows:

3.4.1. Developing Casual Loop Diagram (CDL)

At the preliminary stage of developing the System Dynamics Model, the characteristics of the healthcare system and the clarity of the relationships of main variables shall be analysed through building a Casual Loop Diagram. The diagram is an effective tool for framing and understanding the relations between model different elements and variables. The preliminary model elements and variables relations, in order to be validated, must be tested to gain insights and obtain several perspectives. Relation testing can be done using many methods such as Regression Analysis, individual interviews or focus group interviews.

3.4.2. Validating Casual Loop Diagram using Focus Group Interview

Due to the nature of healthcare system and the effective variables, Focus Group Interview method will be used, as per the guidance of Krueger (2002); Gibbs (1997) and Gill et. al. (2008) to interview experts working in different departments of healthcare services to get their views, opinions and experiences about the research topic

Kitzinger (1994 and 1995) describes the main features of interviewing focus groups method compared to individual interviews, that is the interaction between participants that enables participants to ask question of each other as well as re-evaluating and reconsidering their own understanding of specific experiences.

Although focus group interview method has many advantages, it has its own limitations like the difficulty of group assemble and get a representative sample. The method discussion may discourage certain people from participating like people with less self-confident or people with communication difficulties. It may also discourage some people from trusting others with sensitive or personal information. Documentation methods like video or audio recording may have the same discouraging effect, as it is contradicting with the confidentiality and anonymous.

The Casual Loop Diagram can be validated by interviewing number of groups of six to eight persons working in different healthcare services field to get their insights, opinions and views about the research topic.

3.4.3. Design and Development of System Dynamics Model

To develop the System Dynamics Model further, the validated Casual Loop Diagram relations is transformed to a mathematical model, tested, and analysed using actual healthcare data and statistics.

System Dynamics model is designed and developed using basic building blocks known as “primitives”. The key primitives are Stocks, Flows, Variables and Links. Model equations and variables values will be extracted from healthcare statistics, EWA databases and good practices. Once the model is completed, model equations are specified and time settings are configured, system will be ready for validation and generate results (SDS, 2016).

Simulation software is selected to run and analyse the developed model. Current simulation software’s available are Vensim, STELLA, iThink, PowerSim, AnyLogic, Insight Maker in addition to other software’s. Comparison between software’s is shown in Table 3.1

Table 3.1 - Comparison between System Dynamics Software’s

#	SD Web Address	Developer	Features	Strengths	Weaknesses
1	www.vensim.com	Ventana Systems	Simulation software for improving the performance of real systems. It is used for developing, analysing, and packaging dynamics feedback models.	PLE version is freely available for educational and personal use.	Non-free versions for commercial use.
2	www.iseesystems.com	isee System	Modelling and Simulation software for education and research. Easy, interactive tools that enables researchers to create a system diagrams that can be simulated.		Need to purchase Faculty / PhD Licence.
3	www.powersim.com	PowerSim	Business Intelligence and strategic simulation software supports system dynamics and discrete event modelling.	Free edition of Studio 10 is available with limited features.	Full version of Studio 10 is available for comm. use.
4	www.xjtek.com	Any Logic	Any-Logic, the first and only tool that brings together System Dynamics, Discrete Event and Agent Based methods within one modeling language and one model development environment.	Any-Logic PLE version is freely available for educational and personal use.	Advance version of Any-Logic is available for commercial use.
5	www.Insightmaker.com	Insight Maker	Multi-method, Multi-user, Web-based modelling and simulation software supporting SD Modelling (Stock and Flow simulation modelling and CLD)	Freely available for educational and personal use.	Graphics Library is available under commercial licence.

3.4.4. Validation of System Dynamics Model

System Dynamics has developed a good literature on the validation of the simulation models (Forester, 1961; Forester et. al., 1980; Richardson et. al., 1981; Sterman, 2000; Oliva, 2003). Good explanations of validation schemes are carried out by (Qudrat-Ullah, 2005; Martis, 2006). There are number of strong tests for building confidence in System Dynamics Models adopted from the previous references as described in Table-1 of Sterman (1984) and summarised in three sub-groups; Test of Model Structure that includes structure validation, parameter verification, extreme condition, boundary adequacy (structure) and dimensional consistency; Test of Model Behaviour that includes behaviour reproduction, behaviour anomaly, family member, surprise behaviour, extreme policy, boundary adequacy (behaviour), behaviour sensitivity and statistical character; Test of Policy Implications that includes system improvement, behaviour prediction, boundary adequacy (policy) and policy sensitivity.

Although there is a debate about the importance of historic fit, the ability of a model to replicate the past behaviour of a system, Sterman (1984) believes that although reproducing historical behaviour is one of large number of tests and activities required to build confidence in the model, it is nevertheless an extreme important one. Failure to pass this test is sufficient to dismiss the model and its conclusions while passing the historic behaviour test is a necessary step in the confidence-building process.

3.5. Ethical Considerations in Research Methodology

Before starting this research in healthcare services, ethical part was under consideration to check if there is a need, at any stage of the research, to be in contact with patients or general public in healthcare facilities. Fortunately, the research is focusing on healthcare facilities, economic parameters and environmental parameters that need access to the facilities and facilities secondary data, contact with administration and professional staff working inside these facilities, and does not need any contact with patients. Necessary ethical approvals and consents were obtained from staff participated in the focus group interviews.

3.6. Chapter Summary

This chapter begins by introducing knowledge framework and research philosophy to underlay the design and development of the research Methodology. SD Analysis Methodology literature is reviewed and design elements are selected. The methodology is designed in qualitative-quantitative mixed method. Qualitative method is required to verify relations between factors influencing healthcare sustainability while quantitative method is required to demonstrate the developed model and implement it on actual healthcare System.

Chapter 4: System Dynamics Analysis Model Development

The purpose of this chapter is to satisfy the second objective of this research by developing a System Dynamics Analysis methodology to study and analyse healthcare facilities environmental and economic challenges and its negative impacts.

In chapter 3, System Dynamics methodology design and literature are explained. The main four steps of the methodology design are illustrated, i.e. CLD development, CLD validation, SD Model design, and SD Model validation. In this chapter, the development and implementations of these steps on an actual healthcare system (Kingdom of Bahrain) is taking place as follows:

4.1. Development of Casual Loop Diagram (CLD)

Systematic literature review conducted in chapter 2 leads to a number of concepts participates in forming and developing the Casual Loop Diagram. These concepts are:

1) Demographical and Socio-Economic growth: Population growth and immigration data are very important to forecast future healthcare services as healthcare services are design to match population and resident growth. Economic growth is very important to fund future projects and maintain the required operating budget (BHS, 2012).
2) Healthcare performance Indicators (resources indicators): Healthcare performance indicators are very important to measure and maintain healthcare quality. Resources indicators are measured in conjunction with population to maintain good quality of healthcare facilities ratio to population (BHS, 2012).
3) Sustainability: Sustainability is the main framework to manage the environmental, economic and social interrelated issues related to the use of different types of resources (Brundtland Report, 1987).
4) Environmental Sustainable Building (Green Buildings): Green buildings concept is one of the measures used to mitigate significant impact of the building stock on environment, society and economy. It is used to provide technical solutions to achieve green healthcare (Zuo et. al., 2014).

   Environmental Sustainable Healthcare (Green Healthcare): Green healthcare concept is used to reduce the negative environmental impacts as results of the growing in healthcare services and facilities (Alliance for Natural Health, 2010).

The developed Casual Loop Diagram is based on maintaining the following assumptions during study period (2012-2030):

- Taxed-base (Revenue-base) healthcare system: Where healthcare services are provided for citizens and residents by government.
- Growing economy: Where government with growing economy funding the expansion of healthcare services and operation.
- Steady healthcare system: Taxed-based healthcare system is not changing to any other model.
- Fixed Population Growth Rate and fixed Net Immigration Rate.
- Same Health Performance Indicators are maintained.

The different relations between CLD cause and effect variables are summarised in Table 4.1 & Table 4.2.

Table 4.1 - Summary of relations between different CDL cause & effect variables

#	Cause Variables	Effect Variables	Relation	Description	Reference
1	Population Growth Rate	Population	+	As Population growth Rate is positive, population is increasing.	CIO (2013), BHS (2012), Ciplak et. al. (2012, p.579)
2	Population	Healthcare Facilities and Services	+	As population is increasing, the need for new Healthcare facilities and services is increasing.	CIO (2013), BHS (2012), Ciplak et. al. (2012, p.579)
3	Healthcare Facilities and Services	Healthcare Facilities Medical Waste Generation	+	As Healthcare facilities and services are increasing, its MW generation is increasing. (Other HC Risks added in the revised version)	Chaeruk et. al. (2007, p.445), Ciplak et. al. (2012, p.579),
4	Medical Waste Management Strategy	Healthcare Facilities Medical Waste Generation	-	Good MW Management Strategy will lead to reduce the Health Facilities Waste Generation and CO2e Emissions	
5	Healthcare Facilities Medical Waste Generation	Learning Parameters (MWM)	+	Health Facilities MW Generation process can enforce the learning parameters of good practices	
6	Learning Parameters (MWMS)	Medical Waste Management Strategy	+	Learning parameters of good practices can improve MW Management Strategy	
7	Healthcare Facilities Medical Waste Generation	Healthcare Facilities Energy / Water Consumption	+	As Health Facilities MW Generation is increasing, Health Facilities Energy Consumption is increasing and CO2e Emissions are increasing. (Water added in the revised version)	
8	Healthcare Facilities and Services	Healthcare Facilities Energy / Water Consumption	+	As Healthcare facilities and services are increasing, its environmental challenges in form of Energy Consumption are increasing and CO2e Emissions are increasing. (Other HC Risks added in the revised version)	Asif et. al. (2007, p. 1389-1390), Rabanimotlagh et. al. (2014), Lombard et al. (2008, p. 394)
9	Low Carbon Design Strategies	Healthcare Facilities Energy / Water Consumption	-	Good low Carbon Design strategies will lead to reduce energy consumption of the Healthcare Facilities and CO2e Emissions.	

	Cause Variables	Effect Variables	Relation	Description	Reference
10	Healthcare Facilities Energy / Water Consumption	Learning Parameters (LCD)	+	Health Facilities Energy Consumption process can enforce the learning parameters of good Low Carbon Design	
11	Learning Parameters (LCD)	Low Carbon Design Strategies	+	Learning parameters of good Low Carbon Design can enforce Low Carbon Design Strategies	
12	Healthcare Facilities and Services	Other Healthcare Practices Risks	+	As Healthcare facilities and services are increasing, the risks related to healthcare practice are also increasing.	
13	Other Healthcare Practices Risks	Human Risk	+	As the risks related to healthcare practice are increasing, diseases and health risks may increasing.	
14	Healthcare Facilities Waste Generation	Environmental Risks	+	Medical Waste Generation increases CO2e Emissions and Pollution.	
15	Environmental Risks	Human Risks	+	CO2e Emissions and Pollution may increase diseases and health risks.	Asif et. al. (2007, p.1390)
16	Human Risks	Population Growth	+	Diseases and Health Risks may lead to death (Increase Mortality Rate) and reduce the population growth.	Chaeruk et. al. (2007, p.445)
17	Healthcare Facilities and Services	Healthcare Expenditures	+	As Healthcare facilities and Services are increasing, Healthcare Expenditures are increasing.	BHS (2012)
18	Environmental Risks	Healthcare Expenditures	+	Healthcare Energy Cost and Healthcare Waste Management (incineration or treatment) are directly contributing to Healthcare Expenditures.	Rabanimotlagh et. al. (2014), Eleyan et. al.(2013, p. 993)
19	Health Risks	Healthcare Expenditures	+	Diseases and Health Risks will increase Healthcare Expenditures	Chaeruk et. al. (2007, p.445)
20	Healthcare Expenditures	Population Growth	+	Healthcare Expenditures can improve the quality of life and contribute to Population Growth.	BHS (2012)

Table 4.2 - Summary of relations between CDL exogenous & Endogenous variables

#	Exogenous Variables	Endogenous Variables	Relation	Description	Reference
1	Net Immigration Rate	Population	+	Population is increasing annually by Population Growth Rate & Net Immigration Rate. The Population Growth Rate comprises of row population growth (new born babies) minus mortality rate. Net Immigration Rate comprises immigrant-in minus Immigrant-out	CIO (2013), BHS (2012)
2	KPI's, Benchmarks and Epidemiological Profile	Healthcare Facilities and Services	+	Country Epidemiological Profile (Diseases Science) is very important factor in Healthcare Facility Planning. It will help in improving quality of healthcare services. KPI's will give indication of existing Healthcare services level. Benchmarks will indicate the required improvement of future Healthcare services.	BHS (2012)
3	Public Demand (Added in the revised version)	Healthcare Facilities and Services	+	Public Demand is very important factor in Healthcare Facility Planning as it will reflect public needs for certain services.	
4	Economic Growth	Healthcare Facilities and Services	+	Economic Growth will allow governments to fund new projects and expanding of healthcare services and the allocated funds will improve the quality of services.	BHS (2012)
5	Medical Technologies and Training (Added in the revised version)	Other Risks	+	Advanced Medical Technologies and good training can reduce the risks.	
6	Other Risks	Human Risk	+	Environmental Risk is one among others such as Behavioral, Biomedical, Demographical, Occupational, etc.	WHO (2009)
7	Other Diseases	Population Growth	+	Mortality Rate is due to other diseases such as Chronic, and Infectious diseases. Mortality Rate will reduce population.	(Chaeruk et. al. (2007, p.445)

The Casual Loop Diagram (CLD) describing the basic structure and feedback relationships of Sustainable Healthcare System is shown in Figure 4.1.

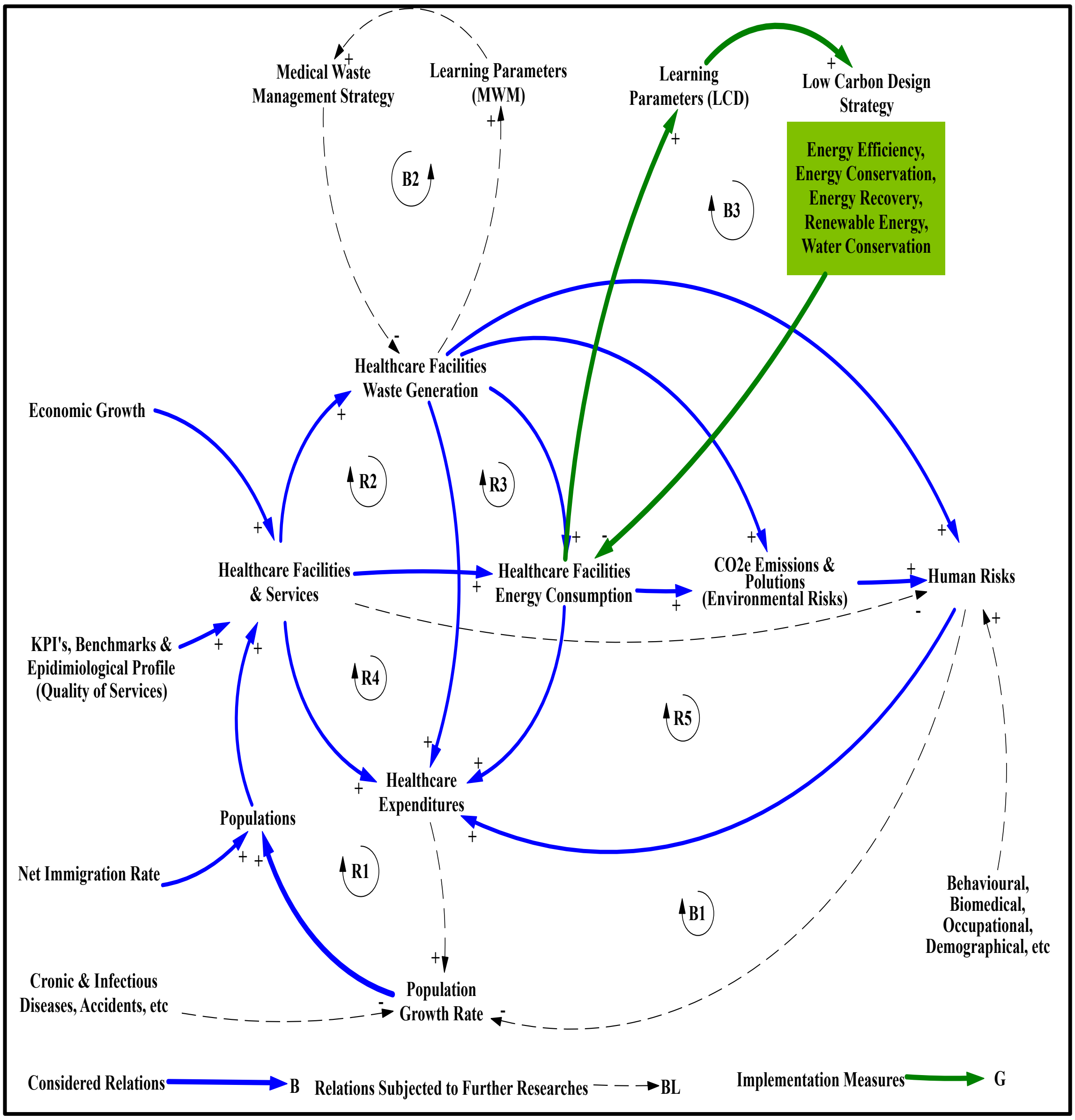


Figure 4.1 - Casual Loop Diagram (CLD) of Sustainable Healthcare System

As the main objective of this research is to review healthcare facilities environmental and economic challenges, its negative impacts, and the environmental and economic sustainability opportunities; and in light of availability of adequate secondary date covering these two sustainability dimensions and supporting quantitative analysis; and in the absences of firmness or uncertainty of relations related to the social dimension of sustainability due to its qualitative nature; the choice is made to only develop a part of the causal loop diagram that it representing the relations in the Blue and Green solid arrows. Black dashed relations are reserved for further researches.

The Casual Loop model considers three main structures, i.e.

1) The relationships between demographical growth and healthcare services demand taking into consideration some factors such as country epidemiological profiles and healthcare resources performance indicators; the relation between healthcare services expansion and negative environmental challenges; the relation between negative environmental challenges and health risks and the resources required to overcome these risks (Positive Loops No.1-14 of Table 4.3)
2) The effect of learning parameters of Medical Waste Management on development of Medical Waste Management Strategy and healthcare facilities energy consumption (Negative Loop No. 15 of Table 4.3).
3) The effect of learning parameters of Low Carbon Design on development of Low Carbon Design Strategy and healthcare facilities waste reduction (Negative Loop No. 16 of Table 4.3).

Qualitative Analysis of feedback loops are summarised in Table 4.3.

Table 4.3 – Qualitative Analysis of Feedback Loops

#	Feedback Loops	Comments
1	Population Growth Rate ➔ Populations-Healthcare Facilities & Services ➔ Human Risks.	Population Growth generates the need for new HCF's. HCF's main purpose is to reduce human risks and maintain the Population Growth.
2	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Human Risks-Healthcare Expenditures.	Population Growth generates the need for new HCF's. HCF's main purpose is to reduce human risks. Reducing human risks leads to reduce Healthcare Expenditures, improve quality of services and maintain the Population Growth.
3	Population Growth Rate ➔ Populations-Healthcare Facilities & Services ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate the need for more expenditure and pressurise the quality of services.
4	Population Growth Rate ➔ Populations ➔Healthcare Facilities & Services ➔ Healthcare Facilities Energy Consumption ➔ CO2e Emissions and Pollution ➔ Human Risks.	Population Growth generates the need for new HCF's, new HCF's generate the need for more energy. More energy leads to more CO2e emissions and Pollutions that increase human risk.
5	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Energy Consumption ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate the need for more energy. More energy generates the need for more expenditure and pressurise the quality of services.
6	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Energy Consumption ➔ CO2e Emissions and Pollution ➔ Human Risks ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate the need for more energy. More energy leads to more CO2e emissions and Pollutions that increase human risk. Increasing human risks leads to increase Healthcare Expenditures and pressurise quality of services.

#	Feedback Loops	Explanation
7	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ Human Risks.	Population Growth generates the need for new HCF's, new HCF's generate more Waste that increase human risk.
8	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate more waste. More waste generates the need for more expenditure and pressurise the quality of services.
9	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ Human Risks ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate more Waste that increase human risk. Increasing human risks leads to increase Healthcare Expenditures and pressurise quality of services.
10	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ Healthcare Facilities ➔ Energy Consumption ➔ CO2e Emissions and Pollution ➔ Human Risks.	Population Growth generates the need for new HCF's, new HCF's generate more Waste. More Waste leads to more CO2e emissions and Pollutions that increase human risk.
11	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ Healthcare Facilities Energy Consumption ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate more Waste. More waste leads to more incineration energy. More energy generates the need for more expenditure and pressurise the quality of services.
12	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ Healthcare Facilities Energy Consumption ➔ CO2e Emissions and Pollution ➔ Human Risks ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate more Waste. More waste leads to more incineration energy. More energy leads to more CO2e emissions and Pollutions that increase human risk. Increasing human risks leads to increase Healthcare Expenditures and pressurise quality of services.
13	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ CO2e Emissions and Pollution ➔ Human Risks.	Population Growth generates the need for new HCF's, new HCF's generate more Waste. More Waste leads to more CO2e emissions and Pollutions that increase human risk.
14	Population Growth Rate ➔ Populations ➔ Healthcare Facilities & Services ➔ Healthcare Facilities Waste Generation ➔ CO2e Emissions and Pollution ➔ Human Risks ➔ Healthcare Expenditures.	Population Growth generates the need for new HCF's, new HCF's generate more Waste. More Waste leads to more CO2e emissions and Pollutions that increase human risk. Increasing human risks leads to increase Healthcare Expenditures and pressurise quality of services.
15	Healthcare Facilities Waste Generation ➔ Learning Parameters (MWMS) ➔ Medical Waste Management Strategy.	Learning parameters of Medical Waste Management lead to develop Medical Waste Management Strategy to reduce Medical Waste Generation.
16	Healthcare Facilities Energy Consumption ➔ Learning Parameters (LCDS) ➔ Low Carbon Design Strategy.	Learning parameters of Low Carbon Design lead to develop Low Carbon Design Strategy to reduce Energy Consumption.

4.2. Validation of Casual Loop Diagram using Focus Group Interview

The Casual Loop Diagram was validated using Focus Group Interview by interviewing six groups (45 Participants) working in different healthcare services to get their insights, opinions and views about the research topic.

- Group's participants (6-8 persons) were selected based on healthcare speciality such as healthcare management, healthcare planners, healthcare economists, Healthcare quality assurance specialists, Medical professionals as Healthcare facilities users, Healthcare building services engineers and healthcare waste specialists.

- Six groups were selected based on services; first group was strategic perspective group and consists of healthcare management, healthcare planners, healthcare economists and quality assurance specialists; second group is hospitals perspective group and consists of administration, medical, nursing and allied health services members; third group was public health perspective group and consists of chemists from different sections of public health laboratory; fourth group was health centres perspective group and consists of administration, medical, nursing and allied health services members ; fifth group was operational perspective group and consists of building services engineers and healthcare waste specialists; and the sixth group was Academic perspective group that consists of healthcare research team of academics and researchers.
- Each Focus group interview takes about two hours in which the participants were briefed about the research topic and asked to give freely their insight, opinions and views. The researcher noted comments and feedback notes. The atmosphere was positive with some interruptions due to the nature of healthcare operation. Some participants refuse to record the interviews due to cultural differences and certain circumstances.
- As the interviews discussion start after the briefing without showing the draft of the Casual Loop Diagram produced from literature, and as the participants are familiar with the questionnaires, some participants missed the objectives of the interview and the expected outcomes. To help participants with the expected outcomes, which may change from group to another or participant to another, an open-ended questions were asked such as:
  - What are the risks / environmental challenges related to your work field?
  - What are the technological changes happened in your field and its effects?
  - What is your expectation for future expansion of Healthcare services?
  - What are the alternative solutions to build new services, to reduce costs, etc.?
  - What are the alternative financial models can be implemented in Healthcare?

Summary of the outcomes of the Interviews are given in Table 4.4.

Table 4.4 - Summary of Focus Groups Interviews Outcomes

Focus Group (Date)	Healthcare Speciality	Participants	Comments & Feedbacks
1 Strategic Perspective (13/09/2015)	Director of H / Centres Head, Resources Healthcare planners Healthcare economists Quality specialist Chief, ESS (Projects) Head, ESS (Projects)	(1) (1) (1) (1) (2) (1) (1)	1) Different Available Healthcare System Financial Models. 2) Define Research Model Assumptions and Boundaries. 3) Definition of Population (citizens vs. citizens + residents). If (residents) are considered, then (net immigration rate) to be considered. 4) Country Epidemiological Profile to be considered to improve service categories and quality. 5) Definition of (% GDP vs. % Government Budget). If only (Government) Services are considered, then (% Government Budget) to be considered. If (Government + Private) Services are considered, then (% GDP) to be considered. 6) To consider the relation between econ. growth and net immigration rate. 7) Facilities Annual Operating Expenditures. 8) Facilities Construction Expenditures. 9) Facilities Furniture's and Equipment Expenditures.
2 Hospital Perspective (15/09/2015)	Hospital Administrator Nurses Radiation Protection Medical Scientist Chemist (Kid. Dialysis) Maint. Supervisor	(1) (3) (1) (1) (1) (2)	10) To consider Public demands and demographical shifting among reasons of new HC facilities construction. 11) To consider direct relation between Health risks and construction of new healthcare facilities. 12) Issues to be considered in new hospitals such as size and availability of services. 13) The challenges of providing adequate and good quality water for special health services such as Kidney Dialysis and Hydro therapy. 14) The challenge of supply water hygiene and biological polluting protection. 15) To consider environmental negative impacts as a major source of health risk. Typical known diseases are spreading in the residential areas close to Airport and industrial areas.
			16) To consider other risks, in addition to energy and waste, such as cleaning chemicals, Laboratory chemicals, etc.
			17) The risk of material handling and management of Radioactive Materials such as Diagnostic, Therapeutic (Cancer Therapy) and Blood Irradiation (High Active Materials).

Focus Group (Date)	Healthcare Speciality	Participants	Comments & Feedbacks
			18) Availability of operation and safety guidelines, manuals and Procedures and its effect in reduction of risks. 19) Availability of good training programed and good awareness and its effect in reduction of risks. 20) Utilization of awareness in conducting effective Energy Saving and Waste Segregation Campaigns.
3 Public Health Perspective (20/09/2015)	Chief Chemist Head Chemist Chemist Maint. Supervisor	(1) (2) (3) (2)	21) For Serology Laboratory Operation, to consider outbreaks of new diseases and new immunization programs among reasons of increasing the need for new laboratory construction. 22) There is direct relation between population growth and sampling strategies that lead to increase laboratory operation. 23) Biological Safety Cabinets infectious fumes (TB, HIV, NIH1, etc. samples) are considered as the major risk and effective HEPA Filtration as a vital safety measures. 24) For Chemical Analysis Laboratory Operation, water and food safety programs among reasons of increasing operation and lead to new laboratory construction. 25) Chemicals in solid and liquid forms are considered as major risks and to be disposal as a vital safety measures. 26) Automated works and developed laboratory technology are potential solutions to accommodate increase of operation. 27) Different Management Financial Models to be considered as alternatives to reduce expenditures such as Outsourcing services and Public Private Partnership to lead the investment in the sector.
4 Health Centres Perspective (14/10/2015)	Regional Administrator H/C Administrator Doctor Dentist Chief, Radiology Chief, Laboratory Maint. Supervisor	(1) (1) (1) (1) (1) (1) (2)	28) To consider Public demands and demographical shifting among reasons of new healthcare facilities construction. 29) To consider construction of big facilities (more than 10,000 m2) to reduce overheads and operating cost. 30) To consider extensions of operating hours to reduce overheads and operating cost (To what extent it is effective?) 31) To consider other risks, in addition to energy and waste, such as mixing between screening and treatment services in the same facility.

Focus Group (Date)	Healthcare Speciality	Participants	Comments & Feedbacks
			32) Development of imaging technologies (Computerized Radiology) leads to increase in work effectiveness and reduction in operating cost. 33) Development of imaging technologies (Computerized Radiology) leads to reduction in Staff & Patients exposure to X-Rays risks, reduction of material handling risks and reduction of waste. 34) Development of Lab. technologies (Automation) leads to increase in work effectiveness and handling capacities and reduction in operating cost 35) Development of Lab. technologies (Automation) leads to reduction in Staff exposure to needle punctures and reduction of handling risks. 36) Availability of operation and safety guidelines, manuals and Procedures and its effect in reduction of risks. 37) Availability of good training programed and good awareness and its effect in reduction of risks. 38) Utilization of awareness in conducting effective Energy Saving and Waste Segregation Campaigns.
5 Operational Perspective (05/10/2015)	Chief Engineer, Maint. Head, Maintenance Bldg. Ser. Engineers Electronics Engineers MW Specialist	(1) (1) (3) (2) (1)	39) More supporting Environmental legislations are required. 40) Availability of potable, clean and filtered water for different hospital operations is a major challenge to be considered among other challenges in countries with limited fresh water resources like Bahrain. 41) Water production and water treatment cost in Healthcare Operations. 42) Importance of considering Water Efficiency measures to reduce water consumption in Healthcare Facilities. 43) Different options of available Technologies related to Energy Efficiency & Renewables systems. 44) Opportunities of implementing new techniques and initiatives to improve Energy Conservation campaigns. 45) The need for local expertise for the implementation plans. 46) Project expenditures, investments issues and funding opportunities. 47) Importance of balancing between maintaining existing facilities and construction of new ones. 48) Availability of safety guidelines, manuals and Procedures to reduce risks in management of critical areas (OT's. Rec. Rooms, ICU, CCU, AKU)

Focus Group (Date)	Healthcare Speciality	Participants	Comments & Feedbacks
			49) Availability of good training programed and good awareness and its effect in reduction of staff exposures to risks. 50) Utilisation of awareness in conducting effective Energy Saving and water saving Campaigns. 51) Development of eco-friendlier Medical Equipment (less energy consumption / Less water consumption / Efficient Filtration) such as Dental Machines and Sterilization Machines and its effect in improving energy issues in Healthcare Facilities. 52) Development of clean imaging technologies, such as (CR) and CT Scan and its effect in improving energy issues and reducing risks and wastes. 53) Unavailability of power metering devices in some customer side facilities. 54) Development of IT and communication technologies to more wireless voice / data networking, servers and LCD / LED screens technologies and its effect in improving energy issues. 55) Medical Waste issues such as annual increment rates, Medical Waste incineration cost, disposal techniques.
6 Academic Perspective (01/10/2015)	Healthcare Researchers	(4)	56) Is Population Growth Model supported by literature? 57) What is the extent of Model Generality and the model outcomes? 58) What are the different scenarios to be considered? 59) What are the differences between Model Scientific Methodology and other approaches (consultation, feasibility studies, etc.)?

Main outcomes of Focus Groups Interviews

The Main outcome of Focus Groups Interviews that made a significant change in the CLD are:

- The relation between economic growth and net immigration rate and how it influences healthcare services (Feedback No. 6 in Table 4.4).
- The influence of public demand through media and other communication channels on plans of providing services such as construction of specialised healthcare services (Feedback No. 10 in Table 4.4).

- Tracing group of environmental challenges related to the practicing of healthcare services neither classified as energy nor waste but it can expose personnel (staff and patients) to high risks. This group of environmental risks consisting of catching of infections; exposure to X-Rays and Diagnostic Radioactive Materials; expose to needle punctures and sharp objects; risk of patients, materials and chemicals handling that may directly harming the staff and patients and need to be efficiently managed in order to improve social sustainability of healthcare system. This group of risks to be subjected to further studies as it is outside the boundary of this research (Feedback No. 31 in Table 4.4).
- The influence of medical technologies, guidelines and training in reducing healthcare risks (Feedback No. 35, 36 and 37 in Table 4.4).
- In addition to healthcare buildings large impact on environment generated from two sources; energy consumed and waste generated (Gunther et. al., 2008), tracing a third healthcare buildings large impact on environment that is water consumption. Availability of enough potable, clean and filtered water for different healthcare operations, especially in countries with limited fresh water resources like Bahrain, is a real environmental challenge need to be considered. Potable water produced by water desalination techniques can be directly linked to energy consumed in the production of this water and hence its environmental impact can be measured and managed (Feedback No. 40 in Table 4.4).

The outcomes of the interviews are incorporated in CLD and the changes are highlighted in the revised Casual Loop Diagram (CLD) shown in Figure 4.2.

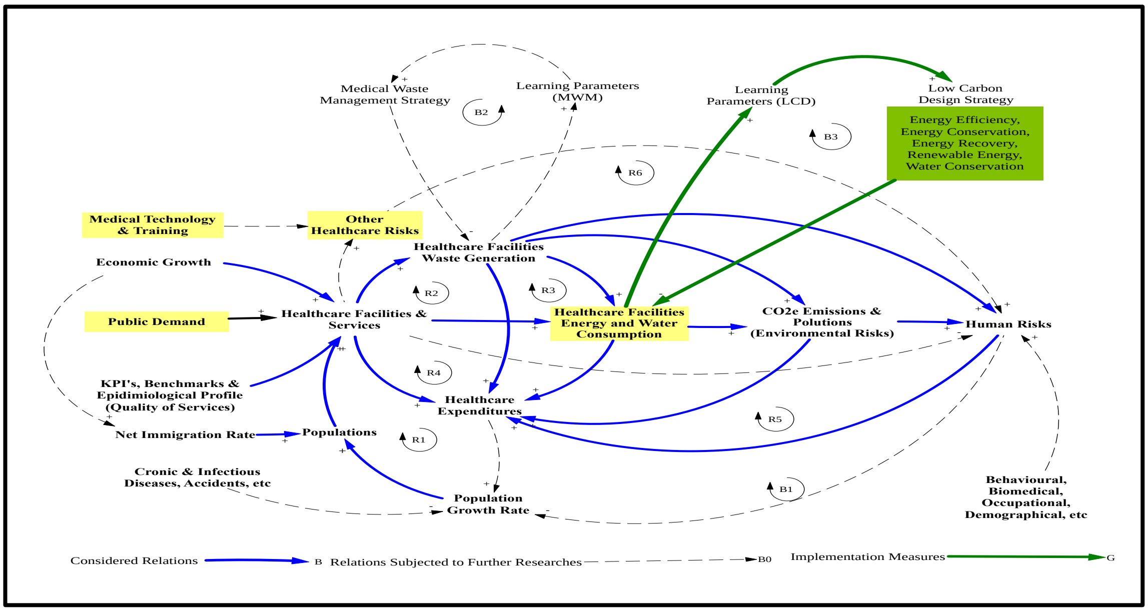


Figure 4.2 - Revised Casual Loop Diagram (CLD) of Sustainable Healthcare System

4.3. Development of System Dynamics Models

System Dynamics Model is required to numerically test and analyse the framed relations of Casual Loop Diagram. To develop System Dynamics Model for healthcare services provision and its environmental impact, five models need to be developed.

4.3.1. Population Growth Model,
4.3.2. Primary Healthcare Services (Health Centers) Model,
4.3.3. Secondary Healthcare Services (Hospitals) Model,
4.3.4. Public Health Services Model, and
4.3.5. Administration services (Office Buildings) Model.

The need for individual models is due to the differences in the nature of operation of each service, different key performance indicators to measure the quality of the services and the different benchmarks used to develop the models.

4.3.1. Development of Population Growth Model:

$$\boldsymbol{X_{n+1} = X_n + \beta} \qquad (\mathbf{4.1})$$

Where: $\mathbf{X_{n+1}}$ **=** magnitude of the population in year n+1,
$\mathbf{X_n}$ **=** magnitude of the population in the preceding year n,
$\boldsymbol{\beta}$ **=** Change of the population in the preceding year n.

Population in the preceding year n, **X**n consist of local population (Citizens/ Residence), **X1**n, and Immigrants, **X2**n. Local population growth is subjected to Natural Growth Rate (Birth Rate – Mortality Rate). Immigrants growth rate is subjected to Net Immigration Rate (Immigrants in Rate – Immigrants out Rate). Change of the population, in the preceding year n, can be re-written as:

$$\boldsymbol{\beta = \gamma 1 * X1n + \gamma 2 * X2n} \qquad (\mathbf{4.2})$$

Where: $\mathbf{X1_n}$ **=** magnitude of the local population in the preceding year n
$\mathbf{X2_n}$ **=** magnitude of the Immigrants in the preceding year n
$\boldsymbol{\gamma 1}$ **=** Natural Growth Rate, $\boldsymbol{\gamma 2}$ **=** Net Immigration Rate

In case of absence of data related to immigration, and since the Population growth Rate covering both the Natural Growth Rate and Net Immigration Rate, Equation (4.2) can be simplified, by assuming $\boldsymbol{\gamma 1} = \boldsymbol{\gamma 2} = \boldsymbol{\gamma}$ (Population growth Rate), to:

$$\boldsymbol{\beta = \gamma * (X1_n + X2_n)} \qquad (\mathbf{4.3})$$

Since $X_n = X1_n + X2_n$, then equation (4.3) can be simplified further to:

$$\boldsymbol{\beta = \gamma * X_n} \qquad (\mathbf{4.4})$$

And equation (4.1) can be re-written in the final form as:

$$\boldsymbol{X_{n+1} = X_n + \gamma * X_n} \qquad (\mathbf{4.5})$$

4.3.2. Development of Primary Healthcare Services Models

Development of PHC model passes through a number of phases. The first phase is related to the assessment of the facilities demand and financial resources required, quantifying utilities in term of energy consumption; water consumption; waste generation and incineration and its environmental and economic impacts. The second phase of the model development is related to the implementation of some energy efficiency, water reduction, waste recovery and introduction of renewable-base strategies and its effect in reducing environmental and economic impacts. The secondary data needed to develop the model are: list of Primary Healthcare Facilities, facilities' areas, facilities' annual energy consumption, facilities' annual water consumption, facilities' annual medical waste generation, new facilities' construction cost, new facilities' annual operating cost.

Vensim software (www.vensim.com) is used to run and analyse the developed model due to the good software capabilities and it is popularity in the academic field. Bahrain healthcare system secondary data is selected as a research context.

System Dynamics Models of Global Primary Healthcare Services is shown in Appendix-O.

The resources part of the SD model is shown Figure 4.3a and the relevant equations used to develop this part of the model are listed in Table 4.5a.

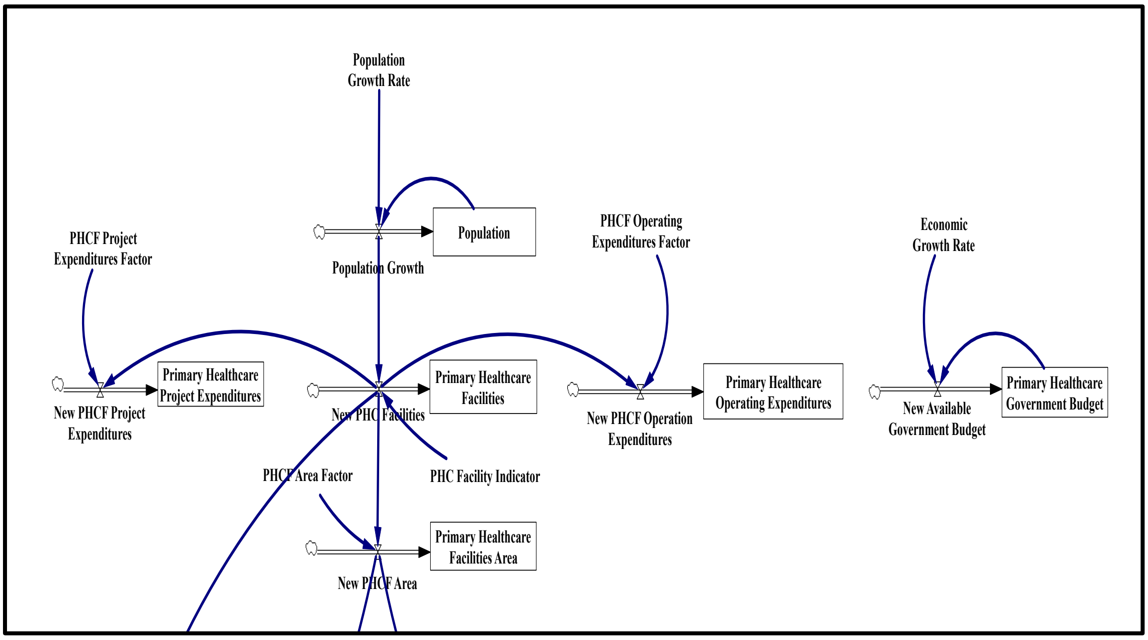


Figure 4.3a - System Dynamics Model of Primary Healthcare Facilities Resources

Table 4.5a - Equations used to develop SD Model of PHC Facilities Resources

#	Parameter	Equation	Variable Values
1	Population growth	$X'(n+1) = \gamma * X(n)$	n = year , γ = 3% Annually
2	Population	$X(n+1) = X(n) + X'(n+1)$	
3	New PHC Facilities	$F'(n+1) = X'(n+1) * PI$	PI= 0.2 facility /10,000 pop.
4	PHC Facilities	$F(n+1) = F(n) + F'(n+1)$	
5	New PHC Facilities Area	$FA'(n+1) = F'(n+1) * AF$	PHC FA= 10,000 m2/Facility
6	PHC Facilities Area	$FA(n+1) = FA(n) + FA'(n+1)$	
7	New PHC Project Expenditures	$PExp'(n+1) = F'(n+1) * PF$	PHC PF = MBD 6/Facility
8	PHC Project Expenditures	$PExp(n+1) = PExp(n) + PExp'(n+1)$	
9	New PHC Operating Expenditures	$OExp'(n+1) = F'(n+1) * OF$	PHC OF = MBD 3/Facility
10	PHC Operating Expenditure	$OExp(n+1) = OExp(n) + OExp'(n+1)$	
11	New PHC Government Funds	$GF'(n+1) = GF(n) * (EGR)$	EGR = 3%
12	PHC Government Funds	$GF(n+1) = GF(n) * GF'(n+1)$	

The utilities part of the SD model is shown in Figure 4.3b and the relevant equations used to develop this part of the model are listed in Table 4.5b.

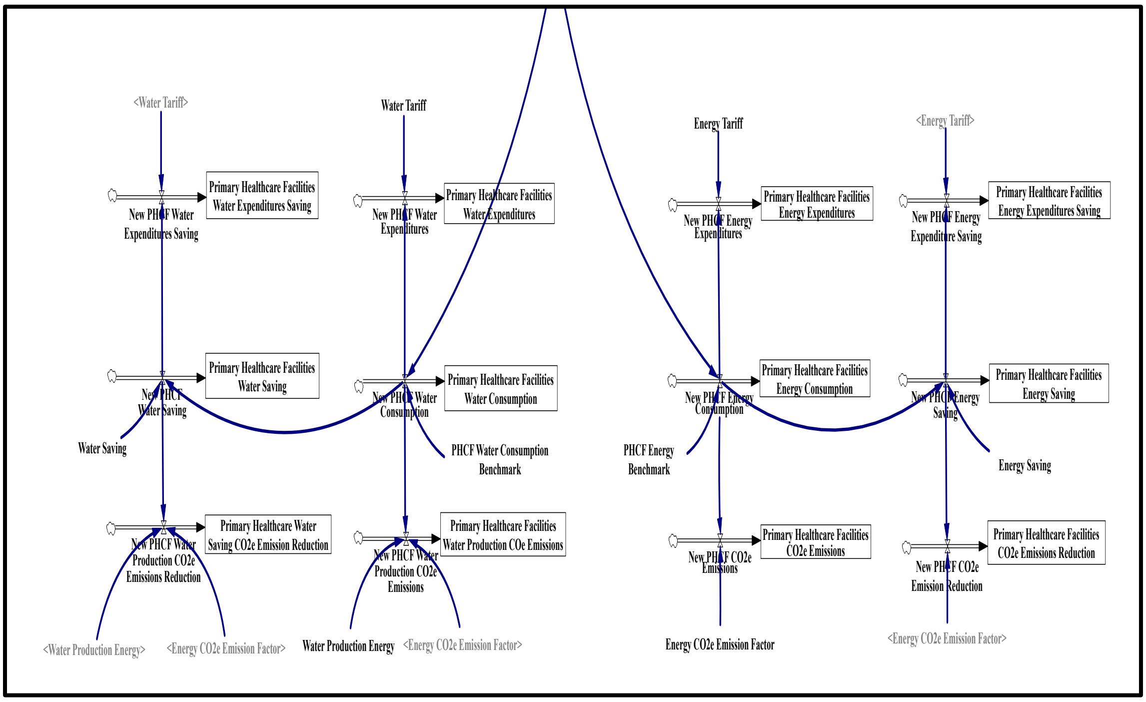


Figure 4.3b - System Dynamics Model of Primary Healthcare Facilities Utilities

Table 4.5b - Equations used to develop SD Model of PHC Facilities Utilities

#	Parameter	Equation	Variable Values
1	New PHCF Energy Consumption	$E'(n+1) = FA'(n+1) * EBM$	PHC EBM = 247 KWh/m2
2	PHCF Energy Consumption	$E(n+1) = FA(n) * EBM + E'(n+1)$	
3	New PHCF CO2e Emissions	$EEm'(n+1) = E'(n+1) * EF$	EF = 0.55 Kg CO2e/KWh
4	PHCF CO2e Emissions	$EEm(n+1) = E(n) * EF + EEm'(n+1)$	
5	New PHCF Energy Expenditures	$EExp'(n+1) = E'(n+1) * ET$	ET = BD 0.016/KWh
6	PHCF Energy Expenditures	$EExp(n+1) = E(n) * ET + EExp'(n+1)$	
7	New PHCF Water Consumption	$W'(n+1) = FA'(n+1) * WBM$	PHC WBM = 0.78 m3/m2
8	PHCF Water Consumption	$W(n+1) = FA(n) * WBM + W'(n+1)$	
9	New PHCF WP CO2e Emissions	$WPEm'(n+1) = W'(n+1) * WPE * EF$	WPE = 6.00 kWh/m3, EF = 0.55 Kg CO2e/KWh.
10	PHCF WP CO2e Emissions	$WPEm(n+1) = W(n) * WPE * EF + WPEm'(n+1)$	
11	New PHCF Water Expenditures	$WExp'(n+1) = W'(n+1) * WT$	WT = BD 0.300/m3
12	PHCF Water Expenditures	$WExp(n+1) = W(n) * WT + W'(n+1)$	

#	Parameter	Equation	Variable Values
13	New PHCF Energy Saving	$\mathrm{ES'(n+1) = E'(n+1) * EEF}$	EEF = 61.25%
14	PHCF Energy Saving	$\mathrm{ES(n+1) = E(n) * EEF + ES'(n+1)}$	
15	New PHCF CO2e Em. Reduction	$\mathrm{EER'(n+1) = ES'(n+1) * EF}$	EF = 0.55 Kg CO2e/KWh
16	PHCF CO2e Emissions Reduction	$\mathrm{EER(n+1) = ES(n) * EF + EER'(n+1)}$	
17	New PHCF Energy Exp. Saving	$\mathrm{EExpS'(n+1) = ES'(n+1) * ET}$	ET = BD 0.016/KWh
18	PHCF Energy Exp. Saving	$\mathrm{EExpS(n+1) = ES(n) * ET + EExpS'(n+1)}$	
19	New PHCF Water Saving	$\mathrm{WS'(n+1) = W'(n+1) * WSF}$	PHC WSF = 18%,
20	PHCF Water Saving	$\mathrm{WS(n+1) = W(n) * WSF + WS'(n+1)}$	
21	New PHCF WP Em. Reduction	$\mathrm{WPER'(n+1) = WS'(n+1) * WPE * EF}$	WPE = 6.00 kWh/m3 EF = 0.55 Kg CO2e/KWh
22	PHCF WP Emissions Reduction	$\mathrm{WPER(n+1) = WS(n) * WPE * EF + WPER'(n+1)}$	
23	New PHCF Water Exp. Saving	$\mathrm{WExpS'(n+1) = WS'(n+1) * WT}$	WT = BD 0.300/m3
24	PHCF Water Exp. Saving	$\mathrm{WExpS(n+1) = WS(n) * WT + WExpS'(n+1)}$	

The Medical Waste part of the SD model is shown in Figure 4.3c and the relevant equations used to develop this part of the model are listed in Table 4.5c.

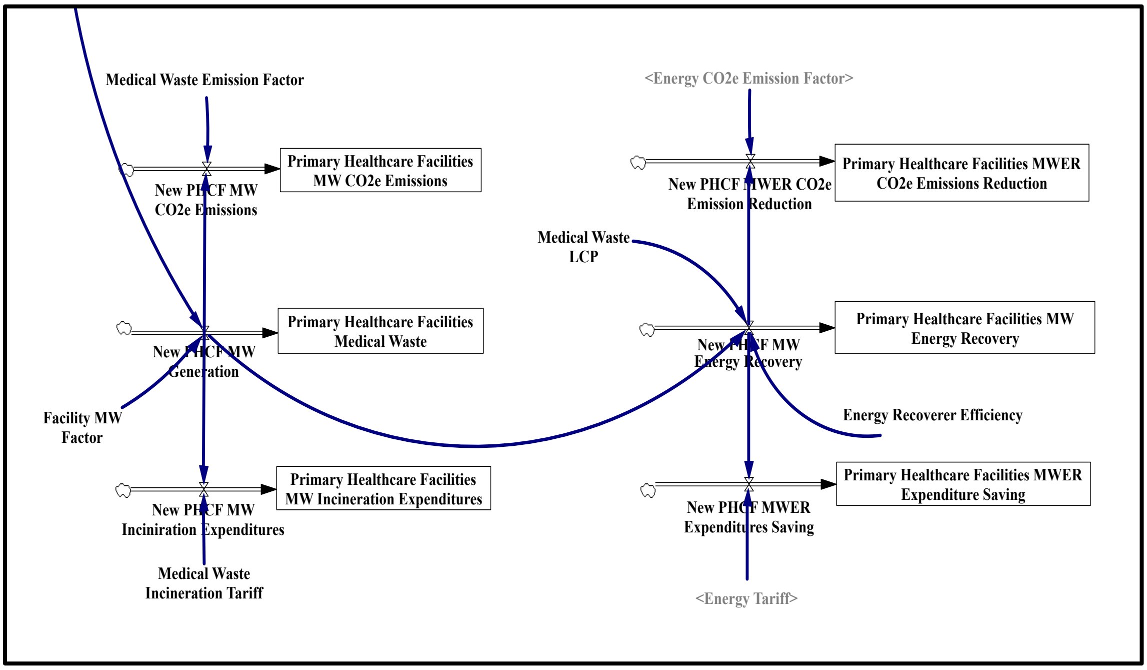


Figure 4.3c - System Dynamics Model of Primary Healthcare Facilities Medical Waste

Table 4.5c - Equations used to develop SD Model of PHC Facilities Medical Waste

#	Parameter	Equation	Variable Values
1	New PHCF MW generation	$\mathrm{MW'(n+1) = F'(n+1) * PTF * MWF}$	PTF = 150,000 Pt./Fac./Ann. PHC MWF = 0.1Kg/Pt./Ann.
2	PHCF MW generation	$\mathrm{MW(n+1) = MW(n) + MW'(n+1)}$	
3	New PHCF MWI CO2e Emissions	$\mathrm{MWEm'(n+1) = MW'(n+1) * MWEF}$	MWEF = 0.86 Kg CO2e/Kg
4	PHCF MWI CO2e Emissions	$\mathrm{MWEm(n+1) = MW(n) * MWEF + MWEm'(n+1)}$	
5	New PHCF MWI Expenditures	$\mathrm{MWIExp'(n+1) = MW'(n+1) * IT}$	IT = BD 0.210/Kg
6	PHCF MWI Expenditures	$\mathrm{MWIExp(n+1) = MW(n) * IT + MWIExp'(n+1)}$	
7	New PHCF MW Energy Recovery	$\mathrm{MWER'(n+1) = MW'(n+1) * LCP * RE}$	LCP = 4 Kw/Kg, RE = 0.77
8	PHCF MW Energy Recovery	$\mathrm{MWER(n+1) = MW(n) * LCP * RE + MWER'(n+1)}$	
9	New PHCF MWI CO2e Em. Reduction	$\mathrm{MWEmR'(n+1) = MWER'(n+1) * MWEF}$	MWEF = 0.86 Kg CO2e/Kg
10	PHCF MWI Emission Reduction	$\mathrm{MWEmR(n+1) = MWER(n) * MWEF + MWEmR'(n+1)}$	MWEF = 0.86 Kg CO2e/Kg
11	New PHCF MW Exp. Saving	$\mathrm{MWExpS'(n+1) = MWER'(n+1) * ET}$	ET = BD 0.016/KWh
12	PHCF MW Exp. Saving	$\mathrm{MWExpS(n+1) = MWER(n) * ET + MWExpS'(n+1)}$	

4.3.3. Secondary Healthcare Services Models

Development of SHC model passes through a number of phases. The first phase is related to the assessment of the facilities demand and financial resources required, quantifying utilities in term of energy consumption; water consumption; waste generation and incineration and its environmental and economic impacts. The second phase of the model development is related to the implementation of some energy efficiency, water reduction, waste recovery and introduction of renewable-base strategies and its effect in reducing environmental and economic impacts. The secondary data needed to develop the model are: list of Secondary Healthcare Facilities, facilities' areas, facilities' annual energy consumption, facilities' annual water consumption, facilities' annual medical waste generation, new facilities' construction cost, new facilities' annual operating cost.

Vensim software (www.vensim.com) is used to run and analyse the developed model due to the good software capabilities and it is popularity in the academic field. Bahrain healthcare system secondary data is selected as a research context.

System Dynamics Models of Global Secondary Healthcare Services is shown in Appendix-O.

The resources part of the SD model is shown in Figure 4.4a and the relevant equations used to develop this part of the model are listed in Table 4.6a.

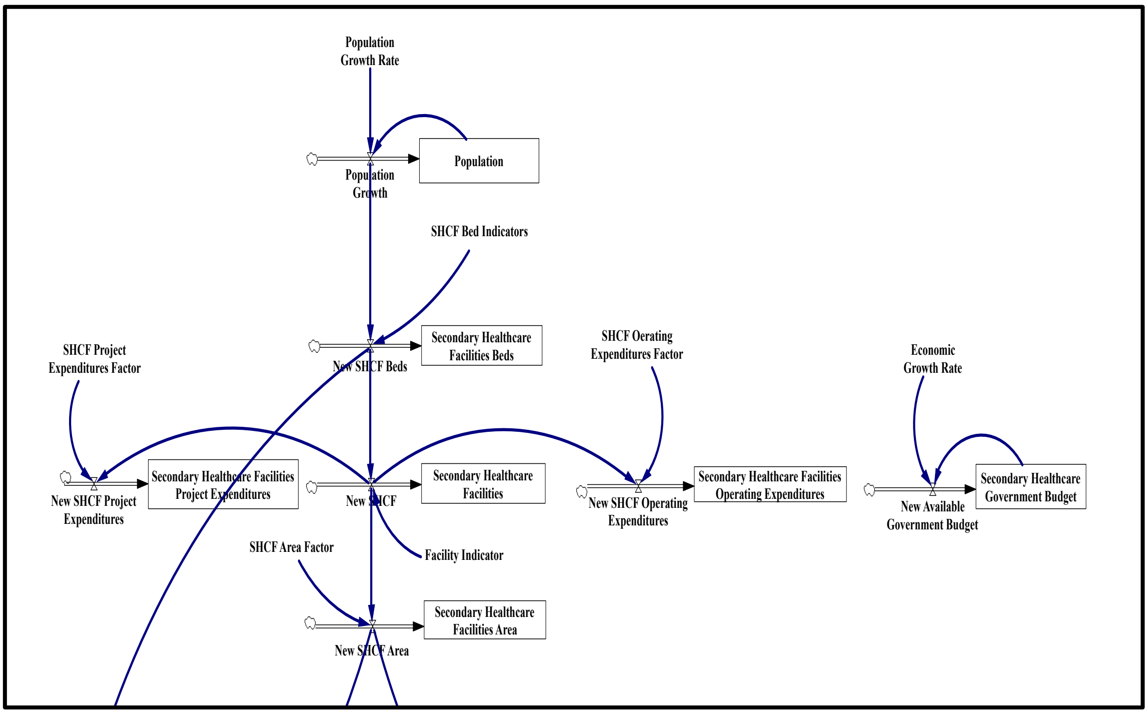


Figure 4.4a - System Dynamics Model of Secondary Healthcare Facilities Resources

Table 4.6a - Equations used to develop SD Model of SHC Facilities Resources

#	Parameter	Equation	Variable Values
1	Population growth	$X'(n+1) = \gamma * X(n)$	n = year , γ = 3% Annually
2	Population	$X(n+1) = X(n) + X'(n+1)$	
3	New SHC Beds	$Beds'(n+1) = X'(n+1) * SI$	SI= 20.4 Beds /10,000 pop.
4	SHC Beds	$Beds(n+1) = Beds(n) + Beds'(n+1)$	
5	New SHC facilities	$F'(n+1) = Beds'(n+1)\ /BF$	BF=300 Beds /Facility
6	SHC Facilities	$F(n+1) = F(n) + F'(n+1)$	
7	New SHC Facilities Area	$FA'(n+1) = F'(n+1) * AF$	SHC FA= 65,000 m2/Facility
8	SHC Facilities Area	$FA(n+1) = FA(n) + FA'(n+1)$	
9	New SHC Project Expenditures	$PExp'(n+1) = F'(n+1) * PF$	PHC PF = MBD 100/Facility
10	SHC Project Expenditures	$PExp(n+1) = PExp(n) + PExp'(n+1)$	
11	New SHC Operating Expenditures	$OExp'(n+1) = F'(n+1) * OF$	PHC OF = MBD 41/Facility
12	SHC Operating Expenditure	$OExp(n+1) = OExp(n) + OExp'(n+1)$	
13	New SHC Government Funds	$GF'(n+1) = GF(n) * (EGR)$	EGR = 3%
14	SHC Government Funds	$GF(n+1) = GF(n) * GF'(n+1)$	

The utilities part of the SD model is shown in Figure 4.4b and the relevant equations used to develop this part of the model are listed in Table 4.6b.

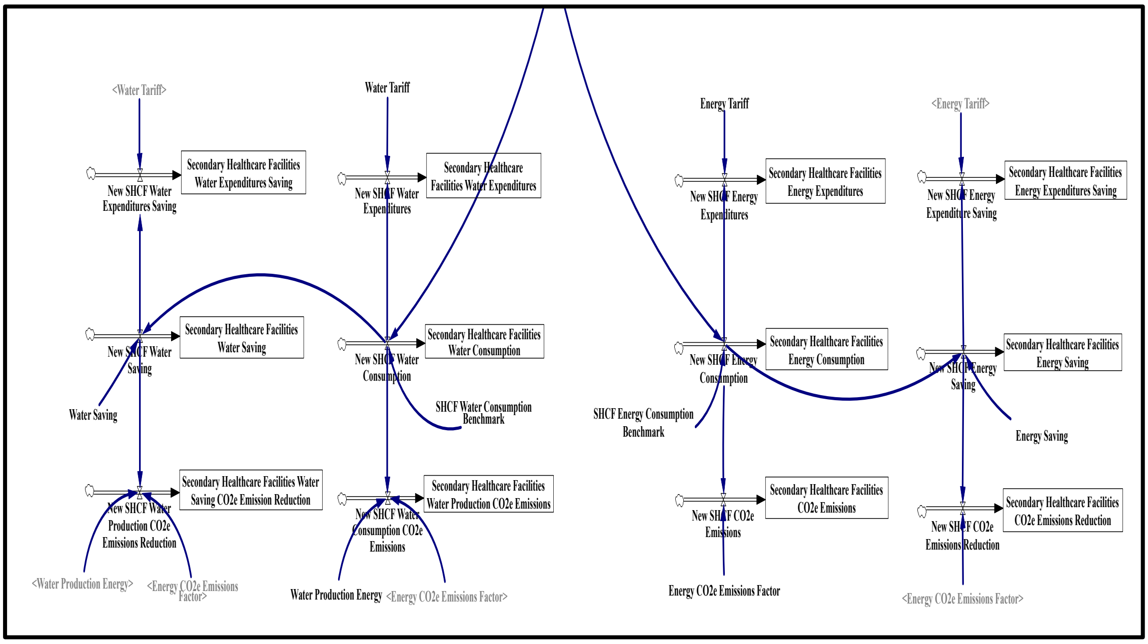


Figure 4.4b - System Dynamics Model of Secondary Healthcare Facilities Utilities

Table 4.6b - Equations used to develop SD Model of SHC Facilities Utilities

#	Parameter	Equation	Variable Values
1	New SHCF Energy Consumption	$E'(n+1) = FA'(n+1) * EBM$	SHC EBM = 322 KWh/m2
2	SHCF Energy Consumption	$E(n+1) = FA(n) * EBM + E'(n+1)$	
3	New SHCF CO2e Emissions	$EEm'(n+1) = E'(n+1) * EF$	EF = 0.55 Kg CO2e/KWh
4	SHCF CO2e Emissions	$EEm(n+1) = E(n) * EF + EEm'(n+1)$	
5	New SHCF Energy Expenditures	$EExp'(n+1) = E'(n+1) * ET$	ET = BD 0.016/KWh
6	SHCF Energy Expenditures	$EExp(n+1) = E(n) * ET + EExp'(n+1)$	
7	New SHCF Water Consumption	$W'(n+1) = FA'(n+1) * WBM$	SHC WBM = 1.35 m3/m2
8	SHCF Water Consumption	$W(n+1) = FA(n) * WBM + W'(n+1)$	
9	New SHCF WP CO2e Emissions	$WPEm'(n+1) = W'(n+1) * WPE * EF$	WPE = 6.00 kWh/m3, EF = 0.55 Kg CO2e/KWh.
10	SHCF WP CO2e Emissions	$WPEm(n+1) = W(n) * WPE * EF + WPEm'(n+1)$	
11	New SHCF Water Expenditures	$WExp'(n+1) = W'(n+1) * WT$	WT = BD 0.300/m3
12	SHCF Water Expenditures	$WExp(n+1) = W(n) * WT + W'(n+1)$	
13	New SHCF Energy Saving	$ES'(n+1) = E'(n+1) * EEF$	EEF = 61.25%

#	Parameter	Equation	Variable Values
14	SHCF Energy Saving	$\mathbf{ES(n+1) = E(n) * EEF + ES'(n+1)}$	
15	New SHCF CO2e Em. Reduction	$\mathbf{EER'(n+1) = ES'(n+1) * EF}$	EF = 0.55 Kg CO2e/KWh
16	SHCF CO2e Emissions Reduction	$\mathbf{EER(n+1) = ES(n) * EF + EER'(n+1)}$	
17	New SHCF Energy Exp. Saving	$\mathbf{EExpS'(n+1) = ES'(n+1) * ET}$	ET = BD 0.016/KWh
18	SHCF Energy Exp. Saving	$\mathbf{EExpS(n+1) = ES(n) * ET + EExpS'(n+1)}$	
19	New PHCF Water Saving	$\mathbf{WS'(n+1) = W'(n+1) * WSF}$	SHC WSF = 32%,
20	PHCF Water Saving	$\mathbf{WS(n+1) = W(n) * WSF + WS'(n+1)}$	
21	New PHCF WP Em. Reduction	$\mathbf{WPER'(n+1) = WS'(n+1) * WPE * EF}$	WPE = 6.00 kWh/m3 EF = 0.55 Kg CO2e/KWh
22	PHCF WP Emissions Reduction	$\mathbf{WPER(n+1) = WS(n) * WPE * EF + WPER'(n+1)}$	
23	New PHCF Water Exp. Saving	$\mathbf{WExpS'(n+1) = WS'(n+1) * WT}$	WT = BD 0.300/m3
24	PHCF Water Exp. Saving	$\mathbf{WExpS(n+1) = WS(n) * WT + WExpS'(n+1)}$	

The Medical Waste part of the SD model is shown in Figure 4.4c and the relevant equations used to develop this part of the model are listed in Table 4.6c.

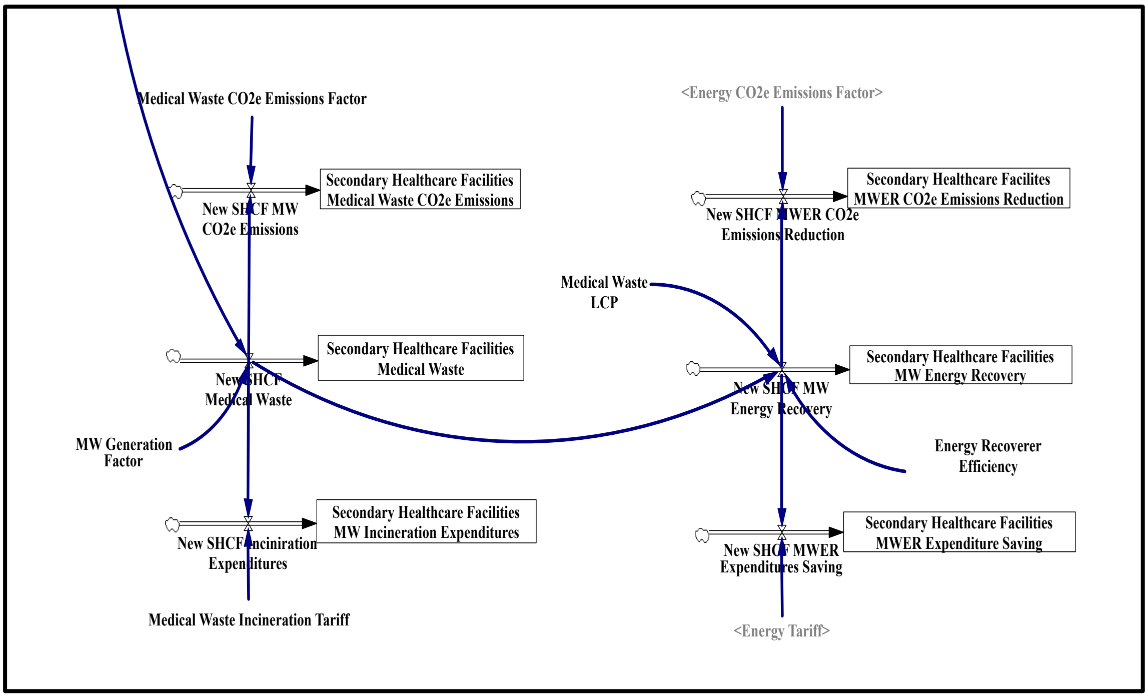


Figure 4.4c - System Dynamics Model of Secondary Healthcare Facilities Medical Waste

Table 4.6c - Equations used to develop SD Model of SHC Facilities Medical Waste

#	Parameter	Equation	Variable Values
1	New SHCF MW generation	$\mathbf{MW'(n+1) = SHC\ Beds'(n+1) * MWF}$	SHC MWF = 2.0 Kg/Bed/Ann.
2	SHCF MW generation	$\mathbf{MW(n+1) = MW(n) + MW'(n+1)}$	
3	New SHCF MWI CO2e Emissions	$\mathbf{MWEm'(n+1) = MW'(n+1) * MWEF}$	MWEF = 0.86 Kg CO2e/Kg
4	SHCF MWI CO2e Emissions	$\mathbf{MWEm(n+1) = MW(n) * MWEF + MWEm'(n+1)}$	
5	New SHCF MWI Expenditures	$\mathbf{MWIExp'(n+1) = MW'(n+1) * IT}$	IT = BD 0.210/Kg
6	SHCF MWI Expenditures	$\mathbf{MWIExp(n+1) = MW(n) * IT + MWIExp'(n+1)}$	
7	New SHCF MW Energy Recovery	$\mathbf{MWER'(n+1) = MW'(n+1) * LCP * RE}$	LCP = 4 Kw/Kg, RE = 0.77
8	SHCF MW Energy Recovery	$\mathbf{MWER(n+1) = MW(n) * LCP * RE + MWER'(n+1)}$	
9	New SHCF MWI CO2e Em. Reduction	$\mathbf{MWEmR'(n+1) = MWER'(n+1) * MWEF}$	MWEF = 0.86 Kg CO2e/Kg
10	SHCF MWI Emission Reduction	$\mathbf{MWEmR(n+1) = MWER(n) * MWEF + MWEmR'(n+1)}$	MWEF = 0.86 Kg CO2e/Kg
11	New SHCF MW Exp. Saving	$\mathbf{MWExpS'(n+1) = MWER'(n+1) * ET}$	ET = BD 0.016/KWh
12	SHCF MW Exp. Saving	$\mathbf{MWExpS(n+1) = MWER(n) * ET + MWExpS'(n+1)}$	

4.3.4. Public Health Facilities

Development of Public Health Facilities models pass through a number of phases. The first phase is related to the assessment of the facilities demand and financial resources required, quantifying utilities in term of energy consumption, water consumption and its environmental and economic impacts. The second phase of the model development is related to the implementation of some energy efficiency, water reduction and introduction of renewable-base strategies and its effect in reducing environmental and economic impacts. The secondary data needed to develop the models are list of Public Health facilities, facilities' areas, facilities' annual energy consumption, facilities' annual water consumption, new facilities' construction cost, new facilities' annual operating cost.

Vensim software (www.vensim.com) is selected to run and analyse the developed model due to the good software capabilities and it is popularity in the academic field. Bahrain healthcare system is selected as a research context to extract variable values.

System Dynamics Models of Global Public Health Services is shown in Appendix-O

The resources part of the SD model is shown in Figure 4.5a and the relevant equations used to develop this part of the model are listed in Table 4.7a.

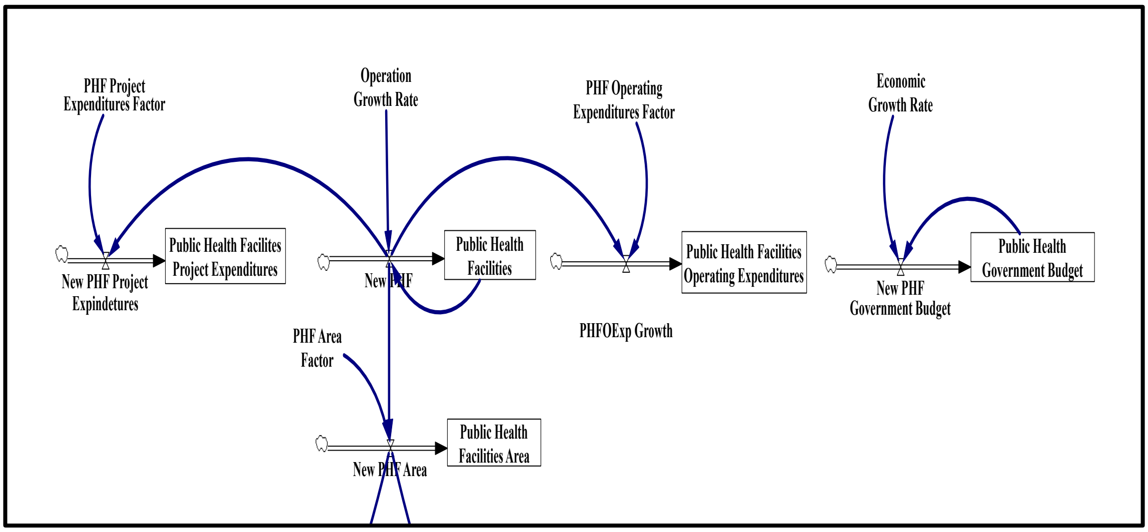


Figure 4.5a - System Dynamics Model of Public Health Facilities Resources

Table 4.7a - Equations used to develop SD Models of PH Facilities Resources

#	Parameter	Equation	Variable Values
1	New PH Facilities	$\mathrm{F'(n+1)} = \mathrm{F(n)} * \mathrm{FGR}$	n = year, FGR=3% Annually
2	PH Facilities	$\mathrm{F(n+1)} = \mathrm{F(n)} + \mathrm{F'(n+1)}$	
3	New PHF Area	$\mathrm{FA'(n+1)} = \mathrm{F'(n+1)} * \mathrm{AF}$	PHF AF = 10,000 m2/Facility
4	PHF Area	$\mathrm{FA(n+1)} = \mathrm{FA(n)} + \mathrm{FA'(n+1)}$	
5	New PHF Project Expenditures	$\mathrm{PExp'(n+1)} = \mathrm{F'\,(n+1)} * \mathrm{PF}$	PHF PF = MBD 4/Facility
6	PHC Project Expenditures	$\mathrm{PExp(n+1)} = \mathrm{PExp(n)} + \mathrm{PExp'\,(n+1)}$	
7	New PHF Operating Expenditures	$\mathrm{OExp'(n+1)} = \mathrm{F'\,(n+1)} * \mathrm{OF}$	PHF OF = MBD 3.00/Facility
8	PHC Operating Expenditure	$\mathrm{OExp(n+1)} = \mathrm{OExp(n)} + \mathrm{OExp'\,(n+1)}$	
9	New PHC Government Funds	$\mathrm{GF'(n+1)} = \mathrm{GF(n)} * \mathrm{(EGR)}$	EGR = 3%
10	PHC Government Funds	$\mathrm{GF(n+1)} = \mathrm{GF(n)} * \mathrm{GF'(n+1)}$	

The utilities part of the SD model is shown in Figure 4.5b and the relevant equations used to develop this part of the model are listed in Table 4.7b.

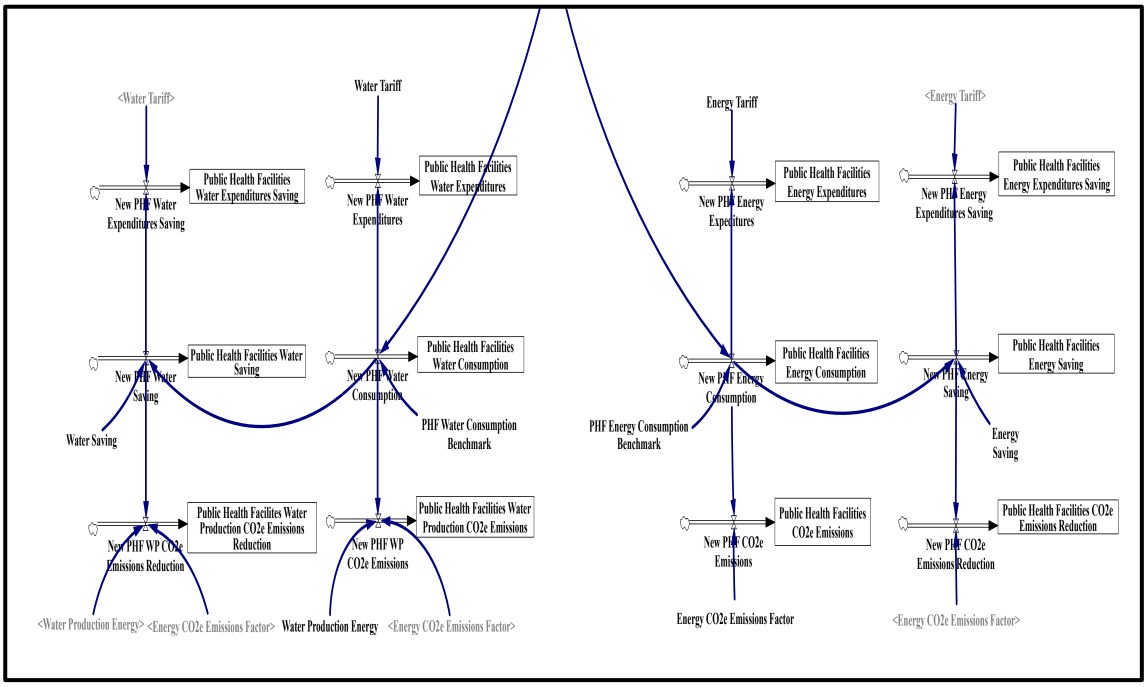


Figure 4.5b - System Dynamics Model of Public Health Facilities Utilities

Table 4.7b - Equations used to develop SD Model of PH Facilities Utilities

#	Parameter	Equation	Variable Values
1	New PHF Energy Consumption	$\mathbf{E'(n+1) = FA'(n+1) * EBM}$	PHC EBM = 206 KWh/m2
2	PHF Energy Consumption	$\mathbf{E\,(n+1) = FA(n) * EBM + E'(n+1)}$	
3	New PHF CO2e Emissions	$\mathbf{EEm'(n+1) = E'(n+1) * EF}$	EF = 0.55 Kg CO2e/KWh
4	PHF CO2e Emissions	$\mathbf{EEm(n+1) = E(n) * EF + EEm'(n+1)}$	
5	New PHF Energy Expenditures	$\mathbf{EExp'(n+1) = E'(n+1) * ET}$	ET = BD 0.016/KWh
6	PHF Energy Expenditures	$\mathbf{EExp(n+1) = E(n) * ET + EExp'(n+1)}$	
7	New PHF Water Consumption	$\mathbf{W'(n+1) = FA'(n+1) * WBM}$	PHC WBM = 1.25 m3/m2
8	PHF Water Consumption	$\mathbf{W(n+1) = FA(n) * WBM + W'(n+1)}$	
9	New PHF WP CO2e Emissions	$\mathbf{WPEm'(n+1) = W'(n+1) * WPE * EF}$	WPE = 6.00 kWh/m3, EF = 0.55 Kg CO2e/KWh.
10	PHF WP CO2e Emissions	$\mathbf{WPEm(n+1) = W(n) * WPE * EF + WPEm'(n+1)}$	
11	New PHF Water Expenditures	$\mathbf{WExp'(n+1) = W'(n+1) * WT}$	WT = BD 0.300/m3
12	PHF Water Expenditures	$\mathbf{WExp(n+1) = W(n) * WT + W'(n+1)}$	
13	New PHF Energy Saving	$\mathbf{ES'(n+1) = E'(n+1) * EEF}$	EEF = 61.25%
14	PHF Energy Saving	$\mathbf{ES(n+1) = E(n) * EEF + ES'(n+1)}$	
15	New PHF CO2e Em. Reduction	$\mathbf{EER'(n+1) = ES'(n+1) * EF}$	EF = 0.55 Kg CO2e/KWh
16	PHF CO2e Emissions Reduction	$\mathbf{EER(n+1) = ES(n) * EF + EER'(n+1)}$	
17	New PHF Energy Exp. Saving	$\mathbf{EExpS'(n+1) = ES'(n+1) * ET}$	ET = BD 0.016/KWh
18	PHF Energy Exp. Saving	$\mathbf{EExpS(n+1) = ES(n) * ET + EExpS'(n+1)}$	
19	New PHF Water Saving	$\mathbf{WS'(n+1) = W'(n+1) * WSF}$	PHC WSF = 10%,
20	PHF Water Saving	$\mathbf{WS(n+1) = W(n) * WSF + WS'(n+1)}$	
21	New PHF WP Em. Reduction	$\mathbf{WPER'(n+1) = WS'(n+1) * WPE * EF}$	WPE = 6.00 kWh/m3 EF = 0.55 Kg CO2e/KWh
22	PHF WP Emissions Reduction	$\mathbf{WPER(n+1) = WS(n) * WPE * EF + WPER'(n+1)}$	
23	New PHF Water Exp. Saving	$\mathbf{WExpS'(n+1) = WS'(n+1) * WT}$	WT = BD 0.300/m3
24	PHF Water Exp. Saving	$\mathbf{WExpS(n+1) = WS(n) * WT + WExpS'(n+1)}$	

4.3.5. Administration Services (Office Buildings)

Development of Office Buildings models pass through a number of phases. The first phase is related to the assessment of the facilities demand and financial resources required, quantifying utilities in term of energy consumption, water consumption and its environmental and economic impacts. The second phase of the model development is related to the implementation of some energy efficiency, water reduction and introduction of renewable-base strategies and its effect in reducing environmental and economic impacts. The secondary data needed to develop the models are list of Administration (Office Buildings) facilities, facilities' areas, facilities' annual energy consumption, facilities' annual water consumption, new facilities' construction cost, new facilities' annual operating cost.

Vensim software (www.vensim.com) is selected to run and analyse the developed model due to the good software capabilities and it is popularity in the academic field. Bahrain healthcare system is selected as a research context to extract variable values.

System Dynamics Models of Global Administration (Office Buildings) facilities is shown in Appendix-O

The resources part of the SD model is shown in Figure 4.6a and the relevant equations used to develop this part of the model are listed in Table 4.8a.

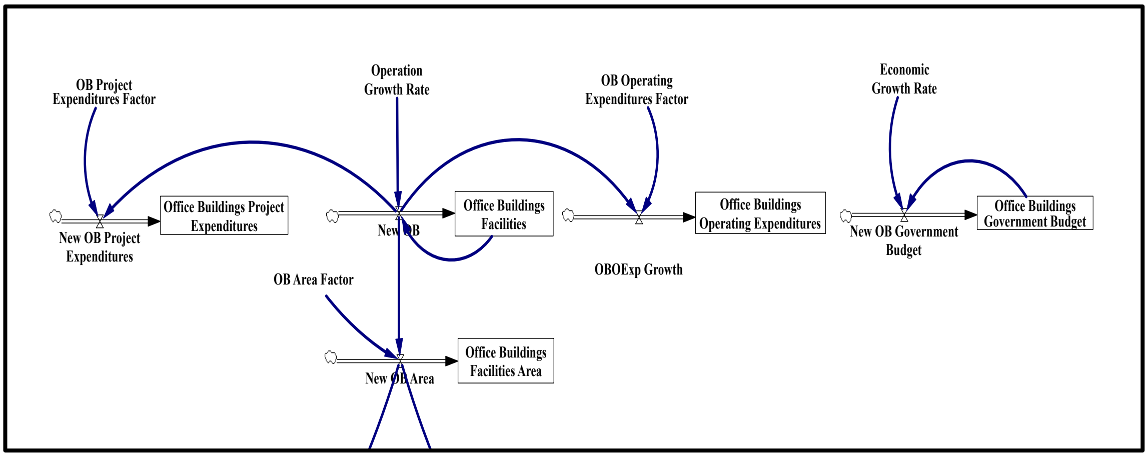


Figure 4.6a - System Dynamics Model of Office Buildings Resources

Table 4.8a - Equations used to develop SD Models of OB Resources

#	Parameter	Equation	Variable Values
1	New OB Facilities	$F'(n+1) = F(n) * FGR$	n = year, FGR=3% Annually
2	OB Facilities	$F(n+1) = F(n) + F'(n+1)$	
3	New OB Area	$FA'(n+1) = F'(n+1) * AF$	OB AF = 10,000 m2/Facility
4	OB Area	$FA(n+1) = FA(n) + FA'(n+1)$	
5	New OB Project Expenditures	$PExp'(n+1) = F'(n+1) * PF$	OB PF = MBD 3/Facility
6	OB Project Expenditures	$PExp(n+1) = PExp(n) + PExp'(n+1)$	
7	New OB Operating Expenditures	$OExp'(n+1) = F'(n+1) * OF$	OB OF = MBD 2.75/Facility
8	OB Operating Expenditure	$OExp(n+1) = OExp(n) + OExp'(n+1)$	
9	New OB Government Funds	$GF'(n+1) = GF(n) * (EGR)$	EGR = 3%
10	OB Government Funds	$GF(n+1) = GF(n) * GF'(n+1)$	

The utilities part of the SD model is shown in Figure 4.6b and the relevant equations used to develop this part of the model are listed in Table 4.8b.

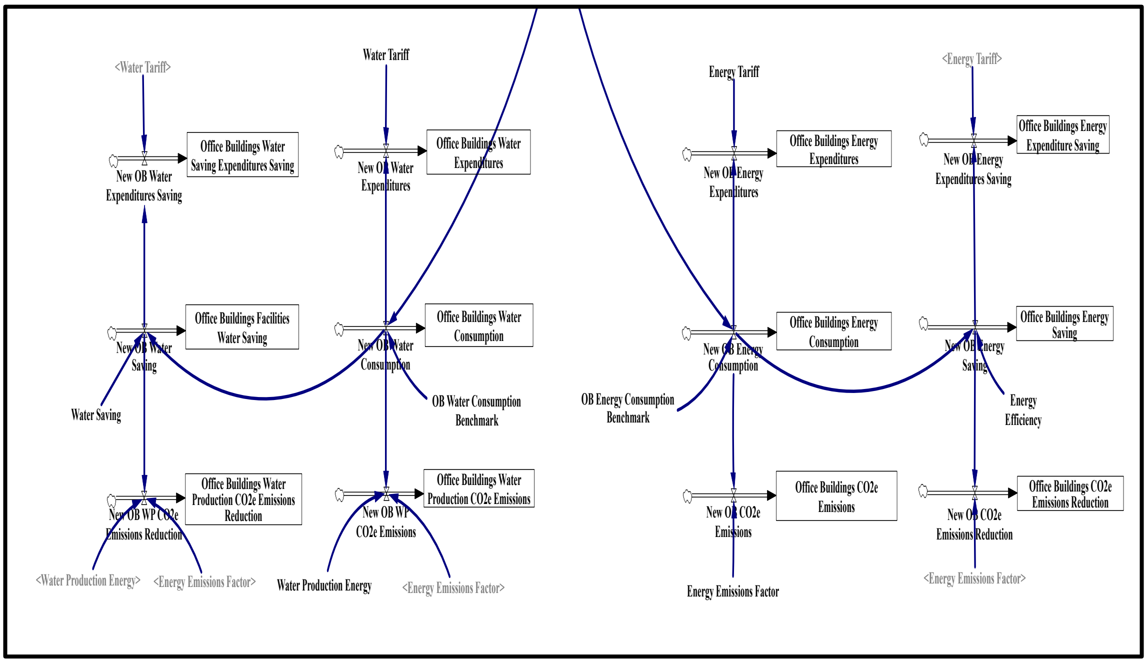


Figure 4.6b - System Dynamics Model of Office Buildings Utilities

Table 4.8b - Equations used to develop SD Model of OB Utilities

#	Parameter	Equation	Variable Values
1	New PHF Energy Consumption	$E'(n+1) = FA'(n+1) * EBM$	OB EBM = 203 KWh/m2
2	PHF Energy Consumption	$E\ (n+1) = FA(n) * EBM + E'(n+1)$	
3	New PHF CO2e Emissions	$EEm'(n+1) = E'(n+1) * EF$	EF = 0.55 Kg CO2e/KWh
4	PHF CO2e Emissions	$EEm(n+1) = E(n) * EF + EEm'(n+1)$	
5	New PHF Energy Expenditures	$EExp'(n+1) = E'(n+1) * ET$	ET = BD 0.016/KWh
6	PHF Energy Expenditures	$EExp(n+1) = E(n) * ET + EExp'(n+1)$	
7	New PHF Water Consumption	$W'(n+1) = FA'(n+1) * WBM$	OB WBM = 0.58 m3/m2
8	PHF Water Consumption	$W(n+1) = FA(n) * WBM + W'(n+1)$	
9	New PHF WP CO2e Emissions	$WPEm'(n+1) = W'(n+1) * WPE * EF$	WPE = 6.00 kWh/m3, EF = 0.55 Kg CO2e/KWh.
10	PHF WP CO2e Emissions	$WPEm(n+1) = W(n) * WPE * EF + WPEm'(n+1)$	
11	New PHF Water Expenditures	$WExp'(n+1) = W'(n+1) * WT$	WT = BD 0.300/m3
12	PHF Water Expenditures	$WExp(n+1) = W(n) * WT + W'(n+1)$	
13	New PHF Energy Saving	$ES'(n+1) = E'(n+1) * EEF$	EEF = 61.25%
14	PHF Energy Saving	$ES(n+1) = E(n) * EEF + ES'(n+1)$	
15	New PHF CO2e Em. Reduction	$EER'(n+1) = ES'(n+1) * EF$	EF = 0.55 Kg CO2e/KWh
16	PHF CO2e Emissions Reduction	$EER(n+1) = ES(n) * EF + EER'(n+1)$	
17	New PHF Energy Exp. Saving	$EExpS'(n+1) = ES'(n+1) * ET$	ET = BD 0.016/KWh
18	PHF Energy Exp. Saving	$EExpS(n+1) = ES(n) * ET + EExpS'(n+1)$	
19	New PHF Water Saving	$WS'(n+1) = W'(n+1) * WSF$	OB WSF = 10%,
20	PHF Water Saving	$WS(n+1) = W(n) * WSF + WS'(n+1)$	
21	New PHF WP Em. Reduction	$WPER'(n+1) = WS'(n+1) * WPE * EF$	WPE = 6.00 kWh/m3 EF = 0.55 Kg CO2e/KWh
22	PHF WP Emissions Reduction	$WPER(n+1) = WS(n) * WPE * EF + WPER'(n+1)$	
23	New PHF Water Exp. Saving	$WExpS'(n+1) = WS'(n+1) * WT$	WT = BD 0.300/m3
24	PHF Water Exp. Saving	$WExpS(n+1) = WS(n) * WT + WExpS'(n+1)$	

4.4. Validation of System Dynamics Models

The developed System Dynamics Model shall be validated using two tests; i.e. Model Structure Test and Model Behaviour Test (Forrester et. al., 1980).

4.4.1. Model Structure Test

Structure Validation: In this test, the model structure consistency with relevant to descriptive knowledge of the system is checked by applying two approaches, using real knowledge during the construction of the model and adoption of the sub-models and structures (Forrester et. al., 1980).

First, during the construction of the model, Bahrain Health Statistics (BHS, 2012) and real knowledge about Bahrain Healthcare System was used. Second, adoption of the sub-models and structures of the existing healthcare models, as given in Table 4.9, are used. The casual relations developed in the model based on the statistical data and available knowledge of the real system provide a sort of empirical structure validation while the adopted sub-models of the existing models serve as a theoretical structure validation.

Table 4.9 - Adopted Sub-models and Structures of the existing healthcare System

Structures / Concepts	Reference	Remarks
Population Growth Rate & Population	CIO (2013), BHS (2012), Ciplak et. al. (2012) P.579	Casual Structure was adopted.
Population & Healthcare Facilities and Services	CIO (2013), BHS (2012), Ciplak et. al. (2012) P.579	Casual Structure was adopted.
Healthcare Facilities and Services & Environmental Challenges	Chaeruk et. al. (2007) p.445, Ciplak et. al. (2012) P.579, Asif et. al. (2007) p. 1389, Rabanimotlagh et. al. (2014), Lombard et al. (2008) P. 394.	Casual Structure was adopted.
Environmental Challenges & Health Risks	Asif et. al. (2007) p.1390	Casual Structure was adopted.
Health Risks & Population Growth	Chaeruk et. al. (2007) p.445	Casual Structure was adopted.
Healthcare Facilities and Services & Healthcare Expenditures	BHS (2012)	Casual Structure was adopted.
Environmental Challenges & Healthcare Expenditures	Rabanimotlagh et. al. (2014), Eleyan et. al. (2013) p. 993	Casual Structure was adopted.
Health Risks & Healthcare Expenditures	Chaeruk et. al. (2007) p.445	Casual Structure was adopted.

Parameter Verification: In this test, the parameters consistency with relevant to descriptive and numerical knowledge of the system is checked (Forrester et. al., 1980) by assigning values to the parameters of the model sourced from the existing knowledge and numerical data of Kingdom of Bahrain (BHS, 2012). These parameters, their values and the sources, are listed in Table 4.10.

Table 4.10 - Model parameters and their assigned values

Parameters in the Model	Assigned Value (PHC)	Assigned Value (SHC)	Source
Bahrain Population Growth Rate	3%	3%	CIO (2013)
Indicator (per 10,000 of pop.)	0.2 Facilities	20.4 Beds	BHS (2012)
Operating Expenditures	MBD. 3.0	MBD. 41.0	Good Practice Real Data
Project Expenditures	MBD. 6.0	MBD. 100.0	Good Practice Real Data
Facility Required Area	10,000 m2	65,000 m2	Good Practice Real Data
Energy Tariff	BD. 0.016 / KWh	BD. 0.016 / KWh	(EWA)
Water Tariff	BD. 0.300 / m3	BD. 0.300 / m3	(EWA)
Water Prod. Energy Consumption	6.00 KWh / m3	6.00 KWh / m3	(EWA)
Energy Emission Factor	0.55 kg CO2e / KWh	0.55 kg CO2e / KWh	(US Energy Inf. Admin.) http://www.eia.gov/
Medical Waste Generation	0.1 Kg /Patient/day	2.0 Kg /Bed/ day	Ibrahim (2008)
Medical Waste Incineration Tariff	BD. 0.210 / kg	BD. 0.210 / kg	Good Practice Real Data
Medical Waste Emission Factor	0.86 kg CO2e / kg	0.86 kg CO2e / kg	Levendis et. al. (2001)

Boundary Adequacy (Structure): Boundary adequacy consistent with the purpose of the model (Forrester et. al., 1980), most of the major aggregates such as facilities, areas, project expenditures, operating expenditures, energy consumptions, water consumptions, waste generations, costs, savings and emissions are generated endogenously. Some variables such as population growth, immigration rate, economic growth, legislations and technologies are exogenous variables.

Dimensional consistency: This test is required to check that each equation used in the model is dimensionally consistent (Forrester et. al., 1980). To satisfy this test, some equations representing the model are illustrated:

- To forecast **population growth**:

$$\boldsymbol{X'n+1 = \gamma * Xn}$$

Where: proceeding year n=2012, $\mathbf{X}2012 = 1{,}234{,}900$ population and $\boldsymbol{\gamma}$ = 3%

$$\boldsymbol{X}2013\ [\boldsymbol{Population}] = 3\%\ [\boldsymbol{dimensionless}] * \boldsymbol{X}2012\ [\boldsymbol{Population}]$$

- To forecast future Primary Healthcare Facilities:

$$\boldsymbol{F_{n+1} = Fn + X'n + 1 * PI}$$

Where: PI = facilities per 10,000 of Population = 0.2 /10,000, $\boldsymbol{F}2012 = 25$

$$\boldsymbol{F}2013\ [facility] = \boldsymbol{F}2012\ [\boldsymbol{facility}] + \boldsymbol{X}n + 1\ [\cancel{\boldsymbol{population}}] * \boldsymbol{PI}\ [\frac{\boldsymbol{facility}}{\cancel{\boldsymbol{population}}}]$$

From the two equations it is clear that the values are based on existing knowledge of the real system and the equations are dimensionally consistent.

4.4.2. Model Behaviour Test

To validate the developed model, true behaviour of the model is examined using historical data of Bahrain population growth and healthcare facilities area development.

Behaviour reproduction: The aim of this test is to check whether the developed model endogenously generate the modes, phases, frequencies and other characteristics of the behaviour of real system (Forrester et. al., 1980).

The historical data of population growth between years1991-2000 as generated in BHS (2012) is shown in Table 4.11 and Figures 4.7.

Table 4.11 - Bahrain Population Historical Data and Model Simulation Results (1991-2010)

Year	Historical Data		Model Simulated	% Error
	Pop.	Growth	Population	
1991	503,052		503,052	0%
1992	516,458	2.7%	525,689	2%
1993	530,225	2.7%	549,345	4%
1994	544,366	2.7%	574,066	5%
1995	558,879	2.7%	599,899	7%
1996	573,792	2.7%	626,894	9%
1997	589,115	2.7%	655,104	11%
1998	604,842	2.7%	684,584	13%
1999	620,989	2.7%	715,390	15%
2000	637,582	2.7%	747,583	17%
2001	661,317	3.7%	781,224	18%
2002	710,554	7.4%	816,379	15%
2003	764,519	7.6%	853,116	12%
2004	823,744	7.7%	891,507	8%
2005	888,824	7.9%	931,624	5%
2006	960,425	8.1%	973,548	1%
2007	1,039,297	8.2%	1,017,360	2%
2008	1,103,496	6.2%	1,063,140	4%
2009	1,178,415	6.8%	1,110,980	6%
2010	1,228,543	4.3%	1,160,970	6%
	Average	**4.8%**		

>

Year	Historical Data		Model Simulated	% Error
	Pop.	Growth	Population	
1991	503,052		503,052	0.0%
1992	516,458	2.7%	516,634	0.0%
1993	530,225	2.7%	530,584	0.1%
1994	544,366	2.7%	544,909	0.1%
1995	558,879	2.7%	559,622	0.1%
1996	573,792	2.7%	574,732	0.2%
1997	589,115	2.7%	590,249	0.2%
1998	604,842	2.7%	606,186	0.2%
1999	620,989	2.7%	622,553	0.3%
2000	637,582	2.7%	639,362	0.3%
	Average	**2.7%**		
2001	661,317	3.7%	661,317	0.0%
2002	710,554	7.4%	706,287	0.6%
2003	764,519	7.6%	754,314	1.3%
2004	823,744	7.7%	805,607	2.2%
2005	888,824	7.9%	860,389	3.2%
2006	960,425	8.1%	918,895	4.3%
2007	1,039,297	8.2%	981,380	5.6%
2008	1,103,496	6.2%	1,048,110	5.0%
2009	1,178,415	6.8%	1,119,390	5.0%
2010	1,228,543	4.3%	1,195,500	2.7%
	Average	**6.8%**		

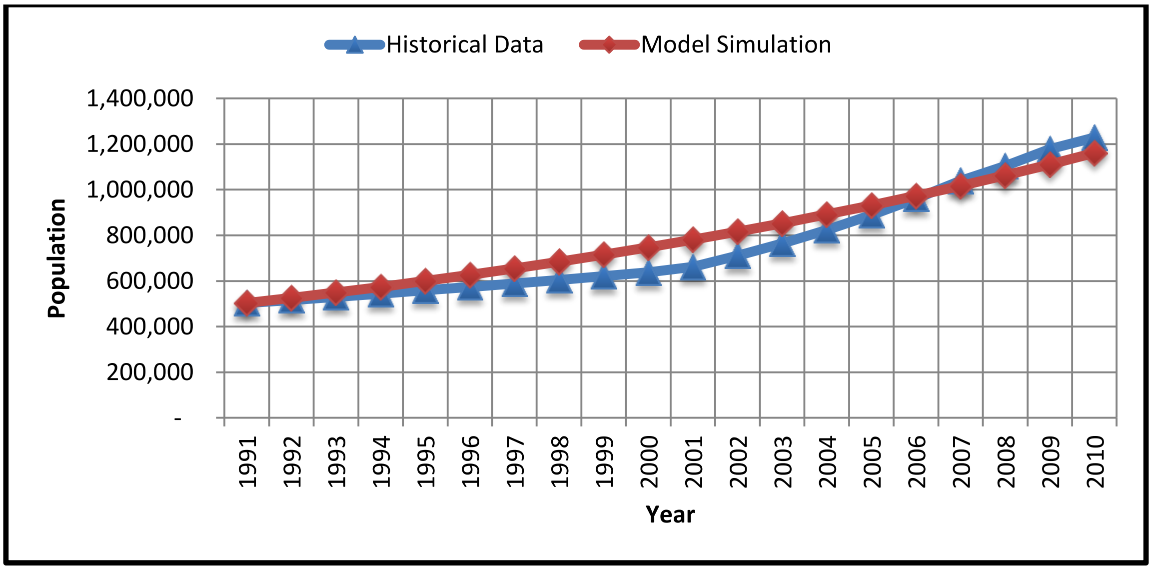


Figure 4.7- Bahrain Population Historical Data and Model Predicted Results (1991-2010)

From Table 4.11, the population growth behaviour between years 1991-2010 pass through two phases. The average population growth for the full period is found to be

4.8%. If the same value is used, the model simulation population is generated with an error reaching up to 18%. If the period is segregated more precisely to two separate phases and take the population growth average for each period separately, then the model simulation population is generated with an erro less than 0.3% for phase 1 and less than 6% for phase 2 as shown in Figure 4.8 and 4.9. This clearly proofs that the developed model is following the characteristic of the behaviour of the real system.

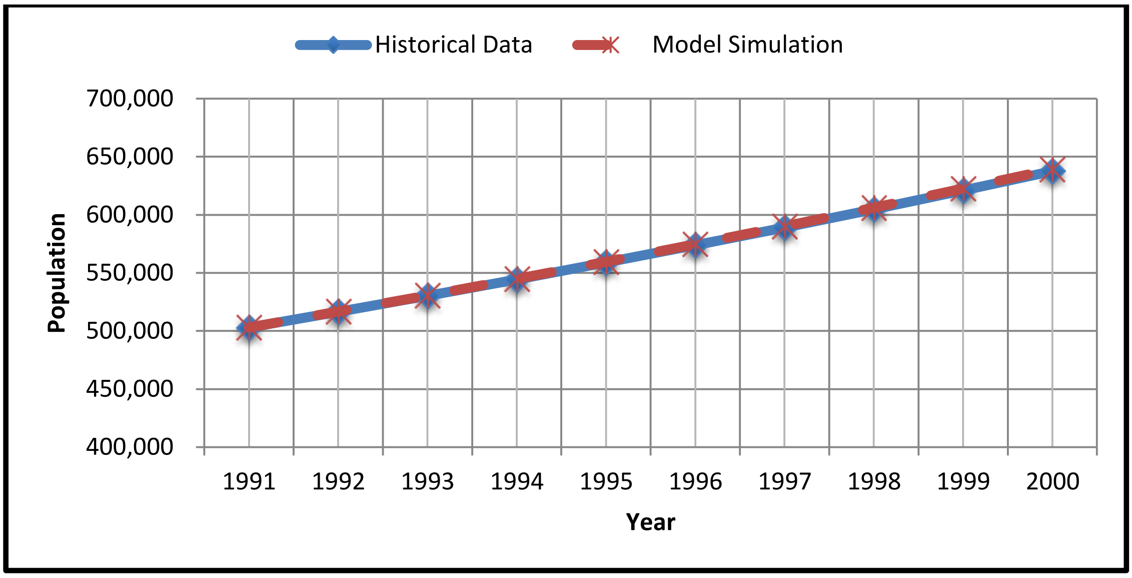


Figure 4.8 - Bahrain Population Historical Data and Model Predicted Results (1991-2000)

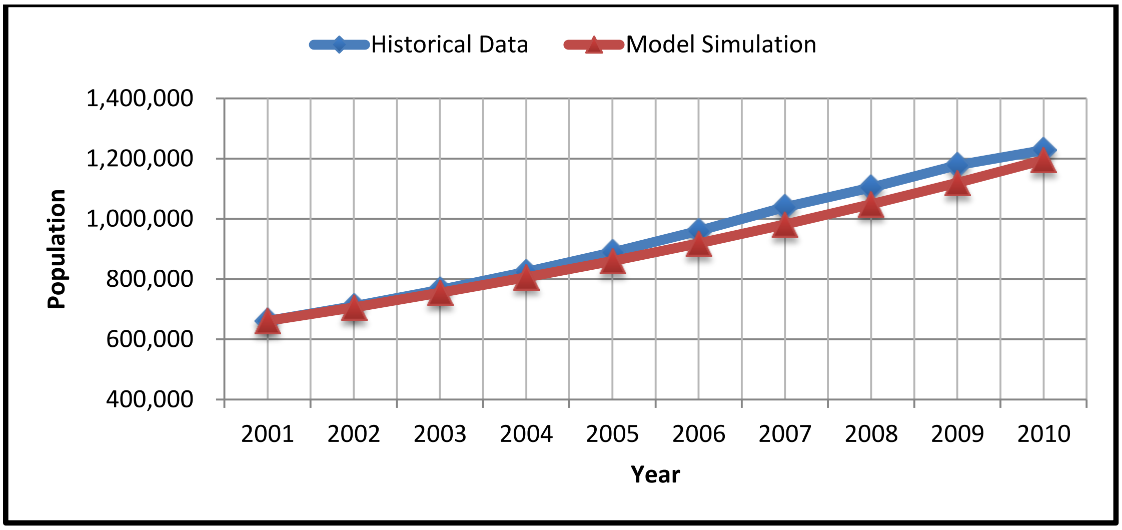


Figure 4.9 - Bahrain Population Historical Data and Model Predicted Results (2001-2010)

Family member: The aim of this test is to check the ability of the model to reproduce the behaviour of other examples of system in the same class as the model (Forrester et. al., 1980).

The historical development of Primary Healthcare Facilities area and Secondary Healthcare Facilities area (MoH secondary data) is shown in Table 4.12 and Figures 4.10 and 4.11.

Table 4.12 - Bahrain Healthcare Facilities Area Historical Data and Model Simulation Results

Year	Historical Data		Model Simulated	% Diff.
	PHC Facilities Area	Annual Area Growth	PHC Facilities Area	
1975	5,017		5,017	0%
1980	12,625	30%	11,305	10%
1985	28,021	24%	22,249	21%
1990	40,025	9%	43,786	9%
1995	56,704	8%	86,171	52%
2000	59,201	1%	169,585	186%
<1995 - 2010	(Policy Change to renovate existing facilities instead of construction of new ones accepts projects in tube)			
	Average	14.5%		

Year	Historical Data		Model Simulated	% Diff.
	SHC Facilities Area	Annual Area Growth	SHC Facilities Area	
1978	41,005		41,005	0%
1983	66,277	62%	52,334	21%
1988	70,081	6%	66,793	5%
1993	78,771	12%	85,247	8%
1998	121,780	55%	108,798	11%
2003	122,840	1%	138,858	13%
2008	133,820	9%	177,221	32%
	Average	5%		

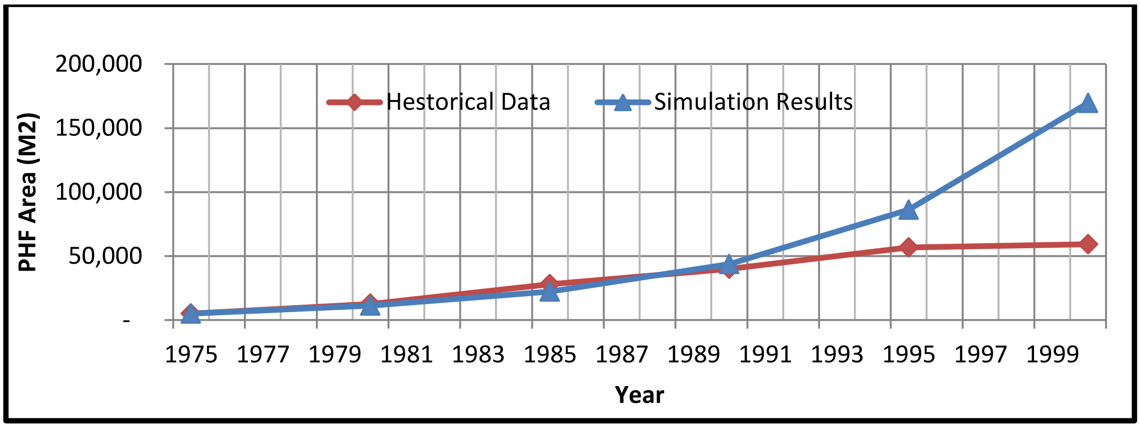


Figure 4.10 - Bahrain PHC Facilities Area Historical Data and Model Predicted Results (1975-2000)

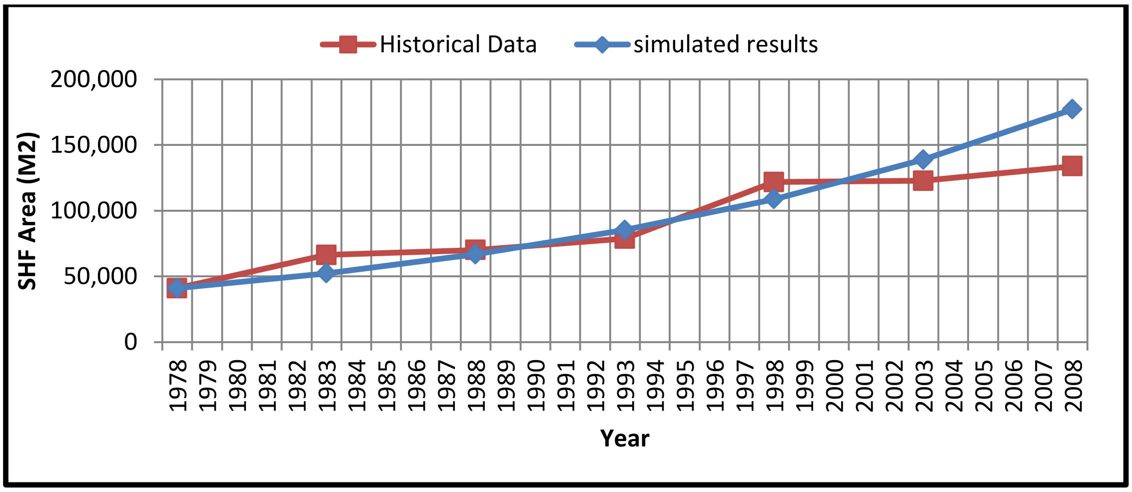


Figure 4.11 - Bahrain SHC Facilities Area Historical Data and Model Predicted Results (1978-2008)

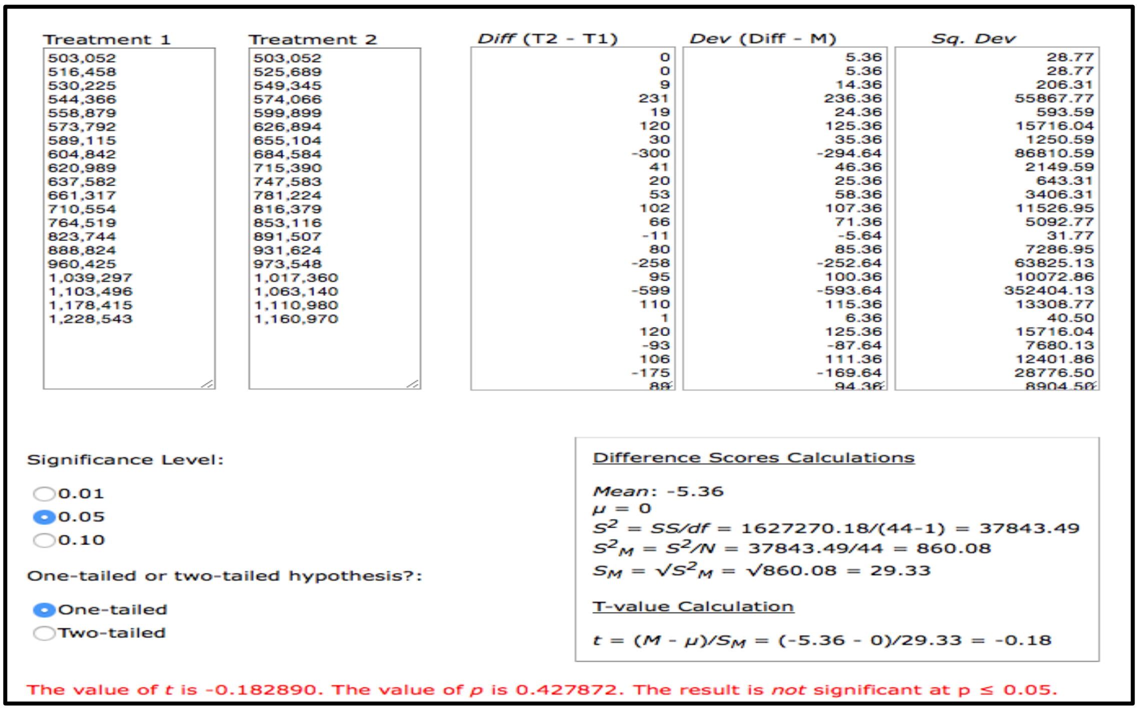
Table 4.9 and Figures 4.10 & 4.11 reflect the ability of the model to reproduce the behaviour of two examples of system in the same class as the model, i.e. Primary Healthcare Facilities and Secondary Healthcare Facilities.

The average annual area growth of Primary Healthcare Facilities is found to be 14.5%. If the same area growth value is used in the model, the model simulatated area growth is generated with a difference up to 52% in the year 1995. This is due to vast facilities construction between years 1975-1995. After 1995, the resources were directed toward Secondary Healthcare Facilities (SMCD Construction) that leads to increase the gap to 186% in year 2000.

The average annual area growth of Secondary Healthcare Facilities is found to be 5%. If the same area growth value is used in the model, the model simulated area growth is generated with a difference up to 32% due to steady facilities construction in the study period that witnessed two major constructions for Salmaniya Medical Complex, SMC construction in 1978 and SMCD construction in 1996.

Statistical character: The previous figures show that outputs of the model have the same statistical characteristics as the outputs of the real system.

Moreover, standard statistical t-tests were performed using Statistical Calculator (2016) to find an evidence of significant difference between two dependent means uses paired values. The results show no significant differences as shown in Figure 4.12 – Figure 4.14.



Treatment 1	Treatment 2	*Diff* (T2 - T1)	*Dev* (Diff - M)	*Sq. Dev*
503,052	503,052	0	5.36	28.77
516,458	525,689	0	5.36	28.77
530,225	549,345	9	14.36	206.31
544,366	574,066	231	236.36	55867.77
558,879	599,899	19	24.36	593.59
573,792	626,894	120	125.36	15716.04
589,115	655,104	30	35.36	1250.59
604,842	684,584	-300	-294.64	86810.59
620,989	715,390	41	46.36	2149.59
637,582	747,583	20	25.36	643.31
661,317	781,224	53	58.36	3406.31
710,554	816,379	102	107.36	11526.95
764,519	853,116	66	71.36	5092.77
823,744	891,507	-11	-5.64	31.77
888,824	931,624	80	85.36	7286.95
960,425	973,548	-258	-252.64	63825.13
1,039,297	1,017,360	95	100.36	10072.86
1,103,496	1,063,140	-599	-593.64	352404.13
1,178,415	1,110,980	110	115.36	13308.77
1,228,543	1,160,970	1	6.36	40.50
		120	125.36	15716.04
		-93	-87.64	7680.13
		106	111.36	12401.86
		-175	-169.64	28776.50
		88	94.36	8904.50

Significance Level:

○ 0.01
● 0.05
○ 0.10

One-tailed or two-tailed hypothesis?:

● One-tailed
○ Two-tailed

Difference Scores Calculations

Mean: -5.36

$\mu = 0$

$S^2 = SS/df = 1627270.18/(44-1) = 37843.49$

$S^2_M = S^2/N = 37843.49/44 = 860.08$

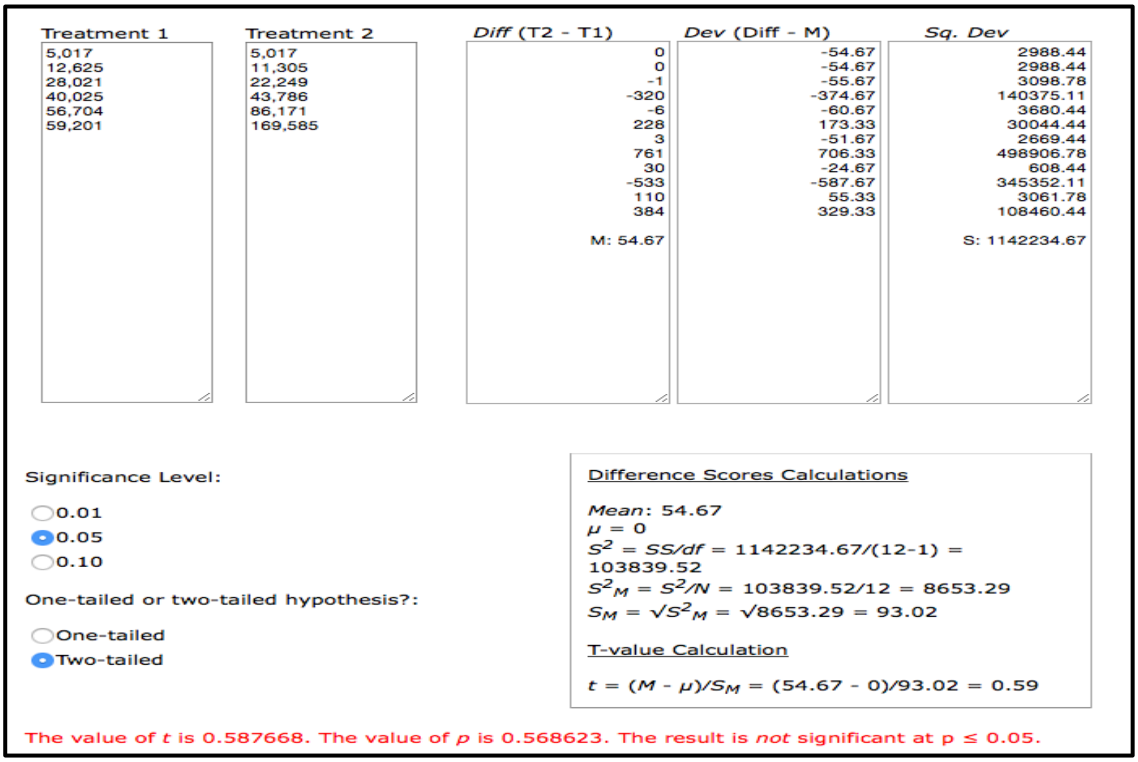
$S_M = \sqrt{S^2_M} = \sqrt{860.08} = 29.33$

T-value Calculation

$t = (M - \mu)/S_M = (-5.36 - 0)/29.33 = -0.18$

The value of *t* is -0.182890. The value of *p* is 0.427872. The result is *not* significant at $p \leq 0.05$.

Figure 4.12 – T-test Results of Bahrain Population (1991 -2010)



Treatment 1	Treatment 2	*Diff* (T2 - T1)	*Dev* (Diff - M)	*Sq. Dev*
5,017	5,017	0	-54.67	2988.44
12,625	11,305	0	-54.67	2988.44
28,021	22,249	-1	-55.67	3098.78
40,025	43,786	-320	-374.67	140375.11
56,704	86,171	-6	-60.67	3680.44
59,201	169,585	228	173.33	30044.44
		3	-51.67	2669.44
		761	706.33	498906.78
		30	-24.67	608.44
		-533	-587.67	345352.11
		110	55.33	3061.78
		384	329.33	108460.44
		M: 54.67		S: 1142234.67

Significance Level:

○ 0.01
● 0.05
○ 0.10

One-tailed or two-tailed hypothesis?:

○ One-tailed
● Two-tailed

Difference Scores Calculations

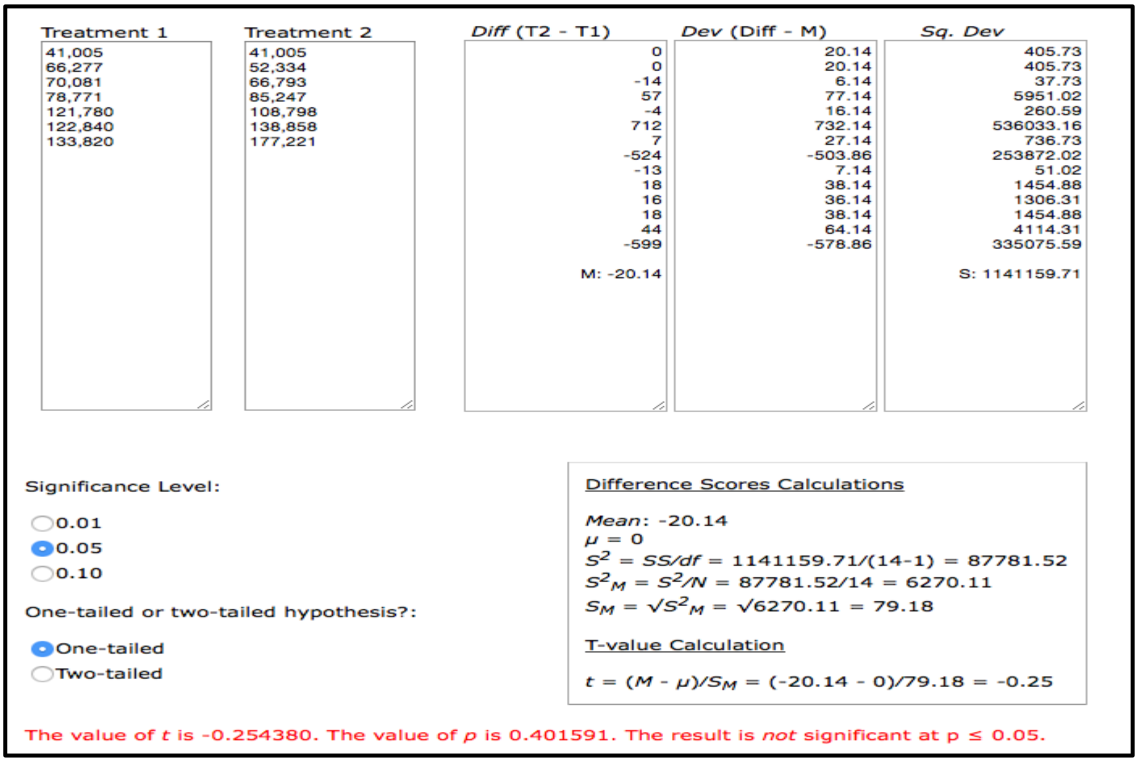
Mean: 54.67
$\mu = 0$
$S^2 = SS/df = 1142234.67/(12-1) = 103839.52$
$S^2_M = S^2/N = 103839.52/12 = 8653.29$
$S_M = \sqrt{S^2_M} = \sqrt{8653.29} = 93.02$

T-value Calculation

$t = (M - \mu)/S_M = (54.67 - 0)/93.02 = 0.59$

The value of *t* is 0.587668. The value of *p* is 0.568623. The result is *not* significant at $p \leq 0.05$.

Figure 4.13 - T-test Results of PHC Area (1975 -2000)



Treatment 1	Treatment 2	*Diff* (T2 - T1)	*Dev* (Diff - M)	*Sq. Dev*
41,005	41,005	0	20.14	405.73
66,277	52,334	0	20.14	405.73
70,081	66,793	-14	6.14	37.73
78,771	85,247	57	77.14	5951.02
121,780	108,798	-4	16.14	260.59
122,840	138,858	712	732.14	536033.16
133,820	177,221	7	27.14	736.73
		-524	-503.86	253872.02
		-13	7.14	51.02
		18	38.14	1454.88
		16	36.14	1306.31
		18	38.14	1454.88
		44	64.14	4114.31
		-599	-578.86	335075.59
		M: -20.14		S: 1141159.71

Significance Level:

○ 0.01
● 0.05
○ 0.10

One-tailed or two-tailed hypothesis?:

● One-tailed
○ Two-tailed

Difference Scores Calculations

Mean: -20.14
$\mu = 0$
$S^2 = SS/df = 1141159.71/(14-1) = 87781.52$
$S^2_M = S^2/N = 87781.52/14 = 6270.11$
$S_M = \sqrt{S^2_M} = \sqrt{6270.11} = 79.18$

T-value Calculation

$t = (M - \mu)/S_M = (-20.14 - 0)/79.18 = -0.25$

The value of *t* is -0.254380. The value of *p* is 0.401591. The result is *not* significant at $p \leq 0.05$.

Figure 4.14 - T-test Results of SHC Area (1978 -2008)

Tests Conclusion:

Based on the conducted tests, there is strong confidence in the structure of the develop model and its ability to generate the right behaviour.

4.5. Chapter Summary

The research methodology uses SD Analysis approach by developing a Casual Loop Diagram (CLD) to frame and understand the relations between different elements and variables of healthcare system. The CLD is validated using Focus Group Interviews. Six groups of healthcare personnel were interviewed to gain insights and obtain perspectives about healthcare services. The validated CLD is numerically transformed to develop SD Model. The developed model was tested using historic data to build confidence in the developed models. The developed SD model was used to study Bahrain's Healthcare Facilities as a research context.

Chapter 5: Implementation and Analysing System Dynamics models

The purpose of this chapter is to satisfy the third objective of this research by following standard methodology to implement and demonstrate SD Analysis models.

Bahrain healthcare system is selected, as a research context to demonstrate SD model, due to the availability of good quality healthcare secondary data, small size of the country that make it good model to implement and test new concepts, limited country resources, country keenness to implement sustainability plans and meet sustainability objectives.

5.1. Environmental and Economic Challenges and Opportunities in Bahrain

Since its establishment in 2000, the Economic Development Board (EDB), in cooperation with the government and a range of partners and stakeholders, has worked to implement a number of development initiatives and raised the performance level of the national economy and supported its on-going sustainability. The EDB has increased economic competitiveness, raised productivity levels and focused on creating a skilled workforce that contributes to the development of the Kingdom of Bahrain (Economic Development Board Report, 2006).

Kingdom of Bahrain launched in October 2008 “Bahrain Economic Vision 2030”. The document presents the comprehensive economic vision and outlines the future economic development. The document highlights sustainability as a guiding principle for the economy and stress that economic growth will not be on the expenses of the environment and well being of people. The vision emphasise Bahraini nationals and residents will enjoy sustainable and attractive living environment by conserving natural spaces for future generation, implementing energy efficiency regulation and directing investments to technologies that reduce carbon emissions, minimising pollution and promoting sustainable energy (Economic Development Board Report, 2008).

Bahrain submitted Initial National Communications to the United Nations Framework Convention on Climate Change (UNFCCC) in March 2005, GCPMREW (2005) and Second National Communications on February 2012, GCPMREW (2012). The document was prepared with public and private involvement with the support of Global Environmental Facility (GEF) and United Nations Environment Programme (UNEP) and reflects the aspects of Bahrain Economic Vision 2030, EDB (2008). The document shows that Bahrain net national emissions in 2000 are 22.374 Million Tonnes CO2e that includes 17.254 Million Tonnes CO2e from energy; 2.515 Million Tonnes CO2e from industrial processes and 2.605 Million Tonnes CO2e from waste Approximately 77% of all GHG emissions is associated with combustion of fossil fuel, 11% from industrial processes and 12% from waste. Over the period 1994 to 2000, GHG emissions increased by 13% from 19.468 Million Tonnes CO2e to 22.374 Million Tonnes CO2e. This is due to increase of energy emissions by 13%, industrial processes by 33%, and waste by 12%.

The document reflects a good intention toward energy efficiency and renewable energy technologies that can help in meeting Bahrain current needs. It shows that there is a widespread perception among policymakers that promoting energy efficiency can be economically beneficial by increasing oil supply available for exports, improving environmental quality and reducing CO2e emissions. Regarding renewable energy, there is growing awareness that Bahrain's future energy situation necessitates an urgent review of the potential development and use of renewable energy resources (BSNC, 2012, p. xxiii).

Currently, There are some pilot renewable energy projects including Wind Turbine installation and Solar Power installations. Middle East and North Africa 2013 report, MENA (2013) shows that Bahrain has a renewable energy target, but this is not supported by renewable energy strategy or plan. The report shows that Bahrain is producing 5 MW from Solar PV and 0.5 MW from Wind with a capacity of 25 MW from biomass and waste.

Although energy efficiency and renewable energy are identified as two strategic options to achieve reduction of CO2e emissions there is not yet any action plan put in place and in the absence of high penetration of these two measures the future CO2e emissions through 2030 are projected to rise rapidly compared to year 2000. It is expected to rise by 37 Million Tonnes to reach about 46 Million Tonnes of CO2e that is equal to grow by 5.6% annually as shown in GCPMREW (2012).

The beginning of Healthcare Services in Bahrain was in year 1892 by an American mission that was practicing in rented property in Bahrain Capital, Manama. The twentieth Century witnessed, in year 1902, the opening of "The American Mission Hospital" as the first hospital in Bahrain and the Gulf. In the same year the British Governor of India ordered to build "The Victoria Memorial Hospital" as a second hospital in the island. The hospital was opened in November 1906 with 12 beds capacity and transferred to Bahrain Government in 1952 to be the origin of Bahrain Healthcare Services (The History of Psychiatric Treatment in Bahrain 1932-2000, 2001).

The twenty-first Century witnessed the healthcare reform program that achieved the following milestones (Economic Development Board Report, 2006):

- The cabinet approval to establish the National Healthcare Regulation Authority to supervise the healthcare system.
- Modifying standards and procedures for the issuance and renewal of licenses for nurses.
- The development of the first draft of the standards of operation and licensing of public and private hospitals in Bahrain.

Number of steps taken to develop a number of operational and administrative areas in Salmaniya medical complex:

- Reducing the waiting time for appointments for ten medical specialties by 95%.
- Reducing the waiting period for appointments for magnetic resonance imaging (MRI) from 223 to 35 days.
- Reducing the waiting period for CT scans from 68 to 21 days.
- Waiting time for operations has been limited to less than 15 minutes from an hour. Additionally, the time it takes to start operations has been reduced to about 20 minutes in all disciplines.

Number of steps taken to develop a number of operational and administrative areas in Primary healthcare service:

- Access to primary healthcare increased by the opening of evening services in 20 new health centres
- A system was developed to classify the cases through the use of nursing staff for all patients attending health centres.
- The duration of patients' visits to the doctor increased from approximately 3 minutes to about 6-8 minutes in four health centres.
- A set of criteria and indicators has been developed for the quality of clinical services and the functioning of the centre.

Bahrain Health Agenda of Ministry of Health, MOH (2012), that is covering Health Improvement Strategy (2011-2014), focused on six strategic objectives to reform Bahrain's health sector, that are:

- Sustaining the population's health through health promotion and prevention,
- Integrating services throughout the health system,
- Putting quality first,
- Providing access for everyone to healthcare services

- Enhancing the Ministry of Health's role in policymaking and governance.
- Ensuring health service sustainability

Although officials at Ministry of Health are committed to fulfil the reform initiatives underlying each of the strategic objectives, economic sustainability is relatively highly considered compared to environmental sustainability that is an important part of health service sustainability and directly influencing social sustainability. It is also noticed that although the cost and expenditure of healthcare services are continually rising there are only limited initiatives been considered to control this rise.

5.2. Healthcare System in Kingdom of Bahrain

Healthcare System in Bahrain, as per Bahrain Health Statistics 2012, BHS (2012), consist of Primary Healthcare Services, Secondary Healthcare Services and Public Health Services distributed among the island as illustrated in Figure 5.1.

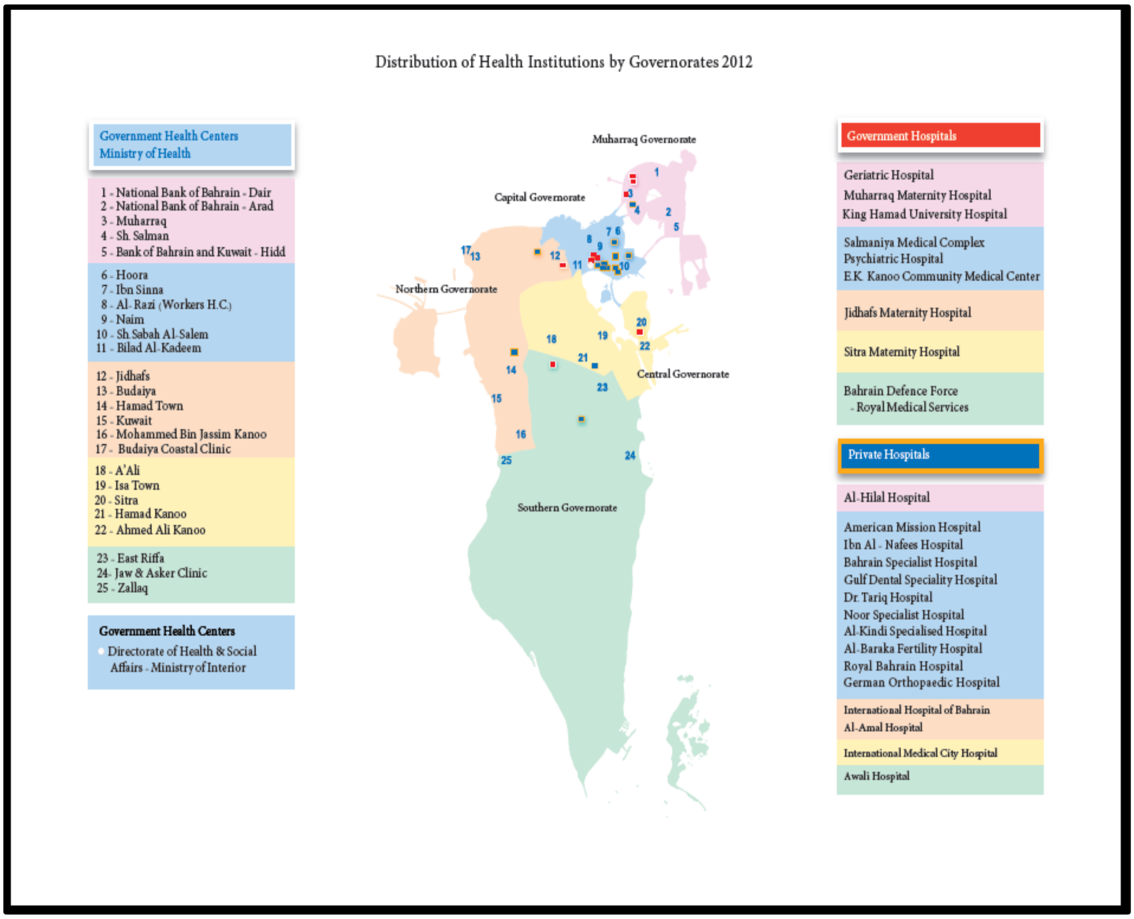


Figure 5.1 - Distribution of Healthcare Facilities in Bahrain, BHS (2012)

Secondary Healthcare Services consist of 24 hospitals, 9 governmental and 15 private, offering 2498 inpatient beds (82% government & 18% private). Salmaniya Medical Complex (SMC) is the main pillar of government health services with 886 beds covering all Medical and Surgical departments, 104 beds for accident and emergency and 74 beds for other applications such as day care and neonatal / special care unit in addition to outpatient clinic services. The government health services supplemented in 2012 with 373-beds general hospital, King Hamad University Hospital (KHUH), to complement SMC operations and accommodate new Medical Services such as Hyperbaric Oxygen treatment and other specialised examinations. Bahrain Defense Force (BDF) Hospital is a 353-beds military Hospital delivering its services to military personnel in addition to public emergency services and outpatient clinic services. BDF has the National Cardiac Center of the Kingdom of Bahrain, Sh. Mohammed Cardiac Centre. The other governmental Secondary Healthcare Services are 226-beds Psychiatric Hospital, two Geriatric Hospitals and three Maternity Hospitals. A 54-beds governmental kidney dialysis center was added to the operation in 2010 (BHS, 2012). Secondary healthcare facilities are summarised in Table 5.1.

Table 5.1 - Secondary Healthcare System (Hospitals) in Bahrain, MoH (2012)

Government Hospitals	Type	Beds	Private Hospitals	Type	Beds
Salmaniya Medical Complex	General	886	International Hospital of Bahrain	General	62
King Hamad University Hospital	General	373	American Mission Hospital	General	37
Bahrain Defense Force Hospital	General	353	Awali Hospital	General	28
Psychiatric Hospital	Specialized	226	Gulf Dental Specialty Hospital	Specialized	8
Geriatric / Long Stay Hospital	Specialized	70	Ibn Al-Nafees Hospital	General	45
E. K. Community Center	Specialized	44	Bahrain Specialist Hospital	General	72
Jidhafs Maternity Hospital	Specialized	54	Noor Specialist Hospital	General	24
Muharraq Maternity Hospital	Specialized	38	Dr. Tariq Hospital	Specialized	22
Sitra Maternity Hospital	Specialized	2	Al-Hillal Hospital	General	45
A. R. Kanoo Kidney Dialysis	Specialized	-	Al-Baraka Fertility Hospital	General	14
			Al-Amal Hospital	General	20
			Al-Kindi Specialized Hospital	General	14
			Inter'l Medical City Hospital	General	-
			German Orthopedic Hospital	Specialized	26
			Royal Bahrain Hospital	General	31
Total		**2046**	**Total**		**452**

Primary healthcare services units and centers are 26 governmental centers (increased to 30 in 2014), 5 company clinics and number of private clinics. Primary healthcare facilities are summarised in Table 5.2.

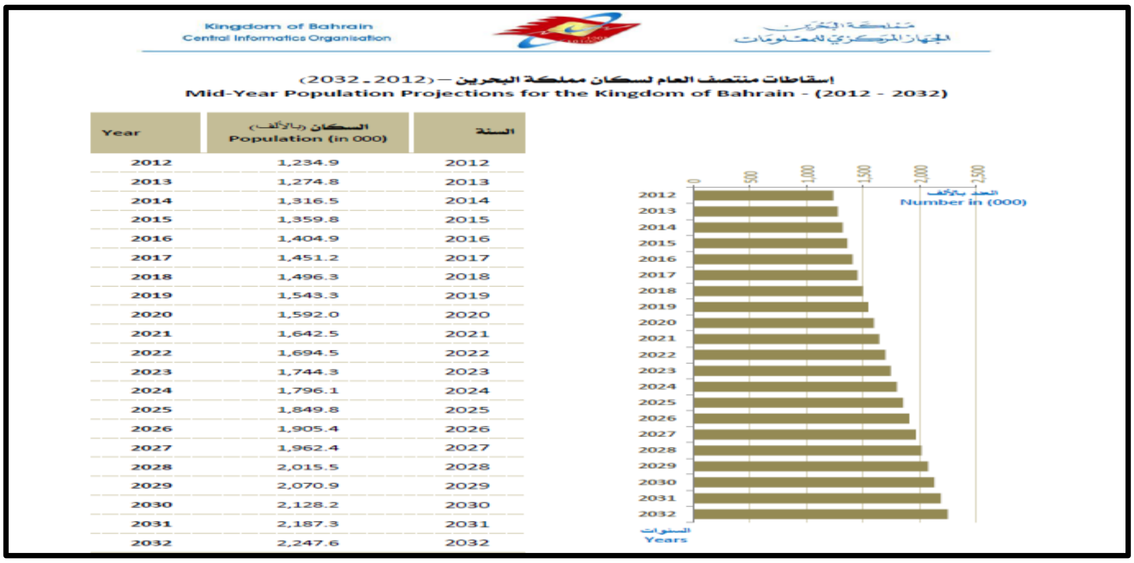
The infrastructure of the healthcare system additionally includes a Public Health Department, 3 Environmental Health Centers (Pest Control), a WHO accredited Public Health Laboratory, a WHO accredited Drug Quality Control Laboratory and number of office buildings.

Table 5.2 - Primary Healthcare System (Health Centers) in Bahrain, MoH (2012)

Government and Private Health Centers / Clinics	
Health Region I Muharraq Sh. Salman National Bank of Bahrain - Arad National Bank of Bahrain - Dair Bank of Bahrain and Kuwait - Hidd Halat Bu-Maher (2014) Bahrain International Airport Clinic	**Health Region II** Naim Ibn-Sinna Sh. Sabah Al Salem Al-Hoora Al-Razi (Workers H.C.) Ministry of Interior Clinic
Health Region III Isa Town Jidhafs Budaiya Bilad Al-Kadeem A' Ali Budaiya Coastal Clinic	**Health Region IV** Sitra Hamad Kanoo East Riffa'a Ahmed Ali Kanoo Y. A. Engineer (2014) Sh. Jabber Al-Subah (2014)
Health Region V Hamad Town Mohammed Jassim Kanoo Kuwait Zallaq Jaw & Asker Clinic	**Private Company Clinics** Aluminum Bahrain (ALBA) Arab Shipbuilding & Repair Yard (ASRY) Gulf Air (GF) Gulf Aluminum Rolling Mill Co. (GARMCO) Gulf Petrochemical Industries Co. (GPIC)

5.3. Population Growth of Kingdom of Bahrain

Central Information Organisation, CIO (2013) published a mid-year population projection for the kingdom of Bahrain for the years 2012-2032 as shown in Figure 5.2.



Kingdom of Bahrain
Central Informatics Organisation

مملكة البحرين
الجهاز المركزي للمعلومات

إسقاطات منتصف العام لسكان مملكة البحرين – (2012 - 2032)
Mid-Year Population Projections for the Kingdom of Bahrain - (2012 - 2032)

Year	السكان (بالألف) Population (in 000)	السنة
2012	1,234.9	2012
2013	1,274.8	2013
2014	1,316.5	2014
2015	1,359.8	2015
2016	1,404.9	2016
2017	1,451.2	2017
2018	1,496.3	2018
2019	1,543.3	2019
2020	1,592.0	2020
2021	1,642.5	2021
2022	1,694.5	2022
2023	1,744.3	2023
2024	1,796.1	2024
2025	1,849.8	2025
2026	1,905.4	2026
2027	1,962.4	2027
2028	2,015.5	2028
2029	2,070.9	2029
2030	2,128.2	2030
2031	2,187.3	2031
2032	2,247.6	2032

Figure 5.2 - Mid-year Population Projection for Kingdom of Bahrain (2012-2032)

The population of year 2012 is found to be 1,234,900 with growth rate between 2.7-3.3% or 3%±0.3. For simplicity, and to meet System Dynamics Software requirements, population growth of 3% will be considered to forecast future population growth between years 2012 and 2030 that is essential in planning future healthcare services. The forecasted population growth is shown in Figure 5.3

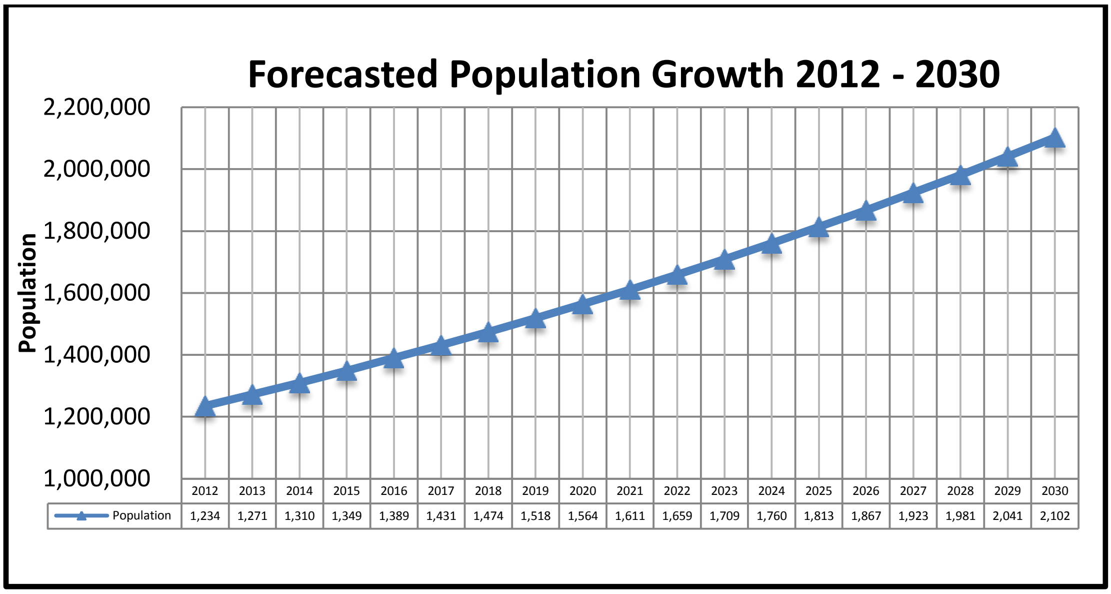


Figure 5.3 - Population Growth for Kingdom of Bahrain (2012-2030)

5.4. Policy Scenarios of Healthcare System in Kingdom of Bahrain

Based on the current situation, five policy scenarios were established. Business as Usual (BAS) scenario to represent facility demand management strategy, Administrative Rules & Regulation Management (ARRM) scenario to represent population control strategy, Technical Progress (TP) scenario to represent facilities sustainability demand strategy, Combined Time Management & Technical Progress (TMTP) scenario to represent facilities time management and sustainability demand strategy. The consideration of these scenarios is based on mitigation measures recommended by literature as per the given details:

5.4.1. Business as Usual (BAU) Scenario

The BAU scenario is selected based on the current situation without any additional policies, i.e. 3% population growth, 3% services operation growth and 3% economic growth. Healthcare performance measuring parameters, facility demand, energy and water consumption, waste generation and CO2 emissions were used as indicated without change to forecast the future healthcare facilities demand.

5.4.2. Administrative Rules & Regulation Management (ARRM–2%) Scenario

This scenario is based on regulating the population growth and subsequently services operation growth at 2% as per World Population Prospect (2015) and investigates its impact on healthcare facilities demand. Environmental and economic impacts related to these changes are also investigated as an example of Government Administration Policies to create change.

5.4.3. Administrative Rules & Regulation Management (ARRM–1%) Scenario

This scenario is based on regulating the population growth and subsequently services operation growth at 1% as per World Population Prospect (2015) and investigates its impact on healthcare facilities demand. Environmental and economic impacts related to these changes are also investigated as an example of Government stringent Administration Policies to create change.

5.4.4. Technical Progress (TP) Scenario

In the recent years, and to fulfill commitments toward climate change, initiatives for energy savings, water savings, reduction of waste generations and reductions of CO2e emissions been encouraged. In this scenario, the effectiveness of International Energy Agency, IEA (2008) recommendations to achieve sustainable building is investigated to study the potential of reduction in healthcare facilities utilities demand under different scenarios (BAU-3%, ARRM-2% and ARRM-1%).

5.4.5. Time Management and Technical Progress (TMTP) Scenario

Due to declining economy and shortage of funds, policy makers are urged to change their strategies from construction of new facilities to extend the operation of existing facilities where applicable. The negative environmental impact of this policy in term of increasing healthcare facilities utilities demand is investigated in combination with Technical Progress policy to reduce the negative impacts of utilities increase under different scenarios (BAU-3%, ARRM-2% and ARRM-1%).

5.4.6. Public Private Partnership (PPP) Scenario

Recalling the assumptions that Casual Loop Diagram development was based on in chapter 3, especially:

- Taxed-base (Revenue-base) healthcare system: Where healthcare services are provided for citizens and residents by government.

- Growing economy: Where government with growing economy funding the expansion of healthcare services and operation.

During declining economy times, these two assumptions are very difficult to maintain as government revenues are decreasing and economy growth is slowing until it is shrinking or contracting leaving limited funds for existing services and no funding for new services. The need for alternative model or scenario is persisted.

The developed SD Model shows strong interaction between environmental sustainability and economic sustainability. Economic sustainability is essential for the environmental sustainability development plans while environmental sustainability is important to continue with economic sustainability development plans. Social sustainability and welfare is an outcome of these positive interactions.

The strong interaction between the two sustainability dimensions, in addition to the limitations of proposed solutions to improve Primary and Secondary Healthcare Services in declining economy times, lead the researcher toward economic sustainability focus by proposing structural changes in the existing healthcare system to serve environmental sustainability by finding alternatives for facilities construction. Re-structuring healthcare system based on Public Private Partnership (PPP) is aiming to minimise or eliminate the construction and operation of new government healthcare facilities by manipulating health alliance facilities under government regulating body.

This macro-economic scenario, as illustrated in Figure 5.4, can be considered as complementing scenario to the earlier driven scenarios and can be subjected to future SD numerical modelling.

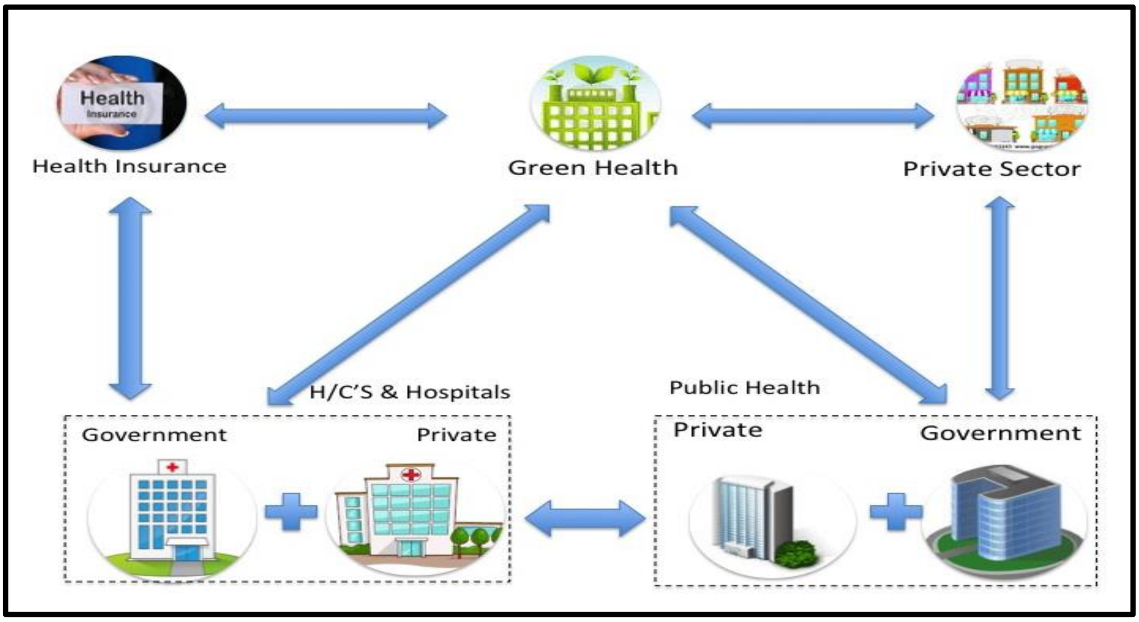


Figure 5.4 - PPP Policy Scenario for Bahrain Healthcare Facilities

For the time being, Bahrain is following the Beveridge Model, a system similar to NHS, where healthcare is provided and financed by the government through Government revenues. In this model most of hospitals, health centres and clinics are owned and operated by government. Countries using Beveridge Model or modified models includes Great Britain, Spain, Scandinavian Countries, New Zealand, Hong Kong and Cuba (Reid, 2009).

The existing model can be modified to incorporate private hospitals, health centres and clinics through bounding agreements and referral system to complement government services. The advantage of this modification is that the government can manipulate health alliance facilities instead of constructing and operating new facilities. The modified system can have a low cost per capita and better service quality due to the control of governing and regulating body created by government. The modified model can be operated under a suggested Identity or Brand called Bahrain Healthcare System (BHS).

The existing model can also be modified by incorporating Bismarck Model insurance plan financed jointly by employers and employees of private sectors, similar to the social insurance scheme implemented by the General Organisation for Social Insurance (GOSI). This option will help to develop private medical insurance industry as well as private hospitals, health centres and clinics revenues. This option also will give private sector an alternatives access to private medical care for its employees against running its own clinic or paying an annual levy to access government medical care system.

As a multi-payer model compare to single-payer Beveridge Model, this model can improve the government cost-control and its services benchmark. The Bismarck Model is implemented in Germany, France, Belgium, the Netherland, Japan, Switzerland and Latin America (Reid, 2009).

A third but a complicated hybrid Model can be implemented by creating the National Health Insurance Model where government is paying for the healthcare services from a government insurance program funded by government revenues for its employees, their families, classified citizens such as senior citizens and special needs people and non-classified citizens such as non-employed citizens and citizens registered to receive social support funds. This model is benefiting from the lower cost per capita of Beveridge Model and the government cost-control of Bismarck Model. It is also flourishing the private medical insurance industry as well as private hospitals, health centres, clinics and medical laboratories role in the healthcare market.

For the success of this model, existing healthcare facilities must be transformed from central operating experiences to de-centralised experiences with full financial, administrative and competitiveness independency.

Public Health Services can be re-structured into two laboratories, Public Health Laboratory and Water & Food Safety Laboratory. While Public Health Laboratory Services must remain under Ministry of Health or National Health Authority for regulatory and technical reasons such as communicable diseases control, part of Water & Food Safety Laboratory Services can be outsourced to private laboratories through bounding agreements to complement government Public Health Services. Examples of services that can be outsourced are supplementary foods and herbs products tests, cosmetics products tests, etc.

Existing, WHO Accredited, Drug Quality Control Laboratory can be converted into independent Laboratory.

The advantage of this modification is that the government can manipulate health alliance facilities instead of constructing and operating new facilities. The modified model can have a higher testing capacity to meet the increasing demands on different testing services, competitive testing cost and better service quality due to investment and deployment of new technologies and due to the control of governing and regulating body created by government. The modified system can be operated under two suggested identity / Marketing Brand called Public Health Laboratory (PHL) and Bahrain Food and Drug Authority (BFDA). As a multi-payer model compare to government single-payer model, this model can improve the government Public Health Services cost-control and its services benchmark.

Re-modelling and outsourcing healthcare services will lead to re-modelling or re-structuring Administration Services by transforming from central Administration Services to efficient governing, regulating and monitoring bodies. This transformation in addition to use new office automation and technologies is expected to reduce the manpower and number of administration buildings. Governing and regulating bodies are expected to operate fluently and efficiently to reduce its operating expenditures and generate its own revenue from the fees of services delivered to public and private clients.

Some additional advantages can be obtained from this model such as expansion of governing and regulating bodies' role to incorporate sustainability concepts in operating policies of private hospitals, health centres, clinics, and medical laboratories.

Healthcare insurance partners and privet sector partners can play good role in sponsoring and funding the environmental sustainability initiatives that will reinforce social responsibility and reflected positively on patient's health and welfare.

5.5. Implementation of Policy Scenarios on Healthcare System in Bahrain

Different policy scenarios are implemented on Bahrain Healthcare System to examine number of parameters as summarised in Table 5.3.

Table 5.3 - Policy Scenarios for Bahrain Healthcare System

Policy		Objective	Examined Parameter	Ref. (Table)
Individual Policies	BAU	To Study the effect of 3% Population Growth OR 3% / 4% Operation Growth as a research reference	Facilities Demand Operating Expenditures MW Generation Energy Consumption Water Consumption CO2e Emissions Utilities Expenditures	5.5
	ARRM – 2%	To Study the effect of 2% Population Growth OR 2% Operation Growth		5.6
	ARRM –1%	To Study the effect of 1% Population Growth OR 1% Operation Growth		5.7
Combined Policies	TP & BAU	To Study the combined effect of 3% Population Growth OR 3% / 4% Operation Growth and implementing of Energy Efficiency Technology	MW Generation Energy Consumption Water Consumption CO2e Emissions Utilities Expenditures	5.9 5.10 5.11 5.12
	TP & ARRM–2%	To Study the combined effect of 2% Population Growth OR 2% Operation Growth and implementing of Energy Efficiency Technology		
	TP & ARRM–1%	To Study the combined effect of 1% Population Growth OR 1% Operation Growth and implementing of Energy Efficiency Technology		
	TM & BAU	To Study the combined effect of 3% Population Growth OR 3-4% Operation Growth and implementing of Time Management	MW Generation Energy Consumption Water Consumption CO2e Emissions Utilities Expenditures	5.14
	TM & ARRM–2%	To Study the combined effect of 2% Population Growth OR 2% Operation Growth and implementing of Time Management		
	TM & ARRM–1%	To Study the combined effect of 1% Population Growth OR 1% Operation Growth and implementing of Time Management		
	TM TP & BAU	To Study the combined effect of 3% Population Growth OR 3-4% Operation Growth and implementing of Time Management and Energy Efficiency Technology	MW Generation Energy Consumption Water Consumption CO2e Emissions Utilities Expenditures	5.15
	TMTP & ARRM–2%	To Study the combined effect of 2% Population Growth OR 2% Operation Growth and implementing of Time Management and Energy Efficiency Technology		
	TMTP & ARRM–1%	To Study the combined effect of 1% Population Growth OR 1% Operation Growth and implementing of Time Management and Energy Efficiency Technology		

Specific technical parameters of the policy scenarios are shown in Table 5.4.

Table 5.4 - Specific Technical Parameters of Policy Scenarios

Scenario	Control Measures	
BAU	PHC	Number of facilities per 10,000 of Population, PI = 0.2 /10,000, Area per facility, FA Factor = 10,000 m2 /Facility, Project Factor, PF = MBD 6.0 /Facility, Operating Factor = MBD 3.0 /Facility, Economic Growth Rate = 3 % , Energy consumption, EBM = 247 KWh /m2, CO2e emissions by KWh of energy consumed, EF = 0.55 Kg CO2e/KWh, Water consumption, WBM = 0.78 m3/m2, Energy required to produce M3 of Water, WPEn = 6 kWh/m3, MW Generation rate = 0.1 Kg/Patient/Day, CO2e emissions by kilogram of Medical Waste Incineration, MWEF = 0.86 Kg CO2e/Kg, ET = BD 0.016/KWh, WT = BD 0.300/m3, IT= BD 0.210 /Kg
	SHC	Number of Beds per 10,000 of Population, SI= 20.4/10,000, Area per facility, FA Factor = 65,000 m2 / Facility, Project Factor, SF = MBD 100.0 / Facility, Operating Factor = MBD 41.0 / Facility, Energy consumption, EBM = 322 KWh/m2, Water consumption, WBM = 1.35 M3/m2, MW Generation rate = 2 Kg/ Bed / Day.
	PHF	PHF Growth Rate = 4 % Annually, FA Factor = 10,000 m2 /Facility, Energy consumption, EBM = 206 KWh/m2, Water consumption, WBM = 1.25 m3/m2, Project Factor = MBD 4.0 / Facility, Operating Factor = MBD 3.0 / Facility,
	OB	OB Growth Rate = 3 % Annually, FA Factor = 10,000 m2 /Facility, Energy consumption, EBM = 203 KWh/m2, Water consumption, WBM = 0.58 m3/m2, Project Factor = MBD 3.0 / Facility, Op. Factor = MBD 2.75 / Facility
ARRM-2%	PHC	Regulating the population growth from 3% to 2% as per (World Pop Prospect, 2015).
	SHC	Regulating the population growth from 3% to 2% as per (World Pop Prospect, 2015).
	PHF	Regulating the Operation growth from 4% to 2%
	OB	Regulating the Operation growth from 3% to 2%
ARRM-1%	PHC	Regulating the population growth from 3% to 1% as per (World Pop Prospect, 2015).
	SHC	Regulating the population growth from 3% to 1% as per (World Pop Prospect, 2015).
	PHF	Regulating the Operation growth from 4% to 1%
	OB	Regulating the Operation growth from 3% to 1%
TP		Introduction of Energy Efficiency Technologies, Energy Recovery Technologies, Medical waste Energy Recovery Technologies (MW LCP Factor = 4 Kw / Kg) and Water Conservation Techniques.
TMTP	PHC	Increase of PHC Services Operating Hours by 46%. Not Applicable for SHC (Operating 24 Hours), PHF & OB (Administrative offices)

5.5.1. Business as Usual (BAU) Scenario

In this scenario healthcare facilities and resources are forecasted based on the current situation without any additional policies, i.e. 3% population growth, 3% services operation growth, 3% economic growth and healthcare performance parameters as indicated. Facilities demand, energy and water consumption, waste generation and CO2 emissions were used to forecast the future healthcare facilities demand. Environmental impacts due to expansion in healthcare services in term of energy consumption, water consumption, waste generation and CO2e emissions and economic impacts in term of utilities expenditures were also examined as summarised in Table 5.5.

Table 5.5 - BAU Policy for Bahrain Healthcare Facilities

Scenario Analysis Parameters	**Variable Modified**: **Population Growth = 3%**			
	PHC	**SHC**	**PHF**	**OB**
Facilities Demand (2030)				
Population	**2,102,330**	**2,102,330**	**2,102,330**	**2,102,330**
No. of Beds	**N/A**	**4268**	**N/A**	**N/A**
No. of Facilities	**42**	**15**	**2**	**12**
Area (M2)	**254,617**	**651,587**	**16,132**	**70,855**
Project Exp. (Total - MBD)	**63.000**	**600.000**	**4.000**	**20.000**
Operation Exp. (MBD)	**112.046**	**464.306**	**4.708**	**15.994**
Environmental Impacts (2030)				
Energy Consumption (GWhr)	**62,890**	**209,811**	**3,323**	**14,384**
Water Consumption (M3)	**198,601**	**879,642**	**20,165**	**41,096**
Medical Waste Generation (Ton)	**638,966**	**3,115,320**	**N/A**	**N/A**
CO2e Emissions (Ton)	**35,684**	**120,978**	**1,894**	**8,047**
Economic Impacts (2030)				
Energy Expenditures (BD.)	**1,006,250**	**3,356,980**	**53,172**	**230,138**
Water Expenditures (BD.)	**59,580**	**263,893**	**6,050**	**12,329**
Med. Waste Expenditures (BD.)	**134,183**	**654,218**	**N/A**	**N/A**
Total Utilities Expenditures (BD.)	**1,200,013**	**4,275,091**	**59,221**	**242,467**

Table 5.5 shows that in order to meet the population growth at 3%, the number of Primary Healthcare Facilities (Health Centers and Clinics) need to be increased from 25 in year 2012 to 42 facilities in 2030, number of Secondary Healthcare Facilities (Hospitals) need to be increased from 9 in year 2012 to 15 in 2030, the number of Public Health Facilities need to be doubled from 1 facility in year 2012 to 2 facilities in 2030 while office buildings need to be increased from 7 buildings in 2012 to 12 buildings in 2030. The increases in number of facilities accompany an increase in project expenditures funds to cover the construction and furnishing with an increase in the operating expenditures to cover the increase in annual operating budget. It is also accompanied with an increase in utilities consumptions, waste generation and environmental impacts in form of CO2e emissions.

5.5.2. Administrative Rules & Regulation Management (ARRM-2%) Scenario

In this scenario, the effectiveness of regulating the population growth at 2% as per World Population Prospect (2015) and the impact of these regulations on healthcare services demand and subsequently environmental and economic impacts of these changes are investigated as summarised in Tables 5.6.

Table 5.6 - ARRM-2% Policy for Bahrain Healthcare Facilities

Scenario Analysis Parameters	**Variable Modified: Population Growth = 2%**			
	PHC	**SHC**	**PHF**	**OB**
Facilities Demand (2030)				
Population	**1,833,930**	**1,833,930**	**1,833,930**	**1,833,930**
No. of Beds	**N/A**	**3,720**	**N/A**	**N/A**
No. of Facilities	**37**	**12**	**1**	**9**
Area (M2)	**200,936**	**532,953**	**10,768**	**52,835**
Project Exp. (Total - MBD)	**40.500**	**300.000**	**0.000**	**8.000**
Operation Exp. (MBD)	**95.941**	**389.474**	**3.526**	**11.038**
Environmental Impacts (2030)				
Energy Consumption (GWhr)	**49,631**	**171,611**	**2,218**	**10,725**
Water Consumption (M3)	**156,730**	**719,486**	**13,460**	**30,644**
Medical Waste Generation (Ton)	**558,445**	**2,715,480**	**N/A**	**N/A**
CO2e Emissions (Ton)	**28,295**	**99,096**	**1,264**	**6,000**
Economic Impacts (2030)				
Total Utilities Expenditures (BD.)	**958,391**	**3,531,868**	**39,529**	**180,799**

Table 5.6 shows that regulating population growth from 3% (BAU Scenario) to 2% by regulating the net immigrant to the country, immigrants' contribution to row growth and citizens' contribution to row growth; can lead to reduction in PHC facilities demand by end of study period (2030) from 42 to 37. For SHC Services, number of beds demand can be reduced from 4268 beds to 3720 that leads to reduction in number of hospitals demand from 15 to 12.

Project expenditures can be reduced by around 35% for both services, operating expenditures can be reduced by around 20% and utilities expenditures can be reduced by more than 20%.

Also, Table 5.6 shows that regulating operation growth to match population growth can lead to stabilising PHF demand to the existing facility. For OB Services, number of facilities demand can be reduced from 12 to 9.

Project expenditures can be eliminated for PHF and can be reduced by around 40% for OB. Operating expenditures can be reduced by 25% for PHF and by 32% for OB. PHF utilities can be reduced by 37% while OB utilities can be reduced by 27%. Utilities expenditure can be reduced with the same percentage.

5.5.3. Administrative Rules & Regulation Management (ARRM-1%) Scenario

In this scenario, the effectiveness of regulating the population growth to 1% as per World Population Prospect (2015) and the impact of these regulations on healthcare services demand and subsequently environmental and economic impacts of these changes are investigated as summarised in Tables 5.7.

Table 5.7 - ARRM-1% Policy for Bahrain Healthcare Facilities

Scenario Analysis Parameters	**Variable Modified: Population Growth = 1%**			
	PHC	**SHC**	**PHF**	**OB**
Facilities Demand (2030)				
Population	**1,597,640**	**1,597,640**	**1,597,640**	**1,597,640**
No. of Beds	**N/A**	**3,238**	**N/A**	**N/A**
No. of Facilities	**32**	**10**	**1**	**8**
Area (M2)	**153,679**	**428,514**	**9,068**	**40,934**
Project Exp. (Total - MBD)	**18.000**	**100.000**	**0.000**	**4.000**
Operation Exp. (MBD)	**81.764**	**323.597**	**3.016**	**7.765**
Environmental Impacts (2030)				
Energy Consumption (GWhr)	**37,959**	**137,981**	**1,868**	**8,310**
Water Consumption (M3)	**119,869**	**578,494**	**11,335**	**23,742**
Medical Waste Generation (Ton)	**487,559**	**2,363,600**	**N/A**	**N/A**
CO2e Emissions (Ton)	**21,692**	**79,832**	**1,065**	**4,649**
Economic Impacts (2030)				
Total Utilities Expenditures (BD.)	**745,686**	**2,877,605**	**33,288**	**140,077**

Table 5.7 shows that regulating population growth from 3% (BAU Scenario) to 1% by regulating the net immigrant to the country, immigrants' contribution to row growth and citizens' contribution to row growth; can lead to reduction in PHC facilities demand by end of study period (2030) from 42 to 32. For SHC Services, number of beds demand can be reduced from 4268 beds to 3238 that lead to reduction in number of hospitals demand from 15 to 10.

Project expenditures can be reduced by around 71% for PHC services while SHC services can be reduced by 84%. Operating expenditures can be reduced by around 40%.

PHC utilities can be reduced by 27% while SHC utilities can be reduced by 30%. Utilities expenditure can be reduced with the same percentage.

Also, Table 5.7 shows that regulating operation growth to match population growth can lead to stabilising of PHF facilities demand to the existing facility. For OB Services, number of facilities demand can be reduced from 12 to 8.

Project expenditures can be eliminated for PHF and can be reduced by around 60% for OB. Operating expenditures can be reduced by 36% for PHF and by 52% for OB. PHF utilities can be reduced by 44% while OB utilities can be reduced by 42%. Utilities expenditure can be reduced with the same percentage.

5.5.4. Technical Progress (TP) Scenario

In this scenario, the effectiveness of implementation of energy efficiency technologies, as shown in Table 5.8, related to Air-Conditioning System & Lighting System, Renewable energy technology related to Domestic Hot Water System, Medical Waste energy recovery technology and some Water Conservation measures are investigated under different scenarios (BAU-3%, ARRM-2% and ARRM-1%) as summarised in Table 5.9 to Table 5.12. Policy results will be thoroughly discussed in section 5.5

Table 5.8 - Energy Efficiency Technologies Effect on Healthcare Facilities

	PHC	**SHC**	**PHF**	**OB**	**Reference**
Energy Consumption Saving					
Energy Efficiency of A/C System	-41.50%	-41.50%	-41.50%	-41.50%	(Appendix-D)
Energy Eff. of Lighting System	-6.67%	-6.67%	-6.67%	-6.67%	(Appendix-E)
Energy Eff. of DHW System	-13.08%	-13.08%	-13.08%	-13.08%	(Appendix-F)
Medical Waste Energy Recovery	-4.50%	-4.50%	-	-	(Appendix-G)
Total	**-66%**	**-66%**	**-61%**	**-61%**	
Water Consumption Saving	**-18%**	**-32%**	**- 10%***	**- 10%***	(Appendix-H)
Reduction in M. Waste Generation	**-**	**-**	**-**	**-**	
Reduction in CO2e Emissions					
From Energy Consumption	-59%	-59%	-61.25%	-61.25%	(Appendices D-F)
From Water Consumption	-0.4%	-0.9%	-0.35%*	-0.15%*	(Appendix-H)
From M. Waste Generation	-5.5%	-5%	N/A	N/A	(Appendix-G)
Total	**-65%**	**65%**	**-61.60%**	**-61.40%**	

Table 5.9 - TP Policy Scenario for Bahrain PHC Facilities

Scenario Analysis Parameters	**TP & BAU - 3%**	**TP & ARRM - 2%**	**TP & ARRM - 1%**
Environmental Impacts (2030)			
Energy Consumption (GWhr)	22,432	17,546	13,241
Water Consumption (M3)	162,852	128,519	98,293
Medical Waste Generation (Ton)	638,966	558,445	487,559
CO2e Emissions (Ton)	13,425	10,555	8,026
Economic Impacts (2030)			
Total Utilities Exp. (BD.)	541,959	436,566	343,736

Table 5.10 - TP Policy Scenario for Bahrain SHC Facilities

Scenario Analysis Parameters	**TP & BAU - 3%**	**TP & ARRM - 2%**	**TP & ARRM - 1%**
Environmental Impacts (2030)			
Energy Consumption (GWhr)	71,853	58,300	46,352
Water Consumption (M3)	598,156	489,250	393,376
Medical Waste Generation (Ton)	3,115,320	2,715,480	2,363,600
CO2e Emissions (Ton)	44,172	36,015	28,825
Economic Impacts (2030)			
Total Utilities Exp. (BD.)	1,983,306	1,649,817	1,356,001

Table 5.11 - TP Policy Scenarios for Bahrain PH Facilities

Scenario Analysis Parameters	**TP & BAU - 3%**	**TP & ARRM - 2%**	**TP & ARRM - 1%**
Environmental Impacts (2030)			
Energy Consumption (GWhr)	1,287,750	859,530	723,840
Water Consumption (M3)	18,149	12,114	10,201
Medical Waste Generation (Ton)	N/A	N/A	N/A
CO2e Emissions (Ton)	768	513	432
Economic Impacts (2030)			
Total Utilities Exp. (BD.)	26,049	17,387	14,642

Table 5.12 - TP Policy Scenario for Bahrain OB

Scenario Analysis Parameters	**TP & BAU - 3%**	**TP & ARRM - 2%**	**TP & ARRM - 1%**
Environmental Impacts (2030)			
Energy Consumption (GWhr)	5,573,630	4,156,090	3,219,980
Water Consumption (M3)	36,987	27,580	21,368
Medical Waste Generation (Ton)	N/A	N/A	N/A
CO2e Emissions (Ton)	3,188	2,377	1,842
Economic Impacts (2030)			
Total Utilities Exp. (BD.)	100,274	74,771	57,930

5.5.5. Time Management and Technical Progress (TMTP) Scenario

Under declining economy, revenue-base economies are facing great difficulties to fund new projects and expand in the essential services such as education services and healthcare services.

The dramatic drop of oil prices by more than 75% during year 2015 and continue in year 2016 is a live example of economic crises, as it is seriously affected the revenues of oil exporters, non-diversified-economy countries and force its economy to inter in a decline cycle. Kingdom of Bahrain is badly affected due to its limited resources and forced to review all its development plans including the ones related to healthcare services. The impact of this crisis is harshly affecting the future development plans and quality of healthcare services.

To overcome these circumstances few available solutions are implemented to improve the PHC Indicator; the favourable one is to extend the operating hours of existing health centres and clinics to increase the capacity of Primary Healthcare Services. Extending the operating hours of the health centres and clinics in the evening sessions gradually up to mid-night and during the weekends will result in increase in weekly operation by 46% as per Table 5.13.

Table 5.13 - Primary Healthcare Facilities Operating Hours

#	Health Centre	Current Operating Hours		Weekend Op. Hrs.	Total Hrs. / Week	Extended Operating Hours	Weekend Op. Hrs.	Total Hrs. / Week
1	NBB-Arad	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
2	NBB-Dair	7:00 - 2.15	5:00 - 9:00	Closed	56.25	5:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
3	Sheikh Salman	7:00 - 2.15	Closed	Closed	36.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	63.5
4	Muharraq	7:00 - 7:00		7:00 - 7:00	168	0	0	0
5	BBK-Hidd	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
6	Bu-Maher	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
7	Hoora	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
8	Ibn Sina'a	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
9	Sheikh Subah	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
10	Naim	7:00 - 2.15	4:00 - 12:00	8:00 - 12:00	102.25	0	0	0
11	Al-Razi	7:00 - 2.15	Closed	Closed	56.25	0	0	0
12	Bilad Al-Qadeem	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
13	Jidhafs	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
14	Sh. J. Al-Subah	7:00 - 2.15	4:00 - 12:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
15	Budayia	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
16	Budayia Clinic	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
17	Kuwait	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
18	Zallaq	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
19	Sitra	7:00 - 2.15	4:00 - 12:00	8:00 - 12:00	102.25	0	0	0
20	A. Ali Kanoo	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
21	Isa Town	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
22	Y. A. Engineer	7:00 - 7:00		7:00 - 7:00	168	0	0	0
23	A'ali	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
24	East Riffa'a	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
25	Hamad Kanoo	7:00 - 7:00		7:00 - 7:00	168	0	0	0
26	Hamad Town	7:00 - 2.15	5:00 - 9:00	Closed	56.25	9:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	43.5
27	M. J. Kanoo	7:00 - 2.15	4:00 - 12:00	8:00 - 12:00	102.25	0	0	0
28	Jaw & Asker	7:00 - 2.15	5:00 - 8:00	Closed	51.25	8:00 - 12:00	7:00 - 2.15 & 5:00 - 12:00	48.5
Total Operating Hours					2,023.2			938.50
%								46%

The increase in operating hours will result in increase in energy consumption, water consumption and waste generation and subsequently increase in CO2e emissions. It will also end by intensive use of the facilities that need more attentions and maintenance that will increase the facilities operating expenditures. Technical progress Policy can be integrated to reduce the negative environmental and economic impacts. The variables modified from original values are shown in Table 5.14 and simulation of the same is shown in Figure 5.5.

Table 5.14 - Primary Healthcare Facilities Operating Hours Equations

#	Scenario Parameters	Modified Equation	Variable Values	Modified Values
1	New PHCF Operating Expenditures	$\mathrm{OExp}'(n+1) = F'(n+1) \ast OF \ast TF$	OF = MBD 3/Facility	TF = 1.3
2	New PHCF Energy Consumption	$E'(n+1) = FA'(n+1) \ast EBM \ast TF$	EBM = 247 KWh/m2	TF = 1.3
3	New PHCF Water Consumption	$W'(n+1) = FA'(n+1) \ast WBM \ast TF$	WBM = 0.78 m3/m2	TF = 1.3
4	New PHCF MW generation	$MW'(n+1) = F'(n+1) \ast PTF \ast MWF \ast TF$	PTF = 150 KPt./Fac./Ann. MWF = 0.1Kg/Pt./Ann.	TF = 1.3

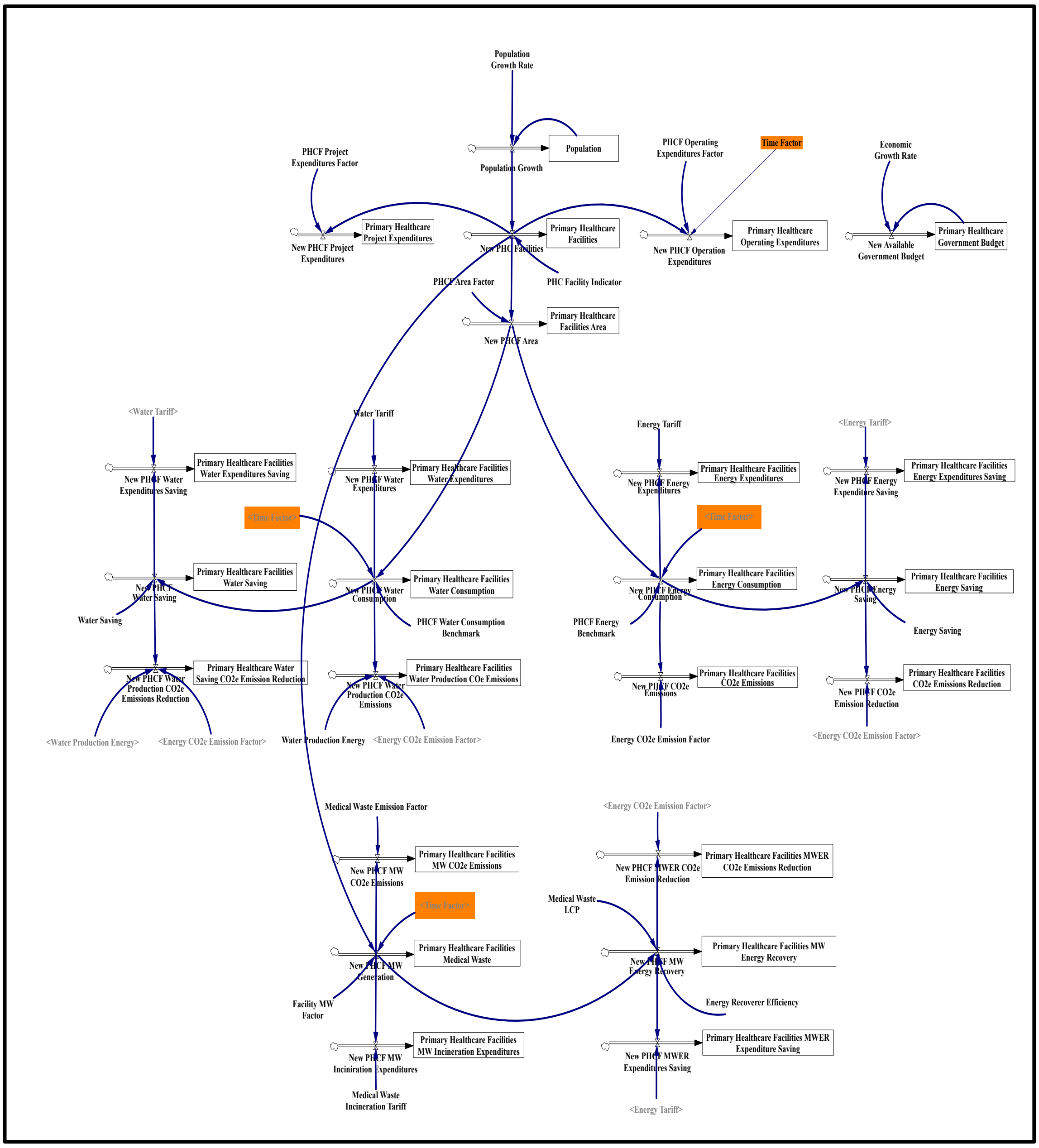


Figure 5.5 - Simulation of TMTP Policies for PHC Services

The effectiveness of this solution is debatable as it has its own limitations. For new rural areas, downtowns and new demographical shifting hubs, such as housing towns, construction of new facilities is an essential. The details of implementing this policy under different scenarios (BAU-3%, ARRM-2% and ARRM-1%) is summarised in Table 5.15 & Table 5.16. Policy results will be thoroughly discussed in section 5.6.

Table 5.15 - TM Policy Scenario for Bahrain PHC Facilities

Scenario Analysis Parameters	TM & BAU	TM & ARRM - 2%	TM & ARRM - 1%
Operating Expenditures (2030)			
Annual Operating Hours	154,011	154,011	154,011
Annual Operating Expenditures (MBD)	127,660	101,250	78,893
Environmental Impacts (2030)			
Energy Consumption (GWhr)	73,448,700	56,211,900	41,037,500
Water Consumption (M3)	231,943	177,511	129,592
Medical Waste Generation (Ton)	703,086	598,409	506,257
CO2e Emissions (Ton)	41,767	32,017	23,434
Economic Impacts (2030)			
Total Utilities Exp. (BD.)	1,392,411	1,078,309	801,792

Table 5.16 - TMTP Policy Scenario for Bahrain PHC Facilities

Scenario Analysis Parameters	TMTP & BAU	TMTP & ARRM - 2%	TMTP & ARRM - 1%
Operating Expenditures (2030)			
Annual Operating Hours	154,011	154,011	154,011
Annual Operating Expenditures (MBD)	127,660	101,250	78,893
Environmental Impacts (2030)			
Energy Consumption (GWhr)	26,329,910	19,973,020	14,376,750
Water Consumption (M3)	190,193	145,559	106,265
Medical Waste Generation (Ton)	703,086	598,409	506,257
CO2e Emissions (Ton)	15,714	11,980	8,693
Economic Impacts (2030)			
Total Utilities Exp. (BD.)	625,984	488,902	368,222

5.6. Results of Implementing Policy Scenarios on Healthcare System in Bahrain

The results of implementing the policy scenarios on the examined parameters, as illustrated in Appendix N, are as follows:

5.6.1. Facilities Demand:

Changes in healthcare facilities demand under different scenarios are shown in Figures 5.6 to Figure 5.9.

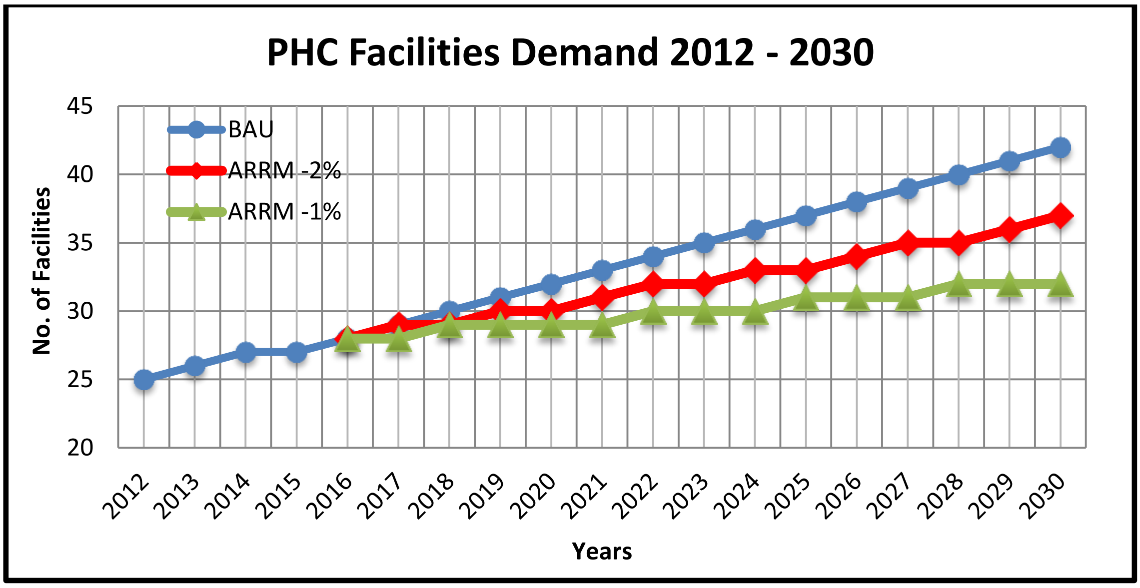


Figure 5.6 - Policy Scenarios of PHC Facilities Demand

From Figure 5.6, PHC facilities demand of 42 Health Centre is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the demand to 37 and 32 facilities respectively. This reduction is direct result of controlling the population variable in the SD Model.

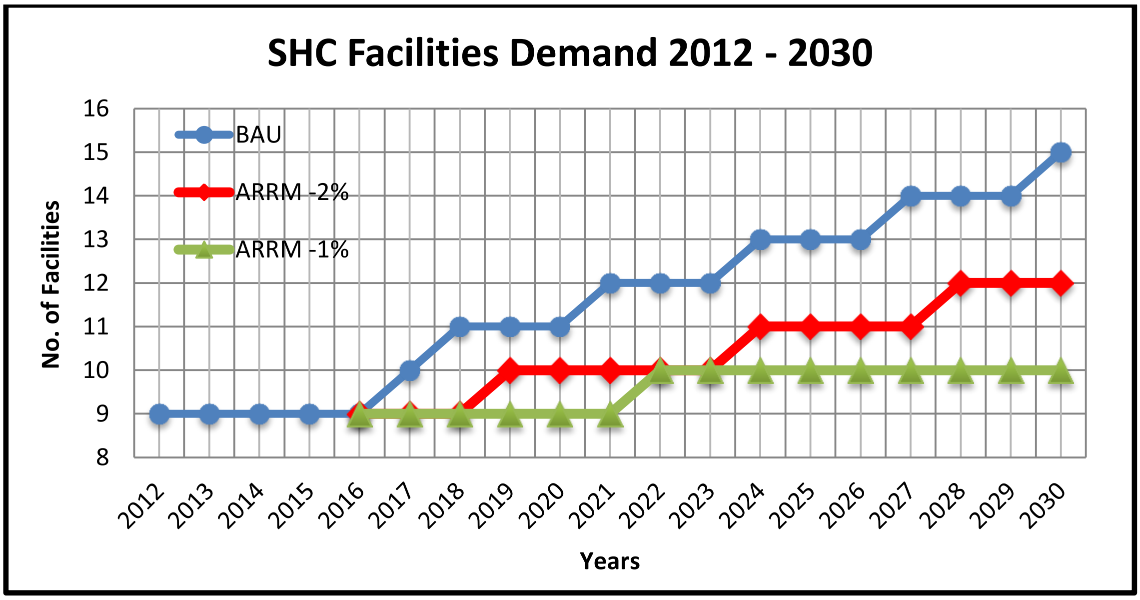


Figure 5.7 - Policy Scenarios of SHC Facilities Demand

From Figure 5.7, SHC facilities demand of 15 Hospitals is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the demand to 12 and 10 facilities respectively. This reduction is direct result of controlling the population variable in the SD Model.

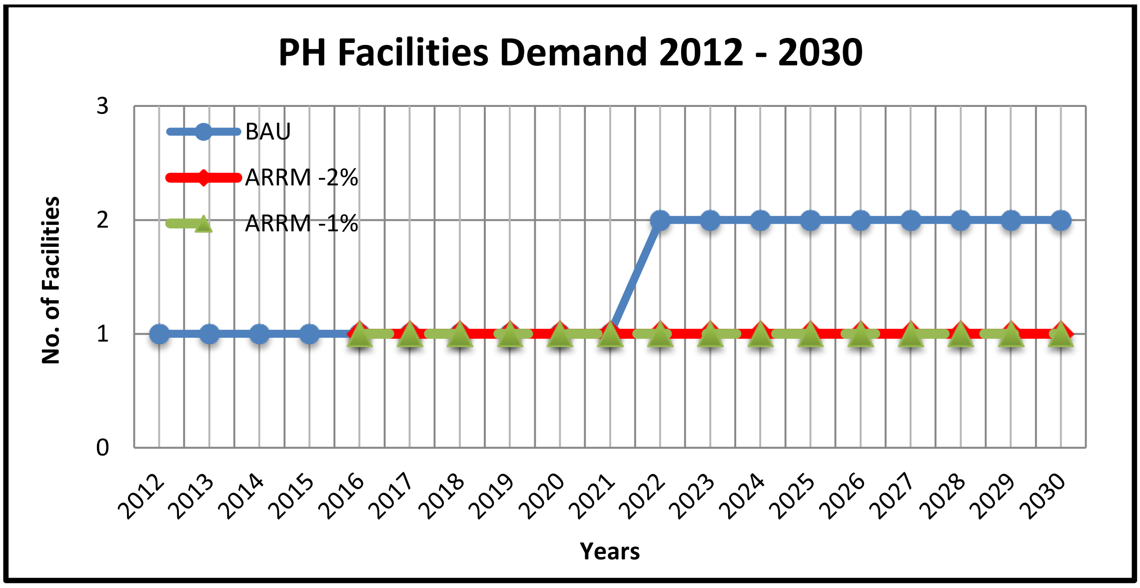


Figure 5.8 - Policy Scenarios of PH Facilities Demand

From Figure 5.8, PH facilities demand of 2 Laboratories is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can lead to steadiness of demand to 1 facility. This reduction is direct result of controlling the population variable in the SD Model.

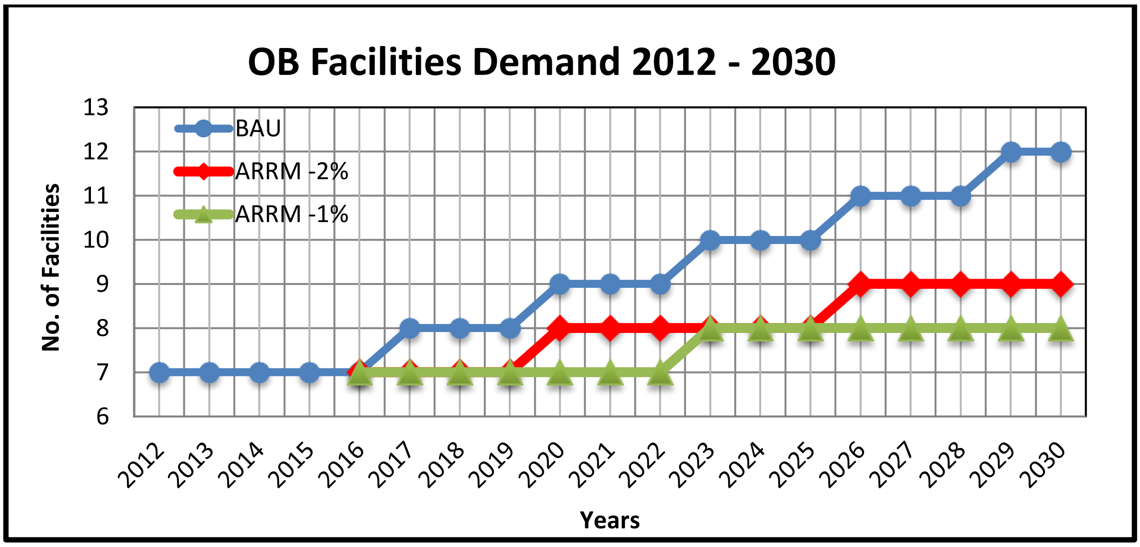


Figure 5.9 - Policy Scenarios of OB Facilities Demand

From Figure 5.9, OB facilities demand of 12 facilities is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the demand to 9 and 8 facilities respectively. This reduction is direct result of controlling the population variable in the SD Model.

5.6.2. Operating Expenditures

Changes in healthcare facilities operating expenditures under different scenarios are shown in Figures 5.10 to Figure 5.13.

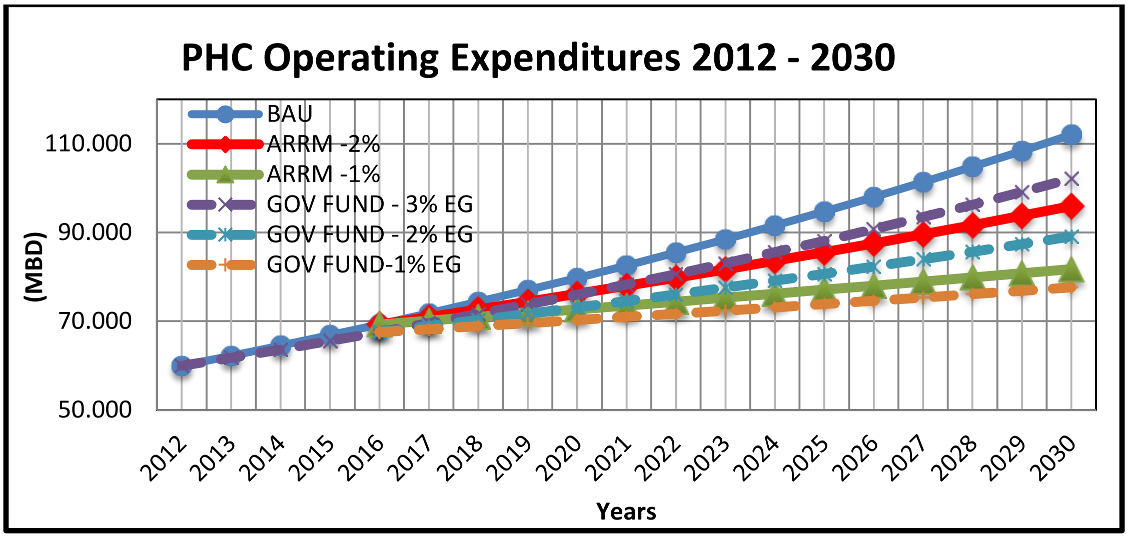


Figure 5.10 - Policy Scenarios of PHC Operating Expenditures

From Figure 5.10, PHC facilities operating expenditures of MBD 112 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the operating expenditures to MBD 96 and MBD 82 respectively. This reduction is direct result of controlling the population variable in the SD Model.

If the PHC facilities operating expenditures are compared to available government funds based on 3%, 2% and 1% economic growth, the figure is showing a spending gap that can be closed by other measures and a capability of ARRM scenarios to reduce PHC facilities operating expenditures and response to tighter economic growth (lower than 3%).

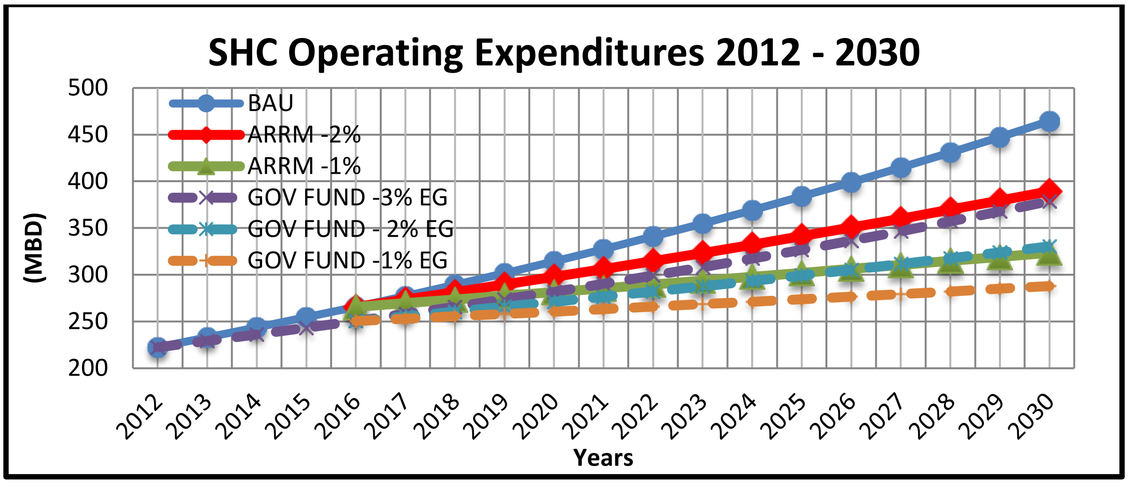


Figure 5.11 - Policy Scenarios of SHC Operating Expenditures

From Figure 5.11, SHC facilities operating expenditures of MBD 464 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the operating expenditures to MBD 389 and MBD 324 respectively. This reduction is direct result of controlling the population variable in the SD Model.

If the SHC facilities operating expenditures are compared to available government funds based on 3%, 2% and 1% economic growth, the figure is showing a spending gap that can be closed by other measures and a capability of ARRM scenarios to reduce PHC facilities operating expenditures and response to tighter economic growth (lower than 3%).

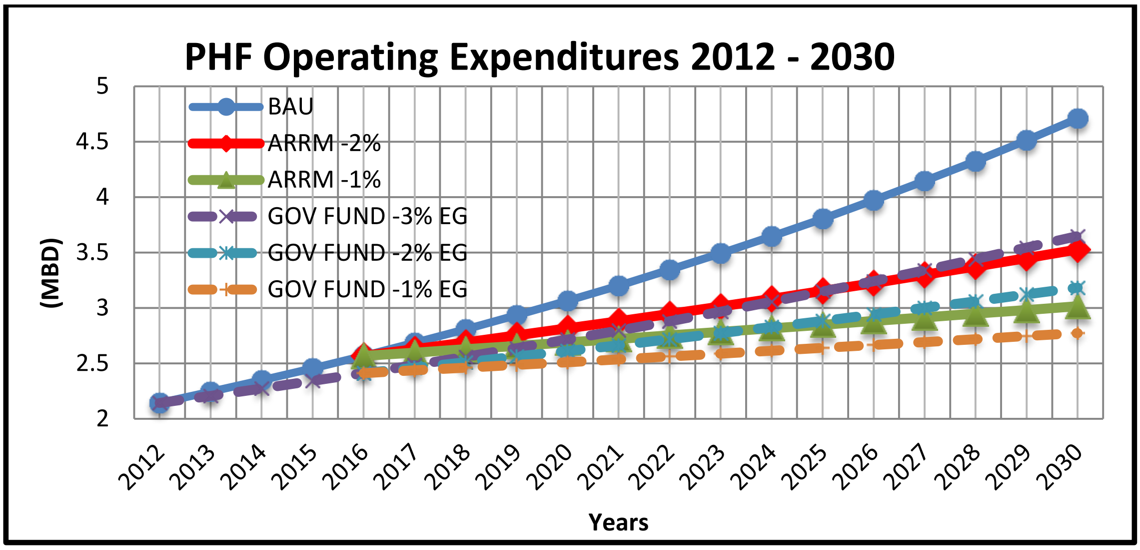


Figure 5.12 Policy Scenarios of PHF Operating Expenditures

From Figure 5.12, PH facilities operating expenditures of MBD 4.7 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the operating expenditures to MBD 3.5 and MBD 2.7 respectively. This reduction is direct result of controlling the population variable in the SD Model.

If the PH facilities operating expenditures are compared to available government funds based on 3%, 2% and 1% economic growth, the figure is showing a spending gap that can be closed by other measures and a capability of ARRM scenarios to reduce PH facilities operating expenditures and response to tighter economic growth (lower than 3%).

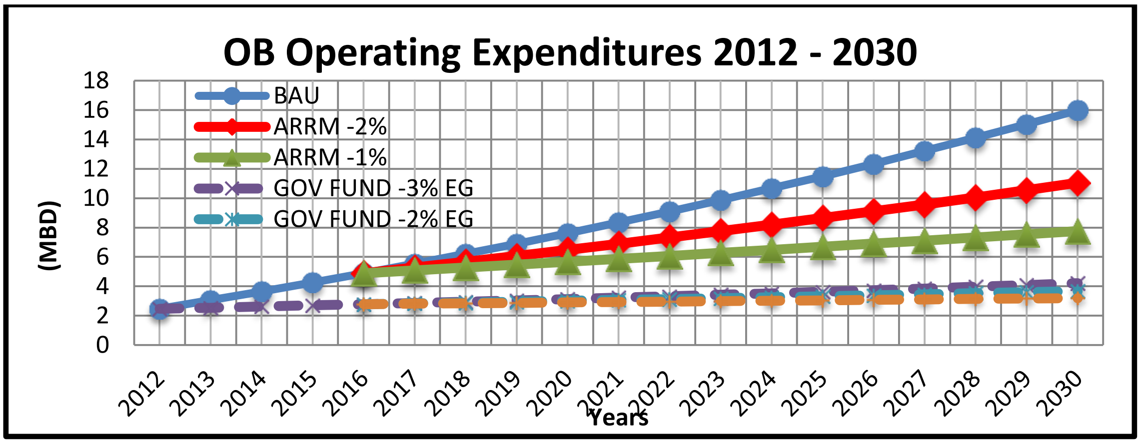


Figure 5.13 - Policy Scenarios of OB Operating Expenditures

From Figure 5.13, OB operating expenditures of MBD 16 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the operating expenditures to MBD 11 and MBD 8 respectively. This reduction is direct result of controlling the population variable in the SD Model.

If the PH facilities operating expenditures are compared to available government funds based on 3%, 2% and 1% economic growth, the figure is showing a spending gap that can be closed by other measures and a capability of ARRM scenarios to reduce OB facilities operating expenditures but not to the extent of meeting the economic growth. The figure reflects high operating expenditures growth compare to slow growth of government funds allocated for administrative services. This needs review of administration activities in order to bring the administration operating expenditures very close to available government funds.

5.6.3. Medical Waste Generation

Changes in healthcare facilities MW generation under different scenarios are shown in Figure 5.14 and Figure 5.15.

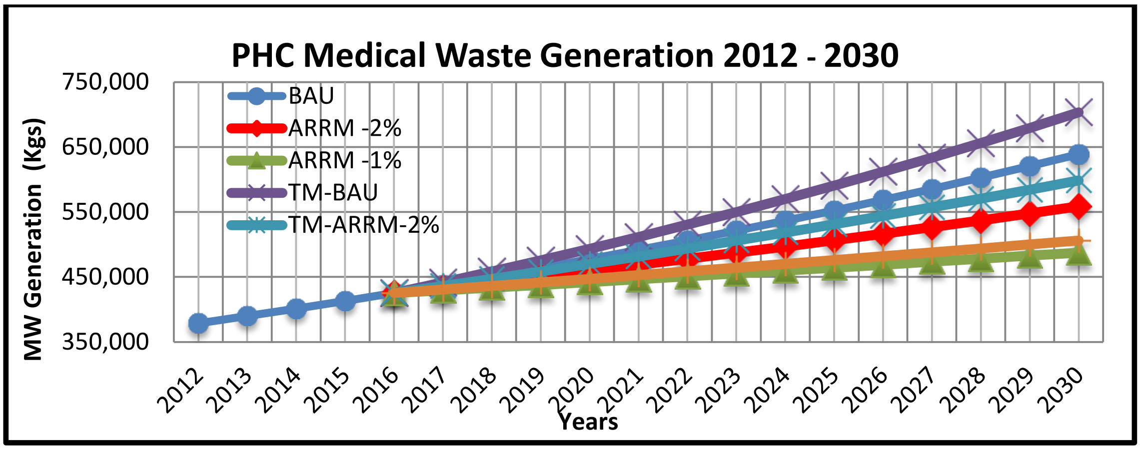


Figure 5.14 - Policy Scenarios of PHC Medical Waste Generation

From Figure 5.14, PHC facilities Medical Waste generation of 639 Tonnes are expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the Medical Waste generation to 558 Tonnes and 488 Tonnes respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When Time Management scenario is composedly implemented, the MW generations in the three scenarios is increased by 30% as a result of introducing time factor variable in the SD Model.

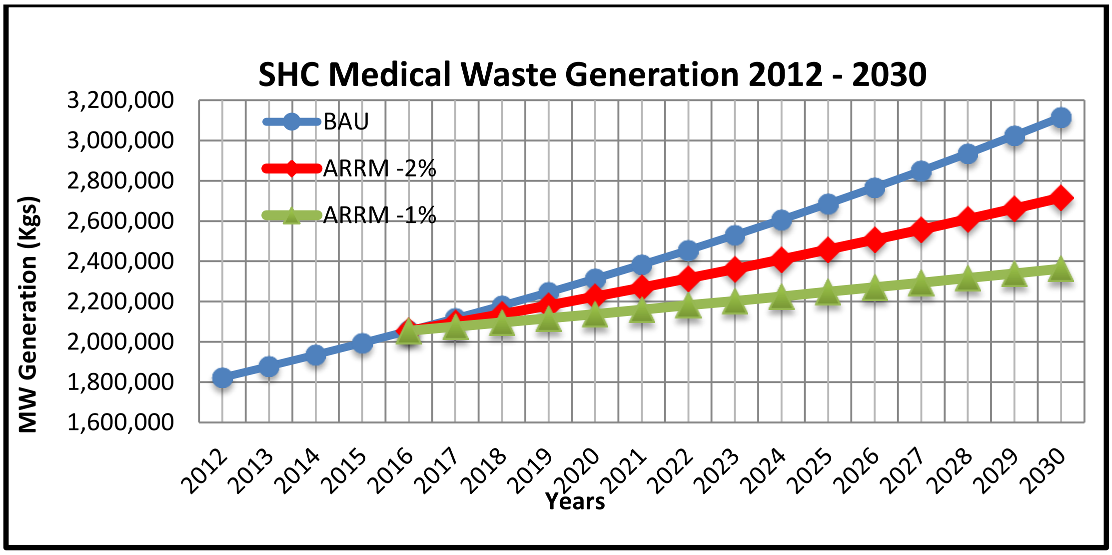


Figure 5.15 - Policy Scenarios of SHC Medical Waste Generation

From Figure 5.15, SHC facilities Medical Waste generation of 3,115 Tonnes are expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the Medical Waste generation to 2715 Tonnes and 2363 Tonnes respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

5.6.4. Energy Consumption

Changes in healthcare facilities energy consumption under different scenarios are shown in Figure 5.16 to Figure 5.20.

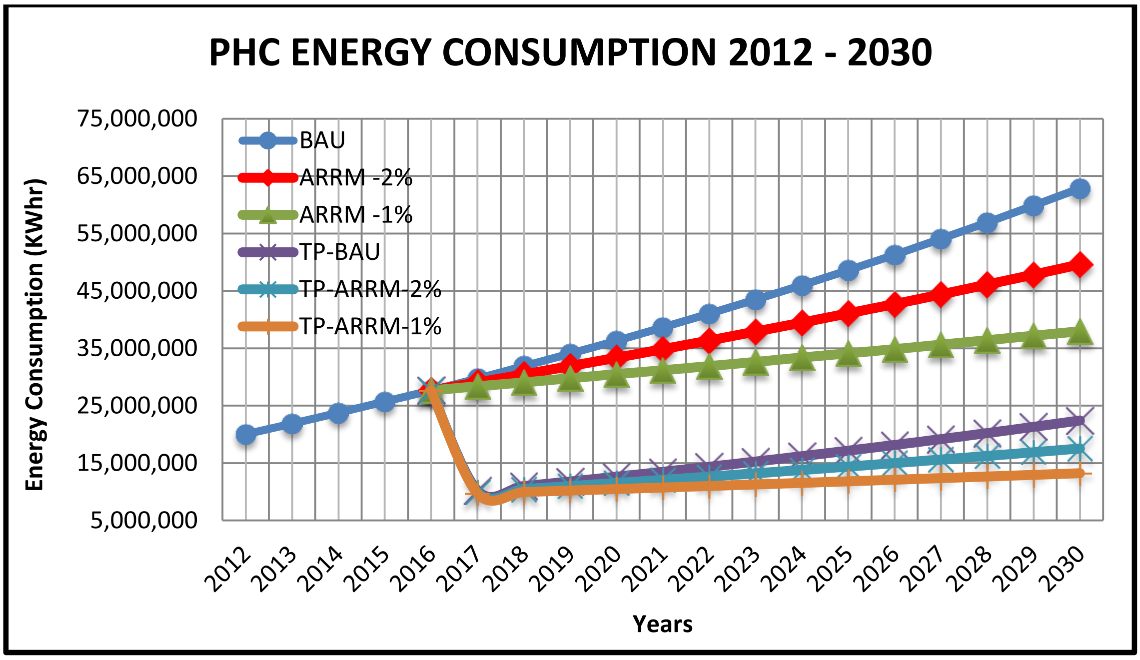


Figure 5.16 - Policy Scenarios of PHC Energy Consumption

From Figure 5.16, PHC facilities energy consumption of around 63 GWhr is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the energy consumption to around 50 GWhr and around 38 GWhr respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the energy consumption in the three scenarios falls as a result of introducing energy saving variable of 66% in the SD Model.

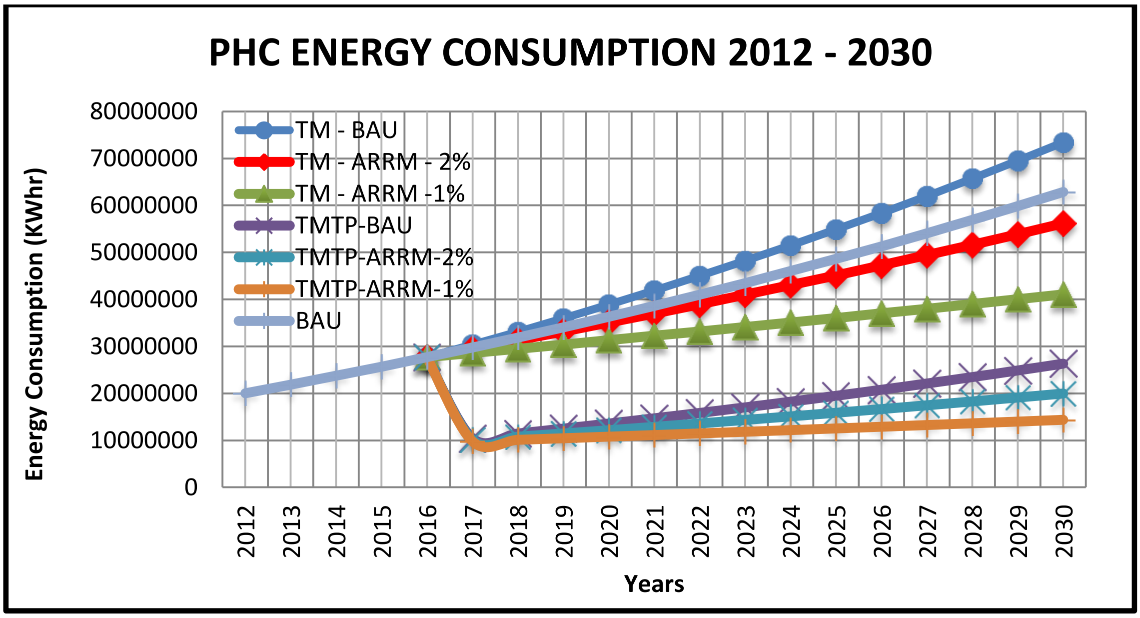


Figure 5.17 - Policy Scenarios of PHC Energy Consumption

When Time Management scenario is composedly implemented as shown in Figure 5.17, the energy consumption in the six scenarios is increased by 30% as a result of introducing time factor variable in the SD Model.

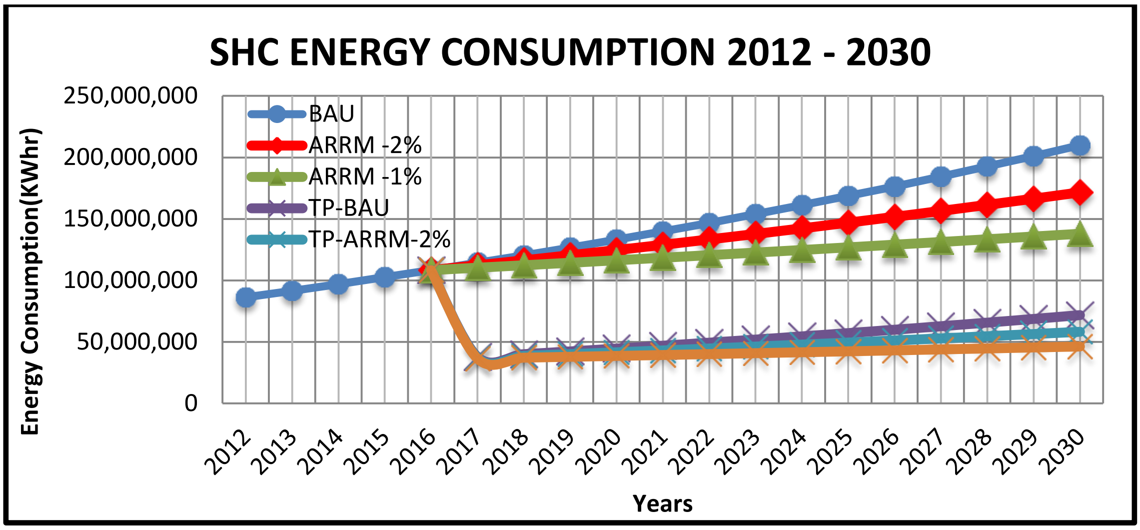


Figure 5.18 - Policy Scenarios of SHC Energy Consumption

From Figure 5.18, SHC facilities energy consumption of around 210 GWhr is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the energy consumption to around 172 GWhr and around 138 GWhr respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the energy consumption in the three scenarios falls as a result of introducing energy saving variable of 66% in the SD Model.

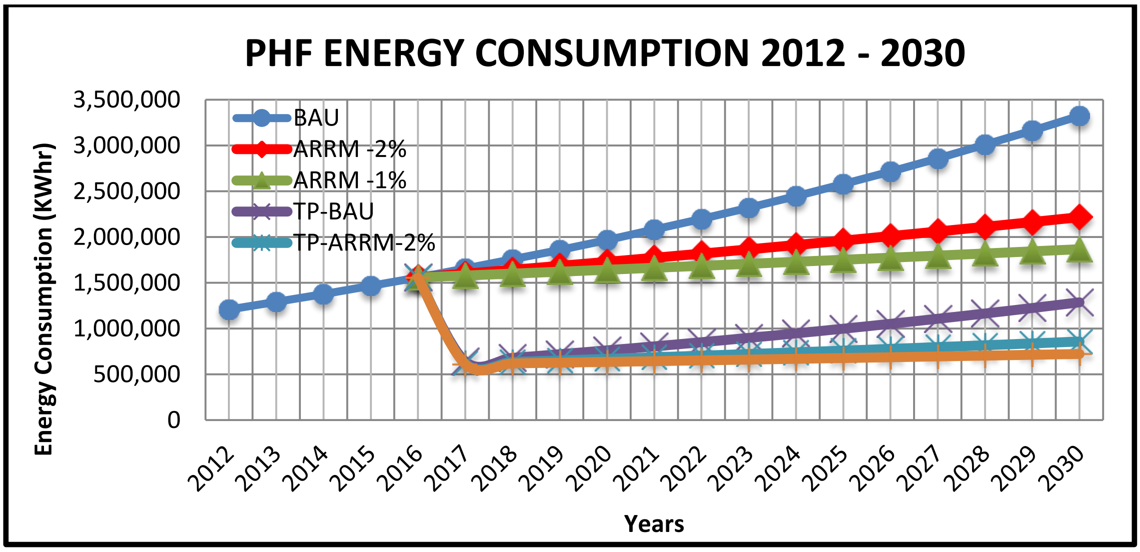


Figure 5.19 Policy Scenarios of PHF Energy Consumption

From Figure 5.19, PH facilities energy consumption of around 3.3 GWhr is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the energy consumption to around 1.9 GWhr and around 1.6 GWhr respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the energy consumption in the three scenarios falls as a result of introducing energy saving variable of 61% in the SD Model.

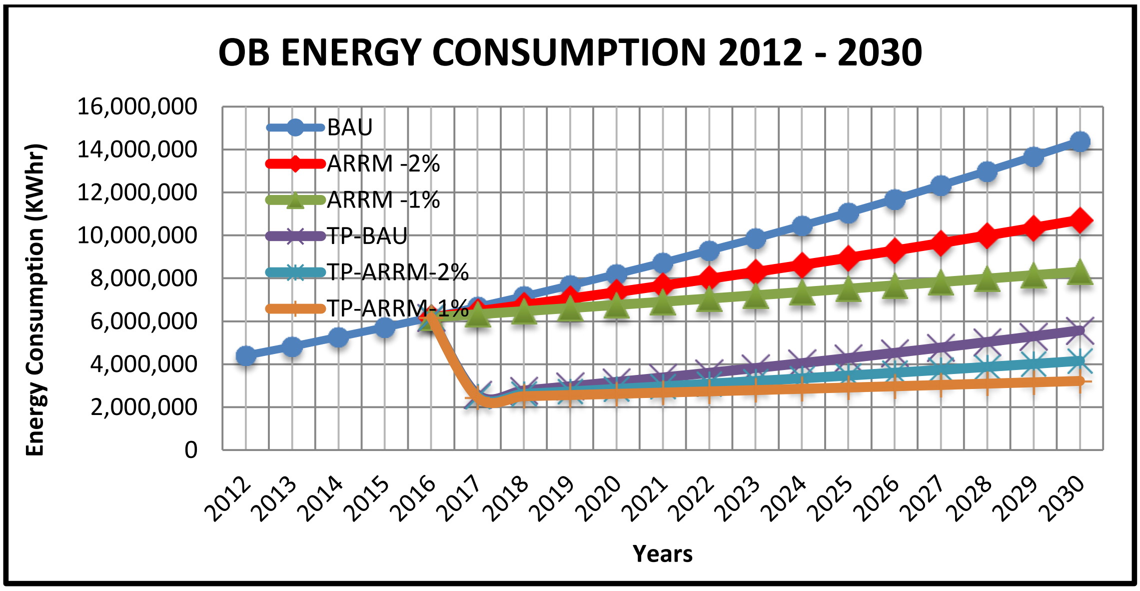


Figure 5.20 - Policy Scenarios of OB Energy Consumption

From Figure 5.20, OB Energy consumption of around 14 GWhr is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the energy consumption to around 11 GWhr and around 8 GWhr respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the energy consumption in the three scenarios falls as a result of introducing energy saving variable of 61% in the SD Model.

5.6.5. Water Consumption

Changes in healthcare facilities water consumption under different scenarios are shown in Figure 5.21 to Figure 5.25.

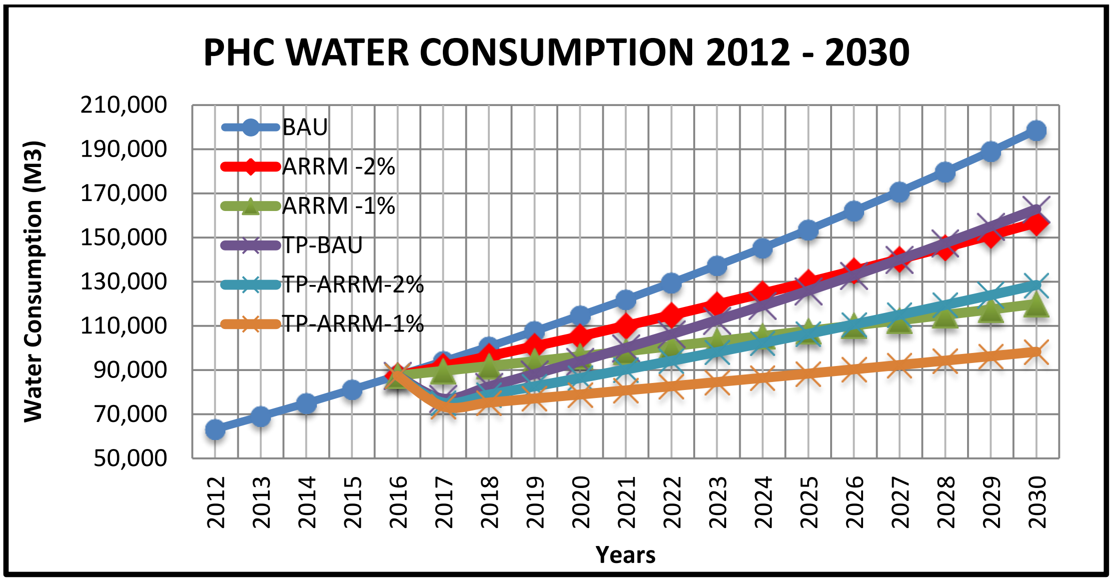


Figure 5.21 - Policy Scenarios of PHC Water Consumption

From Figure 5.21, PHC facilities water consumption of around 199,000 M^3 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the water consumption to around 163,000 M^3 and around 120,000 M^3 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the water consumption in the three scenarios falls as a result of introducing water saving variable of 18% in the SD Model.

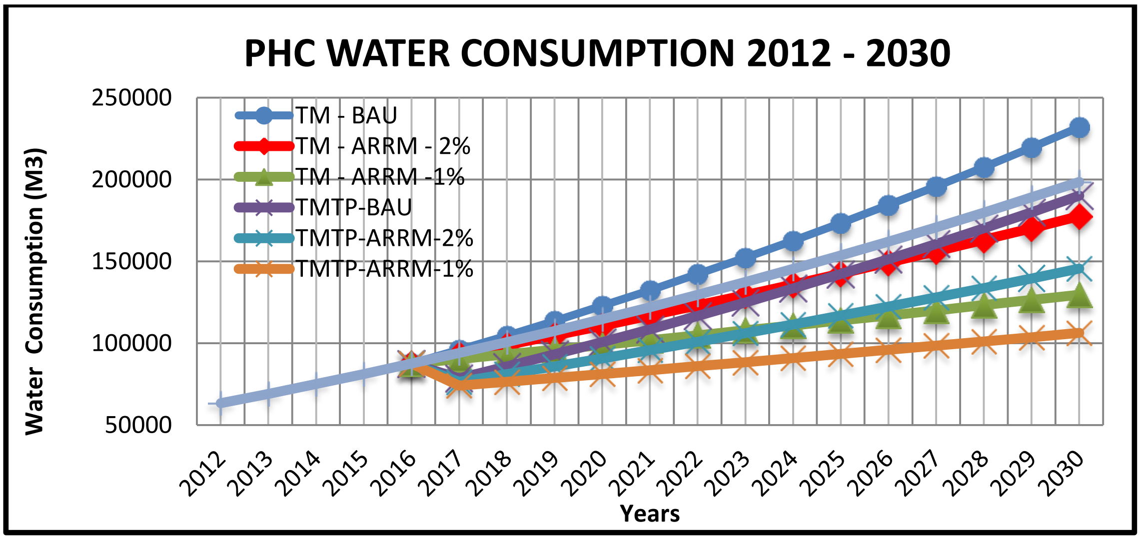


Figure 5.22 - Policy Scenarios of PHC Water Consumption

When Time Management scenario is composedly implemented as shown in Figure 5.22, the water consumption in the six scenarios is increased by 30% as a result of introducing time factor variable in the SD Model.

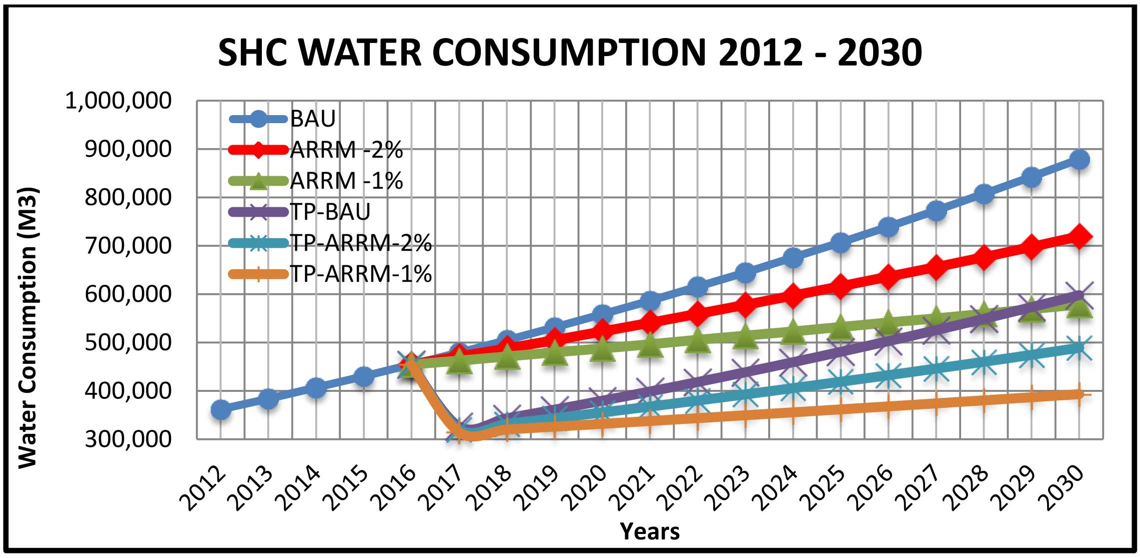


Figure 5.23 - Policy Scenarios of SHC Water Consumption

From Figure 5.23, SHC facilities water consumption of around 880,000 M^3 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the water consumption to around 719,000 M^3 and around 578,000 M^3 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the water consumption in the three scenarios falls as a result of introducing water saving variable of 32% in the SD Model.

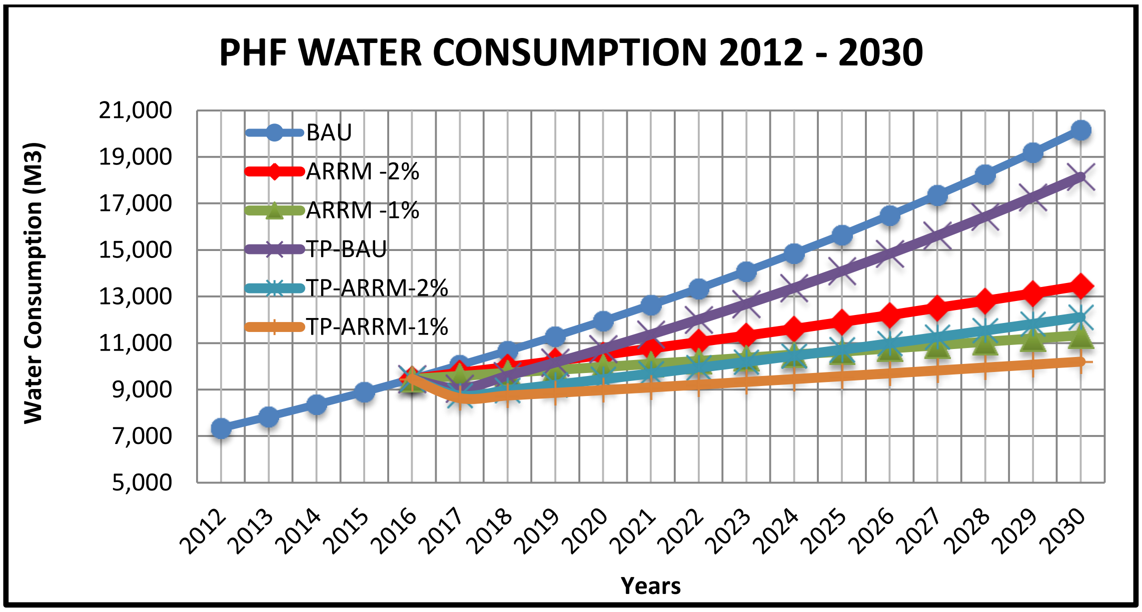


Figure 5.24 - Policy Scenarios of PHF Water Consumption

From Figure 5.24, PH facilities water consumption of around 20,000 M^3 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per

ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the water consumption to around 13,000 M^3 and around 11,000 M^3 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the water consumption in the three scenarios falls as a result of introducing water saving variable of 10% in the SD Model.

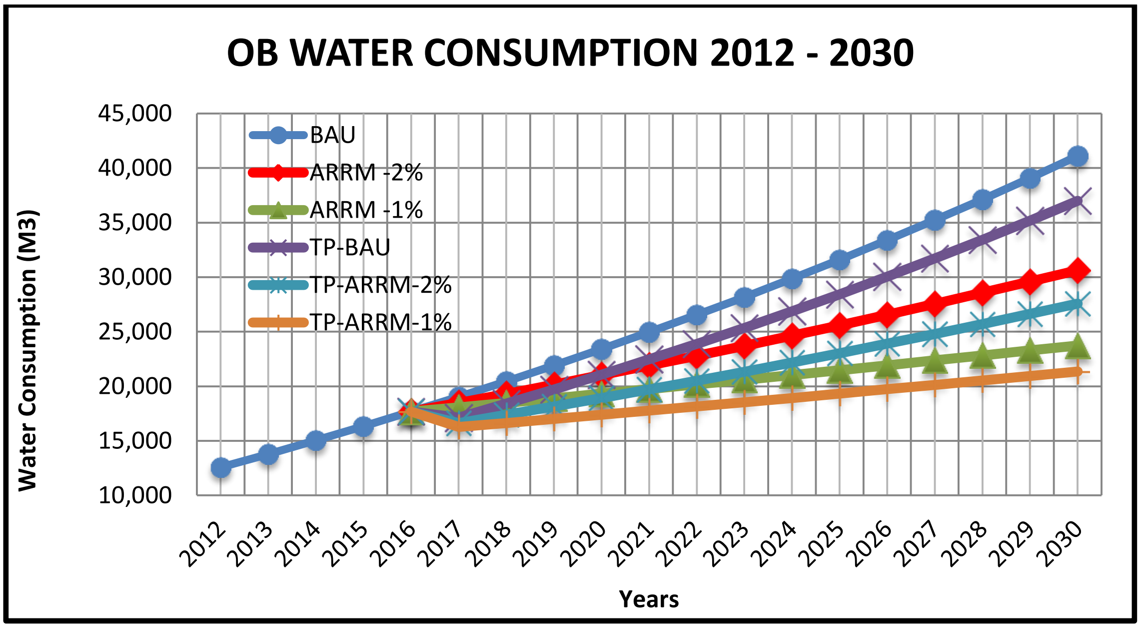


Figure 5.25 - Policy Scenarios of OB Water Consumption

From Figure 5.25, Office Building water consumption of around 41,000 M^3 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the water consumption to around 31,000 M^3 and around 23,000 M^3 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the water consumption in the three scenarios falls as a result of introducing water saving variable of 10% in the SD Model.

5.6.6. CO2e Emissions

Changes in healthcare facilities CO2e emissions under different scenarios are shown in Figure 5.26 to Figure 5.30.

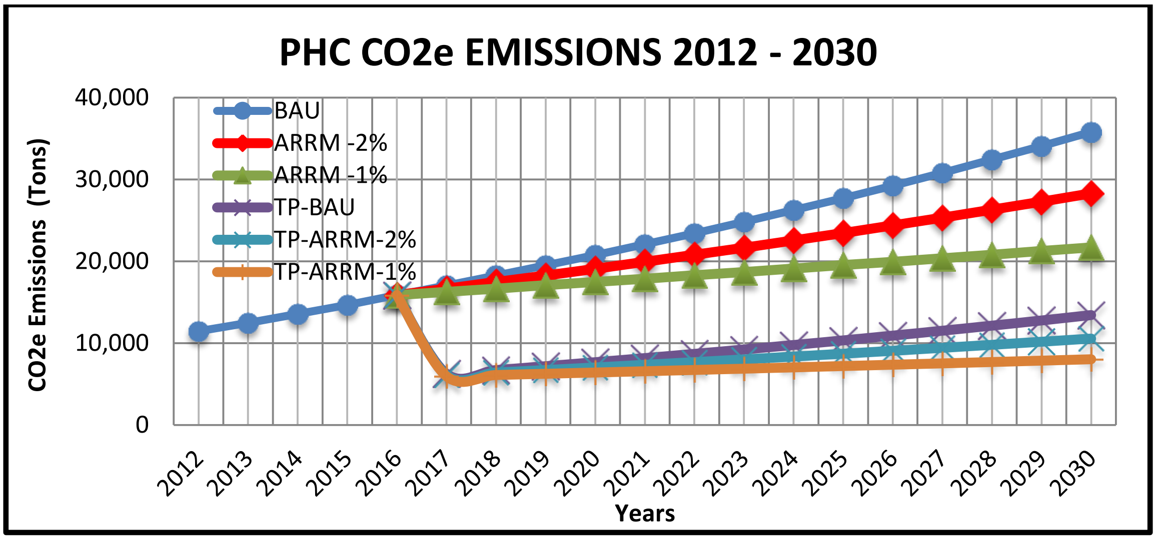


Figure 5.26 - Policy Scenarios of PHC CO2e Emissions

From Figure 5.26, PHC facilities CO2e emissions of around 36,000 Tonnes is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the CO2e emissions to around 28,000 Tonnes and around 22,000 Tonnes respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the CO2e emissions in the three scenarios falls as a result of introducing energy saving, water saving and energy recovery variables in the SD Model.

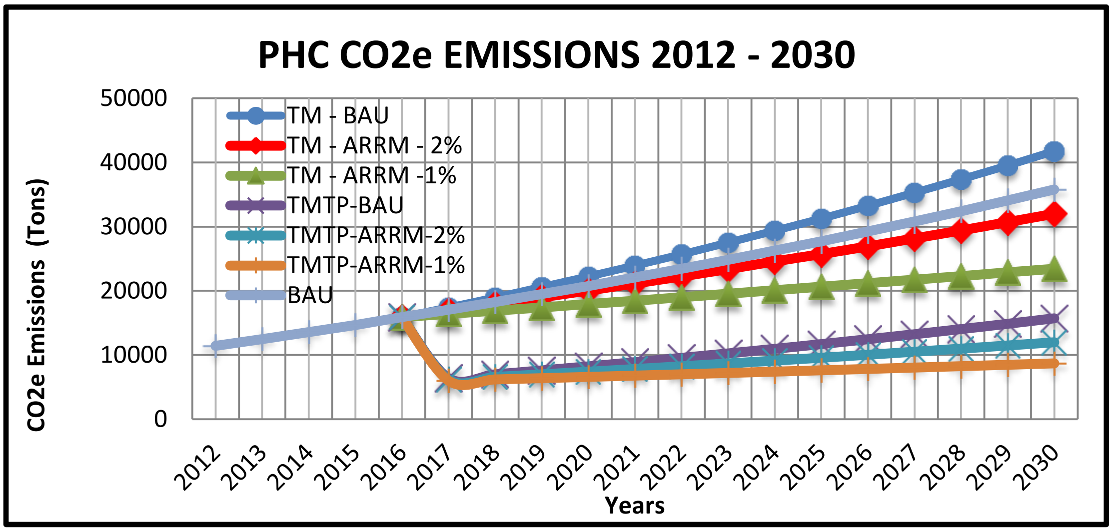


Figure 5.27 - Policy Scenarios of PHC CO2e Emissions

When Time Management scenario is composedly implemented as shown in Figure 5.27, the CO2e emissions in the six scenarios is increased as a result of introducing time factor variable in the SD Model.

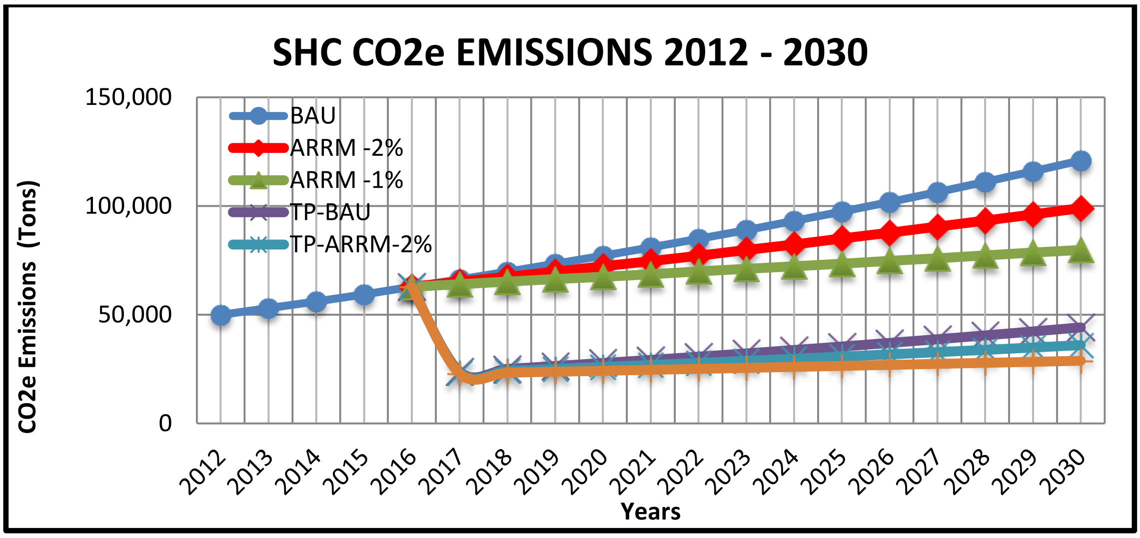


Figure 5.28 - Policy Scenarios of SHC CO2e Emissions

From Figure 5.28, SHC facilities CO2e emissions of around 121,000 Tonnes is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the CO2e emissions to around 99,000 Tonnes and around 80,000 Tonnes respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the CO2e emissions in the three scenarios falls as a result of introducing energy saving, water saving and energy recovery variables in the SD Model.

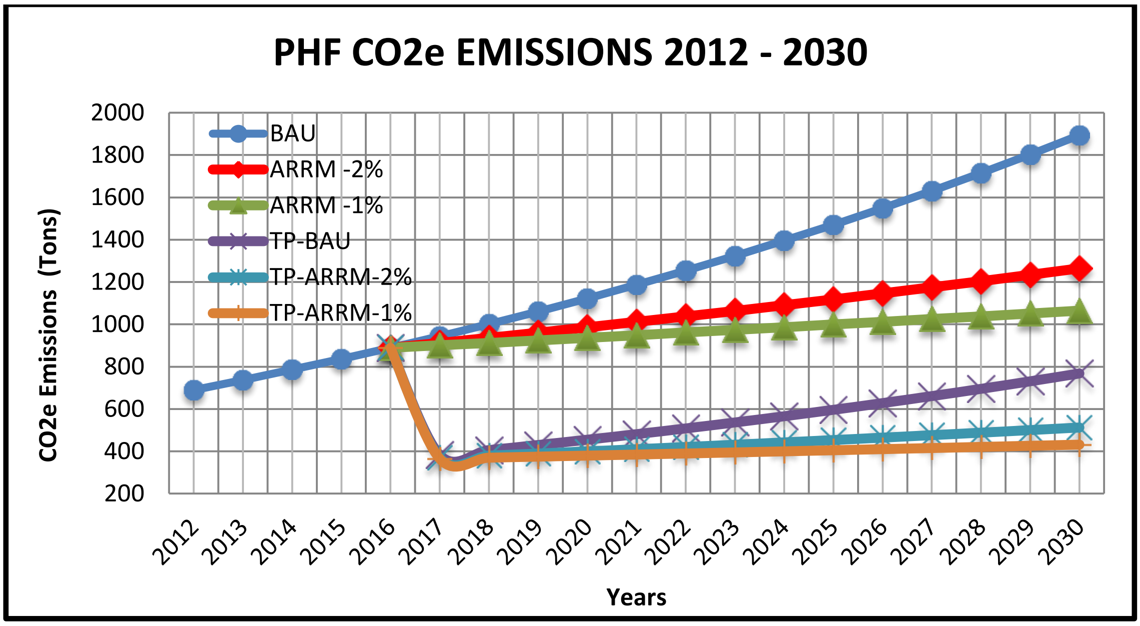


Figure 5.29 - Policy Scenarios of PHF CO2e Emissions

From Figure 5.29, PH facilities CO2e emissions of around 1,900 Tonnes is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per

ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the CO2e emissions to around 1,300 Tonnes and around 1,100 Tonnes respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the CO2e emissions in the three scenarios falls as a result of introducing energy saving and water saving variables in the SD Model.

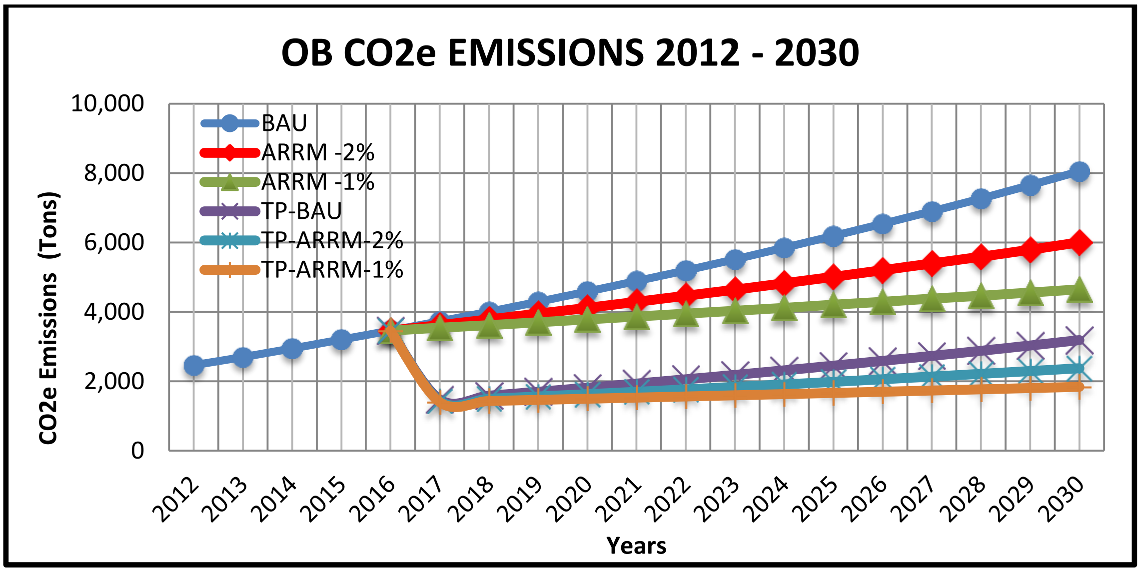


Figure 5.30 - Policy Scenarios of OB CO2e Emissions

From Figure 5.30, OB facilities CO2e emissions of around 8,000 Tonnes is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the CO2e emissions to around 6,000 Tonnes and around 4,600 Tonnes respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the CO2e emissions in the three scenarios falls as a result of introducing energy saving and water saving variables in the SD Model.

5.6.7. Utilities Expenditures

Changes in healthcare facilities utilities expenditures under different scenarios are shown in Figure 5.31 to Figure 5.35.

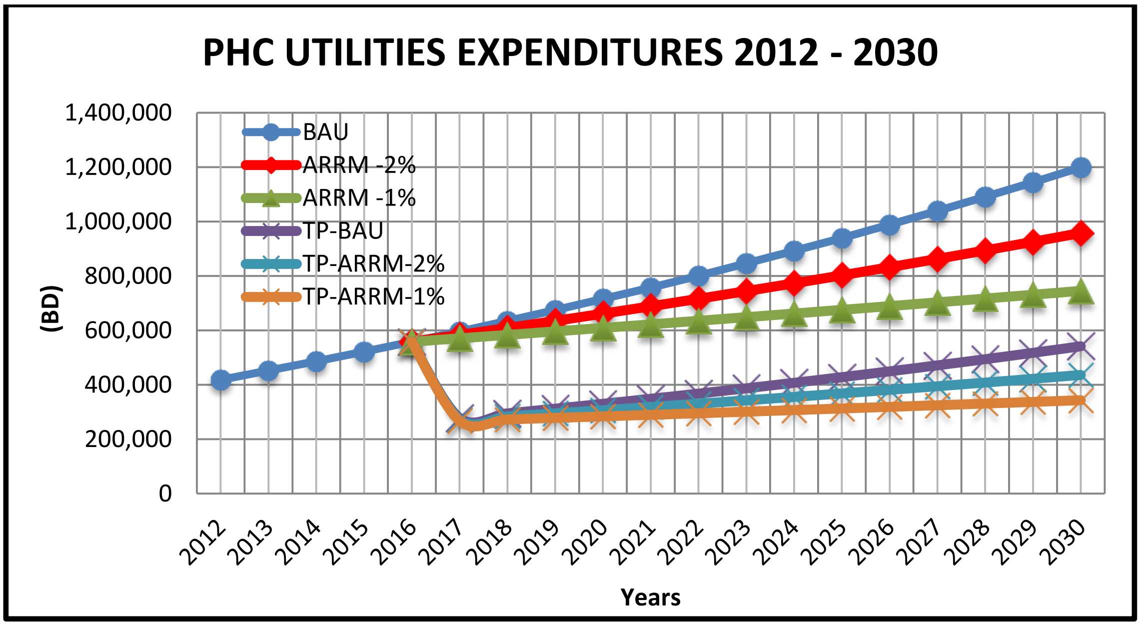


Figure 5.31 - Policy Scenarios of PHC Utilities Expenditures

From Figure 5.31, PHC facilities utilities expenditures of BD 1.200,000 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the utilities expenditures to around BD 960,000 and around BD 750,000 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the utilities expenditures in the three scenarios falls as a result of introducing energy saving, water saving and energy recovery variables in the SD Model.

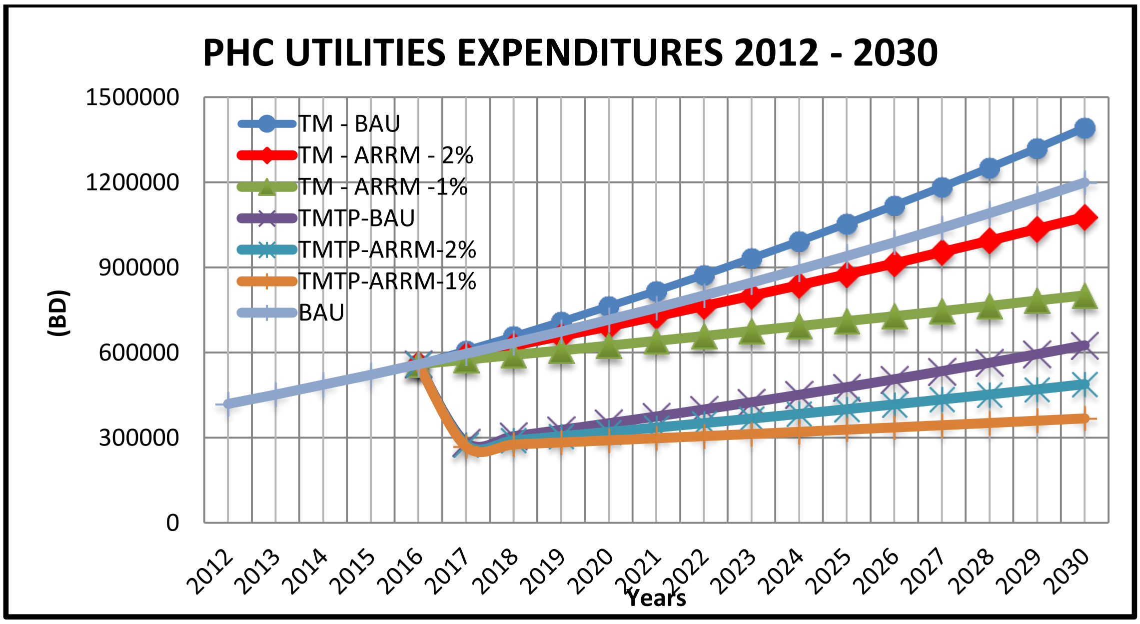


Figure 5.32 - Policy Scenarios of PHC Utilities Expenditures

When Time Management scenario is composedly implemented as shown in Figure 5.32, the utilities expenditures in the six scenarios is increased by 30% as a result of introducing time factor variable in the SD Model.

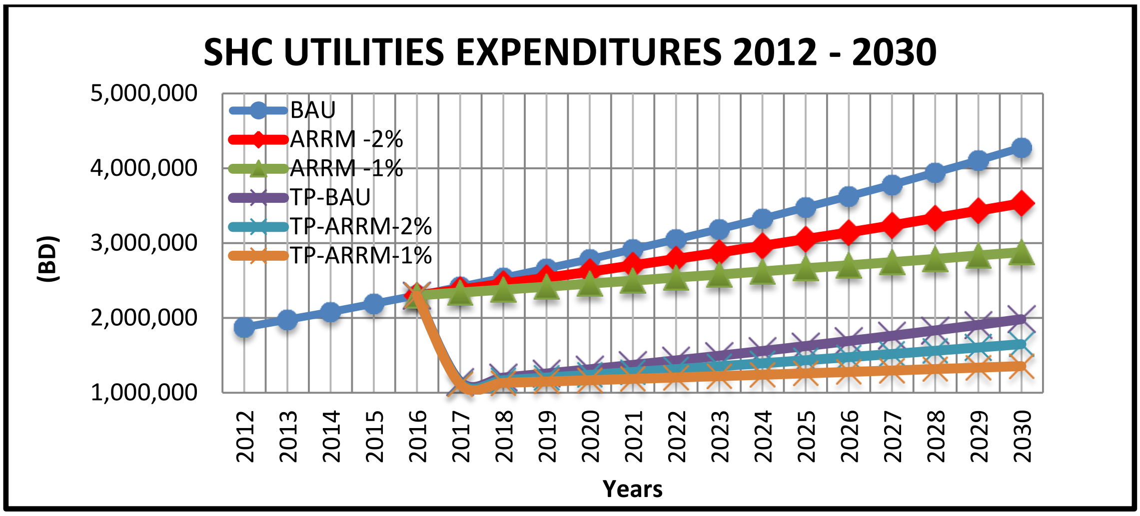


Figure 5.33 - Policy Scenarios of SHC Utilities Expenditures

From Figure 5.33, SHC facilities utilities expenditures of MBD 4.3 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the utilities expenditures to around MBD 3.5 and around MBD 2.9 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the utilities expenditures in the three scenarios falls as a result of introducing energy saving, water saving and energy recovery variables in the SD Model.

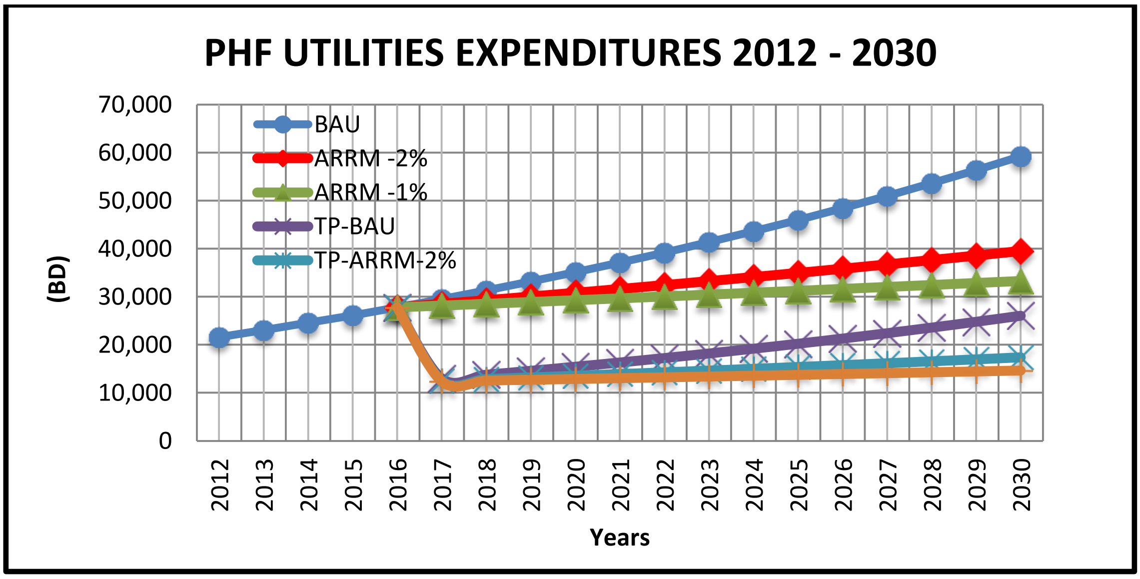


Figure 5.34 - Policy Scenarios of PH Facilities Utilities Expenditures

From Figure 5.34, PH facilities utilities expenditures of BD 59,000 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the utilities expenditures to around BD 40,000 and around BD 33,000 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the utilities expenditures in the three scenarios falls as a result of introducing energy saving, water saving and energy recovery variables in the SD Model.

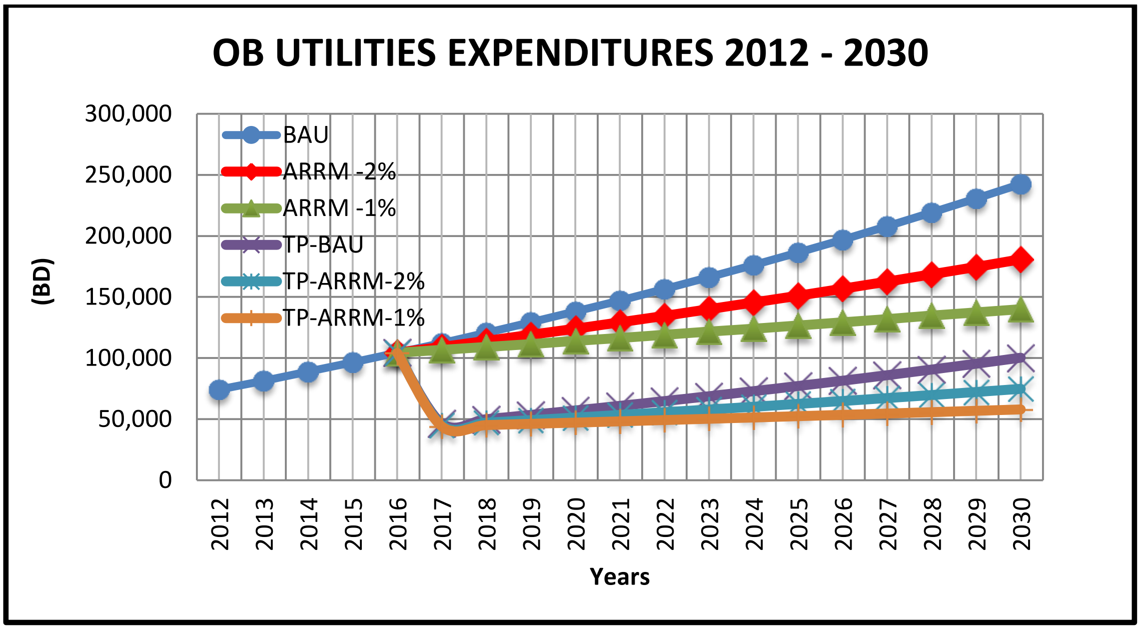


Figure 5.35 - Policy Scenarios of OB Utilities Expenditures

From Figure 5.35, OB facilities utilities expenditures of BD 240,000 is expected in 2030 based on 3% population growth. Regulating the population growth to 2% as per ARRM-2% scenario and to 1% as per ARRM-1% scenario can reduce the utilities expenditures to around BD 180,000 and around BD 140,000 respectively. This reduction is direct result of controlling the population variable that affect the facilities demand in the SD Model.

When some Low Carbon Design parameters are composedly implemented in the TP scenario, the utilities expenditures in the three scenarios falls as a result of introducing energy saving, water saving and energy recovery variables in the SD Model.

5.7. Chapter Summary

After developing and validating the SD model, it is demonstrated and implemented on Bahrain’s healthcare system as a research context using number of scenarios suggested by literatures. ARRM-1% scenario has the lowest parameters values among all individual scenarios while TP scenario is very effective in reducing the values of utilities parameters and subsequently utilities expenditures parameters values. Where TM scenario is applicable, mainly in PHC services, it is noticed that it is increasing all the investigated parameters values and TP scenario is required again to reducing its effect. TM scenario in general is not a preferable scenario from environmental and economic point of view unless there are some strong management justifications and good operational benefits.

The best scenario is obtained by combining TP & ARRM-1% scenarios as it has the lowest investigated parameters values among all combined scenarios.

As a conclusion, it is highly recommended for the policy makers to control population growth as a mean to reduce the demand on healthcare services by move slowly from BAU scenario to ARRM-1% scenario. For the practitioners, it is highly recommended to implement technical measures to reduce energy demand and its negative environmental and economic impact by implementing TP scenario.

Chapter 6 – Research Findings, Limitations, Conclusions, Contributions and recommendations for researchers and practitioners

The purpose of this chapter is to satisfy the forth objective of this research by demonstrating theoretical and technical findings and limitations related to environmental sustainability of healthcare facilities that contribute to better understanding and enhance implementation of this research. Another purpose of this chapter is to satisfy the fifth objective of this research by addressing the conclusions of the research, the research contributions to the body of knowledge and the recommendations for researchers and practitioners in healthcare.

6.1. Energy Consumption in Healthcare Buildings

International Energy Agency's report, IEA (2012) stated that Four-fifths of the potential of energy efficiency in the buildings sector is still remains untapped. The same agency suggested in another report, IEA (2008) implementing some measures to move toward energy efficiency and sustainable buildings such as reducing the heating, cooling and lighting load to minimum, use the energy of renewables and waste energy sources as efficient as possible and use fossil fuel as effective and clean as possible.

The suggested measures were tested using System Dynamics Analysis and found to be very effective. An energy saving of 65% can be achieved by implementing the suggested measures. 48% of the saving is due to use of energy efficiency measures, 13% due to use of renewable sources of Solar Panel Water Heating (Appendix-F) and 4% due to recovery of energy from medical waste incineration process (Appendix-G).

The 48% saving from energy efficiency is comprises of 41.5% from energy recovery of Air-conditioning system (Appendix-D) and 6.5% from replacement of conventional lights with LED lights (Appendix-E).

The fourth Energy Efficiency Indicator Survey results summarised by Smith (2011) shows that improving Heating, Ventilation & Air Conditioning (HVAC) systems and lighting system accounts for saving approximately 60% of all energy used in traditional buildings.

This research and System Dynamics Analysis proofs that a high level of energy saving in buildings in general and in healthcare buildings in specific can be practically achieved by implementing energy efficiency schemes taking into consideration different energy consumption categories' between countries. An additional 10% can be gained by implementing energy conservation schemes.

Kolokotas et.al. (2012) reviews the technologies used to achieve energy efficiency in hospitals and found that the cost of high technology devices represents a barrier for wide scale applications and suggested implementing simple energy conservation techniques (for which no special budget should be needed) to save up to 10% of primary energy consumption.

Some of the suggested techniques have been tested using SD Analysis and found to be very effective in getting an additional energy saving potential added to the potential of energy saving from energy efficiency measures.

Some of the energy saving is taken in the form of higher energy consumption that is the so-called take-back or rebound effect. Saunders (2000) found that a number of recent empirical studies have begun to establish a very strong body of evidence that rebound effects being in the order of 5-10%, Herring (2006) estimated it between 10-20%, Greening (2000) believed that the rebound is not high enough to mitigate the importance of energy efficiency as a way of reducing carbon emission. The rebound effect is considered as a contradictive behavior to the energy conservation efforts as well as water conservation efforts. Although it has a limited effect, disregarding it in energy and water conservation strategy may lead to lose some effective efforts in the saving process.

6.2. CO2e Emissions in Healthcare Buildings

The healthcare buildings large impact on environment is in term of CO2e emissions directly produced as a result of energy consumption and Medical Waste incineration and indirectly from water production in power plants. The potential of CO2e emissions reduction by implementation of energy saving measures was tested using System Dynamics Analysis and found to be around 64%. Good potential of CO2e emissions is achieved by recover energy from Medical Waste Incineration as it can offset double the quantity of CO2e emissions resulting from the incineration process.

6.3. Utilities Expenditures in Healthcare Buildings

The potential of utilities expenditures reduction achieved by implementation of energy saving measures was tested using SD Analysis and found to be small and due to the existing low utilities and fuel tariffs. This is going to be improved after gradual lifting of government subsidies during the next three years.

Kingdom of Bahrain lifted the subsidies of Benzene, Diesel and Kerosene prices and will continue lifting the subsidies of Diesel and Kerosene prices in phases over the years (2016-2019). It is also lifted the power and water tariffs subsidy for non-domestic use effective of March 2016 and will continue the tariffs increase in phases over the years (2016-2019). This step, from one hand, will raise the energy cost by more than 80% and will increase the healthcare facilities operating expenditures in term of direct costs of energy consumption and standby power Diesel fuel, and indirect cost in term of increasing logistics and services cost. From other hand it enforces the energy saving initiatives and the contribution of utilities saving in reducing Healthcare expenditures. The advantage of this change is that it will improve the feasibility and return on investment (ROI) of Energy Efficiency Projects and shorten the payback period to half.

6.4. Sustainability Aspects in Green Buildings

Zue et. al. (2014) in a research related to the performance of green building found that most of green building studies focus on environmental aspects of sustainability such as energy consumption, water consumption and CO2 emission with relative technical solutions while studies of social and economic aspects of sustainability are comparatively lean, despite a large number of literatures emphasise their importance.

In this research, although the researcher follows the trend of similar environmental studies, a good focus on the economic aspects of healthcare system were considered and the strong interaction between environmental sustainability and economic sustainability were deeply studied and quantified using System Dynamics Analysis Modeling. Socio-economic primitives / elements and their interaction are identified but need validation. Social aspects are admitted to be still leaning due to the sociological natures of this dimension compared to the techno-economic natures of the other two dimensions.

6.5. Scenarios Under Declining Economy

Under declining economy, Governments are forced to take robust actions to overcome the negative impacts and save its financial resources. Reviewing taxes to generate funds, lifting subsidy on goods and services to save millions of country currency and implementation of Tax Added Value (TAV) schemes are an effective government short term measures but on long term it will lead to economics inflation, where a general increase in prices take place accompanied with fall in the purchasing value of money. Shrinkage of Government Operating Budget and reviewing spending on infrastructure projects as a government measure to control general spending will lead to shrinkage in job opportunities and will end with economic recession that will badly affect the living standard of people.

Shrinkage in job opportunities and rising of living expenses will encourage immigration outside the country and reduce immigration rate. SD Analysis shows that controlling immigration rate, either due to economic reasons or due to government policies, is an effective measure to control population growth and reduce the demand on healthcare services. The same similar scenarios were suggested by World Population Prospect (2015) to regulate population growth and subsequently services operation growth at 2% and 1%. These scenarios effect on healthcare facilities demand and its environmental and economic impacts were investigated and found very effective to create fundamental changes in the infrastructures of services.

6.6. Research Limitations

It is very helpful for future researches in environmental sustainability of healthcare system to highlight the current research limitations that are:

1) Environmental and energy studies are time consuming researches and need good span of time to log systems behaviours and trends changes. Due to the limited academic research cycle the researcher compensated that by extracting previous years of operations secondary data. The quality of third party secondary data is debatable and to reduce margin of error wide range of data were considered and averaged.
2) Lack of access to energy measuring devices of 50% of Primary and Secondary Healthcare Facilities, as it is under the custody of Electricity & Water Authority. Special permissions were obtained to access these devices. There is also lack of access to High Voltage measuring devices of Secondary Healthcare Facilities.
3) As Business study is the major tier of this research while technical is the minor, energy assessment case study was conducted on one typical healthcare facility to test the effectiveness of proposed mitigation solutions. Good sample that represent the majority of the facilities was selected to reduce this effect.
4) Limited available data related to Immigration in and out of country.

6.7. Meeting Research Aim and Objectives

To achieve the aim of this research, a number of objectives defined in chapter were achieved and accomplished as summarised in the following paragraphs:

- **Objective 1 – Conduct SLR to review environmental and economic challenges and sustainability opportunities in healthcare facilities:**

  This research investigated, in chapter 1 and 2, the current environmental challenges related to expanding in healthcare services, that are found to be increases in energy consumption, water consumption, and waste generation that have an environmental impact in the form of CO2e emissions and economic impacts in the form of project expenditures, operating expenditures and utilities expenditures.

It is also investigated the available opportunities to enhance environmental sustainability of hospitals and healthcare facilities that can be achieved using energy efficiency technologies, renewable-base energy and waste energy recovery.

- **Objective 2 – Design and Develop SD Analysis methodology to study and analyse healthcare facilities environmental and economic challenges and its negative impacts:**
  System Dynamics Analysis model was designed (chapter 3) and developed (chapter 4) in four versions representing different Healthcare Services (PHC, SHC, PHF and OB).

- **Objective 3 – Follow standard methodology to implement and demonstrate the developed SD Model:**
  The developed SD Model was implemented to analyse data of Bahrain healthcare system (chapter 5). The outcome of the research results strongly supported the implications of stated environmental challenges and the effectiveness of suggested measures and scenarios in mitigating the undesirable results on healthcare services. It is highly recommended for researchers and practitioners.

  The developed SD Model was found to be the most appropriate model development and analysis tools to study environmental issues in hospitals and healthcare facilities. It can be used as strategic planning and decision-making administrative tool to forecast future healthcare facilities demand and required resources. It is also can be used as a risk assessment tool to assess environmental challenges related to utilities and its environmental and economic impacts in order to improve healthcare facilities sustainability.

- **Objective 4 – Demonstrate theoretical and technical findings and limitations related to environmental sustainability of healthcare facilities:**
  Research findings and limitations related to utilities consumptions, CO2e emissions, and utilities expenditures in healthcare facilities in addition to green buildings concept that contribute to better understanding and enhance implementation of the research were demonstrated in chapter 6.

- **Objective 5 – Propose recommendations for researchers, Policy Makers and practitioners to overcome the negative impacts related to healthcare facilities environmental and economic challenges:**

Research theoretical, methodological, and conceptual contributions in addition to recommendations for researchers, policy makers and practitioners were demonstrated in chapter 6.

6.8. Research Contributions

6.8.1. Research Theoretical Contributions (Healthcare Buildings Impact on Environment)

Gunther et. al., (2008) in his sustainable healthcare architects review found that Healthcare buildings have large impact on environment. The impact is generated from two sources; energy consumed and waste generated. In order to protect the environment, he suggested hospitals and healthcare facilities to have an efficient operation and management strategies of these resources.

As a complementary to the earlier work in determination of the two sources, this research contributes to the body of theoretical knowledge by identifying a third healthcare buildings large impact on environment that is water consumption. Availability of enough potable, clean and treated water for different healthcare applications, especially in countries with limited fresh water resources like Bahrain, is a real environmental challenge needs to be addressed to have an efficient operation and management strategy.

The three sources, i.e. energy consumption, water consumption and waste generation secondary data were extracted from healthcare Authority and Electricity and Water Authority (EWA) in Bahrain. The data were used to quantify and test the impact of healthcare buildings on environment using System Dynamics Analysis Models. The contribution is presented in the form of number of energy and water consumption benchmarks as discussed in the contextual contributions section.

This research also contributes to the body of theoretical knowledge by identifying group of environmental challenges related to the practice of healthcare services that can expose personnel (staff and patients) and environment to high risks. This group of environmental risks consisting of spread of infections; exposure to X-Rays and diagnostic/treatment radioactive materials; exposure to needle punctures and sharp objects injuries; exposure to handling-injuries; and exposure to harmful chemicals. These challenges need to be efficiently managed in order to improve environmental and social sustainability of healthcare system. This group of risks to be subjected to further research as it is outside the boundary of this research.

6.8.2. Research Methodological Contributions

This research is conducted using System Dynamics Analysis approach methodology in qualitative-quantitative mixed method. Qualitative method is used to verify relations between factors influencing the research topic while quantitative method is used to analyse primary and secondary data of healthcare system. System Dynamics Analysis Research Methodology is shown in Figure 3.3

System Dynamics Analysis Model, as a theoretical contribution of this research, is developed to study the future expanding in healthcare facilities, resources, utilities, and negative impacts as shown in Figure 4.2. Four versions of the SD Model representing different Healthcare Services (PHC, SHC, PHF and OB) were produced to test the services performance under different scenario as shown in Figure 4.3 to Figure 4.6.

As healthcare is a specialised field, relations between factors influencing the research area were developed using Casual Loop Diagram and validated using interviewing focus groups by interviewing six groups (45 Participants) working in different healthcare services to get their insights, opinions and views. The outcomes of the interviews (59 feedbacks and comments) were obtained and incorporated in Casual Loop Diagram (CLD) to produce revised CLD shown in Figure 4.2. Based on the revises CLD, System Dynamics Model is mathematically developed and used to analyse the healthcare system of Bahrain.

Systematic Literature review (SLR) shows number of System Dynamics analysis studies conducted in healthcare sector covering environmental management (mainly medical waste management) but no any SD analysis study found covering the environmental challenges such as energy consumption, water consumption, MW Generation and CO2e emissions in healthcare field.

Using SD Analysis technique to quantify and analyse environmental challenges in healthcare field can be considered as a methodological contribution of this research.

6.8.3. SD analysis use in strategic planning to forecast CO2e emissions from healthcare

System Dynamics Analysis Model is developed, as a strategic planning administrative tool and a methodological contribution of this research, to study the negative impacts of future expanding in healthcare facilities and to quantify the impact of healthcare in term of energy consumption, water consumption, medical waste generation and finally in the form of total CO2e emissions.

In 2016, the carbon footprint of the different healthcare sector in Bahrain is estimated using the SD developed model(s) as shown in Figure 5.26 to Figure 5.30. Different healthcare sectors carbon footprints are summarised in Table 6.1.

Table 6.1 - Summery of Healthcare Sectors Carbon Footprint

#	Healthcare Service	Carbon Footprint (Tones CO2e)
1	Secondary Healthcare (Hospitals)	15,887
2	Primary Healthcare (Health Centers and Clinics)	62,894
3	Public Health Laboratory	889
4	Administration Services Office Buildings	3,460
5	Nursing Hostel Buildings	285
	Total (year 2016)	**83,415**

The estimated Bahrain Healthcare total carbon footprint of 83,415 tones can be considered as Contextual Contributions of this research.

6.8.4. Research Contextual Contributions

As System Dynamics is an appropriate Analysis technique to quantify and analyse environmental and economic challenges in healthcare and in order to run the developed Models, secondary healthcare data was utilised to understand the characteristics of healthcare system by developing number of technical parameters related to Bahrain healthcare system necessary to run the SD Models and predict the future demands. These parameters can be considered as Contextual Contributions of this research.

As some of these parameters are location dependent, it can be generalised and used in the regions sharing Kingdom of Bahrain same climate and weather conditions such as GCC Countries, South of Iraq and West coastal areas of Iran. These technical parameters are:

1) Development of **Nine Bahrain Healthcare Energy Benchmarks** as per details of Appendix A and as summarised in Table 6.2.

Table 6.2 - Summery of Healthcare Energy Benchmarks

#	Healthcare Service	Energy Benchmark (KWh/m2)
1	Secondary Healthcare (Hospitals)	322
2	Primary Healthcare (Health Centers and Clinics)	247
3	Public Health Laboratory	206
4	Administration Services Office Buildings	203
5	Nursing Hostel Buildings	100
6	Psychiatric Hospitals	246
7	Maternity Hospitals	258
8	Kidney Dialysis Hospitals	279
9	Community Medical Centre (Multi Purposes)	**506**

Comparison of Bahrain's hospitals and healthcare facilities actual performance with benchmarks of annual energy consumption per square meter of floor area will permit good standard of energy efficiency assessment that leads to proper corrective actions and overcome any problematic areas within the facilities.

The obtained Energy Benchmarks of 322 KWh/m2/year for SHC and 206 KWh/m2/year for PHC, as per details of Appendix A, are very encouraging if compared to good practice benchmark for health buildings in UK, that is 416 kWh/m2/year, taking into consideration the differences in energy categories between UK and Bahrain.

2) Development of **Nine Bahrain Healthcare Water Benchmarks** as per details of Appendix B and as summarised in Table 6.3.

Table 6.3 - Summery of Healthcare Water Benchmarks

#	Healthcare Service	Water Benchmark (m3 / m2)
1	Secondary Healthcare (Hospitals)	1.35
2	Primary Healthcare (Health Centers and Clinics)	0.78
3	Public Health Laboratory	1.25
4	Administration Services Office Buildings	0.58
5	Nursing Hostel Buildings	0.49
6	Psychiatric Hospitals	0.53
7	Maternity Hospitals	0.64
8	Kidney Dialysis Hospitals	**3.64**
9	Community Medical Centre (Multi Purposes Hospital)	0.51

Comparison of Bahrain's hospitals and healthcare facilities actual performance with benchmarks of annual water consumption per square meter of floor area will permit good standard of water efficiency assessment that leads to proper corrective actions and overcome any problematic areas within the facilities.

The obtained Water Benchmarks of 1.35 m3/m2 for SHC, 0.78 m3/m2 for PHC and 1.25 m3/m2 for PH, as per details of Appendix B, are very encouraging if compared to hospital water use benchmarks for health buildings in Australia (Hospitals Factsheet, 2013), that is 1.3 m3/m2 as a mean and 3.3 m3/m2 as a maximum.

3) Development of **Bahrain Healthcare Energy Consumption Categories** as per details of Appendix C and as summarised in Table 6.4

Table 6.4 - Healthcare Energy Consumption Categories

Energy Consumption Categories	%
Annual Energy Consumption of A/C System	70.18
Annual Energy Consumption of Lighting System	12.25
Annual Energy Consumption of Domestic Hot Water	15.70
Annual Energy Consumption of Other Systems	1.87
Total	100%

Knowing Bahrain’s hospitals and healthcare facilities energy consumption categories is very important to optimize management actions in utilities consumption areas.

The existing distribution of the categories is due to the fact that the tested facilities is peripheral facility and not containing any major services such as Kitchen, Laundry or Sterilisation. The existence of these services definitely can change the categories.

4) Development of **Four System Dynamics Analysis Models for Bahrain Healthcare System** as summarised in Table 6.5.

Table 6.5 - System Dynamics Analysis Models for Bahrain Healthcare System

#	**Healthcare Service**
1	SD Model of Primary Healthcare (Health Centers and Clinics)
2	SD Model of Secondary Healthcare (Hospitals)
3	SD Model of Public Health Laboratory
4	SD Model of Administration Services Office Buildings

The deep insight of Healthcare System leads to segregate the services based on its operation taking into consideration nature of future demand and facilities expansion and the performance indicators controlling the quality of services.

The four versions of the SD model will allow the researchers to find the relevant data related to particular service instead of general healthcare mixed operations mode data.

SD Model of Administration Services (Office Buildings) can be generalised and used in evaluating other office buildings energy performance outside healthcare services.

A fifth SD Model of Nursing Hostel building can be produced (as Energy and Water Benchmarks were produced) and used in evaluating the energy performance of domestic accommodation buildings outside healthcare services.

6.9. Recommendations for Researchers, Policy Makers and Practitioners

To complement the findings and research limitations of Chapter 6, the following are recommendations for researchers, Policy Makers and practitioners to improve sustainability and improve performance in healthcare facilities:

1) Healthcare buildings large impact on environment generated from energy consumption, water consumption, waste generation and CO2e emissions must be professionally operated and managed through an appropriate legislations and an efficient operation and management strategies.
2) Lack of adequate legislations regulating environmental protection, energy management and CO2e emissions is a barrier for wide-scale applications of energy management schemes. Necessary legislations need to be developed and enforced in this direction.
3) Lack of mandatory energy benchmarking system for buildings is a barrier for wide-scale applications of energy management schemes. Necessary legislations need to be developed and enforced in this direction.
4) SD Model shows that the potential of energy saving in healthcare building is high and it is recommended to work toward energy efficiency and renewable energy deployment to achieve sustainable healthcare buildings.
5) The cost of energy efficiency and renewable energy technologies represents a barrier for wide-scale applications. Special funds, grants and incentive schemes need to be created to motivate the investment in this field.
6) The lack of expertise in energy efficiency and renewable energy technologies represents another barrier for wide-scale applications. Scientific collaborations with expert firms need to be created to enforce local expertise and overcome the shortage in this field.
7) Special funding and transfer of renewable technology agreement need to be considered with some leading firms such as UN and other governmental and non-governmental organisations.
8) Special consideration to be given to healthcare Administrative expenditures as SD Model shows high operating expenditures growth compare to government funds allocated for administrative services growth. This needs review of administration

activities in order to close the gap between administration operating expenditures and available government funds.

9) Energy efficiency measures recommended by International Energy Agency to reduce energy consumption such as reducing the heating, cooling and lighting load to minimum, use the energy of renewables and waste energy sources as efficient as possible and use fossil fuel as effective and clean as possible are examined and found to be very effective and highly recommended for implementation.
    - Using energy efficiency measures in Air-Conditioning System such as Energy Recovery Wheel Technology can save up to 59% of A/C System energy consumption and up to 41.5% of facilities energy consumption (Appendix-D).
    - Using LED lighting instead of conventional lighting can save up to 54% of Lighting System energy consumption and up to 6.5% of facilities energy consumption (Appendix-E).
    - Using renewable Solar Panel Water Heating can save up to 77% of Hot Water System energy consumption and up to 13% of facilities energy consumption (Appendix-F).
    - Recovery of energy from Medical Waste incineration can save up to 4% of facilities energy consumption (Appendix-G).
10) Recovery of energy from Medical Waste incineration is highly recommended as it is offsetting double the quantity of CO2e emissions resulting from the incineration process.

11) Safe recycling of waste water (grey water) of some healthcare processes and conducting water saving campaigns is highly recommended as it is can reduce water consumption by up to 30% and contributes to reduction of healthcare facilities CO2e emissions. Source of grey water and gray water applications must be carefully selected to avoid any contradiction with Infection Control regulations or other healthcare regulations.

12) Implementation of simple energy and water conservation techniques can save up to 10% of energy and water consumptions. Conducting energy and water conservation campaigns utilising the good educational level and high environmental awareness of healthcare personnel is highly recommended.

13) Some of the energy saving is taken in the form of higher energy consumption that is the so-called take-back or the rebound effect. The rebound effect is considered as a contradicting behavior toward energy conservation. Special reinforcement campaigns are recommended to reduce its effect on energy saving plans in building in general and healthcare facilities in particular.

14) For energy assessment studies, it is recommended to conduct case studies on wide sample of healthcare facilities to avoid low peaks and odd operation periods.

15) In the SD Model, relations marked with Black Arrows are recommended for further socio-economic healthcare researches.

16) For the existing and future facilities, it is very important to consider and guarantee free access to energy metering devices.

References

Al-Haddad M. and Al-Owfi A. (2001) ‘ The History of Psychiatric Treatment in Bahrain 1932-2000”, Ministry of Health, Bahrain.

Al-Zubari, W. (2014) ‘Energy, environment and resources: the costs of municipal water supply in Bahrain’, Chatham House, The Royal Institute of International Affairs.

Alliance for Natural Health (2010) Alliance for Natural Health International white paper ‘Sustainable Healthcare: working towards the paradigm shift’, Surry, UK.

Afzal, W., Torkar, R. and Robert, F. (2009) ‘A systematic review of search-based testing for non-functional system properties’, Information and Software Technology, 51 (6), pp. 957–976.

Ascione, F., Bianco, N., De Masi, R. and Vanoli, G. (2013) ‘Rehabilitation of the building envelope of hospitals: achievable energy savings and microclimatic control on varying the HVAC systems in Mediterranean climates’, Energy and Buildings, 60, pp.125-138.

Asif, M. and Muneer, T. (2007) ‘Energy supply, its demand and security issues for developed and emerging economies’, Renewable and Sustainable Energy Reviews, 11, pp. 1388–1413.

Betticrew, M. and Roberts, H. (2005) ‘Systematic reviews in the social sciences: a practical guide’, Oxford: Blackwell Publishing.

Bouloiz, H., Garbolino, E., Tkiouat, M. and Guarnieri, F. (2013) ‘A system dynamics model for behavioural analysis of safety conditions in a chemical storage unit’, 58, pp. 32–40.

Brown, L. and Blanchard, I. (2012) ‘Energy, emissions and emergency services: policy matters’, Energy Policy, 46, pp. 585-593.

Brundtland Report (1987) ‘World Commission on Environment and Development (WCED) Report: our common future’. Oxford: Oxford University Press, pp. 43.

CIBSE Guide A (2006a) ‘Environmental design, weather data sheet # 411500 - design conditions for Bahrain International Airport’, 7th edition, London, UK.

CIBSE Guide A (2006b) ‘Environmental design, Appendix 3.A8 - thermal properties of typical construction’, 7th edition, London, UK.

CIBSE SHB, (2006) CIBSE Student member’s data book. Wakefield: Charlesworth Group.

Central Information Organization (2013) Mid-Year Population Projections for the

Kingdom of Bahrain (2012 - 2032) available at http://www.cio.gov.bh (accessed: 15 November 2014).

Chung, W. and Meltzer, O. (2009) ‘Estimate of the carbon footprint of the US healthcare sector’, JAMA, 302, pp. 1970.

Department of Energy and Climate Change (2013-a) 'Energy consumption in the UK-Chapter 1’, London, UK.

Department of Energy and Climate Change (2012) ‘The energy efficiency strategy: the energy efficiency opportunities in the UK’, London, UK.

Department of Energy and Climate Change (2013-b) ‘Energy consumption in the UK-Chapter 5’, London, UK.

Economic Development Board Report (2006).

Economic Development Board Report (2008).

European Environment Agency, (2013-a) ‘Trends and projections in Europe 2013’. Luxembourg: Publication office of the European Union.

European Environment Agency (2013-b) ‘Technical Report No. 5/2013 - Achieving energy efficiency through behaviour changes: what does it take?’, Luxembourg: Publication office of the European Union.

European Commission (2012) Energy efficiency directive in the energy community.

U.S. Energy Information Administration (2013) ‘Annual Energy Outlook 2013’, Washington D.C., USA.

Essa, A. (1989) Bahrain Weather Data (1902-1988), Bahrain: Al-Fajr Press.

Forrester, J.W., (1961) ‘Industrial Dynamics’, Cambridge: MIT Press.

Forrester, J.W. and Singer, P. M. (1980) ‘Test for building confidence in system dynamics models’, TIMS Studies in the Management Sciences, 14, pp. 209-228.

García-Sanz-Calcedo J., López-Rodríguez F. and Cuadros, F. (2014) ‘Quantitative analysis on energy efficiency of health centers according to their size’, Energy and Buildings, 73, pp. 7-12.

Gatenby A. (2011) ‘Modeling carbon footprint of reflux controls’, International Journal of Surgery, 9, pp. 72-74.

GhaffarianHoseini, A., Dahlan, N., Berardi, U., GhaffarianHoseini, A., Makaremi, N., and GhaffarianHoseini, M. (2013) ‘Sustainable energy performances of green buildings: A review of current theories, implementations and challenges’, Renewable and Sustainable Energy Reviews, 25, pp. 1–17.

Gibbs, A. (1997) ‘Focus groups, social research update’, Department of Sociology, University of Surrey, 19.

Gill, P., Stewart, K., Treasure, A. and Chadwick B. (2008) ‘Methods of data collection in qualitative research: interviews and focus groups’, British Dental Journal, 204, pp. 291 – 295.

Guenther, R. and Vittori, G. (2008) ‘Sustainable Healthcare Architecture’, New Jersey: John Willy and Sons Inc.

Heisenberg, H. (1949) ‘The Physical Principles of the Quantum Theory’, Translated by Eckart, C. and Hoyt, F. Chicago: Dover Publications Inc.

Herring, H. (2006) ‘Energy Efficiency – A Critical View’, Energy, 31, pp. 10-20.

Hospital Factsheet (2013) ‘Benchmarking to improve water efficiency in Hospitals’, National Benchmarking factsheet ANZSIC Code: 8401 Hospitals, available at www.nbweb.com.au, (Accessed: 30 November 2015).

Ibrahim, S. (2008) ‘Integrated management of hazard healthcare waste of Kingdom of Bahrain’, MSc Dissertation in Environmental Management, Arabian Gulf University, Bahrain.

Ibrahim, S. (2009) ‘Integrated management of hazard healthcare waste of Kingdom of Bahrain’, Waste Management Journal, 29, pp. 2404-2409

International Energy Agency (2008) ‘Energy conservation in buildings & community systems program (ECBCS), Strategic Plan 2007-2012, towards near-zero primary energy use and carbon emissions in buildings and communities’, Birmingham, UK.

International Energy Agency, (2011) ‘25 Energy efficiency policy recommendations’, Paris, France.

International Energy Agency (2012-a) ‘World energy outlook 2012’, Paris, France.

International Energy Agency, (2012-b) ‘Energy efficiency policy development’, Paris, France.

International Energy Outlook (2010) U.S. Energy Information Administration, Office of Integrated Analysis and Forecasting, U.S. Department of Energy, Washington, DC 20585; 2010.

IEEE-USA Policy Position Statement (2014) National energy policy recommendation.

Jeong, S., Gulbinas, R., Jain, R. and Tylor, J. (2014) ‘The impact of combined water and energy consumption eco-feedback on conservation', Energy and Buildings (80), PP. 114-119

Jouhara, H., Tassou, A., Kolokotroni, M., Tymkow, P. (2009) 'Building services design', MSc. course book. Uxbridge: Brunel University Press.

Kibert, C. (2008) ' Sustainable construction: green building design and delivery', John Wiley and Sons, Inc, Hoboken, NJ, USA.

Kitchenham, B. and Charter, S. (2007) 'Guidelines for performing systematic literature reviews in software engineering', technical report EBSE-2007-001 Keele University and Durham University joint report.

Kitzinger, J. (1994) 'The methodology of focus groups: the importance of interaction between research participants', Society of Health and Illness, 16(1).

Kitzinger, J. (1995) 'Introducing Focus Group', BMJ, 311, pp. 299-302.

Krueger, R. (2002) 'Designing and conducting focus group interviews', University of Minnesota.

Kunc, M. (2016) ' System Dynamics: a behavioral modeling method', Proceedings of the 2016 Winter Simulation Conference T. M. K. Roeder, P. I. Frazier, R. Szechtman, E. Zhou, T. Huschka, and S. E. Chick, eds.

Levendis, Y., Atal, A., Carlson, B. and Quintana, E. (2001) 'PAH and soot emissions from burning component of medical waste: examination/surgical gloves and cotton pads', Chemosphere, 42, pp. 775-783

Martis, S. (2006), 'Validation of simulation based models: a theoretical outlook', The Electronic Journal of Business Research Methods, 4(1), pp. 39-46, available at www.ejbrm.com (Accessed: 20 May 2016).

Michael, R. and Robert, T. (1997) 'Introduction to System Dynamics: a system approach to understanding complex policy issues', U.S. Department of Energy's.

Murray, J., Pahl, O. and Burek, S., (2008) 'Evaluating the scope for energy-efficiency improvements in the public sector: benchmarking NHS Scotland's smaller health buildings', Energy Policy, 36, pp. 1236–1242.

National Energy Board (2013) 'Canada's energy future 2013', Canada.

NHS Carbon Reduction Strategy (2009) 'NHS carbon reduction strategy for England: saving carbon-improving health', Cambridge, UK.

Nidhr, S., Yanamadala, M., Afzal, W. and Torkar, R. (2013) 'Knowledge transfer challenges and mitigation strategies in global software development: a systematic literature review and industrial validation', International Journal of Information Management, 33, pp. 333–355.

Oikonomou, V., Becchis, F., Steg, L. and Russolillo, D. (2009) 'Energy saving and energy efficiency concepts for policy making', Energy Policy, 37 (11), pp. 4787-4796.

Oliva, R., (2003) 'Model calibration as a testing strategy for system dynamics models', European Journal for Operation Research, 152, 552-568.

Perez-Lombard, L., Ortiz, J. and Pout, C. (2008) 'A review on buildings energy consumption information', Energy & Building, 40(3), pp. 394-398.

Qudrat-Ullah, H. (2005) 'Structural validation of system dynamics and agent-based simulation models', Proceeding 19th, European Conference in Modeling and Simulation, Riga, Lativia.

Rashwan, W., Abo-Hamad, W. and Arisha, A. (2015), 'A system dynamics view of the acute bed blockage problem in the Irish healthcare system', European Journal of Operational Research, 247, pp. 276–293

Richardson, P. and Pugh, L. (1981) 'Introduction to System Dynamics Modeling with DYNAMO', Cambridge: MIT Press.

Reddy, B. (2013) 'Barriers and drivers to energy efficiency: a new taxonomical approach', Energy Conversion and Management, 74, pp. 403–416.

Reid, R., (2009) ' The healing of America: a global quest for better, cheaper, and fairer healthcare', London: Penguin Press.

Rabanimotlagh, A., Overcash, M., Twomey, J., Sadkhi, A., Huber, A. and Lutgert, H. (2014) 'Healthcare facilities: planning for increasing extreme heat events', Proceedings of the 2014 Industrial and Systems Engineering Research Conference.

Radhi, H. (2009) 'Evaluating the potential impact of global warming on the UAE residential buildings - a contribution to reduce the CO2 emissions', Building and Environment, 44, pp. 2451–2462.

Saunders, H. (1992) 'The Khazoom-Brooks postulate and neoclassical growth', Energy Journal, 13, pp. 131-148.

System Dynamics Society, (2016) Available at http://www.systemdynamics.org/what-is-s/ (Accessed: 30 November 2016)

Shehab, S. (2010) 'Energy optimization and utilization of efficient A/C systems for buildings in hot and humid climate', MSC dissertation in Building Services Engineering and Sustainable Energy, Brunel University.

Smith, R. (2011) ‘Energy management opportunities and challenges for healthcare industry’, Healthcare Financial Management Association, 65 (4), pp. 98-102.

Statistical Calculator, (2016) Available at http://www.socscistatistics.com/tests/Default.aspx (Accessed: 3 December 2016).

Sterman, D. (1984) ‘Appropriate summery statistics for evaluating the historical fit of system dynamics models’, Dynamica, 10, pp. 51-66.

Sterman, D. (2000) ‘Business Dynamics: System Thinking and Modeling for a Complex World’, Boston: Irwin McGraw-Hill.

TAC, (2006) ‘White paper in Healthcare Energy: Leading techniques for energy savings in healthcare facilities’, North Andover, USA.

Tranfield, D., Denyer, D. and Smart, P. (2003) ‘Towards a methodology for developing evidence-informed management knowledge by means of systematic review’, British Journal of Management, 14, pp. 207-222.

UN, (2016) Available at http://www.un.org/sustainable,development (Accessed: 23 November 2016)

UNECE, (2004-2005) Available at http://www.unece.org/oes/nutshell/2004-2005/focus_sustainable_development.html (Accessed: 23 November 2016)

Wang, H. and Chen, Q. (2014) ‘Impact of climate change heating and cooling energy use in buildings in the United States’, Energy and Buildings, 82. pp. 428-436.

WBCSD, (2007) ‘Energy efficiency in buildings, business realities and opportunities’, The World Business Council for Sustainable Development; 2007.

WBCSD, (2010) ‘Vision 2050: the new agenda for business’, World Business Council for Sustainable Development; 2010.

WHO, (2009) 'Global Health Risks: mortality and burden of diseases attributable to selected major risks’, (ISBN 978 92 4 156387 1).

World Population Prospect, (2015) ‘World Population Prospects: the 2015 revision’, Department of Economic and Social Affairs, Population Division, United Nations New York, USA.

Zotero (2014) Available at https://www.zotero.org (Accessed: 6 August 2014)

Zuo, J. and Zhao, Z., (2014) ‘Green building research-current status and future agenda; a review’, Renewable and Sustainable Energy Reviews, 30, pp. 271-28.

Primary Studies References

[P01] Ahn, B., Jang, C., Leigh, S., Yoo, S. and Jeong, H. (2014) 'Effect of LED lighting on the cooling and heating loads in office buildings', Applied Energy, 113, pp. 1484–1489.

[P02] Allcott, H. and Greenstone, M. (2012) 'Is there an energy efficiency Gap?', Journal of Economic Perspectives, 26 (1), pp. 3–28.

[P03] The Alliance for Natural Health International, (2010), http://www.anhinternational.org (Accessed: 6 June 2014).

[P04] Atkinson, J., Wells, R., Page, A., Dominello, A., Haines, M. and Wilson, A. (2015) 'Applications of system dynamics modeling to support health policy', Public Health Research and Practice, 25(3), http://dx.doi.org/10.17061/phrp2531531 (Accessed: 30 July 2017).

[P05] Brailsford, S. and Hilton, N. (2001) 'A Comparison of Discrete Event Simulation and System Dynamics for Modeling Healthcare Systems', School of Management, University of Southampton, UK.

[P06] Brailsford, S., Harper, P., Patel, B. and Pitt, M. (2009) 'An analysis of the academic literature on simulation and modeling in healthcare', Journal of Simulation, 3, pp. 130–140.

[P07] Brennan, T. (2013) 'Energy efficiency policy puzzles', The Energy Journal, 34(2), pp.1-25.

[P08] Chaerul, M., Tanaka, M. and Shekdar, A. (2007) 'A system dynamics approach for hospital waste management', Waste Management Journal, 28, pp. 442–449.

[P09] Chung, J. (2009), 'Estimate of the Carbon Footprint of the US Health Care Sector', JAMA, 302 (18), pp. 1970-1972.

[P10] Ciplak, N. and Barton, J. (2012) 'A system dynamics approach for healthcare waste management: a case study in Istanbul Metropolitan City, Turkey', Waste Management and Research Journal, 30, pages 576-586.

[P11] Economic Development Board (2008) 'The economic vision 2030 for Bahrain'.

[P12] Eleyan, D., A Al-Khatib, I. and Garfield, J. (2013) 'System dynamics model for hospital waste characterization and generation in developing countries', Waste Management and Research Journal, 31, pp. 986-995.

[P13] Faezipour, M. and Ferreira S. (2013) 'A system dynamics perspective of patient satisfaction in healthcare', Procedia Computer Science, 16, pp.148 – 156.

[P14] Fone, D., Hollinghurst, S., Temple, M., Round, A., Lester, N., Weightman, A., Roberts, K., Coyle, E., Bevan, G. and Palmer S. (2003) 'Systematic review of the use and value of computer simulation modeling in population health and health care delivery', Journal of Public Health Medicine, 25 (4), pp. 325–335

[P15] General Commission for the Protection of Marine Resources, Environment and Wildlife, GCPMREW (2005) 'Bahrain's Initial communications to the United Nations Framework Convention on Climate Change, volume I: Main Summery Report'.

[P16] General Commission for the Protection of Marine Resources, Environment and Wildlife, GCPMREW (2012) 'Bahrain's Second communications under the United Nations Framework Convention on Climate Change'.

[P17] GhaffarianHoseini, A., Dahlan, N., Berardi, U., GhaffarianHoseini, A., Makaremi, N., and GhaffarianHoseini, M. (2013) 'Sustainable energy performances of green buildings: a review of current theories, implementations and challenges', Renewable and Sustainable Energy Reviews, 25, pages 1–17.

[P18] Greening, L., Greene, D. and Difiglio, C. (2000) 'Energy efficiency and consumption, the rebound effect: a survey', Energy Policy, 28, pp. 389-401.

[P19] Herring H. (2006) 'Energy efficiency - A critical view', Energy, 31, pp. 10-20.

[P20] Hertwich, G. and Peters, P. (2012) 'Carbon footprint of nations: A global, trade-linked analysis, Environmental Science and Technology', 43, pages 6414-6420.

[P21] IEC (2010) 'Best environmental Practices in the healthcare sector, A Guide to improve your environmental performance', a partnership between Institute for Ecopreneurship (IEC), University of Applied Sciences Northwestern Switzerland (FHNW), School of Life Sciences (HLS), Sustainable Business Associate (SBA), Royal Scientific Society (RSS), with the support of Swiss Secretariat for Economic Affairs.

[P22] Kaufman, N. and Palmer K. (2012) 'Energy efficiency program evaluations: opportunities for learning and inputs to incentive mechanisms', Energy Efficiency, 5, pp. 243–268.

[P23] Kolokotsa, D., Tsoutsos, T., and Papantoniou, S. (2012) 'Energy conservation techniques for hospital buildings', Advances in Building Energy Research, 6 (1), pp. 159-172.

[P24] Kunc, M. and Kazakov R. (2013) 'Competitive dynamics in pharmaceutical markets : A case study in the chronic cardiac disease market', Journal of the Operational Research Society, 64, pp. 1790-1799

[P25] The LCB-HEALTHCARE Consortium (2011) 'Low Carbon buildings in healthcare sector'.

[P26] MENA Renewables Status Report, MENA (2013) Abu Dhabi International Renewable Energy Conferences (ADIREC), Abu Dhabi, UAE.

[P27] Bahrain's Health Agenda (2012) 'Health improvement strategy (2011-2014)', 2nd edition, Manama, Bahrain.

[P28] NHS Sustainable Development Unit, (2009) 'NHS Carbon reduction strategy for England: saving Carbon improving health', Cambridge, UK.

[P29] NHS Sustainable Development Unit, (2010) 'NHS Carbon Reduction strategy for England: saving Carbon improving health', Cambridge, UK.

[P30] NHS Public Health England, (2014) 'Sustainable, resilient, healthy people and places: a sustainable development strategy for the NHS, Public Health and Social Care System', Cambridge, UK.

[P31] Oikonomou, V., Becchis, F., Steg, L. and Russolillo D. (2009) 'Energy saving and energy efficiency concepts for policy-making', Energy Policy, 37(11), pp. 4787-4796.

[P32] Peterman, A., Kourula, A. and Levitt, R. (2012) 'A roadmap for navigating voluntary and mandated programs for building energy efficiency', Energy Policy, 43, pp. 415-426.

[P33] Rabanimotlagh, A., Overcash, M., Twomey, J., Sadkhi, A., Huber, A. and Lutgert H. (2014) 'Healthcare facilities: planning for increasing extreme heat events', proceedings of the 2014 industrial and systems engineering research conference, Guan, Y. and Liao, H.

[P34] Rashwan, W., Abo-Hamad, W. and Arisha, A. (2015), 'A system dynamics view of the acute bed blockage problem in the Irish healthcare system', European Journal of Operational Research, 247, pp. 276–293

[P35] Rohleder, T., Bischak D. and Baskin L. (2007) 'Modeling patient service centers with simulation and system dynamics', Health Care Manage Science, 10, pp. 1–12.

[P36] Reddy, B. (2013) 'Barriers and drivers to energy efficiency: a new taxonomical approach', Energy Conversion and Management, 74, pp. 403-416.

[P37] Saunders, H. (2000) 'A view from the macro side: rebound, backfire, and Khazzoom-Brookes', Energy Policy, 28, pp. 439-449.

[P38] Short, C., Cook, M., Paul, C., Cropper, P. and Al-Maiyah, S. (2010) 'Low energy refurbishment strategies for health buildings', Journal of Building Performance Simulation, 3 (3), pp.197-216.

[P39] Singer, B., Coughlin, J., and Mathew, P. (2010a) 'Summery of information and resources related to energy use in healthcare facilities', Lawrence Berkeley National Laboratories.

[P40] Singer, B. and Tschudi, W. (2010b) 'High performance healthcare buildings – a road map to improve energy efficiency', Lawrence Berkeley National Laboratories.

[P41] Smith, M. (2012) 'Sustainable healthcare – a path to sustainability', IIIEE theses 2012:14, MESPOM Program: Lund University, Central European University, University of Manchester and University of the Aegean.

[P42] Smith, R. (2011) 'Energy management: opportunities and challenges for healthcare industry', Healthcare Financial Management Association, 65 (4), pp. 98-102.

[P43] Teke, A. and Timur, O. (2014) 'Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals', Renewable and Sustainable Energy Reviews, 33, pp. 224-235.

[P44] Tolba, M. and Saab, N. (2009) 'Report of the Arab Forum for Environment and Development, Arab environment climate change: impact of climate change on Arab countries',

[P45] Vernon, W. (2009) 'Keeping Green: reducing energy consumption without harming the budget', Journal of Healthcare Management, 54 (3), pp. 159-162.

[P46] Wang, T., Li, X., Liao, P. and Fang D. (2016) 'Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers', Energy, 103, pp. 588-597

[P47] Zuo, J. and Zhao, Z. (2014) 'Green building research-current status and future agenda: a review', Renewable and Sustainable Energy Reviews, 30, pp. 271-281.

Appendix A: Developing Healthcare Energy Benchmarks

“Building energy benchmarks provide representative values for common building types, against which you can compare your building’s actual performance. Comparison with simple benchmarks of annual energy use per square meter of floor area will permit the standard of energy efficiency to be assessed and enable remedial action to be taken. More detailed benchmarks can help pinpoint problem areas within a building.” (ECG, 2000)

Healthcare facilities are considered as major energy-demanding buildings. Main sources of energy consumption are the Air Conditioning System, Humidification and Dehumidification processes for stringent indoor air quality, Computer and Communications System Server Rooms cooling, 24/7 lighting, Office Equipment and Systems, Medical Equipment and Systems, Other Systems such as C.C.T.V. and Security Systems. It is of great importance to reduce the energy consumed within these facilities in order to achieve environmental sustainability. Developing a baseline energy benchmark is an important step for good energy and carbon footprint management scheme in healthcare facilities. Good practice benchmark can be developed at a due course to reflect the efforts and measures been implemented to reduce the energy consumption in these facilities.

As Kingdom of Bahrain has a lack of scientific and academic energy studies, especially in healthcare sector, and as energy benchmark is a required parameter (independent variable) to develop the System Dynamics Model, it will be very important to develop four Baseline Energy Benchmarks related to each healthcare facility category and utilize them, These benchmarks are:

A1 - Primary Healthcare (Health Centers and Clinics) Energy Benchmark,

A2 - Secondary Healthcare (Hospitals) Energy Benchmark,

A3 - Public Health Laboratory Energy Benchmark, and

A4 - Administration office building Energy Benchmark.

A1 - Primary Healthcare Energy Benchmark

Primary Healthcare Facility Energy Benchmark is developed by obtaining the annual energy consumptions of health centers and clinics and divides it by the treated floor area of the same facilities. To reduce the differences due to different operation modes, three to five year's (or more) readings are obtained then averaged. The category Energy Benchmark is the mean value of all facilities Energy Benchmark as summarised in Table A1.

Table A1 - Energy Benchmark of Primary Healthcare Facilities

Health Centre		Energy Consumption (KWh)	Reading Period	No. of Years	Average	Floor Area (M2)	Treated F. Area (M2)*	Energy Benchmark (KWh / m2)
1	NBB-Arad	3,916,010	1/1/2010 - 31/12/2014	5	783,202	4,728	4,019	195
2	Sheikh Salman	3,955,076	1/1/2010 - 31/12/2014	5	791,015	3,310	2,814	281
3	Muharraq	2,200,780	1/1/2010 - 31/12/2014	5	440,156	2,462	2,093	210
4	Ibn Sina'a	1,207,602	1/1/2010 - 31/12/2014	5	241,520	1,707	1,451	166
5	Naim	2,162,696	1/1/2010 - 31/12/2014	5	432,539	5,113	4,346	100
6	Al-Razi	2,783,413	1/1/2010 - 31/12/2014	5	556,683	2,160	1,836	303
7	Jidhafs	1,799,741	0/0/0000 - 31/10/2015	2	899,871	2,028	1,724	522
8	Budayia Clinic	459,519	1/5/2013 - 31/10/2015	2.5	183,808	570	485	379
9	Sitra	3,064,540	1/1/2010 - 31/12/2014	5	612,908	3,420	2,907	211
10	Jaw & Asker Clinic	213,517	1/1/2012 - 31/12/2014	3	71,172	226	192	370
11	Y. A. R. Engineer	1,579,029	1/1/2012 - 31/12/2014	3	526,343	6,005	5,104	103
12	Hamad Kanoo	2,265,972	1/1/2010 - 31/12/2014	5	453,194	3,824	3,250	139
13	Hamad Town	4,608,457	1/1/2010 - 31/12/2014	5	921,691	2,892	2,458	375
14	M. Jassim Kanoo	1,734,029	1/1/2010 - 31/12/2014	5	346,806	4,177	3,550	98
							Average	**247**

* 90% of Floor Area

A2 - Secondary Healthcare Energy Benchmark

Secondary Healthcare Facility Energy Benchmark is developed by obtaining the annual energy consumptions of hospitals and divides it by the treated floor area of the same facility. To reduce the differences due to different operation modes three to five year’s readings will be obtained then averaged. The category Energy Benchmark is the mean value of all facilities Energy Benchmark as summarised in Table A2.

Table A2 - Energy Benchmark of Secondary Healthcare System

Hospital		Energy Consumption (KWh)	No. of Years	Average	Floor Area (M2)	Treated Floor Area (M2)*	Energy Benchmark (KWh / m2)		
1	Psychiatric Hospital M#1 - Al-Ghazali Building	-	9	-	8,760	7,884	-	**246**	**322**
2	Psychiatric Hospital M#2 - Ibn Al-Nafees	501,504	1	501,504	930	837	282		
3	Psychiatric Hospital M#2 - Out Patient Dep't.				1,044	940			
4	Psychiatric Hospital M#3 - Ibn Rushd Building	850,318	3	283,439	1,508	1,357	209		
5	Psychiatric Hospital M#4 - Drug Rehabilitation	-	3	-	1,100	990	-		
6	Muharraq Maternity Hospital	1,575,656	3	525,219	2,584	2,196	239	**258**	
7	Jidhafs Maternity Hospital	2,219,935	2	1,109,968	4,403	3,743	297		
8	Sitra Maternity Hospital	537,966	3	179,322	890	757	237		
9	A. R. Kanoo Kidney Dialysis Centre	877,477	1	877,477	3,500	3,150	279	**279**	
10	E. K. Kanoo Community Medical Centre	3,005,985	3	1,001,995	2,200	1,980	506	**506**	

* 90% of Floor Area

A3 - Public Health Laboratory Energy Benchmark

Public Health Laboratory’s Energy Benchmark is developed by obtaining the annual energy consumptions of the Laboratory and divide it by its treated floor area as summarised in Table A3.

Table A3 - Energy Benchmark of Public Health Laboratory

Location		Energy Consumption (KWh)	Reading Period	No. of Years	Average	Floor Area (M2)	Treated Floor Area (M2)*	Energy Benchmark (KWh / m2)
1	Public Health Laboratory - M#1	769,120	16/11/2014 15/11/2015	2	384,560	5,874	5,287	**206**
2	Public Health Laboratory - M#2	1,406,720	16/11/2014 15/11/2015	2	703,360			

* 90% of Floor Area

A4 - Office Building Energy Benchmark

Office Buildings Energy Benchmark is developed by obtaining the annual energy consumptions of building and divides it by its treated floor area of. To reduce the differences due to different operation modes three to five year's readings will be obtained then averaged. The category Energy Benchmark is the mean value of all buildings Energy Benchmark as summarised in Table A4.

Table A4 - Energy Benchmark of Office Buildings

Office Building		Energy Consumption (KWh)	Reading Period	No. of Years	Average	Floor Area (M2)	Treated F. Area (M2)	Energy Benchmark (KWh / m2)
1	Head Quarter Building at Jufair	11,864,419	16/11/2008 15/11/2015	7	1,694,917	12,516	9,994	170
2	Birth & Death Certificate Building	2,998,560	16/11/2010 15/11/2015	5	599,712	1,831	1,648	237
3	Public Health Admin. Building					376	338	
4	Health Cen. Directorate Building					601	541	
							Average	**203**

* 90% of Floor Area

An additional Energy Benchmark of Nursing Hostel is also obtained in Table A5.

Table A5 - Energy Benchmark of Nursing Hostel Buildings

Location		Energy Consumption (KWh)	Reading Period	No. of Years	Average	Floor Area (M2)	Treated Floor Area (M2)*	Energy Benchmark (KWh / m2)
1	Rufaidah Nursing Hostel	2,574,851	1/1/2010 31/12/2014	5	514,970	6,726	5,045	102
1'	Rufaidah Nursing Hostel - M#!	9,755,140	1/1/2010 31/12/2015	32	304,848	6,726	5,045	98
2'	Rufaidah Nursing Hostel - M#2	6,007,800	1/1/2010 31/12/2016	32	187,744			
							Average	**100**

* 75% of Floor Area

Appendix B: Developing Healthcare Water Benchmark

Healthcare facilities are considered as major Water-demanding buildings. Main sources of water consumption are Medical procedures like Kidney Dialysis; Hydrotherapy and Occupational Therapy; Sterilization, laundry and kitchen operations; domestic Cold / Hot water use for toilets, showers and washing; etc. It is very important to reduce the water consumed within these facilities in order to achieve environmental sustainability. Developing a baseline water benchmark is an important step for good water management scheme in healthcare facilities. Good practice water benchmark can be developed at a due course to reflect the efforts and measures been implemented to reduce the water consumption in these facilities.

As Kingdom of Bahrain is suffering a critical water situation, and as water benchmark is a required parameter (independent variable) to develop the System Dynamics Model, it will be very important to develop four Baseline water Benchmarks related to each healthcare facility category, these water benchmarks are:

B1. Primary Healthcare (Health Centers and Clinics) Water Benchmark,
B2. Secondary Healthcare (Hospitals) Water Benchmark,
B3. Public Health Laboratory Water Benchmark, and
B4. Administration office buildings Water Benchmark.

B1 - Primary Healthcare Water Benchmark

Primary Healthcare Facility Water Benchmark is developed by obtaining the annual water consumptions of health centers and clinics and divides it by the floor area of the same facilities. To reduce the differences due to different operation modes, readings from facilities opening are obtained then averaged. The category’s Water Benchmark is the mean value of all facilities Water Benchmark as summarised in Table B1.

Table B1 - Water Benchmark of Primary Healthcare Facilities

Health Centre		**Water Consumption (M3)**	**Reading Period**	**No. of Years**	**Average**	**Floor Area (M2)**	**Water Benchmark (M3 / M2)**
1	NBB-Arad	101,514	1/1/1990 - 31/12/2015	26	3,904	4,728	0.83
2	NBB-Dair	27,316	1/1/2006 - 31/12/2015	10	2,732	2,882	0.95
3	Sheikh Salman	104,981	1/1/1978 - 31/12/2015	37	2,837	3,310	0.86
4	Muharraq	101,874	1/1/1980 - 31/12/2015	30	3,396	2,462	1.38
5	BBK-Hidd	13,488	1/1/2013 - 31/12/2015	3	4,496	6,121	0.73
6	Bu-Maher	3,329	1/1/2015 - 31/12/2016	1	3,329	13,674	0.24
7	Hoora	10,047	1/1/1985 - 31/12/2015	30	335	2,210	0.15
8	Ibn Sina'a	5,410	1/1/1977 - 31/12/2015	42	129	1,707	0.08
9	Sheikh Subah	26,603	1/1/1981 - 31/12/2015	34	782	3,475	0.23
10	Naim	72,017	1/1/1986 - 31/12/2015	29	2,483	5,113	0.49
11	Al-Razi	47,265	1/1/1980 - 31/12/2015	35	1,350	2,160	0.63
12	Bilad Al-Qadeem	15,606	1/1/1984 - 31/10/2015	31	503	2,210	0.23
13	Jidhafs	43,029	1/1/1984 - 31/10/2015	29	1,484	2,028	0.73
14	Sh. Jabber Al-Subah	5,386	1/1/2013 - 31/12/2015	3	1,795	8,344	0.22
15	Budayia	26,440	1/1/1982 - 31/10/2015	33	801	1,230	0.65
16	Budayia Clinic	10,660	1/5/2013 - 31/10/2015	2.5	4,264	570	2.49
17	Kuwait	10,526	1/1/1998 - 31/12/2015	18	585	2,497	0.23
18	Zallaq	44,186	1/1/2006 - 31/12/2015	10	4,419	1,030	4.29
19	Sitra	64,447	1/1/1981 - 31/12/2015	34	1,896	3,420	0.55
20	Ahmed Ali Kanoo	17,878	1/1/2010 - 31/12/2015	6	2,980	9,912	0.30
21	Isa Town	19,245	1/1/1996 - 31/12/2015	20	962	3,526	0.27
22	Yousuf A. Engineer	25,647	1/1/2012 - 31/12/2015	4	6,412	6,005	1.07
23	A'ali	41,369	1/1/1997 - 31/12/2015	19	2,177	3,777	0.58
24	East Riffa’a	110,526	1/1/1980 - 31/12/2015	35	3,158	3,420	0.92
25	Hamad Kanoo	15,155	1/1/2000 - 31/12/2015	15	1,010	3,824	0.26
26	Hamad Town	48,617	1/1/1988 - 31/12/2015	18	2,701	2,892	0.93
27	M. Jassim Kanoo	40,573	1/1/2002- 31/12/2015	14	2,898	4,177	0.69
						Average	**0.78**

B2 - Secondary Healthcare Water Benchmark

Secondary Healthcare Facility Water Benchmark is developed by obtaining the annual water consumptions of hospitals and divides it by the floor area of the same facility. To reduce the differences due to different operation modes, Readings from facilities opening are obtained then averaged. The category Water Benchmark is the mean value of all facilities Water Benchmark as summarised in Table B2.

Table B2 - Water Benchmark of Secondary Healthcare Facilities

Hospital		Water Consumption (M3)	Reading Period	No. of Years	Average	Floor Area (M2)	Water Benchmark (M3 / M2)		
1	Psychiatric Hospital M#1 - Al-Ghazali Building	141,598	1/1/2007 - 31/12/2015	9	15,733	8,760	1.80	0.53	1.35
2	Psychiatric Hospital M#1 - Ibn Al-Nafees	15,033	1/1/1979 - 31/12/2015	36	418	930	0.45		
3	Psychiatric Hospital M#1 - Out Patient Dep't.	16,875	1/1/1983 - 31/12/2015	32	527	1,044	0.51		
4	Psychiatric Hospital M#1 - Drug Rehabilitation	17,781	1/1/1989 - 31/12/2015	26	684	1,100	0.62		
5	Psychiatric Hospital M#2 - Ibn Rushd Building	4,011	1/1/1991 - 31/12/2015	24	167	1,508	0.11		
6	Psychiatric Hospital M#2 - kitchen	7,666	1/1/1981 - 31/12/2016	34	225	930	0.24		
7	Muharraq Maternity Hospital	80,362	1/1/2012 - 31/12/2014	50	1,607	2,584	0.62	0.64	
8	Jidhafs Maternity Hospital	126,294	1/1/1984 - 31/12/2015	31	4,074	4,403	0.93		
9	Sitra Maternity Hospital	17,102	1/1/1965 - 31/12/2015	50	342	890	0.38		
10	A. R. Kanoo Kidney Dialysis Centre	64,583	1/1/2011 - 31/12/2015	5	12,917	3,500	3.69	3.69	
11	E. K. Kanoo Community Medical Centre	10,187	1/1/2012 - 31/12/2014	9	1,132	2,200	0.51	0.51	

B3 - Public Health Laboratory Water Benchmark

Public Health Laboratory Water Benchmark is developed by obtaining the annual energy consumptions of the Laboratory and divide it by its floor area as summarised in Table B3.

Table B3 - Water Benchmark of Public Health Laboratory

Location		Water Consumption (M3)	Reading Period	No. of Years	Average	Floor Area (M2)	Water Benchmark (M3 / M2)
1	Public Health Laboratory	110,053	1/1/2001 - 31/12/2015	15	7,337	5,874	1.25

B4 - Office Building Water Benchmark

Office Buildings Water Benchmark is developed by obtaining the annual water consumptions of building and divides it by its floor area. To reduce the differences due to different operation modes, readings from facilities opening are obtained then averaged. The category Water Benchmark is the mean value of all buildings Water Benchmark as summarised in Table B4.

Table B4 - Water Benchmark of Office Buildings

Location		Water Consumption (M3)	Reading Period	No. of Years	Average	Floor Area (M2)	Water Benchmark (M3 / M2)
1	Head Quarter Building at Jufair	41,332	1/1/2009 - 31/12/2015	7	5,905	12,516	0.47
2	Birth & Death Certificate Building	10,973	1/1/2007 - 31/12/2015	9	1,219	1,831	0.43
3	Public Health Administration Building	111,413	1/1/1961 - 31/12/2015	54	2,063	376	0.77
4	Health Centers Directorate Building	116,892	1/1/1951 - 31/12/2015	64	1,826	601	0.42
5	Tylos Building	211,099	1/1/1948 - 31/12/2015	67	3,151	1,700	0.50
6	Awal Building	104,850	1/1/1948 - 31/12/2015	67	1,565	2,033	0.77
7	Delmon Building - M#1	121,982	1/1/1948 - 31/12/2015	67	1,820.63	2,628	0.69
						Average	**0.58**

An additional Water Benchmark of Nursing Hostel is also obtained in Table B5.

Table B5 Water Benchmark of Nursing Hostel Buildings

Location		Water Consumption (M3)	Reading Period	No. of Years	Average	Floor Area (M2)	Water Benchmark (M3 / M2)
1	Rufaidah Nursing Hostel	105,887	1/1/1983- 31/12/2015	32	3,309	6,726	0.49

Appendix C: Developing of Baseline & Good Practice Energy Benchmarks for E. K. K. Community Medical Centre

One key objective of this technical part of the research is to obtain a Baseline Energy Benchmark and developing a Good Practice Energy Benchmark by investigating the potential of energy saving and building operating efficiency, as recommended by IEA (2008), by considering:

C1. The reduction of the heating, cooling and lighting load to minimum;

C2. Use the energy of renewable and waste energy sources as effectively as possible;

C3. Make fossil fuel use as effective and clean as possible.

In this appendix, researcher is testing the effectiveness of IEA (2008) recommendations to achieve sustainable building by:

- Evaluating the performance of Efficient A/C System by introducing Energy Recovery Technology vs. conventional A/C System. The researcher is reproducing and developing an earlier study of Air Conditioning System conducted as part of Master Degree requirement in Building Services Engineering and Sustainable Energy conducted by Shehab (2010)
- Evaluating the performance of Lighting System by introducing LED lighting vs. the conventional fluorescent lighting.
- Using Renewable Energy for Domestic Water Heating instead of the conventional Electric Heating.
- Producing Energy from Medical Waste.

One typical Healthcare facility in The Kingdom of Bahrain, Ebrahim Khalil Kanoo Community Medical Centre, will be selected to conduct an Energy Assessment Case Study.

C1 - Ebrahim Khalil Kanoo Community Medical Centre

The building is constructed on a plot of 9850 m^2. It consists of 2 floors with a total built area of 2200 m^2, with possibility of future expansion, and shaded car parks.

The Centre is designed by MSCEB and funded by E. K. Kanoo Company (BD. 800,000/-) and furnished by MOH (BD. 200,000/-), i.e. the total cost of the centre is BD. 1,000,000/-

The first floor consists of six wards (3 for Male & 3 for Female) with a total capacity of 54 beds (23 beds for Male, 30 beds for Female and 1 isolation Room) in addition to two recreation halls.

The ground floor contains the main reception, administration offices, clinics, Pharmacy, Laboratory, kitchen, dining room, stores, two prayers rooms and utilities rooms.

The Centre is equipped, as per International Standards, with Central Air Conditioning System, Medical Gas System, two elevators and other Electro-Mechanical Systems used in such buildings.

The building's ground floor and first floor plans are shown in Figure C1 & Figure C2.

Figure C1 - EKK Community Medical Centre – Ground Floor Plan

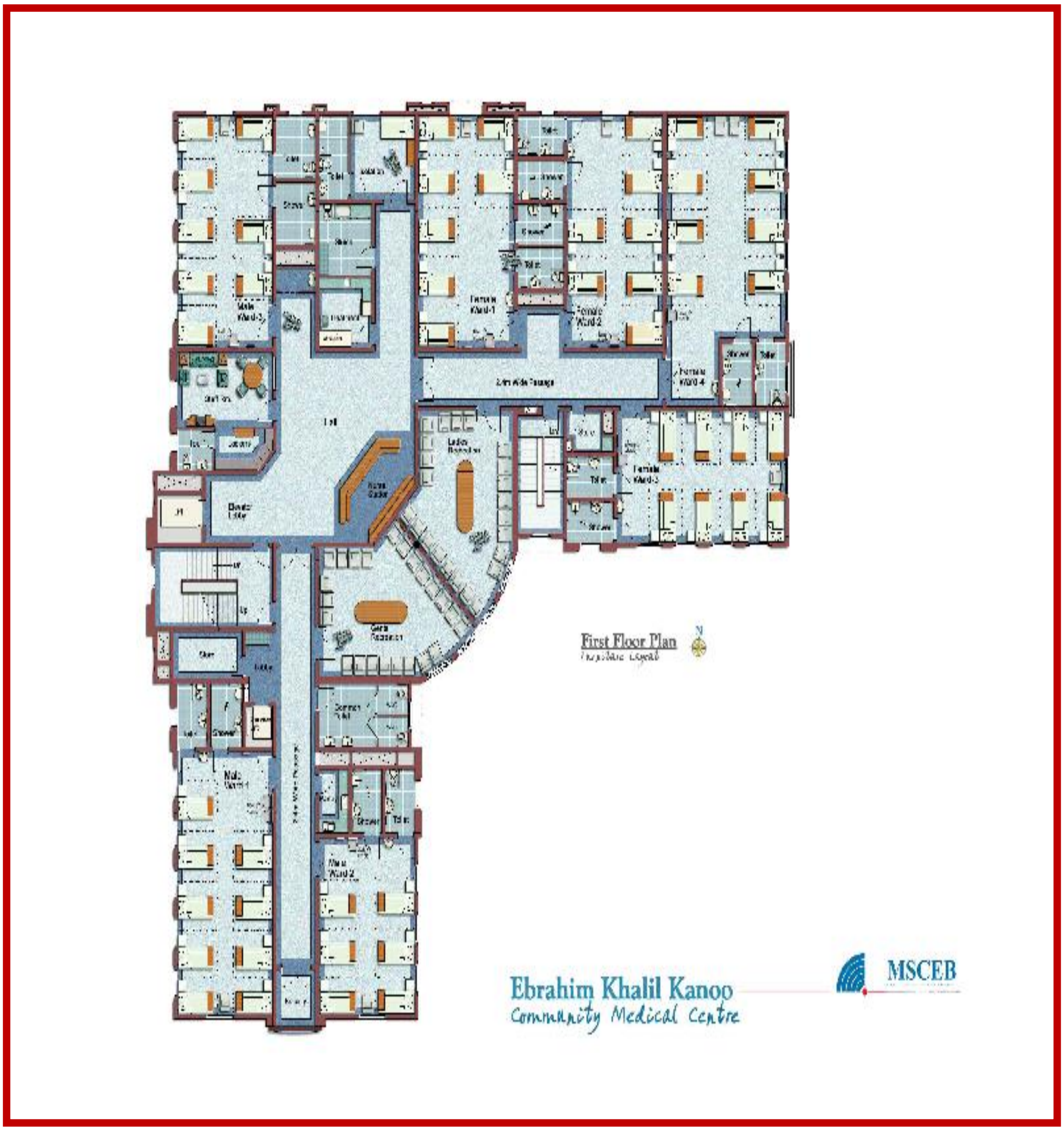


Figure C2 - EKK Community Medical Centre – First Floor Plan

Energy Assessment of EKK Community Medical Centre

The energy consumption of the centre for the period between 1/1/2012 and 31/12/2014, as obtained from Electricity & Water Authority, is found to be 3005985 KWh, i.e. 1001995 KWh/year.

The annual energy consumption, Energy Benchmark, CO2 emissions and CO2 footprint of the building are given in Table C1.

Table C1 - Baseline Energy Benchmark & CO2 Foot print of EKK Com. Medical Centre

Energy Data:	
Annual energy Consumption (kWh/year)	1,001,995
Treated Floor area (m2)	1,980
Baseline Energy Benchmark (KWh/m2/year)	**506**
CO2 Emissions Data:	
Emissions Factor (Kg CO2/KWh)	0.55
Annual CO2 Emissions (kg CO2)	551,097
Baseline CO2 Foot print (Kg CO2/m2/year)	**278**

By referring to the exercises take place in Appendices D, E & F; Good Practice Energy Benchmark can be obtained as shown in Table C2.

Table C2 - Good Practice Energy Benchmark & CO2 Foot print of EKK Com. Medical Centre

Energy Data:	**KWh**	**%**
Annual energy Consumption (kWh/year)	**1,001,995**	**100.00%**
Annual Energy Saving from Efficient A/C System	415,901	41.50%
Annual Energy Saving from Efficient Lighting System	66,836	6.67%
Annual Energy Saving from Efficient DHW System	131,040	13.08%
Revised Annual energy Consumption (kWh/year)	388,218	38.75%
Treated Floor area (m2)	1,870	
Good Practice Energy Benchmark (KWh/m2/year)	**207.6**	
CO2 Emissions Data:		
Emissions Factor (Kg CO2/KWh)	0.55	
Annual CO2 Emissions (kg CO2)	213,520	
Baseline CO2 Foot print (Kg CO2/m2/year)	**114.2**	

C2 - Energy Consumption Categories of EKK Community Medical Centre

By analysing the energy consumption of the centre, it is found that the energy categories are as shown in Table C3.

Table C3 - Energy Consumption Categories

Energy Consumption Categories:	KWh	%
Annual Energy Consumption of A/C System	703,232	70.18
Annual Energy Consumption of Lighting System	122,793	12.25
Annual Energy Consumption of Domestic Hot Water System	157,248	15.70
Annual Energy Consumption of Other Systems	18,722	1.87
Total	1,001,995	100.00%

Appendix D: Evaluating the Performance of A/C System of EKK Community Medical Centre

In this appendix, researcher is testing the effectiveness of (IEA, 2008) first recommendation, i.e. achieve sustainable building by reduction of the cooling load to minimum by pre-cooling the fresh air through heat recovery system. This part of the research is a scientific, comprehensive re-production of an earlier exercise carried out by the researcher as part of in Building Services Engineering and Sustainable Energy MSc dissertation (Shehab, 2010).

D1 - Cooling Load Calculation of EKK Community Medical Centre

The CIBSE Method, The Cyclic Dynamic Model (CDM) and the admittance procedure will be used to calculate the building-cooling load as described by Building Services Design Handbook (Jouhara et. al., 2009).

The Cyclic Dynamic Model (CDM) and the admittance procedure

“This method is based on the calculation of the thermal response of a building using the admittance procedure. It provides a manual method of calculating cooling loads of buildings by assuming a sequence of identical days when the external conditions repeat every 24 hours.

This procedure estimates the proportion of the total heat gain that is absorbed by the internal surfaces of the building and therefore reduces the peak-cooling load (Jouhara et. al., 2009).

Building Specification and Environmental Design Conditions

Table D1: General Specification of the Building

Location:	Kingdom Of Bahrain. Lat. **26.27N** Long. **50.65E**
Building Type:	Heath Services building with suspended ceiling and PVC floors
Number of Floors:	2
Operation Hours:	Wards Operating 24 Hours. Administration8 Hours (7:00 – 15:00) for 5 Days.
External Wall:	Light colour, 215 mm brickwork with 13 mm dense plaster each side.
Internal Wall:	Light colour, 150 mm brickwork with 13 mm dense plaster each side
Roof:	Flat Concrete, 50 mm screed, 150 mm cast concrete, 13 mm dense plaster
Floor:	Contact with ground, Vinyl floor covering, 75 mm screed, 150 mm cast
Floor:	Exposed to internal air below, Vinyl floor covering, 50 mm screed, 150 mm
Glazing Type:	Normal / Sheltered, Double glazing, 6 mm spacing,
Glazing Height:	1.20 m & 2.20 m
Storey Height:	3.65 m
Room Height:	3.40 m
Occupancy:	10-m2/ people.
Lighting Gain:	15 Watts/$m^{2,}$ Fluorescent, Recessed, Louvered,
Equipment Gain:	15 Watts/m^2
Ventilation:	10-15 $l.s^{-1}$ / person.
Infiltration:	0.25 ACH in summer & 0.25 ACH in winter.

Table D2: Environmental Design Conditions (CIBSE GA-1, 2006)

Indoor Condition	**Summer**	**Winter**
Temperature (^{o}C)	23	21
Humidity	50%	50%
Moisture content, g_r (g/kg)	8.8*	7.8*
Ventilation Rate ($l.s^{-1}$/person)	10-15 #	10-15 #
Outdoor Condition	**Summer**	**Winter**
Dry-bulb Temperature	40.1°C	11.6°C
Wet-bulb Temperature	30.2°C	
Relative Humidity	47%*	99.6%
Moisture content, g_0 (g/kg)	27.50	4.40
Enthalpy	107.00 kJ/kg	33.00 kJ/kg*

* Readings from CIBSE Psychometric chart. # Table 4.1.1, CIBSE Guide A, IDA2 Classification.

Building Design Parameters:

Table D3: Thermal properties of Building construction Materials (CIBSE GA-2, 2006)

External Wall			
Description: Light colours 13 mm dense plaster, 215 mm brickwork, and 13 mm dense plaster.			
Parameter	**Reference**	**Value**	**Unit**
U-value, U_w	CIBSE Guide A - Table 3.49 - 11(b)	1.45	W/m^2K
Y-value, Y_w		4.61	W/m^2K
ω_w		1.5	h
Decrement Factor, f_w		-	
Time lag, Φ_w		-	h
Internal Wall			
Description: Light colours 13 mm dense plaster. 150 mm brickwork, 13 mm dense plaster.			
Parameter	**Reference**	**Value**	**Unit**
U-value, U_{iw}	CIBSE Guide A - Table 3.49 - 11(b)	1.45	W/m^2K
Y-value, Y_{iw}		4.61	W/m^2K
ω_{iw}		1.5	h
Decrement Factor, f_{iw}		-	
Time lag, Φ_{iw}		-	h
Flat Roof			
Description: Flat Concrete, 50 mm screed, 150 mm cast concrete, 13 mm dense plaster			
Parameter	**Reference**	**Value**	**Unit**
U-value, U_r	CIBSE Guide A - Table 3.52 – (a)	2.25	W/m^2K
Y-value, Y_r		5.44	W/m^2K
ω_r		1.4	h
Decrement Factor, f_r		0.34	
Time lag, Φ_r		7.0	h

Floor - Typical floor in contact with ground

Description: Vinyl floor covering, 75 mm screed, 150mm cast concrete.

Parameter	Reference	Value	Unit
U-value, U_{gf}	CIBSE Guide A - Table 3.53 - 1(a)	0.38 *	W/m^2K
Y-value, Y_{gf}		3.59	W/m^2K
ω_w		1.3	h
Decrement Factor, f_{gf}		-	
Time lag, Φ_{gf}		-	h

*Table 3.16, Pf / Agf = 158/992 = 0.16, Rf= 0 for un-insulated floor.

Floor - Typical floors exposed to internal air below

Description: Vinyl floor covering, 50 mm screed, 150mm cast concrete.

Parameter	Reference	Value	Unit
U-value, U_{ff}	CIBSE Guide A - Table 3.55 - 1(a)	1.74	W/m^2K
Y-value, Y_{ff}		5.73	W/m^2K
ω_{ff}		0.8	h
Decrement Factor, f_{ff}		0.15	
Time lag, Φ_{ff}		10.7	h

Normal Glazing

Description: Double glazing to comprise 6mm outer grey panel, 6 mm air gap, 6mm inner gray panel

Parameter	Reference	Value	Unit
U-value, U_g	CIBSE Guide A - Table 3.23	3.28	W/m^2K
Decrement Factor, f_g		1	
Time lag, Φ_g		0	h
Y-value, Y_g	Assumption Y = U	3.28	W/m^2K
Correction factor for double glazing, C_g	CIBSE Guide A - Table 5.29 (20^o un shaded)	0.44 (Clear / reflecting)	
Air node correction factor, C_a	CIBSE Guide A - Table 5.29 (20^o un shaded)	0.84	

Sheltered Glazing

Description: Double glazing to comprise 6mm outer grey panel, 6 mm air gap, 6mm inner gray panel

Parameter	Reference	Value	Unit
U-value, U_g	CIBSE Guide A - Table 3.23	3.08	W/m^2K
Decrement Factor, f_g		1	
Time lag, Φ_g		0	h
Y-value, Y_g	Assumption Y = U	3.08	W/m^2K
Correction factor for double glazing, C_g	CIBSE Guide A - Table 5.29 (20^o un shaded)	0.44*	
Air node corr. factor, C_a	CIBSE Guide A - Table 5.29 (20^o un shaded)	0.84	

Occupant			
Description: 14-m2/person in wards, 10 m2/person in treatment room and general areas. Can be considered as 10 m2/ person			
Parameter	**Reference**	**Value**	**Unit**
Sensible Heat	CIBSE Guide A - Table 6.2	80	W/Person
		75% x15 =11.25	W/meal served
Latent Heat		60	W/Person
		25% x15= 3.75	W/meal served
Lighting			
Description: 9 Watts/m2 in wards & 15 Watts/m2 in treatment rooms. Can be considered as 15 W/m2. Description: Florescent, Recessed, Louvered.45% up & 55% down to space			
Parameter	**Reference**	**Value**	**Unit**
Intensity	CIBSE Guide A - Table 6.5	15	W/m^2
Percentage to space		55 %	
Equipment Gain (CIBSE GA-1, 2006)			
Description: 3 W/m2 in wards and treatment rooms + 10 W/m2 for IT applications + 2 W/m2 for others Can be considered as 15 Watts/m2			
Parameter	**Reference**	**Value**	**Unit**
Sensible Heat	CIBSE Guide A - Table 6.2	15	W/m2

Building Thermal Response Factor

Buildings, as per (Jouhara et. al., 2009), are classified as having either a slow or a fast response to heat transfer. Response to the changes in the environmental temperature is characterized by the response factor, fr, given by:

$$f_r = \frac{\Sigma AY + C_v}{\Sigma AU + C_v}$$

Where:

fr : the response factor, Cv: the ventilation conductance

Σ(AY): the sum of the products of surface areas and their corresponding thermal admittance (W/K)

Σ(AU): the sum of the products of surface areas and their corresponding thermal transmittance over surfaces through which heat flow occurs. (W/K).

Taking the corresponding factor into account, buildings then can be classified as follows:

High Thermal Response (fr > 4) → Slow response building (heavy weight)

Low Thermal Response (fr < 4) → Fast response building (Light weight)

Table D4: Building Thermal Response Factor Calculation

Surface	Area A (m2)	U value	(A X U)	Y value	(A X Y)	Dec. Factor (f)	Time Lag Φ (h)
External Walls	992.52	1.45	1,439.15	4.61	4,575.52	-	-
Internal Walls	2,086.00	-	-	4.61	9,616.46	-	-
Internal Floor (ground Floor)	996.00	-	-	3.59	3,575.64	-	-
Intermediate floor / Ceiling (First Floor)	1,024.00	-	-	5.73	5,867.52	-	-
Roof / Ceiling	1,024.00	2.25	2,304.00	5.44	5,570.56	-	-
Glazing (normal)	130.96	3.28	429.55	3.28	429.55	1.00	-
Glazing (shaded)	29.92	3.08	92.15	3.08	92.15	1.00	-
Σ	6,283.40		4,264.86		29,727.40		

Response Factor	$f_r = \frac{\sum AY + C_v}{\sum AU + C_v}$	∑AY	∑AU	C_v	f_r
		29,727	4,265	0.25	6.97

As thermal response factor, fr is greater than 4, the building is a slow response building (heavy weight).

Peak Hour Calculation:

The proposed building all directions facades have glazing. The glazing areas are as follows:

North façade: 50.28 m^2	East façade: 38.76 m^2
West façade: 32.80 m^2	South façade: 39.04 m^2

In order to find peak time, as date is not given in Table 5.29 of (CIBSE GA-1, 2006), the solar cooling loads at each hour for all summer months have to be calculated and then the peak cooling load for each of those months need to be compared to each other in order to determine the peak time. Proper correction factor related to the response factor of the building have to be taken into account.

Comparison calculations for June, July, August and September are given in (Tables D-5 to D-8) respectively. By calculating these loads and applying this comparison it was found that June has the highest solar cooling load and this occurs at 9.30 & 16.30.

Table D5 - Peak Hours Calculation for Month of June

Date	Time										
June	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30
CL $_{North}$ (W /m^2)	170	189	177	162	154	152	153	156	165	179	188
Glazing Area (m2)	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28
North SCL (kW)	8.55	9.50	8.90	8.15	7.74	7.64	7.69	7.84	8.30	9.00	9.45
CL $_{East}$ (W /m^2)	424	531	529	450	318	190	161	156	148	137	124
Glazing Area (m2)	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76
East SCL (kW)	16.43	20.58	20.50	17.44	12.33	7.36	6.24	6.05	5.74	5.\31	4.81
CL $_{South}$ (W /m^2)	59	78	93	104	110	112	112	110	102	91	75
Glazing Area (m2)	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8
South SCL (kW)	1.94	2.56	3.05	3.41	3.61	3.67	3.67	3.61	3.35	2.98	2.46
CL $_{West}$ (W /m^2)	130	145	158	169	176	186	226	356	481	550	538
Glazing Area (m2)	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04
South SCL (kW)	5.08	5.66	6.17	6.60	6.87	7.26	8.82	13.90	18.78	21.47	21.00
Total SCL (kW)	31.99	38.30	38.62	35.60	30.55	25.94	26.43	31.40	36.16	38.77	37.72
Glazing Conf. Corr. Factor	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Air-node Correction Factor	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total SCL (kW)	11.82	14.16	14.27	13.16	11.29	9.59	9.77	11.60	13.36	14.33	13.94

Table D6 - Peak Hours Calculation for Month of July

Date	Time										
July	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30
CL $_{North}$ (W /m^2)	170	182	170	157	149	148	149	152	159	172	181
Glazing Area (m2)	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28
North SCL (kW)	8.55	9.15	8.55	7.89	7.49	7.44	7.49	7.64	7.99	8.65	9.10
CL $_{East}$ (W /m^2)	442	531	530	451	318	190	161	155	147	137	124
Glazing Area (m2)	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76
East SCL (kW)	17.13	20.58	20.54	17.48	12.33	7.36	6.24	6.01	5.70	5.31	4.81
CL $_{South}$ (W /m^2)	58	78	93	104	110	112	112	109	102	91	75
Glazing Area (m2)	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8
South SCL (kW)	1.90	2.56	3.05	3.41	3.61	3.67	3.67	3.58	3.35	2.98	2.46
CL $_{West}$ (W /m^2)	128	145	158	168	176	186	226	357	482	551	539
Glazing Area (m2)	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04
South SCL (kW)	5.00	5.66	6.17	6.56	6.87	7.26	8.82	13.94	18.82	21.51	21.04
Total SCL (kW)	32.58	37.95	38.31	35.34	30.30	25.74	26.23	31.16	35.86	38.45	37.41
Glazing Conf. Corr. Factor	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Air-node Correction Factor	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total SCL (kW)	12.04	14.03	14.16	13.06	11.20	9.51	9.69	11.52	13.25	14.21	13.83

Table D7 - Peak Hours Calculation for Month of August

Date	Time										
July	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30
CL$_{North}$ (W /m^{2})	117	125	119	119	123	125	125	123	121	122	125
Glazing Area (m2)	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28
North SCL (kW)	5.88	6.29	5.98	5.98	6.18	6.29	6.29	6.18	6.08	6.13	6.29
CL$_{East}$ (W /m^{2})	409	538	543	463	325	191	159	153	145	134	121
Glazing Area (m2)	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76
East SCL (kW)	15.85	20.85	21.05	17.95	12.60	7.40	6.16	5.93	5.62	5.19	4.69
CL$_{South}$ (W /m^{2})	57	80	96	107	115	121	120	113	105	93	76
Glazing Area (m2)	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8
South SCL (kW)	1.87	2.62	3.15	3.51	3.77	3.97	3.94	3.71	3.44	3.05	2.49
CL$_{West}$ (W /m^{2})	124	142	154	165	173	184	227	364	494	563	543
Glazing Area (m2)	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04
South SCL (kW)	4.84	5.54	6.01	6.44	6.75	7.18	8.86	14.21	19.29	21.98	21.20
Total SCL (kW)	28.45	35.31	36.19	33.88	29.31	24.84	25.25	30.03	34.43	36.36	34.67
Glazing Conf. Corr. Factor	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Air-node Correction Factor	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total SCL (kW)	10.51	13.05	13.38	12.52	10.83	9.18	9.33	11.10	12.73	13.44	12.81

Table D8 - Peak Hours Calculation for Month of September

Date	Time										
July	7:30	8:30	9:30	10:30	11:30	12:30	13:30	14:30	15:30	16:30	17:30
CL$_{North}$ (W /m^{2})	57	77	91	101	106	106	106	106	99	89	75
Glazing Area (m2)	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28	50.28
North SCL (kW)	2.87	3.87	4.58	5.08	5.33	5.33	5.33	5.33	4.98	4.47	3.77
CL$_{East}$ (W /m^{2})	361	531	550	473	332	188	157	149	139	127	113
Glazing Area (m2)	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76	38.76
East SCL (kW)	13.99	20.58	21.32	18.33	12.87	7.29	6.09	5.78	5.39	4.92	4.38
CL$_{South}$ (W /m^{2})	64	93	125	161	191	206	204	186	153	116	87
Glazing Area (m2)	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8	32.8
South SCL (kW)	2.10	3.05	4.10	5.28	6.26	6.76	6.69	6.10	5.02	3.80	2.85
CL$_{West}$ (W /m^{2})	112	132	145	157	166	180	222	361	501	566	530
Glazing Area (m2)	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04
South SCL (kW)	4.37	5.15	5.66	6.13	6.48	7.03	8.67	14.09	19.56	22.10	20.69
Total SCL (kW)	23.33	32.66	35.65	34.82	30.94	26.40	26.77	31.30	34.94	35.30	31.70
Glazing Conf. Corr. Factor	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44	0.44
Air-node Correction Factor	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84	0.84
Total SCL (kW)	8.62	12.07	13.18	12.87	11.44	9.76	9.90	11.57	12.91	13.05	11.71

Solar Radiation on Walls – The Sol-Air Temperature:

The sol-air temperature is a simple method to account for the effect of solar radiation absorbed by the wall and for radiation from the building envelope to the cooler night sky. The sol-air temperature, Tos, is defined as the effective air temperature that would give the same heat transfer by simple surface conductance analysis as in the actual wall in the presence of more complex radiation exchange.

$$q = ho\,(Tos - Ts) = ho\,(To - Ts) + \propto I \rightarrow Tos = To + \propto I/ho$$

Where:

Tos = sol-air temperature, °C

To = air temperature, °C

Ts = surface temperature, °C

α = solar absorptance of surface

q = heat transfer to the surface, W/m2°C

ho = surface conductance, W/m2°C

I = incident solar radiation on surface, W/m2

The Sol-Air temperature tables for Kingdom of Bahrain are unfortunately not readily available in the reference books, and thus the same have to be calculated from available weather data.

Daily changes of temperature for month of June for Kingdom of Bahrain are obtained from Bahrain Weather Data (Essa, 1989) as shown in Figure D3. Solar Irradiance for latitude 20^{o} N are obtained from Table 2.33(c) of (CIBSE GA-1, 2006). ho, surface conductance values are obtained from Tables A3.6 & A3.7 of (CIBSE SHB, 2006). The data are used to calculate Sol-Air Temperature equation, $Tos = To + \propto I/ho$, to develop Table D9.

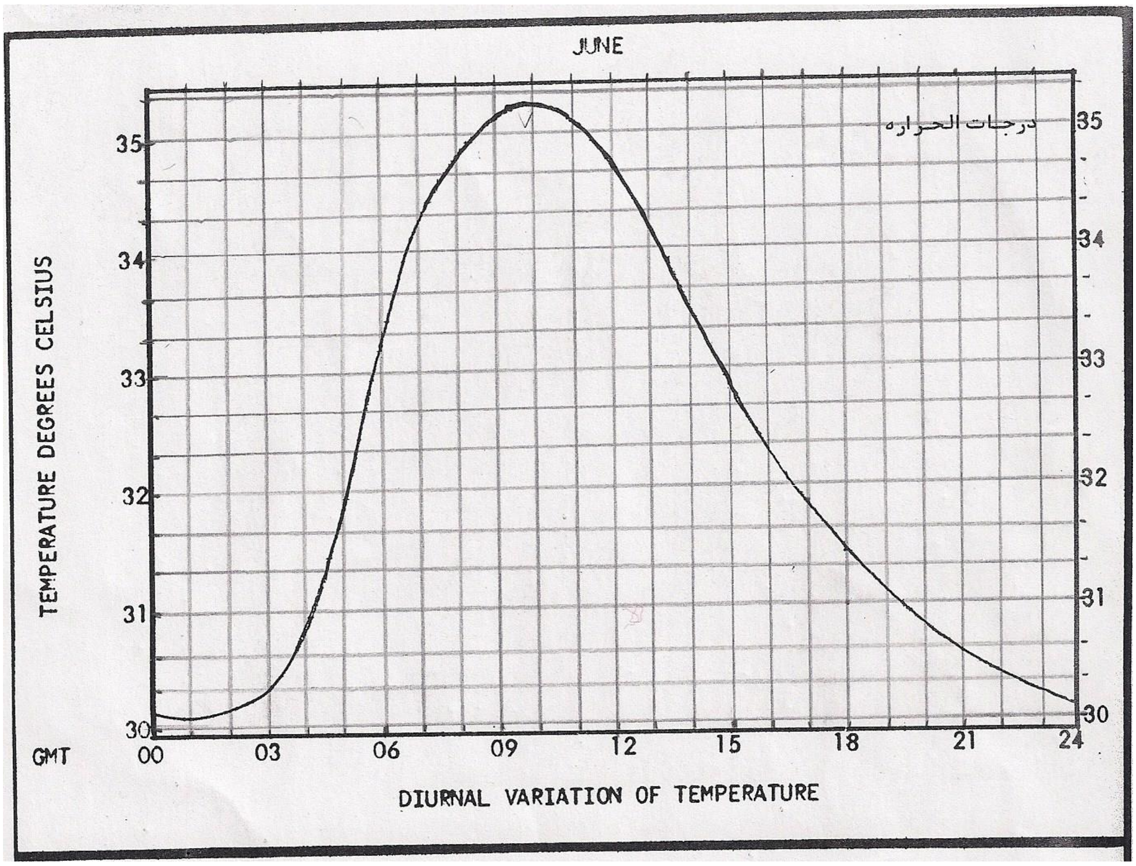


Figure D3 - Daily changes of temperature for month of June for Kingdom of Bahrain

Table D9 - Sol-Air Temperature for month of June for Kingdom of Bahrain

	t_{ao}	I_l	N	I_l	E	I_l	S	I_l	W	I_l	Horizon
Mean	33.6		44.6		52.2		33.6		52.2		70.2
5:30	32.6	73	39.7	168	49.0	0	32.6	0	32.6	12	33.5
6:30	33.8	162	49.6	444	77.1	0	33.8	0	33.8	121	42.8
7:30	34.5	173	51.4	582	91.3	0	34.5	0	34.5	320	58.4
8:30	35.0	146	49.2	579	91.5	0	35.0	0	35.0	526	74.3
9:30	35.3	107	45.7	480	82.1	0	35.3	0	35.3	705	88.0
10:30	35.2	75	42.5	315	65.9	0	35.2	0	35.2	837	97.8
11:30	34.9	57	40.5	109	45.5	0	34.9	0	34.9	906	102.6
12:30	34.5	57	40.0	0	34.5	0	34.5	109	45.1	906	102.2
13:30	33.8	75	41.1	0	33.8	0	33.8	315	64.5	837	96.4
14:30	33.1	107	43.5	0	33.1	0	33.1	480	79.9	705	85.8
15:30	32.6	146	46.8	0	32.6	0	32.6	579	89.0	526	71.9
16:30	32.1	174	49.0	0	32.1	0	32.1	581	88.7	320	56.0
17:30	31.6	162	47.4	0	31.6	0	31.6	444	74.9	121	40.6
18:30	31.3	73	38.4	0	31.3	0	31.3	168	47.6	12	32.1

Building Cooling Load Calculation

Building Heat Gains and Cooling Loads are calculated using the aforementioned data. The summery of the Zones, Modules and calculation tables are shown in the given tables:

Ground Floor – Zone 1

Time		**9:30 AM**		**4:30 PM**			
		Cooling Load (W)		**Cooling Load (W)**		**Fresh Air Required**	
Modules	**No.**	**Sensible**	**Latent**	**Sensible**	**Latent**	**Occupants**	**L / Sec**
GF-Z1-M1	1	1,457.68	516.27	2,108.65	516.27	3	15
GF-Z1-M2	1	733.63	236.30	1,164.13	236.30	1	
GF-Z1-M3	1	1,655.49	855.63	2,145.14	855.63	10	
GF-Z1-M4	1	500.18	190.67	491.05	190.67	1	
GF-Z1-M5	1	445.96	139.85	440.37	139.85	1	
GF-Z1-M6	1	4,429.56	796.07	3,443.07	796.07	6	
GF-Z1-M7	1	1,347.89	161.63	1,340.78	161.63	1	
GF-Z1-M8	1	2,139.10	796.07	1,613.42	796.07	6	
GF-Z1-M9	1	1,963.00	610.43	1,987.68	610.43	3	
Σ		**14,672.50**	**4,302.92**	**14,734.29**	**4,302.92**	**32**	**480**

Ground Floor – Zone 2

Time		**9:30 AM**		**4:30 PM**			
		Cooling Load (W)		**Cooling Load (W)**		**Fresh Air Required**	
Modules	**No.**	**Sensible**	**Latent**	**Sensible**	**Latent**	**Occupants**	**L / Sec**
GF-Z2-M1	1	2,113.56	390.67	2,637.34	390.67	2	15
GF-Z2-M2	1	1,298.49	375.63	1,809.24	375.63	2	
GF-Z2-M3	1	1,166.73	375.63	1,656.38	375.63	2	
GF-Z2-M4	1	499.04	272.44	488.38	272.44	2	
GF-Z2-M5	1	2,378.46	1,334.66	2,314.49	1,334.66	7	
GF-Z2-M6	1	464.62	267.79	454.28	267.78	2	
GF-Z2-M7	1	531.95	300.44	519.33	300.44	2	
GF-Z2-M8	1	712.96	420.74	691.93	421.65	2	
GF-Z2-M9	1	2033.06	870.67	2000.43	870.67	10	
GF-Z2-M10	1	1,432.18	326.43	1,362.75	326.43	2	
Σ		**12,631.05**	**4,935.08**	**13,934.55**	**4,935.08**	**33**	**495**

Ground Floor – Zone 3

Time		**9:30 AM**		**4:30 PM**			
		Cooling Load (W)		**Cooling Load (W)**		**Fresh Air Required**	
Modules	**No.**	**Sensible**	**Latent**	**Sensible**	**Latent**	**Occupants**	**L / Sec**
GF-Z3-M1	1	4,688.63	2,176.29	4,442.96	2,176.29	10	15
GF-Z3-M2	1	2,001.01	885.70	1,982.75	885.70	10	
GF-Z3-M3	1	4,707.19	543.48	2,830.77	543.48	2	
GF-Z3-M4	1	485.04	312.80	471.56	312.80	2	
GF-Z3-M5	1	1,318.37	245.11	1,305.43	245.11	1	
GF-Z3-M6	1	472.80	250.55	459.47	250.55	1	
GF-Z3-M7	1	1,246.03	250.55	1,030.47	250.55	1	
GF-Z3-M8	1	1,078.73	461.10	1,059.07	461.10	3	
GF-Z3-M9	1	962.59	292.41	958.06	292.41	2	
GF-Z3-M10	1	962.59	292.41	958.06	292.41	2	
GF-Z3-M11	1	962.59	292.41	958.06	292.41	2	
GF-Z3-M12	1	962.59	292.41	958.06	292.41	2	
GF-Z3-M13	1	1,978.93	292.41	1,394.92	292.41	2	
Σ		**17,922.98**	**5,710.39**	15,498.59	5,710.39	**40**	**600**

First Floor – Zone 4

Time		9:30 AM		4:30 PM			
		Cooling Load (W)		Cooling Load (W)		Fresh Air Required	
Modules	**No.**	**Sensible**	**Latent**	**Sensible**	**Latent**	**Occupants**	**L / Sec**
FF-Z4-M1	1	1,439.36	516.27	2,449.67	516.27	3	15
FF-Z4-M2	1	662.89	168.89	1,064.98	168.89	1	
FF-Z4-M3	1	4,588.49	1,352.14	7,593.33	1,352.14	8	
FF-Z4-M4	1	3,341.69	946.44	5,341.25	946.44	6	
FF-Z4-M5	1	3,406.10	826.66	3,932.27	826.66	6	
FF-Z4-M6	1	2,369.15	752.39	3,395.55	752.39	5	
Σ		**15,807.70**	**4,562.80**	**23,777.05**	**4,562.80**	**29**	**435**

First Floor – Zone 5

Time		9:30 AM		4:30 PM			
		Cooling Load (W)		Cooling Load (W)		Fresh Air Required	
Modules	**No.**	**Sensible**	**Latent**	**Sensible**	**Latent**	**Occupants**	**L / Sec**
FF-Z5-M1	1	4,409.67	1,246.89	7,054.37	1,246.89	8	15
FF-Z5-M2	1	1,229.49	360.59	1,965.77	360.59	2	
FF-Z5-M3	1	5,149.78	1,394.66	6,627.55	1,394.66	8	
FF-Z5-M4	1	507.47	192.74	640.99	192.74	2	
FF-Z5-M5	1	507.47	192.74	640.99	192.74	2	
FF-Z5-M6	1	732.69	339.61	1,200.88	339.61	2	
Σ		**12,536.56**	**3,727.23**	**18,130.55**	**3,727.23**	**24**	**360**

First Floor – Zone 6

Time		9:30 AM		4:30 PM			
		Cooling Load (W)		Cooling Load (W)		Fresh Air Required	
Modules	**No.**	**Sensible**	**Latent**	**Sensible**	**Latent**	**Occupants**	**L / Sec**
FF-Z6-M1	1	6,286.40	1,511.33	7,810.54	1,511.33	8	15
FF-Z6-M2	1	6,249.71	1,511.33	7,781.44	1,511.33	8	
FF-Z6-M3	1	6,621.23	1,369.26	6,637.07	1,369.26	8	
FF-Z6-M4	1	5,805.14	1,542.96	6,381.01	1,542.96	8	
FF-Z6-M5	1	3,406.10	826.66	3,932.27	826.66	6	
FF-Z6-M6	1	2,872.06	641.88	3,696.12	641.88	4	
Σ		**31,240.64**	**7,403.42**	**36,238.45**	**7,403.42**	**42**	**630**

Summary of Building Blocks (Zones) Loads and Fresh Air:

G / F Modules	Sensible Cooling Load (W)			Latent Load (W)			Fresh Air
	Calculated	10 -15%	Total	Calculated	10 -15%	Total	L / Sec
Zone 1	14,734.29	2,210.14	16,944.43	4,302.92	645.44	4,948.36	480
Zone 2	13,934.54	2,090.18	16,024.72	4,936.00	740.40	5,676.40	495
Zone 3	17,922.98	1,792.30	19,715.28	5,710.39	571.04	6,281.43	600
Zone 4	23,777.05	1,188.85	24,965.90	4,562.80	228.14	4,790.94	435
Zone 5	18,130.55	906.53	19,037.08	3,727.23	186.36	3,913.59	360
Zone 6A	18,119.23	905.96	19,025.19	7,403.42	370.17	7,773.59	315
Zone 6B	18,119.23	905.96	19,025.19	7,403.42	370.17	7,773.59	315
Σ							**3000**

It is normal practice to use Packaged A/C Units to satisfy the cooling requirements of the zones with 80-90% return & 10-20% fresh air supply. Practices show that the healthcare system need better quality treated fresh air to satisfy stringent air quality requirement, to improve the internal environment and to dilute and remove odours and other harmful fumes. These criteria cannot be fully satisfied through such system.

Alternative arrangement is to use dual system Air Handling Units. Central Fresh Air Handling Unit (Primary Coil) to supply the required fresh air to zones for ventilation and remove odours and harmful fumes. Zones Air Handling Units (Secondary Coils) to satisfy cooling requirements. Air Handling Units are connected either to Condensing Units (or Chilled Water System). Energy recovery technology such as Energy Recovery Heat Wheel or Energy Recover Heat Exchanger can be added to the Fresh Air Handling Units for energy optimization.

D2 - Performance of Conventional Air Conditioning System (No Energy Recovery)

Based on zones loads suitable size Air Handling Units are selected. For the reliability of the hospital A/C System the selected direct-expansion condensing unit must come with dual compressors (two independent refrigerant cycles). Meeting this criterion will dominate the selection of the unit size more than cooling load criteria.

Secondary (indoor) Air Handling Unit Model selected, in collaboration with Cooline A/C, Zamil Group, KSA, is (CU-CL100) as shown in (Figure D-4) connected to Direct Expansion Condensing Unit (TW6P3B P3) with cooling coil capacity of 24.83 kW.

Primary (external) Fresh Air Unit Model selected is (CU-CDL080) as shown in (Figure D-5) connected to Direct Expansion Condensing Unit (TW11P5BD - P5) with cooling coil capacity of 239.52 kW at the maximum peak design conditions of 46.10 ^{o}C db & 32.0 ^{o}C wb. The calculation is valid as it is very close to June and August calc. values.

The performance of this arrangement is shown in Tables D10A and D10B

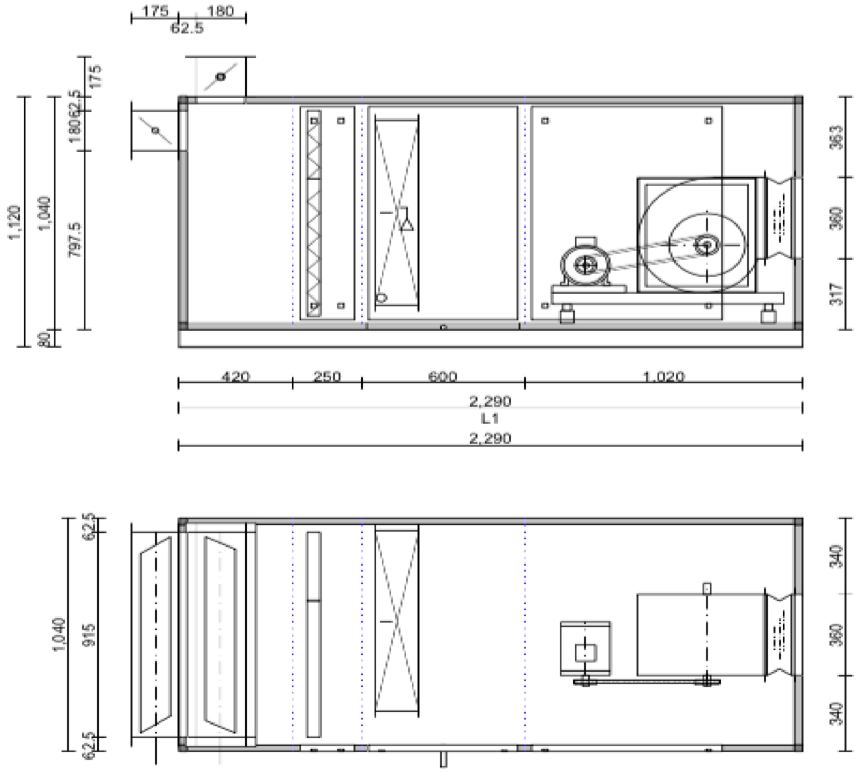


Figure D4 - Indoor Air Handling Unit

(Source: courtesy of Cooline A / C, Zamil Group, KSA)

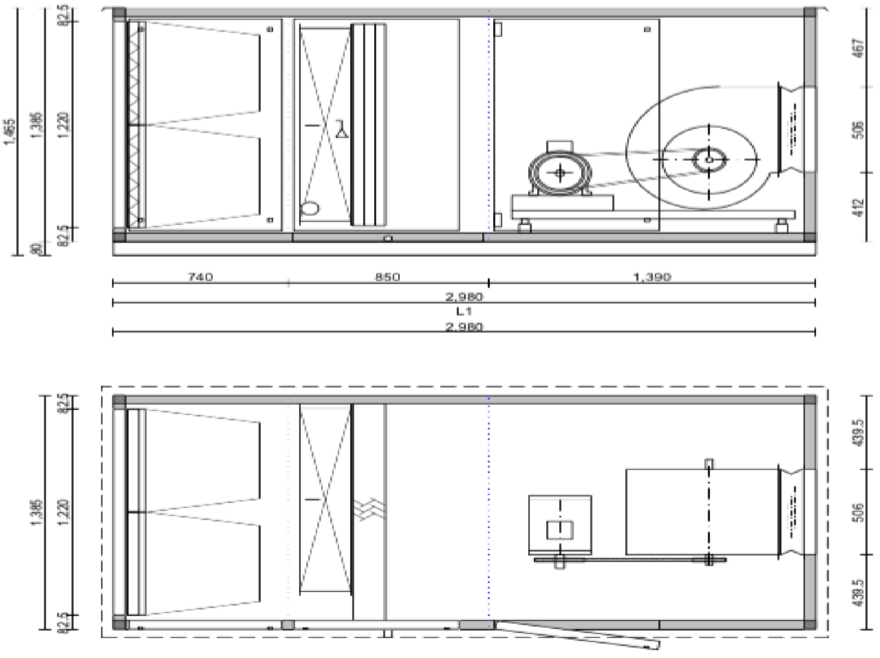


Figure D5 – External Fresh-Air Air Handling Unit

(Source: courtesy of Cooline A / C, Zamil Group, KSA)

Table D10A - Performance of A/C system with out energy recovery Technology
(air volume 3 m3/s)

	Jan	Feb	Mar	Apr	May	Jun
Outside Air db (^{o}C)	31.7	34.7	38.0	41.7	46.7	45.7
Outside Air wb (^{o}C)	21.5	22.0	24.0	27.5	30.5	34.0
Specific Enthalpy, ho (kJ/kg)	62.0	63.5	72.0	86.5	101.5	121.5
Specific Volume (m^3/kg)	0.879	0.887	0.900	0.916	0.936	0.945
Mass Flow Rate (kg/s)	3.41	3.38	3.33	3.28	3.21	3.17
Air off cooling Coil db (^{o}C)	13.7	13.7	13.7	13.7	13.7	13.7
Air off cooling Coil wb (^{o}C)	13.0	13.0	13.0	13.0	13.0	13.0
Specific Enthalpy, hc (kJ/kg)	37.0	37.0	37.0	37.0	37.0	37.0
Supply Air db (^{o}C)	20.0	20.0	20.0	20.0	20.0	20.0
Supply Air wb (^{o}C)	15.4	15.4	15.4	15.4	15.4	15.4
Electrical Reheat Capacity (kW)	23.03	23.03	23.03	23.03	23.03	23.03
AHU Motor Power (kW)	5.50	5.50	5.50	5.50	5.50	5.50
Cooling Capacity (kW)	85.32	89.63	116.67	162.12	206.73	268.25
Operating Hours per month (hr)	150	150	150	240	240	360
Total Energy Consumption (kWh)	17077.5	17724	21780	45756	56462.4	106840.8

Table D10B - Performance of A/C system with out energy recovery Technology
(air volume 3 m3/s)

	Jul	Aug	Sep	Oct	Nov	Dec
Outside Air db (^{o}C)	45.6	45.0	42.8	41.4	35.0	29.4
Outside Air wb (^{o}C)	33.5	34.0	32.0	31.0	28.5	24.0
Specific Enthalpy, ho (kJ/kg)	118.5	121.5	110.0	104.5	92.0	72.0
Specific Volume (m^3/kg)	0.943	0.943	0.933	0.926	0.904	0.880
Mass Flow Rate (kg/s)	3.18	3.18	3.22	3.24	3.32	3.41
Air off cooling Coil db (^{o}C)	13.7	13.7	13.7	13.7	13.7	13.7
Air off cooling Coil wb (^{o}C)	13.0	13.0	13.0	13.0	13.0	13.0
Specific Enthalpy, hc (kJ/kg)	37.0	37.0	37.0	37.0	37.0	37.0
Supply Air db (^{o}C)	20.0	20.0	20.0	20.0	20.0	20.0
Supply Air wb (^{o}C)	15.4	15.4	15.4	15.4	15.4	15.4
Electrical Reheat Capacity (kW)	23.03	23.03	23.03	23.03	23.03	23.03
AHU Motor Power (kW)	5.50	5.50	5.50	5.50	5.50	5.50
Cooling Capacity (kW)	259.28	268.82	234.73	218.68	182.52	119.32
Operating Hours per month (hr)	360	360	360	240	240	150
Total Energy Consumption (kWh)	103611.6	107046	94773.6	59330.4	50652	22177.5

From Tables D10A & D10B, we can note that the air off cooling coil condition is selected and maintained, through system control, at 13.7 db ^{o}C & 13.0 db ^{o}C to serve the main objective of FAHU, remove water moisture from the outside air. This point on the Psychometric chart is very close to the saturation (dew point) line and satisfy the neutral air conditions; i.e. t db = 20 ^{o}C and g=0.009 kg/kg dry air. Electrical reheating will satisfy the other condition by reheating to 20 ^{o}C.

D3 - Performance of Efficient Air Conditioning System (with Energy Recovery Heat Wheel)

At second phase of the study an efficient A/C System Technology will be introduced, Energy Recovery Heat Wheel as shown in Figure D-6.

Figure D6 - Energy Recovery Wheel
(Source: courtesy of Cooline Air Conditioning, Zamil Group, KSA.)

Indoor Air Handling Unit Model selected is (CU-CL100), as shown in Figure D4, connected to Direct Expansion Condensing Unit (TW6P3B P3) with cooling coil capacity of 24.83 kW.

External Fresh Air Unit with Energy Recovery Heat Wheel is selected (CU-CDL055), as shown in Figure D7, connected to Direct Expansion Condensing Unit (TW11P5BD - P5) with cooling coil capacity of 81.93 kW at the maximum peak design conditions of 46.10 oC db & 32.0 oC wb.

The performance of this arrangement is shown in Tables D11A and D11B.

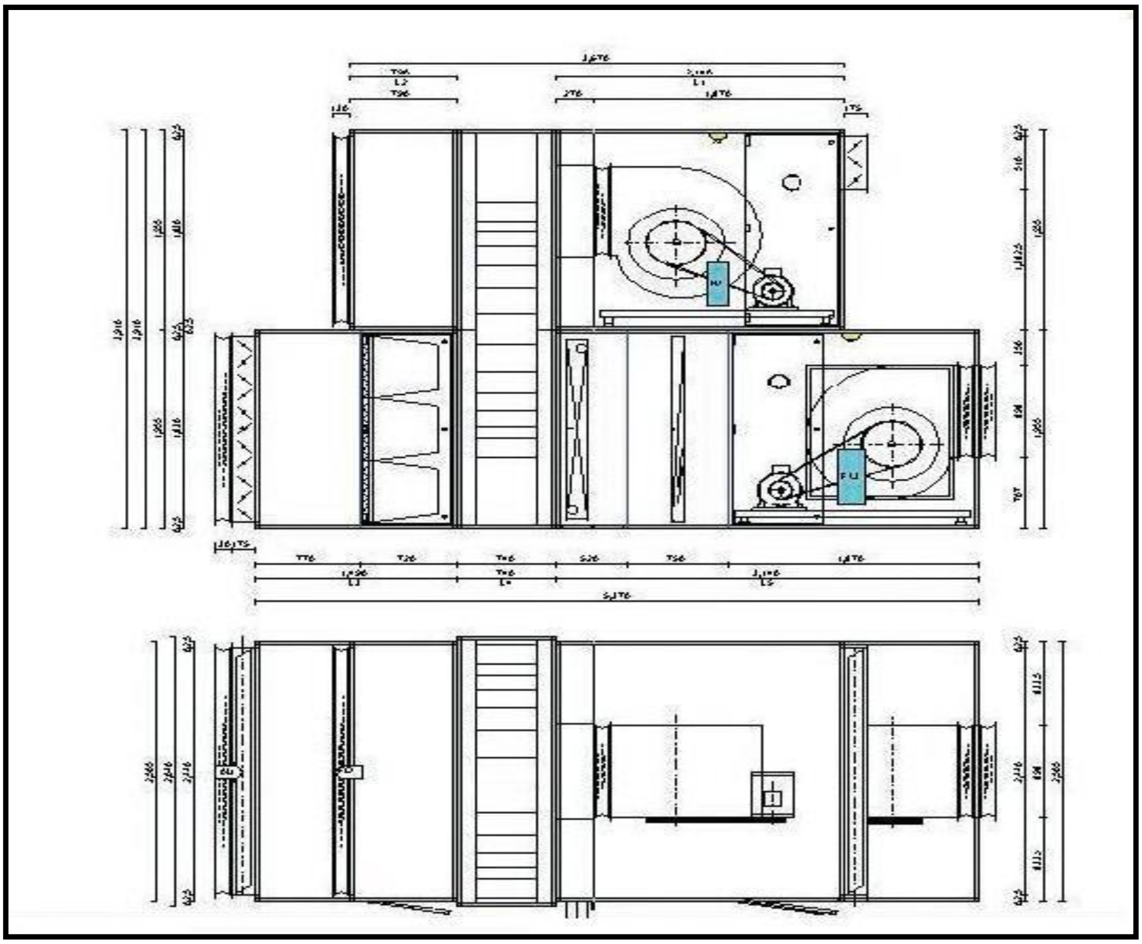


Figure D7 – External Fresh-Air Air Handling Unit with Energy Recovery Heat Wheel

(Source: courtesy of Cooline A / C, Zamil Group, KSA)

Energy Recovery Heat Wheel Effectiveness

Following ARI Standard 1060, as described in chapter 3, section 3.3.1, the total effectiveness of the wheel is determined using the local design conditions as follows:

$E = m_s (x_1 – x_2) / m_{min} (x_1 - x_3)$ –> $E = 3.21 (46.10 – 32.70) / 3.16 (46.10 - 24.0) =$

61.6%

That effectiveness is considered to be constant, also the exhaust air temperature is maintained at 24 °C then the precool condition can be calculated for all months of the year using:

Dry Bulb Temperature: Cooling: Tsa = Toa – (E x (Toa + Tra))

Enthalpy: Cooling: Hsa = Hoa – (E x (Hoa + Hra))

Off Cooling Coil and supply conditions are remain the same.

Table D11A - Performance of A/C system with Energy Recovery Heat Wheel
(Air volume 3 m3/s)

	Jan	Feb	Mar	Apr	May	Jun
Outside Air, toa db (^{o}C)	31.7	34.7	38.0	41.7	46.7	45.7
Outside Air, toa wb (^{o}C)	21.5	22.0	24.0	27.5	30.5	34.0
Specific Enthalpy, hao (kJ/kg)	62.0	63.5	72.0	86.5	101.5	121.5
Specific Volume, Voa (m^{3}/kg)	0.879	0.887	0.900	0.916	0.936	0.945
Mass Flow Rate, m$_{s}$ (kg/s)	3.41	3.38	3.33	3.28	3.21	3.17
E.R.H.W. Effectiveness (%)	61.60	61.60	61.60	61.60	61.60	61.60
Return Air, tra db (^{o}C)	24.0	24.0	24.0	24.0	24.0	24.0
Return Air, tra wb (^{o}C)	17.0	17.0	17.0	17.0	17.0	17.0
Specific Enthalpy, hra (kJ/kg)	47.50	47.50	47.50	47.50	47.50	47.50
Specific Volume, Vra (m^{3}/kg)	0.854	0.854	0.854	0.854	0.854	0.854
Mass Flow Rate, m$_{min}$ (kg/s)	3.16	3.16	3.16	3.16	3.16	3.16
Pre-cooling Capacity (kW)	28.24	31.16	47.71	75.95	105.17	144.12
Air off precool, tsa db (^{o}C)	27.3	28.5	29.8	31.2	32.9	32.4
Air off precool, tsa wb (^{o}C)	19.10	19.20	20.20	21,9	23.30	25.00
Specific Enthalpy, hsa (kJ/kg)	53.7	54.3	57.7	63.3	68.7	76.1
Specific Volume, Vsa (m^{3}/kg)	0.865	0.868	0.874	0.879	0.886	0.890
Mass Flow Rate, m$_{sa}$ (kg/s)	3.47	3.46	3.43	3.41	3.39	3.37
Air off cooling Coil db (^{o}C)	13.7	13.7	13.7	13.7	13.7	13.7
Air off cooling Coil wb (^{o}C)	13.0	13.0	13.0	13.0	13.0	13.0
Specific Enthalpy, hc (kJ/kg)	37.0	37.0	37.0	37.0	37.0	37.0
Supply Air db (^{o}C)	20.0	20.0	20.0	20.0	20.0	20.0
Supply Air wb (^{o}C)	15.4	15.4	15.4	15.4	15.4	15.4
Electrical Reheat Capacity(kW)	23.03	23.03	23.03	23.03	23.03	23.03
Supply Air Motor Power(kW)	5.50	5.50	5.50	5.50	5.50	5.50
Exhaust Air Motor Power(kW)	3.00	3.00	3.00	3.00	3.00	3.00
Heat Wheel Motor Power (kW)	1.00	1.00	1.00	1.00	1.00	1.00
Cooling Capacity (kW)	58.01	59.75	71.00	89.79	107.30	131.81
Operating Hours per month (hr)	150	150	150	240	240	360
Total Energy Consumption (kWh)	13581	13842	15529.5	29356.8	33559.2	59162.4

Table D11B - Performance of A/C system with Energy Recovery Heat Wheel
(Air volume 3 m3/s)

	Jul	Aug	Sep	Oct	Nov	Dec
Outside Air, toa db (^{o}C)	45.6	45.0	42.8	41.4	35.0	29.4
Outside Air, toa wb (^{o}C)	33.5	34.0	32.0	31.0	28.5	24.0
Specific Enthalpy, hao (kJ/kg)	118.5	121.5	110.0	104.5	92.0	72.0
Specific Volume, Voa (m^{3}/kg)	0.943	0.943	0.933	0.926	0.904	0.880
Mass Flow Rate m_s (kg/s)	3.18	3.18	3.22	3.24	3.32	3.41
E.R.H.W. Effectiveness (%)	61.60	61.60	61.60	61.60	61.60	61.60
Return Air, tra db (^{o}C)	24.0	24.0	24.0	24.0	24.0	24.0
Return Air, tra wb (^{o}C)	17.0	17.0	17.0	17.0	17.0	17.0
Specific Enthalpy, hra (kJ/kg)	47.50	47.50	47.50	47.50	47.50	47.50
Specific Volume, Vra (m^{3}/kg)	0.854	0.854	0.854	0.854	0.854	0.854
Mass Flow Rate, m_{min} (kg/s)	3.16	3.16	3.16	3.16	3.16	3.16
Pre-cooling Capacity (kW)	138.28	144.12	121.72	111.01	86.67	47.71
Air off precool, tsa db (^{o}C)	32.4	32.1	31.4	30.9	28.5	26.3
Air off precool, tsa wb (^{o}C)	24.80	25.00	24.00	23.50	22.40	21.30
Specific Enthalpy, hsa (kJ/kg)	75.0	76.2	72.1	70.2	65.9	58.0
Specific Volume, Vsa (m^{3}/kg)	0.889	0.888	0.885	0.883	0.864	0.866
Mass Flow Rate, m_{sa} (kg/s)	3.37	3.38	3.39	3.40	3.47	3.46
Air off cooling Coil db (^{o}C)	13.7	13.7	13.7	13.7	13.7	13.7
Air off cooling Coil wb (^{o}C)	13.0	13.0	13.0	13.0	13.0	13.0
Specific Enthalpy, hc (kJ/kg)	37.0	37.0	37.0	37.0	37.0	37.0
Supply Air db (^{o}C)	20.0	20.0	20.0	20.0	20.0	20.0
Supply Air wb (^{o}C)	15.4	15.4	15.4	15.4	15.4	15.4
Electrical Reheat Capacity (kW)	23.03	23.03	23.03	23.03	23.03	23.03
Supply Air Motor Power(kW)	5.50	5.50	5.50	5.50	5.50	5.50
Exhaust Air Motor Power (kW)	3.00	3.00	3.00	3.00	3.00	3.00
Heat Wheel Motor Power (kW)	1.00	1.00	1.00	1.00	1.00	1.00
Cooling Capacity (kW)	128.35	132.43	119.13	112.92	100.29	72.76
Operating Hours per month (hr)	360	360	360	240	240	150
Total Energy Consumption (kWh)	57916.8	59385.6	54597.6	34908	31876.8	15793.5

D4 - A/C Energy and Cost Analysis

A/C Capital Cost Analysis

As the Fresh Air Handlin Unit remains the same, there is a significant reduction in the size of Condensing Unit. And as the price of the FAHU doubled due to the incorporating of the Heat Recovery Wheel, there is a good reduction in the price of the Condensing Unit. This results in a net additional capital cost of about £ 684.20 (~ BD 404/100) only.

A/C Energy Saving Analysis

Table D12A - Energy Saving Analysis of A/C system with Energy Recovery Heat Wheel

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Outside Air, toa db (^oC)	31.7	34.7	38.0	41.7	46.7	45.7
Outside Air, toa wb (^oC)	21.5	22.0	24.0	27.5	30.5	34.0
Reduction in Cooling Coil Capacity (kW)	38.80	38.80	38.80	38.80	38.80	38.80
Reduction in Electrical Reheat (kW)	0.00	0.00	0.00	0.00	0.00	0.00
Pre-cooling energy cons. saving (kW)	28.24	31.16	47.71	75.95	105.17	144.12
Elec. reheat energy cons. saving (kW)	0.00	0.00	0.00	0.00	0.00	0.00
Supply Air Motor Power(kW)	0.00	0.00	0.00	0.00	0.00	0.00
Exhaust Air Motor Power(kW)	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00
Heat Wheel Motor Power(kW)	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Operating Hours per month (hr)	150	150	150	240	240	360
Total Energy saving (kWh)	9456	9894	12376.5	26580	33592.8	64411.2
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Reduction (kg CO2)	5200	5441	6807	14619	18476	35426
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	945.6	989.4	1237.65	2658	3359.28	6441.12
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	151.296	158.304	198.024	425.28	537.485	1030.579

(Table D-12B) Energy Saving Analysis of A/C system with Energy Recovery Heat Wheel

	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Outside Air, toa db (^{o}C)	45.6	45.0	42.8	41.4	35.0	29.4
Outside Air, toa wb (^{o}C)	33.5	34.0	32.0	31.0	28.5	24.0
Reduction in Cooling Coil Capacity (kW)	38.80	38.80	38.80	38.80	38.80	38.80
Reduction in Electrical Reheat (kW)	0.00	0.00	0.00	0.00	0.00	0.00
Pre-cooling energy cons. saving (kW)	138.28	144.12	121.72	111.01	86.67	47.71
Elec. reheat energy cons. saving (kW)	0.00	0.00	0.00	0.00	0.00	0.00
Supply Air Motor Power(kW)	0.00	0.00	0.00	0.00	0.00	0.00
Exhaust Air Motor Power(kW)	-3.00	-3.00	-3.00	-3.00	-3.00	-3.00
Heat Wheel Motor Power(kW)	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
Operating Hours per month (hr)	360	360	360	240	240	150
Total Energy saving (kWh)	62308.8	64411.2	56347.2	34994.4	29152.8	12376.5
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Reduction (kg CO2)	34269.84	35426.16	30990.96	19246.92	16034.04	6807.075
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	6230.88	6441.12	5634.72	3499.44	2915.28	1237.65
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	996.9408	1030.5792	901.5552	559.9104	466.4448	198.024

A/C Financial and Payback Analysis

Table D13 - Financial & Payback Analysis of Efficient A/C system (with Energy Recovery Heat Wheel)

	(£)	(BD)
Energy Recovery Heat Wheel System Cost	15742.10	9297.680
Conventional A/C System Cost	15057.90	8893.580
Additional Capital Cost	684.20	404.1000
Additional Control & material Cost	2000.00	1000.000
Additional Installation Cost	2000.00	1000.000
Total Additional Capital Cost	4684.20	2404.100
Total Annual Energy saving	41,590.14	6,654.42
Simple Payback Period (years)	0.11	0.36

A/C General Analysis

Table D14 - General Analysis of Efficient A/C system (with Energy Recovery Heat Wheel)

	(kWh)	(kg CO2)	(£)	(BD)
Total Energy Consumption of EKK Centre	1,001,995	551097.25	100199.50	16031.92
Total Energy Consumption of A/C System	703231.8			
%	70.18			
Total Energy Saving from A/C System	415,901.40	228,745.77	41,590.14	6,654.42
Saving from Total Energy Consumption (%)	41.50	41.50	41.50	41.50
Saving from Total A/C Energy Consumption (%)	59.14	59.14		

Appendix E: Evaluating the Performance of Lighting System of EKK Com. Medical Centre

To support sustainability of Healthcare System, LED lighting system performance will be evaluated vs. conventional lighting system, in collaboration with Al Bait Lighting, Bahrain, using Thorn-UK LED Lighting Technology.

LED lighting system is a preferable user option because it can create better visual environments through better lighting, reducing the glare and providing better dimming controls and multiple colour temperatures. It cuts operation cost by reducing lighting heat load by 50% and reduces energy consumption dramatically. It is also reduce maintenance expenses by cutting pulp and ballast replacement.

E1 - Performance of Internal Lighting System

Table E1 - Performance of Conventional Lighting System

	Luminaires	Type	Label	QTY	Lum. Watts	Total Watts	Lum. Lumens	LLF
Ground Floor								
	4 X 18 W	RSA	A#	77	74.00	5,698.00	3,406.00	0.764
	2 X 26 W	CFL	B#	83	52.40	4,349.20	2,125.00	0.764
	2 X 18 W	CFL	C#	16	36.50	584.00	1,489.00	0.764
	2 X 36 W	TLD	D#	14	80.00	1,120.00	4,849.00	0.764
	2 X 14 W	CFL	E#	20	34.00	680.00	1,231.00	0.764
First Floor								
	4 X 18 W	RSA	A#	90	74.00	6,660.00	3,406.00	0.764
	2 X 26 W	CFL	B#	33	52.40	1,729.20	2,125.00	0.764
	2 X 18 W	CFL	C#	31	36.50	1,131.50	1,489.00	0.764
	2 X 36 W	TLD	D#	2	80.00	160.00	4,849.00	0.764
					Total	22,111.90		

Table E2 - Performance of LED Lighting System

	Luminaires	Type	Label	QTY	Lum. Watts	Total Watts	Lum. Lumens	LLF
Ground Floor	CR22 (2)	LED	A	77	35.52	2,735.04	3,279.00	0.780
	CR150 (#1)	LED	B	83	27.00	2,241.00	1,983.00	0.903
	CR150 (#2)	LED	C	16	12.70	203.20	956.00	0.903
	CS14	LED	D	14	33.90	474.60	3,814.00	0.920
	CR150 (#3)	LED	E	20	9.17	183.40	677.00	0.903
First Floor	CR22 (2)	LED	A	90	35.52	3,196.80	3,279.00	0.780
	CR150 (#1)	LED	B	33	27.00	891.00	1,983.00	0.903
	CR150 (#2)	LED	C	31	12.70	393.70	956.00	0.903
	CS14	LED	D	2	33.90	67.80	3,814.00	0.920
					Total	10,386.54		

E2 - Internal Lighting Energy Saving analysis

Table E3A - Energy Saving Analysis of Internal LED Lighting System

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy Saving (kW)	11.73	11.73	11.73	11.73	11.73	11.73
Operating Hours per month (hr)	360	336	372	360	372	360
Total Energy saving (kWh)	3,753.60	3,941.28	4,363.56	3,753.60	4,363.56	3,753.60
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Reduction (kg CO2)	2,064.48	2,167.70	2,399.96	2,064.48	2,399.96	2,064.48
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	375.36	394.13	436.36	375.36	436.36	375.36
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	60.06	63.06	69.82	60.06	69.82	60.06

Table E3B - Energy Saving Analysis of Internal LED Lighting System

	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy Saving (kW)	11.73	11.73	11.73	11.73	11.73	11.73
Operating Hours per month (hr)	372	372	360	372	360	372
Total Energy saving (kWh)	4,363.56	4,363.56	3,753.60	4,363.56	3,753.60	4,363.56
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Reduction (kg CO2)	2,399.96	2,399.96	2,064.48	2,399.96	2,064.48	2,399.96
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	436.36	436.36	375.36	436.36	375.36	436.36
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	69.82	69.82	60.06	69.82	60.06	69.82

E3 - Internal Lighting Financial and Payback Analysis

Table E4 - Financial Analysis of Internal LED Lighting System

	TYPE 1		TYPE 2		TYPE 3		TYPE 4		TYPE 5	
Luminaires	4X18W	CR22 (2)	2X26 W	CR150 (#1)	2X18 W	CR150 (#2)	2X36W	CS14	2X14W	CR150 (#3)
Type	RSA	LED	CFL	LED	CFL	LED	TLD	LED	CFL	LED
No. Of Fixtures	167	167	116	116	47	47	16	16	20	20
Initial Cost:										
Fixture Initial Cost (BD)	33.000	51.000	2.000	23.000	31.000	23.000	48.000	85.000	30.000	21.000
Total Initial Cost (BD)	5,511	8,517	3,712	2,668	1,457	1,081	768	1,360	600	420
Lamp Replacement Cost:										
Average Lamp Life (hrs)	10000	50,000	8000	50,000	8000	50,000	10000	50,000	8000	50,000
Annual Total Operating Hours	4380	4380	4380	4380	4380	4380	4380	4380	4380	4380
Lamp Re-lamping Period (years)	2.3	11.4	1.8	11.4	1.8	11.4	2.3	11.4	1.8	11.4
Total No. of Lamps	668	0	232	0	141	0	32	0	40	0
No. of Lamps to be Replace in a year	293	0	127	0	77	0	14	0	22	0
Lamp Unit Price (BD)	0.500	0	1.950	0	1.650	0	0.750	0	1.350	0
Starter Unit Price (BD)	0.200	0	0.000	0	0.000	0	0.200	0	0.000	0
Lamp Installation Cost (BD)	0.200	0	0.200	0	0.200	0	0.200	0	0.200	0
Total (Lamp + Installation) Cost (BD)	0.900	0.000	2.150	0.000	1.850	0.000	0.950	0.000	1.550	0.000
Annual Lamp Replacement Cost (BD)	263	0	273	0	143	0	13	0	34	0
Ballast / Drivers Replacement Cost:										
Average Ballast Life (hrs)	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000	50,000
Annual Total Operating Hours	4380	4380	4380	4380	4380	4380	4380	4380	4380	4380
Ballast Re-lamping Period (years)	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4	11.4
No. of Ballast / Drivers	167	167	116	116	47	47	16	16	20	20
No. of Ballast / Drivers to be Rep. / year	15	0	10	0	4	0	1	0	2	0
Ballast / Drivers Unit Price (BD)	12.000	0	12.000	0	12.000	0	12.000	0	12.000	0
Ballast / Drivers Inst. Cost (BD)	0.200	0	0.200	0	0.200	0	0.200	0	0.200	0
Total (Ballast / Drivers + Inst.) Cost (BD)	12.20	0	12.20	0	12.20	0	12.20	0	12.20	0
Annual Ballast / Drivers Rep. Cost (BD)	178	-	124	-	50	-	17	-	21	-

Table E5 - Financial & Payback Analysis of Internal LED Lighting System

	(£)	(BD)
LED Lighting Initial Cost	8,287.14	14,046.000
Conventional Lighting Cost	7,108.32	12,048.000
Additional Capital Cost	1,178.82	1,998.000
Lamp Replacement Cost	428.63	726.494
Ballast Replacement Cost	230.78	391.152
Total Additional Capital Cost	1,838.23	3,115.646
Total Annual Energy saving	4,889.090	782.280
Simple Payback Period (years)	0.4	4.0

E4 - Performance of External Lighting System

Table E6 - Performance of External Conventional & LED Lighting System

	Luminaires	QTY	Luminaires Watts	Total Watts
Conventional Lights	Metal Halide	24	250	6,000.00
LED Lights	LED XSP2	24	101	2,424.00
			Energy Saving	3,576.00

E5 - External Lighting Energy Saving analysis

Table E7A - Energy Saving Analysis of External LED Lighting System

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy Saving (kW)	3.576	3.576	3.576	3.576	3.576	3.576
Operating Hours per month (hr)	360	336	372	360	372	360
Total Energy saving (kWh)	1,287	1,201	1,330	1,287	1,330	1,287
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Red. (kg CO2)	708.05	660.84	731.65	708.05	731.65	708.05
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	128.74	120.15	133.03	128.74	133.03	128.74
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	20.60	19.22	21.28	20.60	21.28	20.60

Table E7B - Energy Saving Analysis of External LED Lighting System

	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy Saving (kW)	3.576	3.576	3.576	3.576	3.576	3.576
Operating Hours per month (hr)	372	372	360	372	360	372
Total Energy saving (kWh)	1,330	1,330	1,287	1,330	1,287	1,330
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Red. (kg CO2)	731.65	731.65	708.05	731.65	708.05	731.65
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	133.03	133.03	128.74	133.03	128.74	133.03
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	21.28	21.28	20.60	21.28	20.60	21.28

E6 - External Lighting Financial and Payback Analysis

Table E8 - Financial Analysis of External LED Lighting System

Luminaires	Conventional	LED
Type	1X250 W Metal Halide	XSP2
No. Of Fixtures	24	24
Initial Cost:		
Fixture Initial Cost (BD)	145	245
Total Initial Cost (BD)	3,480.00	5,880.00
Lamp Replacement Cost:		
Average Lamp Life (hrs)	12,000	100,000
Annual Total Operating Hours	4380	4380
Lamp Re-lamping Period (years)	2.7	22.8
Total No. of Lamps	24	24
No. of Lamps to be Replace in a year	8	0
Lamp Unit Price (BD)	12	0
Lamp Installation Cost (BD)	6	0
Total (Lamp + Installation) Cost (BD)	18	0
Annual Lamp Replacement Cost (BD)	144	0
Ballast / Drivers Replacement Cost:	30,000	100,000
Average Ballast Life (hrs)	4380	4380
Annual Total Operating Hours	6.8	22.8
Ballast Re-lamping Period (years)	24	24
No. of Ballast / Drivers	1	0
No. of Ballast / Drivers to be Rep. / year	8	0
Ballast / Drivers Unit Price (BD)	20	0
Ballast / Drivers Inst. Cost (BD)	6	0
Total (Ballast / Drivers + Inst.) Cost (BD)	26	0
Annual Ballast / Drivers Rep. Cost (BD)	208	0

Table E9 - Financial & Payback Analysis of External LED Lighting System

	(£)	(BD)
LED Lighting Initial Cost	9,966.17	5,880.000
Conventional Lighting Cost	5,898.31	3,480.000
Additional Capital Cost	4,067.86	2,400.000
Lamp Replacement Cost	244.07	144.000
Ballast Replacement Cost	352.54	208.000
Total Additional Capital Cost	4,664.47	2,752.000
Total Annual Energy saving	1,562.00	249.920
Simple Payback Period (years)	0.33	11.00

E7 - Internal & External Lighting General Analysis

Table E10 - General Analysis of Internal & External LED Lighting System

	(KWh)	(Kg CO2)	(£)	(BD)
Total Energy Consumption of EKK Centre	1,001,995	551,097.25	100,199.50	16,031.92
Total Energy Con. of Internal Lighting System	96,584.78			
Total Energy Con. of External Lighting System	26,208.00			
Total	122,792.78			
%	12.25			
Total Energy Saving from Int. Lighting System	51,216.37			
Total Energy Saving from Ext. Lighting System	15,619.97			
Total	66,836.34	3676.32	66836.63	1069.381
Saving from Total Energy Consumption (%)	6.67	6.67	6.67	6.67
Saving from Total Lighting Energy Con. (%)	54.43	54.43		

Appendix F: Evaluating the Performance of Domestic Hot Water System of EKK Com. Medical Centre

Domestic Hot water is an essential service in Healthcare facilities as it is has round-the-year wide applications in equipment operations in addition to washing and bathing of patients, especially children and geriatric.

In this appendix, researcher is testing, in collaboration with Galaxy Arabia Trading, Bahrain using AST Solar Industry Technology-Greece, the effectiveness of (IEA, 2008) second recommendation to achieve sustainable building by using Renewable Source of Energy for Domestic Water Heating (Solar Panel Water Heater) instead of the conventional Electric Water Heaters.

F1 - Performance of Conventional Domestic Hot Water System

Table F1 - Performance of Conventional Electric Water Heater System

Water Heaters Capacity (L)	Water Heaters Element Watts	QTY	Total Hot Water Capacity (L)	Total Watts
80	1500 W	10	800	15000
120	3000 W	13	1560	39000
120	4500 W	4	480	18000
Total		27	2840	72000

Table F2 - Performance of Solar Panel Water Heater System

Solar Panel Water Heaters Capacity (L)	Emergency Electric Booster Element Watts	QTY	Total Hot Water Capacity (L)	Total Watts
200	2000 W	6	1200	12000

F2 - Solar Panel Water Heater Energy saving analysis

Table F3A - Energy Saving Analysis of Solar Panel Water Heater System

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
Energy Saving (kW)	60	60	60	60	60	60
Operating Hours per month (hr)	180	168	186	180	186	180
Total Energy saving (kWh)	10,800	10,080	11,160	10,800	11,160	10,800
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Reduction (kg CO2)	5,940.0	5,544.0	6,138.0	5,940.0	6,138.0	5,940.0
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	1,080.00	1,008.00	1,116.00	1,080.00	1,116.00	1,080.00
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	172.800	161.280	178.560	172.800	178.560	172.800

Table F3B - Energy Saving Analysis of Solar Panel Water Heater System

	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Energy Saving (kW)	60	60	60	60	60	60
Operating Hours per month (hr)	186	186	180	186	180	186
Total Energy saving (kWh)	11,160	11,160	10,800	11,160	10,800	11,160
Emissions Factor (Kg CO2/KWh)	0.55	0.55	0.55	0.55	0.55	0.55
Total Monthly CO2 Em. Reduction (kg CO2)	6,138.0	6,138.0	5,940.0	6,138.0	5,940.0	6,138.0
Energy Cost (£/kWh)	0.1	0.1	0.1	0.1	0.1	0.1
Total Monthly Energy saving (£)	1,116.00	1,116.00	1,080.00	1,116.00	1,080.00	1,116.00
Energy Cost (BD/kWh)	0.016	0.016	0.016	0.016	0.016	0.016
Total Monthly Energy saving (BD)	178.560	178.560	172.800	178.560	172.800	178.560

F3 - Solar Panel Water Heater Financial and Payback Analysis

Table F4 - Financial & Payback Analysis of Solar Panel Water Heater System

	(£)	**(BD)**
Solar Panel Water Heater Initial Cost	3,540.00	6,000.000
Conventional Electric Water Heater Cost	1,026.60	1,740.000
Additional Capital Cost	2,513.40	4,260.000
Element Replacement Cost	177.00	300.000
Element Installation Cost	94.40	160.000
Total Additional Capital Cost	2,784.80	4,720.000
Total Annual Energy saving	13,104.00	2,096.640
Simple Payback Period (years)	0.2 (3 months)	2.25 (27 months)

F4 - Solar Panel Water Heater General Analysis

Table F5 - General Analysis of Solar Panel Water Heater System

	(KWh)	(Kg CO2)	(£)	(BD)
Total Energy Consumption of EKK Centre	1,001,995	551,097.25	100,199.50	16,031.92
Total Energy Consumption of DHW System	157,248			
%	15.70			
Total Energy Saving from DHW System	131,040	72,072	13,104.00	2,096.640
Saving from Total Energy Consumption (%)	13.08	13.08	13.08	13.08
Saving from Total DHW Energy Consumption (%)	76.97	76.97		

Appendix G: Energy Recovery from Medical Waste Incineration

In this appendix, researcher is testing the effectiveness of (IEA, 2008) second recommendation, i.e. achieve sustainable building by using the waste energy sources, by recovering the energy of Medical Waste during incineration process using efficient heat recovery system.

G1 - Primary Healthcare Services Recovered Energy

Energy recovered from Primary Healthcare and Public Health Laboratory Medical Waste incineration can be forecasted as shown in Table G1).

Table G1 - Energy recovered from Primary Healthcare and Public Health Laboratory Medical Waste

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Medical Waste Generation (Kg/ Annum)	378,736	389,850	401,298	413,089	425,233	437,742	450,627	463,897	477,566	491,645	506,147	521,083	536,468	552,314	568,635	585,446	602,762	620,596	638,966
Medical Waste Generation (Kg/ Hr.) (24 Hrs. Operation)	43	45	46	47	49	50	51	53	55	56	58	59	61	63	65	67	69	71	73
Medical Waste Generation (Kg/ Hr.) (12 Hrs. Operation)	86	89	92	94	97	100	103	106	109	112	116	119	122	126	130	134	138	142	146
LCP Factor (KW /Kg)	4.0																		
Energy Recovery Efficiency (HP 1000)	85%																		
Medical Waste Heating Power (KW/ Annum)	1,287,702	1,325,490	1,364,413	1,404,503	1,445,792	1,488,323	1,532,132	1,577,250	1,623,724	1,671,593	1,720,900	1,771,682	1,823,991	1,877,868	1,933,359	1,990,516	2,049,391	2,110,026	2,172,484
Medical Waste Heating Power (KWh) (24 Hrs. Operation)	147	151	156	160	165	170	175	180	185	191	196	202	208	214	221	227	234	241	248
Medical Waste Heating Power (KWh) (12 Hrs. Operation)	294	303	312	321	330	340	350	360	371	382	393	404	416	429	441	454	468	482	496

To explain the difference between 24 hours operation and 12 hours operation of the incineration plant; in the first scenario if 43 Kg of medical waste is incinerated every hour, 147 KWh of heating power will be produced; while in the second scenario if 86 Kg of medical waste is incinerated every hour, 294 KWh of heating power will be produced. The 147 KWh heating power will be enough to cover the Domestic Hot Water requirement in Appendix – F (72 KW). From the two scenarios it is clear that the hourly destruction capacity is small, so it is more feasible to go for Central Plant.

G2 - Secondary Healthcare Services Medical Waste Energy

Energy generated from Medical Waste of the Secondary Healthcare Services (Seven MoH Hospitals) can be forecasted as shown in Table G2.

Table G2 - Energy recovered from Secondary Healthcare Medical Waste

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Medical Waste Generation (Kg/ Annum)	1,823,540	1,878,710	1,935,540	1,994,070	2,054,350	2,116,450	2,180,400	2,246,280	2,314,130	2,384,020	2,456,010	2,530,150	2,606,520	2,685,180	2,766,200	2,849,650	2,935,600	3,024,130	3,115,320
Medical Waste Generation (Kg/ Hr.) (24 Hrs. Operation)	208	214	221	228	235	242	249	256	264	272	280	289	298	307	316	325	335	345	356
Medical Waste Generation (Kg/ Hr.) (12 Hrs. Operation)	416	429	442	455	469	483	498	513	528	544	561	578	595	613	632	651	670	690	711
LCP Factor (KW /Kg)	4.0																		
Energy Recovery Efficiency (HP 2000)	75%																		
Medical Waste Heating Power (KW/ Annum)	5,470,620	5,636,130	5,806,620	5,982,210	6,163,050	6,349,350	6,541,200	6,738,840	6,942,390	7,152,060	7,368,030	7,590,450	7,819,560	8,055,540	8,298,600	8,548,950	8,806,800	9,072,390	9,345,960
Medical Waste Heating Power (KWh) (24 Hrs. Operation)	625	643	663	683	704	725	747	769	793	816	841	866	893	920	947	976	1,005	1,036	1,067
Medical Waste Heating Power (KWh) (12 Hrs. Operation)	1,249	1,287	1,326	1,366	1,407	1,450	1,493	1,539	1,585	1,633	1,682	1,733	1,785	1,839	1,895	1,952	2,011	2,071	2,134

By reviewing the hourly destruction capacity it is very clear that the plant is feasible to be operated with recovery system following the optimal operating scenario based on the following factor:

- Operating Hours of the recipient services,
- Optimization of plant capacity,
- Optimization of plant operation,
- Consideration of future expansion.

G3 - Integrated Healthcare Services Medical Waste Energy

By integrating Primary Healthcare and Secondary Healthcare Medical Waste Incineration Operation, it is ended with the forecast illustrated in Table G3.

Table G3 - Integrated Energy recovered from PHC, SHC & PHL Medical Waste

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Medical Waste Generation (Kg/ Annum)	2,202,276	2,268,560	2,336,838	2,407,159	2,479,583	2,554,192	2,631,027	2,710,177	2,791,696	2,875,665	2,962,157	3,051,233	3,142,988	3,237,494	3,334,835	3,435,096	3,538,362	3,644,726	3,754,286
Medical Waste Generation (Kg/ Hr.) (24 Hrs. Operation)	251	259	267	275	283	292	300	309	319	328	338	348	359	370	381	392	404	416	429
Medical Waste Generation (Kg/ Hr.) (12 Hrs. Operation)	503	518	534	550	566	583	601	619	637	657	676	697	718	739	761	784	808	832	857
LCP Factor (KW /Kg)	4.0																		
Energy Recovery Efficiency (HP 2000)	75%																		
Medical Waste Heating Power (KW/ Annum)	6,606,828	6,805,680	7,010,514	7,221,477	7,438,749	7,662,576	7,893,081	8,130,531	8,375,088	8,626,995	8,886,471	9,153,699	9,428,964	9,712,482	10,004,505	10,305,288	10,615,086	10,934,178	11,262,858
Medical Waste Heating Power (KWh) (24 Hrs. Operation)	754	777	800	824	849	875	901	928	956	985	1,014	1,045	1,076	1,109	1,142	1,176	1,212	1,248	1,286
Medical Waste Heating Power (KWh) (12 Hrs. Operation)	1,508	1,554	1,601	1,649	1,698	1,749	1,802	1,856	1,912	1,970	2,029	2,090	2,153	2,217	2,284	2,353	2,424	2,496	2,571

Plant is required to cover the operation until year 2030. Three numbers of 1000 kg/hr. incinerators shall be selected to meet diversity of load and to improve the plant reliability.

By selecting well-known technology in Medical Waste Incineration, ATI Environment - France, it is found that High Pressure Incinerator Model HP 2000 is meeting the required criteria.

Recovered heat power can be used in Domestic Hot Water, steam applications in Laundry, Sterilization and other hospital applications. It can also be used in absorption A/C system to cool the Medical Waste storage room in the incineration Plant.

G4 - Equivalent Energy Saving and Emissions Reduction

Utilizing recovered Heat Power will give a provision for some energy saving in electrical heating and subsequently some emissions reductions that can be calculated as shown in Table G4.

Table G4 - Equivalent Energy Saving and Emissions Reduction

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Medical Waste Generation (Kg/ Hr.) (12 Hrs. Operation)	1,508	1,554	1,601	1,649	1,698	1,749	1,802	1,856	1,912	1,970	2,029	2,090	2,153	2,217	2,284	2,353	2,424	2,496	2,571
LCP Factor (KW /Kg)	4.0																		
Energy Recoverer Efficiency (HP 2000)	75%																		
Medical Waste Heating Power (KWh) (12 Hrs. Operation)	4,524	4,662	4,803	4,947	5,094	5,247	5,406	5,568	5,736	5,910	6,087	6,270	6,459	6,651	6,852	7,059	7,272	7,488	7,713
Total MW Heating Power **(= Saving in Electricity)** (KWh)	19,815,120	20,419,560	21,037,140	21,667,860	22,311,720	22,981,860	23,678,280	24,387,840	25,123,680	25,885,800	26,661,060	27,462,600	28,290,420	29,131,380	30,011,760	30,918,420	31,851,360	32,797,440	33,782,940
Total CO2e Emissions Saving (Kg CO2e)	10,898,316	11,230,758	11,570,427	11,917,323	12,271,446	12,640,023	13,023,054	13,413,312	13,818,024	14,237,190	14,663,583	15,104,430	15,559,731	16,022,259	16,506,468	17,005,131	17,518,248	18,038,592	18,580,617

Appendix H: Recycling of Waste Water (Gray Water)

In this appendix, researcher is testing the effectiveness of recycling of waste water (gray water) in reducing water consumption and achieving sustainable building by re-using the Hydrotherapy pools wastewater and Reverse Osmoses rejected water in irrigation of Primary healthcare Facilities and secondary Healthcare Facilities respectively. This exercise is reproducing of pilot study conducted in collaboration with Electricity and Water Authority in year 2006.

H1 - Primary Healthcare Facilities Hydrotherapy Pools Water Consumption

Primary Healthcare Facilities Hydrotherapy Services is consuming water as per details given in Table H1.

Table H1 - Primary Healthcare Facilities Hydrotherapy Pools Water Consumption

Health Centre		Hydrotherapy Pool Weekly Water Consumption (M3)	No. of Weeks	Annual Water Consumption (M3)
1	N.B.B Arad	19	52	983
2	Bu-Maher	70	52	3,640
3	Ibn-Sina’a	19	52	970
4	Ahmed Ali Kanoo	33	52	1,702
5	Isa Town	19	52	983
6	Sheikh Jabber Al-Subah	58	52	2,995
7	M. Jassim kanoo	~~20~~	52	~~1,053~~
8	Hamad Kanoo	~~40~~	52	~~2,080~~
Total		217		11,284
%				17.83%

As there is no clear policy governing the expansion of the Physiotherapy and Hydrotherapy Services, it will be assumed that the existing services are following the expansions of primary healthcare facilities. Table H2 showing projected Primary Healthcare Facilities Water saving based on 17.83% water saving.

Table H2 - Primary Healthcare Facilities Water Saving (2012-2030)

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Consumption (M3)	63,281	69,061	75,013	81,145	87,460	93,965	100,664	107,565	114,673	121,994	129,535	137,302	145,302	153,542	162,029	170,771	179,775	189,049	198,601
Water Saving (17.83%) (M3)	11,283	12,314	13,375	14,468	15,594	16,754	17,948	19,179	20,446	21,752	23,096	24,481	25,907	27,377	28,890	30,448	32,054	33,707	35,411
New Water Consumption (M3)	51,998	56,747	61,638	66,677	71,866	77,211	82,716	88,386	94,227	100,242	106,439	112,821	119,395	126,165	133,139	140,323	147,721	155,342	163,190

Water saving from recycling of waste water (will give a provision for some water production (in desalination plant) energy saving and subsequently some emissions reductions that can be calculated as shown in (Table H-3) below:

Table H3 - Equivalent Energy Saving and Emissions Reduction from PHC water saving (2012-2030)

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Saving (M3)	11,283	12,314	13,375	14,468	15,594	16,754	17,948	19,179	20,446	21,752	23,096	24,481	25,907	27,377	28,890	30,448	32,054	33,707	35,411
Energy Consumed for Water Production (KWh /M3)	5.78																		
Emissions Factor (Kg/KWh)	0.55																		
Total CO2e Emissions Saving (Kg CO2e)	35,869	39,146	42,519	45,994	49,573	53,261	57,057	60,970	64,998	69,150	73,422	77,825	82,358	87,031	91,841	96,794	101,900	107,155	112,572

H2 - Secondary Healthcare Facilities Reverse Osmoses Water Production

Salmaniya Medical Complex is treating annually around 500,000 M3 of potable water, with Total Dissolved Solids (TDS) of 200-1200 ppm, supplied by government to suit hospital applications. These quantities of water is filtered and desalinated through four Reverse Osmoses Plants to a Total Dissolved Solids (TDS) of 100 ppm. This level of TDS is acceptable for drinking purposes and safe for smooth operation of hospital equipment using sweet water and steam.

Part of this good quality water is re-desalinated in the Kidney Dialysis Reverse Osmoses plant to almost zero TDS (1-2 ppm) to increase its dialysis capacity with human blood to remove poisons.

Part of this water also is used to fill Hydrotherapy treatment pool.

Good quality water with low TDS will give high quality product and good quality reject water. Re-using the rejected wastewater of the R. O. plant after mixing it with the reject of Kidney Dialysis R. O. plant and hydrotherapy wastewater in irrigation of secondary Healthcare Facilities can save good percentage of water consumption as given in Table H4.

Table H4 - Secondary Healthcare Facilities Water Production and reject

Service		Water Production (M3)	Reject / Waste Water (M3)
1	R.O. Plant Summer Operation	4 Nos. X 18 M3/Hrs. X 16 Hrs./Day X 260 Days X 70% = 209,644 M3	4 Nos. X 18 M3/Hrs. X 16 Hrs./Day X 260 Days X 30% = 89,856 M3
2	R.O. Plant Winter Operation	4 Nos. X 18 M3/Hrs. X 7.5 Hrs./Day X 090 Days X 70% = 34,020 M3	4 Nos. X 18 M3/Hrs. X 7.5 Hrs./Day X 090 Days X 30% = 14,580 M3
Total Water Consumption		348,120	
3	Kidney Dialysis Unit (Re-Desalination)	2.5 M3/Hrs. X 24 Hrs./Day X 365 Days X 75% = 16,425 M3	2.5 M3/Hrs. X 24 Hrs./Day X 365 Days X 25% = 5,475 M3
4	Hydrotherapy Pool Waste Water		63 M3 X 26 Weeks = 1,638 M3
Total			111,549
%			32 %

Table H5 - showing projected Secondary Healthcare Facilities Water saving based on 32% water saving.

Table H5 - Secondary Healthcare Facilities Water Saving (2012-2030)

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Consumption Footprint (M3)	362,044	384,150	406,919	430,372	454,527	479,408	505,035	531,430	558,618	586,621	615,464	645,173	675,772	707,290	739,754	773,191	807,631	843,105	879,642
Water Saving (32%) (M3)	111,549	118,623	125,909	133,414	141,144	149,105	157,306	165,752	174,452	183,414	192,643	202,150	211,942	222,028	232,416	243,116	254,137	265,488	277,180
New Water Consumption Footprint (M3)	250,495	265,527	281,010	296,958	313,383	330,303	347,729	365,678	384,166	403,207	422,821	443,023	463,830	485,262	507,338	530,075	553,494	577,617	602,462

Water saving from recycling of waste water will give a provision for some water production energy saving and subsequently some emissions reductions that can be calculated as shown in Table H6 below:

Table H6 - Equivalent Energy Saving and Emissions Reduction from SHC water saving (2012-2030)

Time (Year)	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Water Saving (M3)	111,549	118,623	125,909	133,414	141,144	149,105	157,306	165,752	174,452	183,414	192,643	202,150	211,942	222,028	232,416	243,116	254,137	265,488	277,180
Energy Consumed for Water Production (KWh /M3)	5.78																		
Emissions Factor (Kg/KWh)	0.55																		
Total CO2e Emissions Saving (Kg CO2e)	354,614	377,103	400,265	424,123	448,697	474,005	500,076	526,926	554,583	583,073	612,412	642,635	673,764	705,827	738,850	772,866	807,902	843,986	881,155

The outcomes of this exercise show are encouraging, especially in a country producing 88% of its water needs through sea water desalination plants that consume good part of country energy and expected to face shortage of natural gas used to run these plants and turn for importing by 2030 (Zubari, 2014)

Appendix I: Business as Usual (BAU) Scenario Details

The BAU scenario was set based on the current situation without any additional policies. Setting related to population growth of 3%, economic growth (growing economy assumption), healthcare performance measuring parameters, facility demand, energy and water consumption, waste generation and CO2 emissions were used without change to forecast the future healthcare facilities demand as illustrated in Tables I1 to I8.

Table I1 - BAU Policy Scenario for Bahrain PHC Facilities Demand (2012-2030)

Year	Population Growth = 3%				
	PHC (PI = 0.2 Facility / 10,000 Population)				
	Population	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	25	81,130	-	60.000
2013	1,271,950	26	88,539	6.000	62.223
2014	1,310,110	27	96,171	6.000	64.512
2015	1,349,410	27	104,032	-	66,871
2016	1,389,890	28	112,128	6.000	69.299
2017	1,431,590	29	120,468	6.000	71.801
2018	1,474,540	30	129,057	6.000	74.378
2019	1,518,770	31	137,904	6.000	77.032
2020	1,564,330	32	147,017	6.000	79.766
2021	1,611,260	33	156,403	6.000	82.582
2022	1,659,600	33	166,070	-	85.482
2023	1,709,390	34	176,028	6.000	88.469
2024	1,760,670	36	186,284	12.000	91.546
2025	1,813,490	37	196,848	6.000	94.716
2026	1,867,900	38	207,729	6.000	97.980
2027	1,923,930	39	218,937	6.000	101.342
2028	1,981,650	40	230,480	6.000	104.805
2029	2,041,100	41	242,370	6.000	108.372
2030	2,102,330	42	254,617	6.000	112.046

Table I2 - BAU Policy Scenario for Bahrain PHC Facilities Utilities (2012-2030)

Year	Population Growth = 3%							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	20,039,100	63,281	378,736	11,446	320,626	18,984	79,535	419,145
2013	21,869,200	69,061	389,850	12,481	349,908	20,718	81,869	452,495
2014	23,754,300	75,013	401,298	13,547	380,068	22,504	84,273	486,845
2015	25,695,800	81,145	413,089	14,645	411,133	24,343	86,749	522,225
2016	27,695,700	87,460	425,233	15,777	443,131	26,238	89,299	558,668
2017	29,755,500	93,965	437,742	16,942	476,088	28,189	91,926	596,203
2018	31,877,100	100,664	450,627	18,142	510,033	30,199	94,632	634,864
2019	34,062,300	107,565	463,897	19,378	544,998	32,270	97,418	674,686
2020	36,313,200	114,673	477,566	20,651	581,011	34,402	100,289	715,702
2021	38,631,500	121,994	491,645	21,962	618,104	36,598	103,246	757,948
2022	41,019,400	129,535	506,147	23,313	656,311	38,861	106,291	801,463
2023	43,478,900	137,302	521,083	24,704	695,663	41,191	109,427	846,281
2024	46,012,300	145,302	536,468	26,137	736,196	43,591	112,658	892,445
2025	48,621,600	153,542	552,314	27,613	777,945	46,063	115,986	939,994
2026	51,309,200	162,029	568,635	29,133	820,947	48,609	119,413	988,969
2027	54,077,400	170,771	585,446	30,699	865,238	51,231	122,944	1,039,413
2028	56,928,700	179,775	602,762	32,312	910,859	53,932	126,580	1,091,371
2029	59,865,500	189,049	620,596	33,973	957,848	56,715	130,325	1,144,888
2030	62,890,400	198,601	638,966	35,684	1,006,250	59,580	134,183	1,200,013

Table I3 - BAU Policy Scenario for Bahrain SHC Facilities Demand (2012-2030)

Year	**Population Growth = 3%**					
	SHC (SI = 20.4 Beds / 10,000 Population, 1/300 HBF)					
	Population	No. of Beds	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	2,498	9	268,181	-	222.465
2013	1,271,950	2,574	9	284,556	-	232.794
2014	1,310,110	2,651	10	301,422	100.000	243.432
2015	1,349,410	2,732	10	318,794	-	254.390
2016	1,389,890	2,814	10	336,687	-	265.676
2017	1,431,590	2,899	10	355,117	-	277.301
2018	1,474,540	2,987	11	374,100	100.000	289.275
2019	1,518,770	3,077	11	393,652	-	301.608
2020	1,564,330	3,170	11	413,791	-	314.311
2021	1,611,260	3,266	12	434,534	100.000	327.395
2022	1,659,600	3,364	12	455,899	-	340.872
2023	1,709,390	3,466	12	477,906	-	354.753
2024	1,760,670	3,571	13	500,572	100.000	369.050
2025	1,813,490	3,678	13	523,919	-	383.777
2026	1,867,900	3,789	13	547,966	-	398.945
2027	1,923,930	3,904	14	572,734	100.000	414.568
2028	1,981,650	4,021	14	598,245	-	430.659
2029	2,041,100	4,143	14	624,522	-	447.234
2030	2,102,330	4,268	15	651,587	100.000	464.306

Table I4 - BAU Policy Scenario for Bahrain SHC Facilities Utilities (2012-2030)

Year	**Population Growth = 3%**							
	SHC (En. Benchmark = 322 KWh/M2, W. Benchmark = 1.35 M3/M2)				**SHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	86,354,300	362,044	1,823,540	49,946	1,381,670	108,613	382,943	1,873,226
2013	91,627,000	384,150	1,878,710	52,967	1,466,030	115,245	394,529	1,975,804
2014	97,057,800	406,919	1,935,540	56,078	1,552,930	122,076	406,462	2,081,468
2015	102,652,000	430,372	1,994,070	59,282	1,642,430	129,111	418,754	2,190,295
2016	108,413,000	454,527	2,054,350	62,582	1,734,610	136,358	431,414	2,302,382
2017	114,348,000	479,408	2,116,450	65,982	1,829,560	143,822	444,454	2,417,836
2018	120,460,000	505,035	2,180,400	69,483	1,927,360	151,510	457,885	2,536,755
2019	126,756,000	531,430	2,246,280	73,090	2,028,100	159,429	471,719	2,659,248
2020	133,241,000	558,618	2,314,130	76,804	2,131,850	167,585	485,968	2,785,403
2021	139,920,000	586,621	2,384,020	80,630	2,238,720	175,986	500,645	2,915,351
2022	146,800,000	615,464	2,456,010	84,571	2,348,790	184,639	515,761	3,049,190
2023	153,886,000	645,173	2,530,150	88,630	2,462,170	193,552	531,332	3,187,054
2024	161,184,000	675,772	2,606,520	92,811	2,578,950	202,732	547,369	3,329,051
2025	168,702,000	707,290	2,685,180	97,118	2,699,230	212,187	563,888	3,475,305
2026	176,445,000	739,754	2,766,200	101,553	2,823,120	221,926	580,902	3,625,948
2027	184,420,000	773,191	2,849,650	106,122	2,950,730	231,957	598,426	3,781,113
2028	192,635,000	807,631	2,935,600	110,827	3,082,160	242,289	616,477	3,940,926
2029	201,096,000	843,105	3,024,130	115,674	3,217,540	252,931	635,068	4,105,539
2030	209,811,000	879,642	3,115,320	120,666	3,356,980	263,893	654,218	4,275,091

Table I5 - BAU Policy Scenario for Bahrain PH Facilities Demand (2012-2030)

Year	**PHF (4% Operation Growth)**				
	Population	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	1	5,874	-	2.144
2013	1,271,950	1	6,274	-	2.244
2014	1,310,110	1	6,690	-	2.348
2015	1,349,410	1	7,123	-	2.456
2016	1,389,890	1	7,573	-	2.568
2017	1,431,590	1	8,041	-	2.685
2018	1,474,540	1	8,527	-	2.807
2019	1,518,770	1	9,033	-	2.934
2020	1,564,330	1	9,560	-	3.065
2021	1,611,260	1	10,107	-	3.202
2022	1,659,600	2	10,676	4.000	3.344
2023	1,709,390	2	11,269	-	3.492
2024	1,760,670	2	11,884	-	3.646
2025	1,813,490	2	12,525	-	3.806
2026	1,867,900	2	13,191	-	3.973
2027	1,923,930	2	13,883	-	4.146
2028	1,981,650	2	14,604	-	4.326
2029	2,041,100	2	15,353	-	4.513
2030	2,102,330	2	16,132	-	4.708

Table I6 - BAU Policy Scenario for Bahrain PH Facilities Utilities (2012-2030)

Year	**PHF (4% Operation Growth)**					
	PHF (En. Benchmark = 206 KWh/M2, W. Benchmark = 1.25 M3/M2)			**PHF (En= BD 0.016/KWh, W= BD 0.300/M3)**		
	Energy Consumption (KWh)	Water Consumption (M3)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Total Expenditures (BD.)
2012	1,210,040	7,343	690	19,361	2,203	21,563
2013	1,292,440	7,843	737	20,679	2,353	23,032
2014	1,378,140	8,363	786	22,050	2,509	24,559
2015	1,467,260	8,903	836	23,476	2,671	26,147
2016	1,559,950	9,466	889	24,959	2,840	27,799
2017	1,656,350	10,051	944	26,502	3,015	29,517
2018	1,756,600	10,659	1,001	28,106	3,198	31,303
2019	1,860,860	11,292	1,061	29,774	3,387	33,161
2020	1,969,300	11,950	1,123	31,509	3,585	35,094
2021	2,082,070	12,634	1,187	33,313	3,790	37,103
2022	2,199,350	13,346	1,254	35,190	4,004	39,193
2023	2,321,320	14,086	1,323	37,141	4,226	41,367
2024	2,448,170	14,855	1,396	39,171	4,457	43,627
2025	2,580,100	15,656	1,471	41,282	4,697	45,978
2026	2,717,300	16,489	1,549	43,477	4,947	48,423
2027	2,859,990	17,354	1,630	45,760	5,206	50,966
2028	3,008,390	18,255	1,715	48,134	5,476	53,611
2029	3,162,720	19,191	1,803	50,604	5,757	56,361
2030	3,323,230	20,165	1,894	53,172	6,050	59,221

Table I7 - BAU Policy Scenario for Bahrain OB Facilities Demand (2012-2030)

Year	OB (3% Operation Growth)				
	Population	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	7	21,685	-	2.472
2013	1,271,950	7	23,785	-	3.050
2014	1,310,110	7	25,948	-	3.645
2015	1,349,410	8	28,176	3.000	4.257
2016	1,389,890	8	30,471	-	4.888
2017	1,431,590	8	32,834	-	5.538
2018	1,474,540	8	35,269	-	6.208
2019	1,518,770	9	37,776	3.000	6.897
2020	1,564,330	9	40,359	-	7.608
2021	1,611,260	9	43,019	-	8.339
2022	1,659,600	9	45,759	-	9.093
2023	1,709,390	10	48,581	3.000	9.869
2024	1,760,670	10	51,488	-	10.668
2025	1,813,490	10	54,482	-	11.492
2026	1,867,900	11	57,566	3.000	12.340
2027	1,923,930	11	60,743	-	13.213
2028	1,981,650	11	64,014	-	14.113
2029	2,041,100	12	67,384	3.000	15.040
2030	2,102,330	12	70,855	-	15.994

Table I8 - BAU Policy Scenario for Bahrain OB Facilities Utilities (2012-2030)

Year	OB (3% Operation Growth)					
	OB (En. Benchmark = 203 KWh/M2, W. Benchmark = 0.58 M3/M2)			OB (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Consumption (KWh)	Water Consumption (M3)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Total Expenditures (BD.)
2012	4,402,060	12,577	2,462,635	70,433	3,773	74,206
2013	4,828,360	13,795	2,701,125	77,254	4,139	81,392
2014	5,267,440	15,050	2,946,755	84,279	4,515	88,794
2015	5,719,710	16,342	3,199,769	91,515	4,903	96,418
2016	6,185,540	17,673	3,460,361	98,969	5,302	104,270
2017	6,665,340	19,044	3,728,785	106,645	5,713	112,358
2018	7,159,540	20,456	4,005,254	114,553	6,137	120,690
2019	7,668,560	21,910	4,290,014	122,697	6,573	129,270
2020	8,192,860	23,408	4,583,317	131,086	7,022	138,108
2021	8,732,880	24,951	4,885,419	139,726	7,485	147,211
2022	9,289,110	26,540	5,196,593	148,626	7,962	156,588
2023	9,862,020	28,177	5,517,095	157,792	8,453	166,245
2024	10,452,100	29,863	5,847,209	167,234	8,959	176,193
2025	11,059,900	31,600	6,187,239	176,959	9,480	186,439
2026	11,686,000	33,388	6,537,462	186,975	10,017	196,992
2027	12,330,800	35,231	6,898,182	197,292	10,569	207,861
2028	12,994,900	37,128	7,269,734	207,919	11,139	219,058
2029	13,679,000	39,083	7,652,434	218,864	11,725	230,589
2030	14,383,600	41,096	8,046,617	230,138	12,329	242,467

Appendix J: Administrative Rules & Regulation Management (ARRM-2%) Scenario Details

In this scenario, the change in facilities demand and its Environmental and Economic impacts are investigated as illustrated in Tables I1 to I8.

Table J1 - ARRM-2% Policy Scenario for Bahrain PHC Facilities Demand (2012-2030)

Year	Population Growth = 2%				
	PHC (PI = 0.2 Facility / 10,000 of Population)				
	Population	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	25	81,130	-	60.000
2013	1,259,600	25	86,070	-	61.482
2014	1,284,790	26	91,108	4.500	62.993
2015	1,310,490	27	96,247	4.500	64.535
2016	1,336,700	27	101,489	-	66.108
2017	1,363,430	28	106,836	4.500	67.712
2018	1,390,700	28	112,290	-	69.348
2019	1,418,510	29	117,852	4.500	71.017
2020	1,446,880	29	123,526	-	72.719
2021	1,475,820	30	129,314	4.500	74.455
2022	1,505,340	30	135,217	-	76.226
2023	1,535,440	31	141,239	4.500	78.033
2024	1,566,150	32	147,380	4.500	79.875
2025	1,597,470	32	153,645	-	81.755
2026	1,629,420	33	160,035	4.500	83.671
2027	1,662,010	34	166,553	4.500	85.627
2028	1,695,250	34	173,201	-	87.621
2029	1,729,160	35	179,982	4.500	89.656
2030	1,763,740	36	186,898	4.500	91.731

Table J2 - ARRM-2% Policy Scenario for Bahrain PHC Facilities Utilities (2012-2030)

Year	Population Growth = 2%							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	20,039,100	63,281	378,736	11,556	320,626	18,984	79,535	419,145
2013	21,259,200	67,134	386,145	12,246	340,147	20,140	81,091	441,378
2014	22,503,700	71,064	393,703	12,950	360,059	21,319	82,678	464,056
2015	23,773,000	75,073	401,412	13,668	380,369	22,522	84,297	487,187
2016	25,067,800	79,162	409,275	14,401	401,085	23,748	85,948	510,781
2017	26,388,500	83,332	417,295	15,148	422,215	25,000	87,632	534,847
2018	27,735,500	87,586	425,475	15,909	443,768	26,276	89,350	559,394
2019	29,109,500	91,925	433,820	16,687	465,753	27,578	91,102	584,433
2020	30,511,000	96,351	442,331	17,479	488,176	28,905	92,889	609,971
2021	31,940,600	100,865	451,012	18,288	511,049	30,260	94,713	636,021
2022	33,398,700	105,469	459,867	19,113	534,379	31,641	96,572	662,592
2023	34,885,900	110,166	468,899	19,954	558,175	33,050	98,469	689,694
2024	36,402,900	114,957	478,112	20,812	582,447	34,487	100,403	717,337
2025	37,950,300	119,843	487,508	21,687	607,205	35,953	102,377	745,535
2026	39,528,600	124,827	497,093	22,580	632,458	37,448	104,390	774,296
2027	41,138,500	129,911	506,870	23,491	658,216	38,973	106,443	803,632
2028	42,780,500	135,096	516,842	24,420	684,489	40,529	108,537	833,555
2029	44,455,500	140,386	527,013	25,367	711,288	42,116	110,673	864,077
2030	46,163,900	145,781	537,388	26,333	738,622	43,734	112,852	895,208

Table J3 - ARRM-2% Policy Scenario for Bahrain SHC Facilities Demand (2012-2030)

Year	Population Growth = 2%					
	SHC (PI = 0.2 Facility / 10,000 Population, 1/300 HBF)					
	Population	No. of Beds	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	2,498	9	268,181	-	222.465
2013	1,259,600	2,548	9	279,098	-	229.351
2014	1,284,790	2,600	9	290,232	-	236.374
2015	1,310,490	2,652	10	301,590	100.000	243.538
2016	1,336,700	2,706	10	313,175	-	250.846
2017	1,363,430	2,760	10	324,991	-	258.299
2018	1,390,700	2,816	10	337,044	-	265.901
2019	1,418,510	2,873	10	349,337	-	273.656
2020	1,446,880	2,930	10	361,877	-	281.566
2021	1,475,820	2,989	11	374,668	100.000	289.633
2022	1,505,340	3,050	11	387,714	-	297.863
2023	1,535,440	3,111	11	401,021	-	306.256
2024	1,566,150	3,174	11	414,594	-	314.818
2025	1,597,470	3,238	11	428,439	-	323.551
2026	1,629,420	3,303	12	442,561	100.000	332.458
2027	1,662,010	3,369	12	456,965	-	341.544
2028	1,695,250	3,437	12	471,657	-	350.811
2029	1,729,160	3,506	12	486,643	-	360.264
2030	1,763,740	3,577	13	501,929	100.000	369.906

Table J4 - ARRM-2% Policy Scenario for Bahrain SHC Facilities Utilities (2012-2030)

Year	Population Growth = 2%							
	SHC (En. Benchmark = 322 KWh/M2, W. Benchmark = 1.35 M3/M2)				SHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	86,354,300	362,044	1,823,540	50,258	1,381,670	108,613	382,943	1,873,226
2013	89,869,400	376,782	1,860,320	52,271	1,437,910	113,034	390,667	1,941,611
2014	93,454,800	391,814	1,897,840	54,325	1,495,280	117,544	398,546	2,011,370
2015	97,112,000	407,146	1,936,100	56,420	1,553,790	122,144	406,581	2,082,515
2016	100,842,000	422,786	1,975,130	58,557	1,613,480	126,836	414,778	2,155,094
2017	104,647,000	438,738	2,014,950	60,737	1,674,350	131,621	423,139	2,229,110
2018	108,528,000	455,009	2,055,550	62,960	1,736,450	136,503	431,666	2,304,619
2019	112,487,000	471,606	2,096,970	65,227	1,799,790	141,482	440,365	2,381,637
2020	116,524,000	488,534	2,139,220	67,540	1,864,390	146,560	449,237	2,460,187
2021	120,643,000	505,801	2,182,320	69,900	1,930,290	151,740	458,287	2,540,317
2022	124,844,000	523,414	2,226,270	72,306	1,997,500	157,024	467,517	2,622,041
2023	129,129,000	541,378	2,271,110	74,761	2,066,060	162,414	476,933	2,705,407
2024	133,499,000	559,702	2,316,840	77,264	2,135,990	167,911	486,536	2,790,437
2025	137,957,000	578,393	2,363,490	79,818	2,207,320	173,518	496,332	2,877,170
2026	142,505,000	597,457	2,411,070	82,423	2,280,070	179,237	506,324	2,965,631
2027	147,143,000	616,903	2,459,600	85,080	2,354,280	185,071	516,515	3,055,866
2028	151,874,000	636,737	2,509,100	87,790	2,429,980	191,021	526,911	3,147,912
2029	156,699,000	656,968	2,559,590	90,554	2,507,190	197,090	537,514	3,241,794
2030	161,621,000	677,604	2,611,090	93,373	2,585,940	203,281	548,329	3,337,550

Table J5 - ARRM-2% Policy Scenario for Bahrain PH Facilities Demand (2012-2030)

Year	PHF (Operation Growth = 2%)			
	No. of Facilities	Area (M2)	Project Expenditures (MBD)	Operating Expenditures (MBD)
2012	1	5,874	-	2.144
2013	1	6,074	-	2.204
2014	1	6,278	-	2.265
2015	1	6,486	-	2.327
2016	1	6,698	-	2.391
2017	1	6,915	-	2.456
2018	1	7,136	-	2.522
2019	1	7,361	-	2.590
2020	1	7,591	-	2.659
2021	1	7,825	-	2.729
2022	1	8,064	-	2.801
2023	1	8,308	-	2.874
2024	1	8,556	-	2.948
2025	1	8,810	-	3.025
2026	1	9,069	-	3.102
2027	1	9,333	-	3.181
2028	1	9,602	-	3.262
2029	1	9,876	-	3.344
2030	1	10,157	-	3.428

Table J6 - ARRM-2% Policy Scenario for Bahrain PH Facilities Utilities (2012-2030)

Year	Operation Growth = 2%					
	PHF (En. Benchmark = 206 KWh/M2, W. Benchmark = 1.25 M3/M2)			PHF (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Consumption (KWh)	Water Consumption (M3)	CO2e Emissions (Ton)	Energy Expenditure (BD)	Water Expenditure (BD)	Total Expenditures (BD)
2012	1,210,040	7,343	690	19,361	2,203	21,563
2013	1,251,240	7,593	713	20,020	2,278	22,298
2014	1,293,270	7,848	737	20,692	2,354	23,047
2015	1,336,130	8,108	762	21,378	2,432	23,810
2016	1,379,850	8,373	787	22,078	2,512	24,590
2017	1,424,450	8,644	812	22,791	2,593	25,384
2018	1,469,940	8,920	838	23,519	2,676	26,195
2019	1,516,340	9,201	864	24,261	2,760	27,022
2020	1,563,660	9,488	891	25,019	2,846	27,865
2021	1,611,930	9,781	919	25,791	2,934	28,725
2022	1,661,170	10,080	947	26,579	3,024	29,603
2023	1,711,400	10,385	976	27,382	3,115	30,498
2024	1,762,620	10,696	1,005	28,202	3,209	31,411
2025	1,814,870	11,013	1,035	29,038	3,304	32,342
2026	1,868,170	11,336	1,065	29,891	3,401	33,292
2027	1,922,530	11,666	1,096	30,761	3,500	34,260
2028	1,977,980	12,002	1,127	31,648	3,601	35,248
2029	2,034,540	12,346	1,160	32,553	3,704	36,256
2030	2,092,230	12,696	1,193	33,476	3,809	37,284

Table J7 - ARRM-2% Policy Scenario for Bahrain OB Facilities Demand (2012-2030)

Year	OB (Operation Growth = 2%)			
	No. of Facilities	Area (M2)	Project Expenditures (MBD)	Operating Expenditures (MBD)
2012	7	21,685	-	2.472
2013	7	23,085	-	2.857
2014	7	24,513	-	3.250
2015	7	25,970	-	3.651
2016	8	27,455	3.000	4.059
2017	8	28,971	-	4.476
2018	8	30,516	-	4.901
2019	8	32,093	-	5.334
2020	8	33,701	-	5.777
2021	8	35,342	-	6.228
2022	9	37,015	3.000	6.688
2023	9	38,721	-	7.157
2024	9	40,462	-	7.636
2025	9	42,238	-	8.124
2026	9	44,049	-	8.622
2027	9	45,896	-	9.130
2028	10	47,780	3.000	9.648
2029	10	49,702	-	10.177
2030	10	51,662	-	10.716

Table J8 - ARRM-2 Policy Scenario for Bahrain OB Facilities Utilities (2012-2030)

Year	Operation Growth = 2%					
	OB (En. Benchmark = 203 KWh/M2, W. Benchmark = 0.58 M3/M2)			OB (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Consumption (KWh)	Water Consumption (M3)	CO2e Emissions (Ton)	Energy Expenditure (BD)	Water Expenditure (BD)	Total Expenditures (BD)
2012	4,402,060	12,577	2,463	70,433	3,773	74,206
2013	4,686,260	13,389	2,622	74,980	4,017	78,997
2014	4,976,140	14,218	2,784	79,618	4,265	83,883
2015	5,271,820	15,062	2,949	84,349	4,519	88,868
2016	5,573,420	15,924	3,118	89,175	4,777	93,952
2017	5,881,040	16,803	3,290	94,097	5,041	99,138
2018	6,194,820	17,700	3,466	99,117	5,310	104,427
2019	6,514,880	18,614	3,645	104,238	5,584	109,822
2020	6,841,330	19,547	3,827	109,461	5,864	115,325
2021	7,174,320	20,498	4,014	114,789	6,149	120,938
2022	7,513,970	21,469	4,204	120,223	6,441	126,664
2023	7,860,400	22,458	4,397	125,766	6,737	132,503
2024	8,213,770	23,468	4,595	131,420	7,040	138,460
2025	8,574,200	24,498	4,797	137,187	7,349	144,536
2026	8,941,850	25,548	5,002	143,070	7,664	150,734
2027	9,316,840	26,620	5,212	149,070	7,986	157,056
2028	9,699,340	27,712	5,426	155,189	8,314	163,503
2029	10,089,500	28,827	5,644	161,432	8,648	170,080
2030	10,487,400	29,964	5,867	167,799	8,989	176,788

Appendix K: Administrative Rules & Regulation Management (ARRM-1%) Scenario Details

In this scenario, the change in facilities demand and its Environmental and Economic impacts are investigated as illustrated in Tables K1 to K8.

Table K1 - ARRM-1% Policy Scenario for Bahrain PHC Facilities Demand between years 2012-2030

Year	**Population Growth = 1%**				
	PHC (PI = 0.2 Facility / 10,000 of Population)				
	Population	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	25	81,130	-	60.000
2013	1,247,250	25	83,600	-	60.741
2014	1,259,720	25	86,094	-	61.489
2015	1,272,320	26	88,614	4.500	62.245
2016	1,285,040	26	91,158	-	63.009
2017	1,297,890	26	93,729	-	63.780
2018	1,310,870	27	96,324	4.500	64.558
2019	1,323,980	27	98,946	-	65.345
2020	1,337,220	27	101,594	-	66.139
2021	1,350,590	27	104,268	-	66.942
2022	1,364,100	28	106,970	4.500	67.752
2023	1,377,740	28	109,698	-	68.570
2024	1,391,520	28	112,453	-	69.397
2025	1,405,430	28	115,236	-	70.232
2026	1,419,490	29	118,047	4.500	71.075
2027	1,433,680	29	120,886	-	71.927
2028	1,448,020	29	123,753	-	72.787
2029	1,462,500	30	126,650	4.500	73.656
2030	1,477,120	30	129,574	-	74.533

Table K2 - ARRM-1% Policy Scenario for Bahrain PHC Facilities Utilities (2012-2030)

Year	**Population Growth = 1%**							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	20,039,100	63,281	378,736	11,556	320,626	18,984	79,535	419,145
2013	20,649,200	65,208	382,441	11,901	330,386	19,562	80,313	430,261
2014	21,265,300	67,154	386,182	12,250	340,245	20,146	81,098	441,489
2015	21,887,600	69,119	389,962	12,602	350,202	20,736	81,892	452,830
2016	22,516,100	71,104	393,779	12,957	360,258	21,331	82,694	464,283
2017	23,150,900	73,108	397,634	13,316	370,415	21,933	83,503	475,851
2018	23,792,100	75,133	401,527	13,679	380,673	22,540	84,321	487,534
2019	24,439,700	77,178	405,460	14,045	391,035	23,153	85,147	499,335
2020	25,093,700	79,243	409,432	14,415	401,499	23,773	85,981	511,253
2021	25,754,300	81,329	413,444	14,789	412,069	24,399	86,823	523,291
2022	26,421,500	83,436	417,495	15,166	422,744	25,031	87,674	535,449
2023	27,095,300	85,564	421,588	15,547	433,526	25,669	88,533	547,729
2024	27,775,900	87,714	425,721	15,932	444,415	26,314	89,401	560,131
2025	28,463,400	89,884	429,895	16,321	455,414	26,965	90,278	572,657
2026	29,157,600	92,077	434,112	16,714	466,522	27,623	91,164	585,309
2027	29,858,900	94,291	438,370	17,111	477,742	28,287	92,058	598,087
2028	30,567,100	96,528	442,671	17,511	489,074	28,958	92,961	610,993
2029	31,282,400	98,787	447,015	17,916	500,519	29,636	93,873	624,028
2030	32,004,900	101,068	451,403	18,324	512,078	30,320	94,795	637,193

Table K3 - ARRM-1% Policy Scenario for Bahrain SHC Facilities Demand (2012-2030)

Year	Population Growth = 1%					
	SHC (PI = 0.2 Facility / 10,000 Population, 1/300 HBF)					
	Population	No. of Beds	No. of Facilities	Area (M2)	Pro. Exp. (MBD)	Op. Exp. (MBD)
2012	1,234,900	2,498	9	268,181	-	222.465
2013	1,247,250	2,523	9	273,639	-	225.908
2014	1,259,720	2,549	9	279,152	-	229.385
2015	1,272,320	2,574	9	284,720	-	232.897
2016	1,285,040	2,600	9	290,344	-	236.445
2017	1,297,890	2,627	9	296,024	-	240.027
2018	1,310,870	2,653	10	301,760	100.000	243.646
2019	1,323,980	2,680	10	307,554	-	247.300
2020	1,337,220	2,707	10	313,406	-	250.992
2021	1,350,590	2,734	10	319,317	-	254.720
2022	1,364,100	2,762	10	325,286	-	258.485
2023	1,377,740	2,789	10	331,316	-	262.288
2024	1,391,520	2,818	10	337,405	-	266.130
2025	1,405,430	2,846	10	343,556	-	270.009
2026	1,419,490	2,875	10	349,768	-	273.927
2027	1,433,680	2,904	10	356,042	-	277.885
2028	1,448,020	2,933	10	362,379	-	281.882
2029	1,462,500	2,962	11	368,779	100.000	285.919
2030	1,477,120	2,992	11	375,243	-	289.997

Table K4 - ARRM-1% Policy Scenario for Bahrain SHC Facilities Utilities (2012-2030)

Year	Population Growth = 1%							
	SHC (En. Benchmark = 322 KWh/M2, W. Benchmark = 1.35 M3/M2)				SHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Consumption (KWh)	Water Consumption (M3)	Med. Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	86,354,300	362,044	1,823,540	50,258	1,381,670	108,613	382,943	1,873,226
2013	88,111,800	369,413	1,841,930	51,265	1,409,790	110,824	386,805	1,907,419
2014	89,887,000	376,855	1,860,500	52,281	1,438,190	113,057	390,706	1,941,953
2015	91,679,900	384,372	1,879,260	53,309	1,466,880	115,312	394,645	1,976,837
2016	93,490,700	391,964	1,898,210	54,346	1,495,850	117,589	398,624	2,012,063
2017	95,319,600	399,632	1,917,350	55,394	1,525,110	119,890	402,643	2,047,643
2018	97,166,800	407,376	1,936,680	56,452	1,554,670	122,213	406,702	2,083,585
2019	99,032,500	415,198	1,956,200	57,520	1,584,520	124,560	410,802	2,119,882
2020	100,917,000	423,099	1,975,910	58,600	1,614,670	126,930	414,942	2,156,542
2021	102,820,000	431,078	1,995,830	59,690	1,645,120	129,323	419,124	2,193,567
2022	104,742,000	439,137	2,015,940	60,791	1,675,880	131,741	423,348	2,230,969
2023	106,684,000	447,276	2,036,260	61,903	1,706,940	134,183	427,614	2,268,737
2024	108,645,000	455,497	2,056,770	63,026	1,738,310	136,649	431,922	2,306,881
2025	110,625,000	463,800	2,077,500	64,161	1,770,000	139,140	436,274	2,345,414
2026	112,625,000	472,187	2,098,420	65,307	1,802,000	141,656	440,669	2,384,325
2027	114,646,000	480,657	2,119,560	66,464	1,834,330	144,197	445,108	2,423,635
2028	116,686,000	489,212	2,140,910	67,633	1,866,980	146,763	449,592	2,463,335
2029	118,747,000	497,852	2,162,480	68,813	1,899,950	149,356	454,120	2,503,426
2030	120,828,000	506,579	2,184,260	70,006	1,933,250	151,974	458,694	2,543,918

Table K5 - ARRM-1% Policy Scenario for Bahrain PH Facilities Demand (2012-2030)

Year	**PHF (Operation Growth = 1%)**			
	No. of Facilities	Area (M2)	Project Expenditures (MBD)	Operating Expenditures (MBD)
2012	1	5,874	-	2.144
2013	1	5,974	-	2.174
2014	1	6,075	-	2.204
2015	1	6,177	-	2.235
2016	1	6,280	-	2.266
2017	1	6,384	-	2.297
2018	1	6,489	-	2.328
2019	1	6,595	-	2.360
2020	1	6,703	-	2.392
2021	1	6,811	-	2.425
2022	1	6,920	-	2.458
2023	1	7,031	-	2.491
2024	1	7,142	-	2.524
2025	1	7,255	-	2.558
2026	1	7,369	-	2.592
2027	1	7,484	-	2.627
2028	1	7,600	-	2.661
2029	1	7,717	-	2.697
2030	1	7,835	-	2.732

Table K6 - ARRM-1% Policy Scenario for Bahrain PH Facilities Utilities (2012-2030)

Year	**Operation Growth = 1%**					
	PHF (En. Benchmark = 206 KWh/M2, W. Benchmark = 1.25 M3/M2)			**PHF (En= BD 0.016/KWh, W= BD 0.300/M3)**		
	Energy Consumption (KWh)	Water Consumption (M3)	CO2e Emissions (Ton)	Energy Expenditure (BD)	Water Expenditure (BD)	Total Expenditures (BD)
2012	1,210,040	7,343	690	19,361	2,203	21,563
2013	1,230,640	7,468	701	19,690	2,240	21,931
2014	1,251,450	7,594	713	20,023	2,278	22,301
2015	1,272,460	7,721	725	20,359	2,316	22,676
2016	1,293,690	7,850	737	20,699	2,355	23,054
2017	1,315,120	7,980	750	21,042	2,394	23,436
2018	1,336,780	8,112	762	21,388	2,433	23,822
2019	1,358,640	8,244	774	21,738	2,473	24,212
2020	1,380,730	8,378	787	22,092	2,513	24,605
2021	1,403,040	8,514	800	22,449	2,554	25,003
2022	1,425,570	8,650	813	22,809	2,595	25,404
2023	1,448,320	8,788	826	23,173	2,637	25,810
2024	1,471,300	8,928	839	23,541	2,678	26,219
2025	1,494,520	9,069	852	23,912	2,721	26,633
2026	1,517,960	9,211	865	24,287	2,763	27,051
2027	1,541,640	9,355	879	24,666	2,806	27,473
2028	1,565,560	9,500	892	25,049	2,850	27,899
2029	1,589,710	9,646	906	25,435	2,894	28,329
2030	1,614,110	9,794	920	25,826	2,938	28,764

Table K7 - ARRM-1% Policy Scenario for Bahrain OB Facilities Demand (2012-2030)

Year	OB (Operation Growth = 1%)			
	No. of Facilities	Area (M2)	Project Expenditures (MBD)	Operating Expenditures (MBD)
2012	7	21,685	-	2.472
2013	7	22,385	-	2.665
2014	7	23,092	-	2.859
2015	7	23,806	-	3.056
2016	7	24,527	-	3.254
2017	7	25,256	-	3.454
2018	7	25,991	-	3.657
2019	8	26,735	3.000	3.861
2020	8	27,485	-	4.067
2021	8	28,243	-	4.276
2022	8	29,009	-	4.486
2023	8	29,782	-	4.699
2024	8	30,563	-	4.914
2025	8	31,352	-	5.131
2026	8	32,148	-	5.350
2027	8	32,953	-	5.571
2028	8	33,766	-	5.794
2029	8	34,586	-	6.020
2030	8	35,415	-	6.248

Table K8 - ARRM-1% Policy Scenario for Bahrain OB Facilities Utilities (2012-2030)

Year	Operation Growth = 1%					
	OB (En. Benchmark = 203 KWh/M2, W. Benchmark = 0.58 M3/M2)			OB (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Consumption (KWh)	Water Consumption (M3)	CO2e Emissions (Ton)	Energy Expenditure (BD)	Water Expenditure (BD)	Total Expenditures (BD)
2012	4,402,060	12,577	2,463	70,433	3,773	74,206
2013	4,544,160	12,983	2,542	72,707	3,895	76,601
2014	4,687,680	13,393	2,622	75,003	4,018	79,021
2015	4,832,630	13,808	2,704	77,322	4,142	81,464
2016	4,979,040	14,226	2,785	79,665	4,268	83,932
2017	5,126,910	14,648	2,868	82,031	4,394	86,425
2018	5,276,260	15,075	2,952	84,420	4,523	88,943
2019	5,427,100	15,506	3,036	86,834	4,652	91,485
2020	5,579,450	15,941	3,121	89,271	4,782	94,054
2021	5,733,320	16,381	3,207	91,733	4,914	96,647
2022	5,888,740	16,825	3,294	94,220	5,047	99,267
2023	6,045,700	17,273	3,382	96,731	5,182	101,913
2024	6,204,240	17,726	3,471	99,268	5,318	104,586
2025	6,364,360	18,184	3,560	101,830	5,455	107,285
2026	6,526,080	18,646	3,651	104,417	5,594	110,011
2027	6,689,420	19,113	3,742	107,031	5,734	112,765
2028	6,854,400	19,584	3,835	109,670	5,875	115,545
2029	7,021,020	20,060	3,928	112,336	6,018	118,354
2030	7,189,310	20,541	4,022	115,029	6,162	121,191

Appendix L: Technical progress (TP) Scenario Details

In this scenario, the effectiveness of implementation of energy efficiency technologies related to Air-Conditioning System & Lighting System, Renewable energy technology related to Domestic Hot Water System, Medical Waste energy recovery technology and some Water Conservation measures are investigated as illustrated in details in Tables L1 to L12.

Table L1 - TP-BAU Policy Scenario for Bahrain PHC Facilities Utilities Reduction (2012-2030)

Year	**PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)**				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW ER Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	12,274,000	11,391	1,166,510	7,430	196,383	3,417	18,664	218,464
2013	13,394,900	12,431	1,200,740	8,069	214,318	3,729	19,212	237,259
2014	14,549,500	13,503	1,236,000	8,727	232,792	4,051	19,776	256,619
2015	15,738,700	14,606	1,272,310	9,404	251,819	4,382	20,357	276,558
2016	16,963,600	15,743	1,309,720	10,102	271,417	4,723	20,956	297,095
2017	18,225,200	16,914	1,348,250	10,821	291,604	5,074	21,572	318,250
2018	19,524,700	18,120	1,387,930	11,562	312,396	5,436	22,207	340,039
2019	20,863,200	19,362	1,428,800	12,325	333,811	5,809	22,861	362,481
2020	22,241,800	20,642	1,470,900	13,110	355,869	6,192	23,535	385,596
2021	23,661,800	21,959	1,514,270	13,919	378,589	6,588	24,228	409,405
2022	25,124,400	23,317	1,558,930	14,753	401,990	6,995	24,943	433,928
2023	26,630,800	24,715	1,604,940	15,611	426,094	7,414	25,679	459,187
2024	28,182,500	26,155	1,652,320	16,495	450,920	7,846	26,437	485,204
2025	29,780,700	27,638	1,701,130	17,406	476,491	8,291	27,218	512,000
2026	31,426,900	29,166	1,751,400	18,344	502,830	8,750	28,022	539,602
2027	33,122,400	30,739	1,803,170	19,310	529,958	9,222	28,851	568,031
2028	34,868,800	32,360	1,856,510	20,306	557,901	9,708	29,704	597,313
2029	36,667,600	34,029	1,911,440	21,331	586,682	10,209	30,583	627,474
2030	38,520,400	35,749	1,968,020	22,387	616,326	10,725	31,488	658,539

Table L2 - TP-BAU Policy Scenario for Bahrain SHC Facilities Utilities Reduction (2012-2030)

Year	**SHC (En. Benchmark = 322 KWh/M2, W. Benchmark = 1.35 M3/M2)**				**SHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	52,892,000	115,854	4,500,370	32,562	846,272	34,756	89,864	970,892
2013	56,121,500	122,928	4,670,300	34,455	897,944	36,878	92,583	1,027,405
2014	59,447,900	130,214	4,845,320	36,405	951,167	39,064	95,383	1,085,614
2015	62,874,100	137,719	5,025,590	38,413	1,005,990	41,316	98,268	1,145,573
2016	66,403,100	145,449	5,211,270	40,482	1,062,450	43,635	101,238	1,207,323
2017	70,037,900	153,410	5,402,530	42,612	1,120,610	46,023	104,299	1,270,932
2018	73,781,800	161,611	5,599,520	44,807	1,180,510	48,483	107,450	1,336,443
2019	77,638,000	170,058	5,802,420	47,067	1,242,210	51,017	110,697	1,403,924
2020	81,609,900	178,758	6,011,400	49,396	1,305,760	53,627	114,040	1,473,427
2021	85,701,000	187,718	6,226,660	51,794	1,371,220	56,316	117,485	1,545,021
2022	89,914,800	196,948	6,448,370	54,264	1,438,640	59,085	121,032	1,618,757
2023	94,255,000	206,455	6,676,730	56,808	1,508,080	61,937	124,686	1,694,703
2024	98,725,400	216,247	6,911,950	59,428	1,579,610	64,874	128,449	1,772,933
2025	103,330,000	226,333	7,154,220	62,127	1,653,280	67,900	132,326	1,853,506
2026	108,073,000	236,721	7,403,760	64,907	1,729,160	71,016	136,318	1,936,494
2027	112,957,000	247,421	7,660,790	67,770	1,807,320	74,226	140,431	2,021,977
2028	117,989,000	258,442	7,925,530	70,720	1,887,820	77,533	144,667	2,110,020
2029	123,171,000	269,793	8,198,210	73,757	1,970,740	80,938	149,029	2,200,707
2030	128,509,000	281,485	8,479,070	76,886	2,056,150	84,446	153,523	2,294,119

Table L3 - TP-BAU Policy Scenario for Bahrain PHF Facilities Utilities Reduction (2012-2030)

Year	PHF (En. Benchmark = 206 KWh/M2, W. Benchmark = 1.25 M3/M2)			PHF (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Saving (KWh)	Water Saving (M3)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD)	Water Exp. Saving (BD)	Total Expenditures Saving (BD)
2012	741,152	734	410	11,858	220	12,079
2013	791,622	784	438	12,666	235	12,901
2014	844,111	836	467	13,506	251	13,757
2015	898,699	890	497	14,379	267	14,646
2016	955,471	947	529	15,288	284	15,571
2017	1,014,510	1,005	561	16,232	302	16,534
2018	1,075,920	1,066	595	17,215	320	17,534
2019	1,139,780	1,129	631	18,237	339	18,575
2020	1,206,190	1,195	667	19,299	358	19,658
2021	1,275,270	1,263	706	20,404	379	20,783
2022	1,347,100	1,335	745	21,554	400	21,954
2023	1,421,810	1,409	787	22,749	423	23,171
2024	1,499,500	1,486	830	23,992	446	24,438
2025	1,580,310	1,566	874	25,285	470	25,755
2026	1,664,340	1,649	921	26,630	495	27,124
2027	1,751,740	1,735	969	28,028	521	28,549
2028	1,842,640	1,825	1,019	29,482	548	30,030
2029	1,937,170	1,919	1,072	30,995	576	31,570
2030	2,035,480	2,017	1,126	32,568	605	33,173
Saving	61%	10%	61%			56%

Table L4 - TP-BAU Policy Scenario for Bahrain OB Facilities Utilities Reduction (2012-2030)

Year	OB (En. Benchmark = 203 KWh/M2, W. Benchmark = 0.58 M3/M2)			OB (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Saving (KWh)	Water Saving (M3)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD)	Water Exp. Saving (BD)	Total Exp. Saving (BD.)
2012	2,696,260	1,257	1,487	43,140	377	43,517
2013	2,957,370	1,379	1,631	47,318	414	47,731
2014	3,226,310	1,504	1,779	51,621	451	52,072
2015	3,503,320	1,633	1,932	56,053	490	56,543
2016	3,788,640	1,766	2,090	60,618	530	61,148
2017	4,082,520	1,903	2,252	65,320	571	65,891
2018	4,385,220	2,045	2,419	70,164	613	70,777
2019	4,696,990	2,190	2,591	75,152	657	75,809
2020	5,018,130	2,340	2,768	80,290	702	80,992
2021	5,348,890	2,494	2,950	85,582	748	86,330
2022	5,689,580	2,653	3,138	91,033	796	91,829
2023	6,040,490	2,817	3,332	96,648	845	97,493
2024	6,401,920	2,985	3,531	102,431	896	103,327
2025	6,774,200	3,159	3,736	108,387	948	109,335
2026	7,157,650	3,338	3,948	114,522	1,001	115,523
2027	7,552,600	3,522	4,166	120,842	1,057	121,899
2028	7,959,400	3,712	4,390	127,350	1,114	128,464
2029	8,378,400	3,907	4,621	134,054	1,172	135,226
2030	8,809,970	4,109	4,859	140,960	1,233	142,193
Saving	61%	10%	61%			59%

Table L5 - TP-ARRM-2% Policy Scenario for Bahrain PHC Facilities Utilities Reduction (2012-2030)

Year	Population Growth = 2%,							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	12,274,000	11,391	1,166,510	7,430	196,383	3,417	18,664	218,464
2013	13,021,300	12,085	1,189,330	7,856	208,340	3,625	19,029	230,995
2014	13,783,500	12,792	1,212,610	8,290	220,536	3,838	19,402	243,775
2015	14,561,000	13,513	1,236,350	8,733	232,976	4,054	19,782	256,812
2016	15,354,000	14,249	1,260,570	9,185	245,665	4,275	20,169	270,109
2017	16,162,900	15,000	1,285,270	9,646	258,607	4,500	20,564	283,671
2018	16,988,000	15,766	1,310,460	10,116	271,808	4,730	20,967	297,505
2019	17,829,600	16,547	1,336,160	10,596	285,274	4,964	21,379	311,617
2020	18,688,000	17,344	1,362,380	11,085	299,008	5,203	21,798	326,009
2021	19,563,600	18,156	1,389,120	11,584	313,017	5,447	22,226	340,690
2022	20,456,700	18,985	1,416,390	12,093	327,307	5,695	22,662	355,665
2023	21,367,600	19,830	1,444,210	12,612	341,882	5,949	23,107	370,938
2024	22,296,800	20,693	1,472,580	13,141	356,749	6,208	23,561	386,518
2025	23,244,600	21,572	1,501,530	13,682	371,913	6,472	24,024	402,409
2026	24,211,300	22,469	1,531,050	14,232	387,380	6,741	24,497	418,618
2027	25,197,300	23,384	1,561,160	14,794	403,157	7,015	24,979	435,151
2028	26,203,100	24,318	1,591,870	15,367	419,249	7,295	25,470	452,014
2029	27,229,000	25,270	1,623,200	15,952	435,664	7,581	25,971	469,216
2030	28,275,400	26,241	1,655,160	16,548	452,406	7,872	26,483	486,761

Table L6 - TP-ARRM-2% Policy Scenario for Bahrain SHC Facilities Utilities Reduction (2012-2030)

Year	Population Growth = 2%							
	SHC (En. Benchmark = 322 KWh/M2, W. Benchmark = 1.35 M3/M2)				SHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	52,892,000	115,854	5,616,500	32,562	846,272	34,756	89,864	970,892
2013	55,045,000	120,570	5,729,790	33,824	880,720	36,171	91,677	1,008,568
2014	57,241,100	125,380	5,845,340	35,111	915,857	37,614	93,525	1,046,997
2015	59,481,100	130,287	5,963,200	36,424	951,697	39,086	95,411	1,086,194
2016	61,765,900	135,291	6,083,410	37,764	988,254	40,587	97,335	1,126,176
2017	64,096,300	140,396	6,206,030	39,130	1,025,540	42,119	99,297	1,166,955
2018	66,473,400	145,603	6,331,110	40,523	1,063,580	43,681	101,298	1,208,559
2019	68,898,100	150,914	6,458,680	41,944	1,102,370	45,274	103,339	1,250,983
2020	71,371,200	156,331	6,588,810	43,394	1,141,940	46,899	105,421	1,294,260
2021	73,893,800	161,856	6,721,540	44,873	1,182,300	48,557	107,545	1,338,402
2022	76,466,900	167,492	6,856,920	46,381	1,223,470	50,248	109,711	1,383,429
2023	79,091,400	173,241	6,995,020	47,919	1,265,460	51,972	111,920	1,429,352
2024	81,768,400	179,105	7,135,870	49,488	1,308,290	53,731	114,174	1,476,195
2025	84,498,900	185,085	7,279,540	51,089	1,351,980	55,526	116,473	1,523,979
2026	87,284,000	191,186	7,426,080	52,721	1,396,540	57,356	118,817	1,572,713
2027	90,124,900	197,409	7,575,560	54,387	1,442,000	59,223	121,209	1,622,432
2028	93,022,600	203,756	7,728,020	56,085	1,488,360	61,127	123,648	1,673,135
2029	95,978,200	210,230	7,883,540	57,818	1,535,650	63,069	126,137	1,724,856
2030	98,992,900	216,833	8,042,160	59,585	1,583,890	65,050	128,675	1,777,615

Table L7 - TP-ARRM-2% Policy Scenario for Bahrain PH Facilities Utilities Reduction (2012-2030)

Year	Operation Growth = 2%					
	PHF (En. Benchmark = 206 KWh/M2, W. Benchmark = 1.25 M3/M2)			PHF (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Saving (KWh)	Water Saving (M3)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	741,152	734	410	11,858	220	12,079
2013	766,387	759	424	12,262	228	12,490
2014	792,127	785	438	12,674	235	12,909
2015	818,381	811	453	13,094	243	13,337
2016	845,161	837	468	13,523	251	13,774
2017	872,476	864	483	13,960	259	14,219
2018	900,337	892	498	14,405	268	14,673
2019	928,756	920	514	14,860	276	15,136
2020	957,743	949	530	15,324	285	15,609
2021	987,310	978	546	15,797	293	16,090
2022	1,017,470	1,008	563	16,280	302	16,582
2023	1,048,230	1,038	580	16,772	312	17,083
2024	1,079,610	1,070	597	17,274	321	17,595
2025	1,111,610	1,101	615	17,786	330	18,116
2026	1,144,250	1,134	633	18,308	340	18,648
2027	1,177,550	1,167	652	18,841	350	19,191
2028	1,211,510	1,200	670	19,384	360	19,744
2029	1,246,160	1,235	689	19,939	370	20,309
2030	1,281,490	1,270	709	20,504	381	20,885

Table L8 - TP-ARRM-2% Policy Scenario for Bahrain OB Facilities Utilities Reduction (2012-2030)

Year	Operation Growth = 2%					
	OB (En. Benchmark = 203 KWh/M2, W. Benchmark = 0.58 M3/M2)			OB (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Saving (KWh)	Water Saving (M3)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	2,696,260	1,257	1,487	43,140	377	43,517
2013	2,870,330	1,338	1,583	45,925	401	46,327
2014	3,047,890	1,421	1,681	48,766	426	49,192
2015	3,228,990	1,505	1,781	51,664	452	52,115
2016	3,413,720	1,591	1,883	54,620	477	55,097
2017	3,602,140	1,679	1,987	57,634	504	58,138
2018	3,794,330	1,769	2,093	60,709	531	61,240
2019	3,990,360	1,860	2,201	63,846	558	64,404
2020	4,190,320	1,954	2,311	67,045	586	67,631
2021	4,394,270	2,049	2,424	70,308	615	70,923
2022	4,602,300	2,146	2,538	73,637	644	74,281
2023	4,814,500	2,245	2,655	77,032	673	77,705
2024	5,030,930	2,346	2,775	80,495	704	81,199
2025	5,251,700	2,449	2,897	84,027	735	84,762
2026	5,476,880	2,554	3,021	87,630	766	88,396
2027	5,706,570	2,661	3,147	91,305	798	92,103
2028	5,940,840	2,770	3,277	95,054	831	95,885
2029	6,179,810	2,882	3,408	98,877	865	99,742
2030	6,423,550	2,995	3,543	102,777	899	103,676

Table L9 - TP-ARRM-1% Policy Scenario for Bahrain PHC Facilities Utilities Reduction (2012-2030)

Year	**Population Growth = 1%**							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	12,274,000	11,391	1,166,510	7,430	196,383	3,417	18,664	218,464
2013	12,647,600	11,738	1,177,920	7,643	202,362	3,521	18,847	224,730
2014	13,025,000	12,088	1,189,440	7,858	208,400	3,626	19,031	231,058
2015	13,406,200	12,442	1,201,080	8,075	214,498	3,733	19,217	237,448
2016	13,791,100	12,799	1,212,840	8,294	220,658	3,840	19,405	243,903
2017	14,179,900	13,160	1,224,710	8,516	226,879	3,948	19,595	250,422
2018	14,572,700	13,524	1,236,700	8,740	233,162	4,057	19,787	257,007
2019	14,969,300	13,892	1,248,820	8,966	239,509	4,168	19,981	263,658
2020	15,369,900	14,264	1,261,050	9,194	245,918	4,279	20,177	270,374
2021	15,774,500	14,640	1,273,410	9,425	252,392	4,392	20,375	277,158
2022	16,183,200	15,019	1,285,890	9,658	258,931	4,506	20,574	284,011
2023	16,595,900	15,402	1,298,490	9,893	265,534	4,621	20,776	290,930
2024	17,012,800	15,789	1,311,220	10,130	272,204	4,737	20,980	297,920
2025	17,433,800	16,180	1,324,080	10,370	278,941	4,854	21,185	304,980
2026	17,859,100	16,574	1,337,060	10,613	285,745	4,972	21,393	312,110
2027	18,288,600	16,973	1,350,180	10,857	292,617	5,092	21,603	319,312
2028	18,722,400	17,375	1,363,430	11,105	299,558	5,213	21,815	326,585
2029	19,160,500	17,782	1,376,810	11,354	306,568	5,335	22,029	333,931
2030	19,603,000	18,193	1,390,320	11,606	313,648	5,458	22,245	341,351

Table L10 - TP-ARRM-1% Policy Scenario for Bahrain SHC Facilities Environmental & Economic Impact Reduction (2012-2030)

Year	**Population Growth = 1%**							
	SHC (En. Benchmark = 322 KWh/M2, W. Benchmark = 1.35 M3/M2)				**SHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	52,892,000	115,854	5,616,500	32,562	846,272	34,756	89,864	970,892
2013	53,968,500	118,212	5,673,140	33,193	863,496	35,464	90,770	989,730
2014	55,055,800	120,594	5,730,350	33,830	880,892	36,178	91,686	1,008,756
2015	56,153,900	122,999	5,788,130	34,474	898,463	36,900	92,610	1,027,973
2016	57,263,000	125,428	5,846,490	35,124	916,209	37,629	93,544	1,047,381
2017	58,383,300	127,882	5,905,430	35,781	934,132	38,365	94,487	1,066,984
2018	59,514,700	130,360	5,964,960	36,444	952,235	39,108	95,439	1,086,783
2019	60,657,400	132,863	6,025,090	37,114	970,518	39,859	96,401	1,106,778
2020	61,811,600	135,391	6,085,820	37,790	988,985	40,617	97,373	1,126,976
2021	62,977,300	137,945	6,147,150	38,474	1,007,640	41,383	98,354	1,147,378
2022	64,154,600	140,524	6,209,100	39,164	1,026,470	42,157	99,346	1,167,973
2023	65,343,700	143,128	6,271,670	39,861	1,045,500	42,939	100,347	1,188,786
2024	66,544,800	145,759	6,334,860	40,565	1,064,720	43,728	101,358	1,209,806
2025	67,757,800	148,416	6,398,680	41,276	1,084,120	44,525	102,379	1,231,024
2026	68,983,000	151,100	6,463,150	41,994	1,103,730	45,330	103,410	1,252,470
2027	70,220,400	153,810	6,528,260	42,719	1,123,530	46,143	104,452	1,274,125
2028	71,470,200	156,547	6,594,020	43,452	1,143,520	46,964	105,504	1,295,988
2029	72,732,500	159,312	6,660,430	44,192	1,163,720	47,794	106,567	1,318,081
2030	74,007,400	162,105	6,727,510	44,939	1,184,120	48,632	107,640	1,340,392

Table L11 CP-ARRM-1% Policy Scenario for Bahrain PH Facilities Utilities Reduction (2012-2030)

Year	Operation Growth = 1%					
	PHF (En. Benchmark = 206 KWh/M2, W. Benchmark = 1.25 M3/M2)			PHF (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Saving (KWh)	Water Saving (M3)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	741,152	734	410	11,858	220	12,079
2013	753,769	747	417	12,060	224	12,284
2014	766,513	759	424	12,264	228	12,492
2015	779,384	772	431	12,470	232	12,702
2016	792,384	785	438	12,678	236	12,914
2017	805,514	798	446	12,888	239	13,128
2018	818,775	811	453	13,100	243	13,344
2019	832,169	824	460	13,315	247	13,562
2020	845,696	838	468	13,531	251	13,782
2021	859,359	851	475	13,750	255	14,005
2022	873,159	865	483	13,971	260	14,230
2023	887,096	879	491	14,194	264	14,457
2024	901,173	893	499	14,419	268	14,687
2025	915,391	907	506	14,646	272	14,918
2026	929,751	921	514	14,876	276	15,152
2027	944,254	935	522	15,108	281	15,389
2028	958,903	950	531	15,342	285	15,627
2029	973,698	965	539	15,579	289	15,869
2030	988,641	979	547	15,818	294	16,112

Table L12 - ARRM-1% Policy Scenario for Bahrain OB Facilities Utilities Reduction (2012-2030)

Year	Operation Growth = 1%					
	OB (En. Benchmark = 203 KWh/M2, W. Benchmark = 0.58 M3/M2)			OB (En= BD 0.016/KWh, W= BD 0.300/M3)		
	Energy Saving (KWh)	Water Saving (M3)	CO2e Em. Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	2,696,260	1,257	1,487	43,140	377	43,517
2013	2,783,300	1,297	1,535	44,533	389	44,922
2014	2,871,200	1,338	1,584	45,939	402	46,341
2015	2,959,990	1,380	1,633	47,360	414	47,774
2016	3,049,660	1,422	1,682	48,795	426	49,221
2017	3,140,230	1,464	1,732	50,244	439	50,683
2018	3,231,710	1,507	1,782	51,707	452	52,159
2019	3,324,100	1,550	1,833	53,186	465	53,650
2020	3,417,410	1,593	1,885	54,679	478	55,157
2021	3,511,660	1,637	1,937	56,187	491	56,678
2022	3,606,850	1,682	1,989	57,710	504	58,214
2023	3,702,990	1,726	2,042	59,248	518	59,766
2024	3,800,100	1,772	2,096	60,802	531	61,333
2025	3,898,170	1,817	2,150	62,371	545	62,916
2026	3,997,230	1,864	2,205	63,956	559	64,515
2027	4,097,270	1,910	2,260	65,556	573	66,129
2028	4,198,320	1,957	2,316	67,173	587	67,760
2029	4,300,380	2,005	2,372	68,806	602	69,408
2030	4,403,450	2,053	2,429	70,455	616	71,071

Appendix M: Time Management and Technical progress (TMTP) Scenario

In this scenario, the change in PHC facilities Utilities demand and its Environmental and Economic impacts are investigated as illustrated in Tables M1 to M6.

Table M1 - TMTP- BAU Policy Scenario for Bahrain PHC Facilities Utilities (2012-2030)

Year	Population Growth = 3%							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	Med. Waste Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	12,274,000	11,391	1,166,510	7,430	196,383	3,417	18,664	218,464
2013	13,731,200	12,743	1,211,010	8,260	219,699	3,823	19,376	242,898
2014	15,232,100	14,136	1,256,840	9,116	243,714	4,241	20,110	268,064
2015	16,778,100	15,571	1,304,050	9,997	268,450	4,671	20,865	293,986
2016	18,370,500	17,049	1,352,680	10,904	293,928	5,115	21,643	320,686
2017	20,010,600	18,571	1,402,770	11,839	320,170	5,571	22,444	348,186
2018	21,699,900	20,139	1,454,360	12,801	347,199	6,042	23,270	376,510
2019	23,440,000	21,753	1,507,490	13,793	375,039	6,526	24,120	405,685
2020	25,232,200	23,417	1,562,220	14,814	403,715	7,025	24,996	435,736
2021	27,078,200	25,130	1,618,600	15,866	433,250	7,539	25,898	466,686
2022	28,979,500	26,894	1,676,660	16,950	463,672	8,068	26,827	498,567
2023	30,937,900	28,712	1,736,460	18,066	495,007	8,614	27,783	531,404
2024	32,955,100	30,584	1,798,060	19,215	527,281	9,175	28,769	565,225
2025	35,032,700	32,512	1,861,510	20,399	560,524	9,754	29,784	600,062
2026	37,172,700	34,498	1,926,860	21,619	594,764	10,349	30,830	635,943
2027	39,376,900	36,544	1,994,170	22,875	630,031	10,963	31,907	672,901
2028	41,647,300	38,650	2,063,510	24,168	666,356	11,595	33,016	710,967
2029	43,985,700	40,821	2,134,920	25,501	703,771	12,246	34,159	750,176
2030	46,394,300	43,056	2,208,470	26,874	742,308	12,917	35,336	790,560

Table M2 - TMTP-BAU Policy Scenario for Bahrain PHC Facilities Utilities Reduction (2012-2030)

Year	Population Growth = 3%							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)			
	Energy Consumption (KWh)	Water Consumption (M3)	M. Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	20,039,100	63,281	378,736	11,556	320,626	18,984	79,535	419,145
2013	22,418,300	70,795	393,184	12,902	358,692	21,238	82,569	462,499
2014	24,868,800	78,533	408,066	14,288	397,901	23,560	85,694	507,155
2015	27,392,800	86,504	423,394	15,716	438,286	25,951	88,913	553,150
2016	29,992,600	94,714	439,182	17,186	479,882	28,414	92,228	600,524
2017	32,670,400	103,170	455,444	18,701	522,726	30,951	95,643	649,320
2018	35,428,500	111,879	472,194	20,261	566,856	33,564	99,161	699,581
2019	38,269,300	120,850	489,446	21,868	612,309	36,255	102,784	751,348
2020	41,195,400	130,091	507,215	23,523	659,126	39,027	106,515	804,668
2021	44,209,200	139,608	525,518	25,228	707,348	41,882	110,359	859,589
2022	47,313,500	149,411	544,370	26,984	757,016	44,823	114,318	916,157
2023	50,510,900	159,508	563,787	28,792	808,174	47,852	118,395	974,421
2024	53,804,200	169,908	583,787	30,655	860,867	50,972	122,595	1,034,434
2025	57,196,300	180,620	604,387	32,574	915,141	54,186	126,921	1,096,248
2026	60,690,200	191,653	625,605	34,550	971,043	57,496	131,377	1,159,916
2027	64,288,900	203,017	647,459	36,586	1,028,620	60,905	135,966	1,225,491
2028	67,995,500	214,723	669,969	38,682	1,087,930	64,417	140,694	1,293,041
2029	71,813,400	226,779	693,155	40,842	1,149,010	68,034	145,562	1,362,606
2030	75,745,700	239,197	717,035	43,066	1,211,930	71,759	150,577	1,434,266

Table M3 - TMTP-ARRM-2% Scenario for Bahrain PHC Facilities Utilities (2012-2030)

Year	**Population Growth = 2%**							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	20,039,100	63,281	378,736	11,556	320,626	18,984	79,535	419,145
2013	21,625,200	68,290	388,368	12,453	346,003	20,487	81,557	448,047
2014	23,243,000	73,399	398,193	13,368	371,889	22,020	83,621	477,529
2015	24,893,200	78,610	408,214	14,302	398,292	23,583	85,725	507,600
2016	26,576,400	83,926	418,436	15,254	425,223	25,178	87,872	538,272
2017	28,293,300	89,347	428,862	16,225	452,692	26,804	90,061	569,557
2018	30,044,500	94,877	439,497	17,215	480,711	28,463	92,294	601,469
2019	31,830,700	100,518	450,345	18,226	509,291	30,155	94,572	634,019
2020	33,652,600	106,271	461,409	19,256	538,442	31,881	96,896	667,219
2021	35,511,000	112,140	472,695	20,308	568,176	33,642	99,266	701,084
2022	37,406,500	118,126	484,206	21,380	598,504	35,438	101,683	735,625
2023	39,340,000	124,232	495,948	22,473	629,440	37,269	104,149	770,858
2024	41,312,100	130,459	507,924	23,589	660,994	39,138	106,664	806,796
2025	43,323,700	136,812	520,140	24,727	693,179	41,044	109,229	843,452
2026	45,375,500	143,291	532,601	25,887	726,007	42,987	111,846	880,840
2027	47,468,300	149,900	545,310	27,071	759,493	44,970	114,515	918,978
2028	49,603,000	156,641	558,274	28,279	793,648	46,992	117,237	957,877
2029	51,780,400	163,517	571,497	29,510	828,486	49,055	120,014	997,555
2030	54,001,300	170,530	584,984	30,767	864,021	51,159	122,847	1,038,027

Table M4 - TMTP-ARRM-2% Scenario for Bahrain PHC Facilities Utilities Reduction (2012-2030)

Year	**Population Growth = 2%**							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW ER Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	12,274,000	11,391	1,166,510	7,430	196,383	3,417	18,664	218,464
2013	13,245,400	12,293	1,196,170	7,983	211,927	3,688	19,139	234,754
2014	14,236,400	13,212	1,226,430	8,548	227,782	3,964	19,623	251,369
2015	15,247,100	14,150	1,257,300	9,124	243,954	4,245	20,117	268,316
2016	16,278,100	15,107	1,288,780	9,712	260,449	4,532	20,621	285,602
2017	17,329,600	16,083	1,320,900	10,311	277,274	4,825	21,134	303,233
2018	18,402,200	17,078	1,353,650	10,922	294,436	5,123	21,658	321,218
2019	19,496,300	18,094	1,387,060	11,546	311,941	5,428	22,193	339,562
2020	20,612,200	19,129	1,421,140	12,181	329,796	5,739	22,738	358,273
2021	21,750,500	20,186	1,455,900	12,830	348,008	6,056	23,294	377,358
2022	22,911,500	21,263	1,491,350	13,492	366,584	6,379	23,862	396,825
2023	24,095,700	22,362	1,527,520	14,167	385,532	6,709	24,440	416,681
2024	25,303,700	23,483	1,564,410	14,855	404,859	7,045	25,031	436,934
2025	26,535,700	24,626	1,602,030	15,557	424,572	7,388	25,633	457,592
2026	27,792,500	25,793	1,640,410	16,273	444,680	7,738	26,247	478,664
2027	29,074,300	26,982	1,679,550	17,004	465,189	8,095	26,873	500,157
2028	30,381,800	28,196	1,719,480	17,749	486,109	8,459	27,512	522,079
2029	31,715,500	29,433	1,760,210	18,509	507,448	8,830	28,163	544,441
2030	33,075,800	30,696	1,801,750	19,284	529,213	9,209	28,828	567,250

Table M5 - TMTP- ARRM-1% Scenario for Bahrain PHC Facilities Utilities (2012-2030)

Year	**Population Growth = 1%**							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Consumption (KWh)	Water Consumption (M3)	Medical Waste Generation (Kg)	CO2e Emissions (Ton)	Energy Expenditures (BD.)	Water Expenditures (BD.)	Med. Waste Expenditures (BD.)	Total Expenditures (BD.)
2012	20,039,100	63,281	378,736	11,556	320,626	18,984	79,535	419,145
2013	20,832,200	65,786	383,552	12,005	333,315	19,736	80,546	433,597
2014	21,633,100	68,315	388,416	12,458	346,130	20,495	81,567	448,192
2015	22,442,100	70,870	393,329	12,915	359,074	21,261	82,599	462,934
2016	23,259,200	73,450	398,291	13,378	372,148	22,035	83,641	477,824
2017	24,084,500	76,056	403,303	13,844	385,352	22,817	84,694	492,863
2018	24,918,000	78,688	408,365	14,316	398,688	23,607	85,757	508,051
2019	25,759,800	81,347	413,477	14,792	412,157	24,404	86,830	523,391
2020	26,610,100	84,032	418,641	15,273	425,761	25,210	87,915	538,885
2021	27,468,800	86,744	423,856	15,759	439,502	26,023	89,010	554,535
2022	28,336,200	89,483	429,123	16,249	453,379	26,845	90,116	570,340
2023	29,212,200	92,249	434,443	16,745	467,396	27,675	91,233	586,304
2024	30,097,000	95,043	439,816	17,245	481,552	28,513	92,361	602,426
2025	30,990,600	97,865	445,243	17,751	495,850	29,360	93,501	618,711
2026	31,893,200	100,715	450,724	18,261	510,291	30,215	94,652	635,158
2027	32,804,800	103,594	456,260	18,777	524,877	31,078	95,815	651,770
2028	33,725,500	106,502	461,852	19,298	539,608	31,951	96,989	668,547
2029	34,655,400	109,438	467,499	19,824	554,487	32,832	98,175	685,493
2030	35,594,600	112,404	473,203	20,355	569,514	33,721	99,373	702,608

Table M6 - TMTP- ARRM-1% Scenario for Bahrain PHC Facilities Utilities Reduction (2012-2030)

Year	**Population Growth = 1%**							
	PHC (En. Benchmark = 247 KWh/M2, W. Benchmark = 0.78 M3/M2)				**PHC (En= BD 0.016/KWh, W= BD 0.300/M3, MW In = BD 0.210/ Kg)**			
	Energy Saving (KWh)	Water Saving (M3)	MW Energy Recovery (KWh)	CO2e Emissions Reduction (Ton)	Energy Exp. Saving (BD.)	Water Exp. Saving (BD.)	MW ER Exp. Saving (BD.)	Total Exp. Saving (BD.)
2012	12,274,000	11,391	1,166,510	7,430	196,383	3,417	18,664	218,464
2013	12,759,700	11,842	1,181,340	7,707	204,155	3,553	18,901	226,609
2014	13,250,300	12,297	1,196,320	7,986	212,005	3,689	19,141	234,835
2015	13,745,800	12,757	1,211,450	8,269	219,933	3,827	19,383	243,143
2016	14,246,300	13,221	1,226,740	8,554	227,940	3,966	19,628	251,534
2017	14,751,700	13,691	1,242,170	8,842	236,028	4,107	19,875	260,010
2018	15,262,300	14,164	1,257,760	9,133	244,196	4,249	20,124	268,569
2019	15,777,900	14,643	1,273,510	9,427	252,446	4,393	20,376	277,215
2020	16,298,700	15,126	1,289,410	9,723	260,779	4,538	20,631	285,947
2021	16,824,700	15,614	1,305,480	10,023	269,195	4,684	20,888	294,767
2022	17,355,900	16,107	1,321,700	10,326	277,695	4,832	21,147	303,674
2023	17,892,500	16,605	1,338,080	10,632	286,280	4,982	21,409	312,671
2024	18,434,400	17,108	1,354,630	10,940	294,951	5,132	21,674	321,758
2025	18,981,800	17,616	1,371,350	11,252	303,708	5,285	21,942	330,934
2026	19,534,600	18,129	1,388,230	11,567	312,553	5,439	22,212	340,203
2027	20,092,900	18,647	1,405,280	11,886	321,487	5,594	22,485	349,566
2028	20,656,900	19,171	1,422,500	12,207	330,510	5,751	22,760	359,021
2029	21,226,400	19,699	1,439,900	12,531	339,623	5,910	23,038	368,571
2030	21,801,700	20,233	1,457,460	12,859	348,828	6,070	23,319	378,217

Appendix N: Results of Implementation of Policy Scenarios on Healthcare System in Kingdom of Bahrain

	PHC FACILITIES DEMAND			SHC FACILITIES DEMAND		
Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	BAU - 3%	ARRM - 2%	ARRM - 1%
2012	25			9		
2013	26			9		
2014	27			9		
2015	27			9		
2016	28	28	28	9	9	9
2017	29	29	28	10	9	9
2018	30	29	29	11	9	9
2019	31	30	29	11	10	9
2020	32	30	29	11	10	9
2021	33	31	29	12	10	9
2022	34	32	30	12	10	10
2023	35	32	30	12	10	10
2024	36	33	30	13	11	10
2025	37	33	31	13	11	10
2026	38	34	31	13	11	10
2027	39	35	31	14	11	10
2028	40	35	32	14	12	10
2029	41	36	32	14	12	10
2030	42	37	32	15	12	10

	PH FACILITIES DEMAND			OB FACILITIES DEMAND		
Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	BAU - 3%	ARRM - 2%	ARRM - 1%
2012	1			7		
2013	1			7		
2014	1			7		
2015	1			7		
2016	1	1	1	7	7	7
2017	1	1	1	8	7	7
2018	1	1	1	8	7	7
2019	1	1	1	8	7	7
2020	1	1	1	9	8	7
2021	1	1	1	9	8	7
2022	2	1	1	9	8	7
2023	2	1	1	10	8	8
2024	2	1	1	10	8	8
2025	2	1	1	10	8	8
2026	2	1	1	11	9	8
2027	2	1	1	11	9	8
2028	2	1	1	11	9	8
2029	2	1	1	12	9	8
2030	2	1	1	12	9	8

PHC FACILITIES OPERATING EXPENDITURES

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	GOV. FUND - 3% EG	GOV. FUND - 2% EG	GOV. FUND - 1% EG
2012	60.000			60.000		
2013	62.223			61.800		
2014	64.512			63.654		
2015	66.871			65.564		
2016	69.299	69.299	69.299	67.531	67.531	67.531
2017	71.801	70.967	70.133	69.556	68.882	68.206
2018	74.378	72.668	70.975	71.643	70.259	68.888
2019	77.032	74.403	71.826	73.792	71.664	69.577
2020	79.766	76.173	72.685	76.006	73.098	70.273
2021	82.582	77.979	73.553	78.286	74.560	70.976
2022	85.482	79.820	74.429	80.635	76.051	71.686
2023	88.469	81.698	75.315	83.054	77.572	72.402
2024	91.546	83.614	76.209	85.546	79.123	73.126
2025	94.716	85.568	77.112	88.112	80.706	73.858
2026	97.98	87.562	78.024	90.755	82.320	74.596
2027	101.342	89.595	78.945	93.478	83.966	75.342
2028	104.805	91.669	79.875	96.282	85.646	76.096
2029	108.372	93.784	80.815	99.171	87.359	76.857
2030	112.046	95.941	81.764	102.146	89.106	77.625

SHC FACILITIES OPERATING EXPENDITURES

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	GOV. FUND - 3% EG	GOV. FUND - 2% EG	GOV. FUND - 1% EG
2012	222.465			222.465		
2013	232.794			229.139		
2014	243.432			236.013		
2015	254.39			243.094		
2016	265.676	265.676	265.676	250.386	250.386	250.386
2017	277.301	273.426	269.551	257.898	255.394	252.890
2018	289.275	281.331	273.465	265.635	260.502	255.419
2019	301.608	289.394	277.418	273.604	265.712	257.973
2020	314.311	297.619	281.410	281.812	271.026	260.553
2021	327.395	306.007	285.442	290.266	276.446	263.158
2022	340.872	314.564	289.515	298.974	281.975	265.790
2023	354.753	323.292	293.629	307.944	287.615	268.448
2024	369.05	332.194	297.783	317.182	293.367	271.132
2025	383.777	341.275	301.979	326.697	299.234	273.843
2026	398.945	350.537	306.217	336.498	305.219	276.582
2027	414.568	359.984	310.498	346.593	311.324	279.348
2028	430.659	369.620	314.821	356.991	317.550	282.141
2029	447.234	379.449	319.187	367.701	323.901	284.963
2030	464.306	389.474	323.597	378.732	330.379	287.812

PH FACILITIES OPERATING EXPENDITURES

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	GOV. FUND - 3% EG	GOV. FUND - 2% EG	GOV. FUND - 1% EG
2012	2.144			2.144		
2013	2.244			2.208		
2014	2.348			2.274		
2015	2.456			2.343		
2016	2.568	2.568	2.568	2.413	2.413	2.413
2017	2.685	2.628	2.598	2.485	2.461	2.437
2018	2.807	2.689	2.628	2.560	2.510	2.462
2019	2.934	2.752	2.659	2.637	2.561	2.486
2020	3.065	2.815	2.690	2.716	2.612	2.511
2021	3.202	2.880	2.721	2.797	2.664	2.536
2022	3.344	2.946	2.753	2.881	2.717	2.561
2023	3.492	3.014	2.784	2.967	2.772	2.587
2024	3.646	3.083	2.817	3.056	2.827	2.613
2025	3.806	3.153	2.849	3.148	2.884	2.639
2026	3.973	3.225	2.882	3.243	2.941	2.665
2027	4.146	3.298	2.915	3.340	3.000	2.692
2028	4.326	3.373	2.948	3.440	3.060	2.719
2029	4.513	3.449	2.982	3.543	3.121	2.746
2030	4.708	3.526	3.016	3.650	3.184	2.774

OB FACILITIES OPERATING EXPENDITURES

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	GOV. FUND - 3% EG	GOV. FUND - 2% EG	GOV. FUND - 1% EG
2012	2.472			2.472		
2013	3.05			2.546		
2014	3.645			2.623		
2015	4.257			2.701		
2016	4.888	4.888	4.888	2.783	2.783	2.783
2017	5.538	5.273	5.081	2.866	2.839	2.811
2018	6.208	5.666	5.275	2.952	2.895	2.839
2019	6.897	6.066	5.471	3.041	2.953	2.867
2020	7.608	6.475	5.670	3.132	3.012	2.896
2021	8.339	6.892	5.870	3.226	3.073	2.925
2022	9.093	7.317	6.072	3.323	3.134	2.954
2023	9.869	7.750	6.277	3.422	3.197	2.984
2024	10.668	8.192	6.483	3.525	3.261	3.014
2025	11.492	8.644	6.691	3.631	3.326	3.044
2026	12.340	9.104	6.902	3.740	3.392	3.074
2027	13.213	9.573	7.115	3.852	3.460	3.105
2028	14.113	10.052	7.329	3.967	3.530	3.136
2029	15.040	10.540	7.546	4.086	3.600	3.167
2030	15.994	11.038	7.765	4.209	3.672	3.199

PHC MW GENERATION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TM- BAU	TM - ARRM - 2%	TM - ARRM - 1%
2012	378,736					
2013	389,850					
2014	401,298					
2015	413,089					
2016	425,233	425,233	425,233	425,233	425,233	425,233
2017	437,742	433,572	429,403	441,495	436,074	430,654
2018	450,627	442,078	433,614	458,244	447,132	436,128
2019	463,897	450,755	437,868	475,496	458,411	441,658
2020	477,566	459,604	442,164	493,266	469,916	447,243
2021	491,645	468,631	446,502	511,569	481,651	452,883
2022	506,147	477,839	450,885	530,420	493,620	458,580
2023	521,083	487,230	455,311	549,838	505,829	464,334
2024	536,468	496,809	459,781	569,838	518,282	470,146
2025	552,314	506,580	464,297	590,438	530,984	476,016
2026	568,635	516,546	468,857	611,655	543,940	481,944
2027	585,446	526,712	473,463	633,510	557,156	487,932
2028	602,762	537,081	478,115	656,020	570,635	493,979
2029	620,596	547,657	482,813	679,205	584,385	500,087
2030	638,966	558,445	487,559	703,086	598,409	506,257

SHC MW GENERATION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%
2012	1,823,540		
2013	1,878,710		
2014	1,935,540		
2015	1,994,070		
2016	2,054,220	2,054,220	2,054,220
2017	2,116,450	2,095,620	2,074,920
2018	2,180,400	2,137,840	2,095,820
2019	2,246,280	2,180,910	2,116,940
2020	2,314,130	2,224,840	2,138,260
2021	2,384,020	2,269,650	2,159,800
2022	2,456,010	2,315,350	2,181,560
2023	2,530,150	2,361,970	2,203,530
2024	2,606,520	2,409,520	2,225,720
2025	2,685,180	2,458,030	2,248,130
2026	2,766,200	2,507,500	2,270,770
2027	2,849,650	2,557,960	2,293,630
2028	2,935,600	2,609,430	2,316,730
2029	3,024,130	2,661,930	2,340,050
2030	3,115,320	2,715,480	2,363,600

PHC ENERGY CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	20,039,100					
2013	21,869,200					
2014	23,754,300					
2015	25,695,800					
2016	27,695,700	27,695,600	27,695,600.0	27,695,700	27,695,700	27,695,700
2017	29,755,500	29,068,800	28,382,200	10,212,350	9,962,720	9,709,560
2018	31,877,100	30,469,500	29,075,700	10,994,770	10,479,320	9,965,290
2019	34,062,300	31,898,200	29,776,100	11,800,600	11,006,290	10,223,590
2020	36,313,200	33,355,500	30,483,500	12,630,790	11,543,740	10,484,450
2021	38,631,500	34,841,900	31,198,000	13,485,730	12,091,930	10,747,990
2022	41,019,400	36,358,000	31,919,600	14,366,370	12,650,980	11,014,090
2023	43,478,900	37,904,500	32,648,500	15,273,460	13,221,350	11,282,960
2024	46,012,300	39,481,800	33,384,600	16,207,780	13,803,050	11,554,390
2025	48,621,600	41,090,800	34,128,100	17,170,070	14,396,450	11,828,580
2026	51,309,200	42,731,900	34,879,000	18,161,200	15,001,660	12,105,540
2027	54,077,400	44,405,800	35,637,500	19,182,120	15,618,950	12,385,350
2028	56,928,700	46,113,300	36,403,500	20,233,690	16,248,710	12,667,820
2029	59,865,500	47,854,800	37,177,200	21,316,760	16,890,930	12,953,150
2030	62,890,400	49,631,200	37,958,600	22,432,280	17,546,110	13,241,340

PHC ENERGY CONSUMPTION

Time (Year)	TM – BAU	TM - ARRM - 2%	TM - ARRM - 1%	TMTP – BAU	TMTP - ARRM-2%	TMTP - ARRM-1%
2012						
2013						
2014						
2015						
2016	27,695,700	27,695,700	27,695,700	27,695,700	27,695,700	27,695,700
2017	30,373,400	29,480,800	28,588,200	10,443,910	10,114,710	9,785,510
2018	33,131,500	31,301,700	29,489,700	11,461,130	10,786,250	10,117,940
2019	35,972,300	33,159,000	30,400,200	12,508,790	11,471,210	10,453,710
2020	38,898,400	35,053,400	31,319,900	13,587,860	12,169,880	10,793,010
2021	41,912,200	36,985,700	32,248,700	14,699,390	12,882,430	11,135,540
2022	45,016,500	38,956,700	33,186,800	15,844,220	13,609,370	11,481,490
2023	48,213,900	40,967,100	34,134,300	17,023,420	14,350,760	11,830,870
2024	51,507,200	43,017,700	35,091,300	18,238,020	15,107,010	12,183,870
2025	54,899,300	45,109,300	36,057,800	19,488,970	15,878,390	12,540,290
2026	58,393,200	47,242,800	37,034,100	20,777,520	16,665,280	12,900,330
2027	61,991,800	49,418,900	38,020,000	22,104,610	17,467,780	13,263,890
2028	65,698,500	51,638,500	39,015,900	23,471,680	18,286,360	13,631,260
2029	69,516,300	53,902,600	40,021,600	24,879,570	19,121,410	14,002,050
2030	73,448,700	56,211,900	41,037,500	26,329,910	19,973,020	14,376,750

SHC ENERGY CONSUMOTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	86,354,300					
2013	91,627,000					
2014	97,057,800					
2015	102,652,000					
2016	108,413,000	108,413,000	108,413,000	108,413,000	108,413,000	108,413,000
2017	114,348,000	112,370,000	110,391,000	37,937,330	37,253,540	36,549,890
2018	120,460,000	116,405,000	112,389,000	40,108,440	38,686,790	37,259,800
2019	126,756,000	120,521,000	114,407,000	42,345,340	40,148,940	37,976,770
2020	133,241,000	124,720,000	116,445,000	44,649,450	41,641,130	38,700,790
2021	139,920,000	129,002,000	118,504,000	47,022,100	43,162,120	39,432,650
2022	146,800,000	133,370,000	120,583,000	49,466,580	44,713,950	40,171,150
2023	153,886,000	137,825,000	122,683,000	51,984,020	46,296,360	40,917,370
2024	161,184,000	142,370,000	124,803,000	54,576,400	47,911,400	41,670,020
2025	168,702,000	147,005,000	126,946,000	57,247,530	49,557,810	42,431,990
2026	176,445,000	151,734,000	129,109,000	59,997,990	51,238,440	43,200,070
2027	184,420,000	156,556,000	131,294,000	62,831,960	52,951,120	43,976,350
2028	192,635,000	161,475,000	133,501,000	65,750,230	54,698,580	44,760,420
2029	201,096,000	166,493,000	135,730,000	68,756,550	56,481,580	45,552,290
2030	209,811,000	171,611,000	137,981,000	71,852,690	58,299,640	46,351,830

PHF ENERGY CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	1,210,040					
2013	1,292,440					
2014	1,378,140					
2015	1,467,260					
2016	1,559,950	1,559,950	1,559,950	1,559,950	1,559,950	1,559,950
2017	1,656,350	1,601,240	1,580,640	641,840	620,482	612,499
2018	1,756,600	1,643,260	1,601,440	680,680	636,760	620,556
2019	1,860,860	1,686,130	1,622,460	721,080	653,380	628,704
2020	1,969,300	1,729,850	1,643,680	763,110	670,320	636,920
2021	2,082,070	1,774,440	1,665,120	806,800	687,590	645,230
2022	2,199,350	1,819,930	1,686,770	852,250	705,220	653,620
2023	2,321,320	1,866,330	1,708,640	899,510	723,200	662,100
2024	2,448,170	1,913,660	1,730,720	948,670	741,550	670,650
2025	2,580,100	1,961,930	1,753,030	999,790	760,250	679,300
2026	2,717,300	2,011,170	1,775,560	1,052,960	779,330	688,030
2027	2,859,990	2,061,390	1,798,310	1,108,250	798,790	696,840
2028	3,008,390	2,112,620	1,821,300	1,165,750	818,640	705,760
2029	3,162,720	2,164,870	1,844,510	1,225,550	838,890	714,750
2030	3,323,230	2,218,160	1,867,960	1,287,750	859,530	723,840

OB ENERGY CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	4,402,060					
2013	4,828,360					
2014	5,267,440					
2015	5,719,710					
2016	6,185,540	6,185,540	6,185,540	6,185,540	6,185,540	6,185,540
2017	6,665,340	6,469,810	6,327,710	2,582,820	2,507,050	2,451,990
2018	7,159,540	6,759,700	6,471,230	2,774,320	2,619,390	2,507,600
2019	7,668,560	7,055,380	6,616,190	2,971,570	2,733,960	2,563,770
2020	8,192,860	7,356,970	6,762,600	3,174,730	2,850,820	2,620,510
2021	8,732,880	7,664,600	6,910,470	3,383,990	2,970,030	2,677,810
2022	9,289,110	7,978,380	7,059,810	3,599,530	3,091,620	2,735,670
2023	9,862,020	8,298,440	7,210,660	3,821,530	3,215,650	2,794,130
2024	10,452,100	8,624,890	7,363,010	4,050,180	3,342,140	2,853,170
2025	11,059,900	8,957,880	7,516,880	4,285,700	3,471,180	2,912,790
2026	11,686,000	9,297,520	7,672,290	4,528,350	3,602,790	2,973,010
2027	12,330,800	9,643,960	7,829,260	4,778,200	3,737,030	3,033,840
2028	12,994,900	9,997,330	7,987,800	5,035,500	3,873,970	3,095,270
2029	13,679,000	10,357,800	8,147,920	5,300,600	4,013,670	3,157,320
2030	14,383,600	10,725,400	8,309,640	5,573,630	4,156,090	3,219,980

PHC WATER CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	63,281					
2013	69,061					
2014	75,013					
2015	81,145					
2016	87,460	87,460	87,460	87,460	87,460	87,460
2017	93,965	91,796	89,628	77,051	75,273	73,495
2018	100,664	96,220	91,818	82,544	78,900	75,291
2019	107,565	100,731	94,030	88,203	82,599	77,104
2020	114,673	105,333	96,264	94,032	86,373	78,936
2021	121,994	110,027	98,520	100,035	90,222	80,786
2022	129,535	114,815	100,799	106,218	94,148	82,655
2023	137,302	119,698	103,100	112,587	98,152	84,542
2024	145,302	124,680	105,425	119,147	102,238	86,449
2025	153,542	129,760	107,773	125,904	106,403	88,374
2026	162,029	134,943	110,144	132,863	110,653	90,318
2027	170,771	140,229	112,539	140,032	114,988	92,282
2028	179,775	145,621	114,958	147,415	119,409	94,266
2029	189,049	151,120	117,402	155,020	123,918	96,270
2030	198,601	156,730	119,869	162,852	128,519	98,293

PHC WATER CONSUMPTION

Time (Year)	TM – BAU	TM - ARRM - 2%	TM - ARRM - 1%	TMTP – BAU	TMTP - ARRM-2%	TMTP - ARRM-1%
2012						
2013						
2014						
2015						
2016	87,460	87,460	87,460	87,460	87,460	87,460
2017	95,916	93,097	90,279	78,651	76,340	74,028
2018	104,626	98,847	93,125	85,793	81,055	76,363
2019	113,597	104,713	96,001	93,150	85,865	78,721
2020	122,837	110,695	98,905	100,726	90,770	81,102
2021	132,354	116,797	101,838	108,530	95,774	83,507
2022	142,157	123,021	104,800	116,569	100,877	85,936
2023	152,254	129,370	107,793	124,848	106,083	88,390
2024	162,654	135,845	110,815	133,376	111,393	90,868
2025	173,366	142,450	113,867	142,160	116,809	93,371
2026	184,399	149,188	116,950	151,207	122,334	95,899
2027	195,764	156,060	120,063	160,527	127,969	98,452
2028	207,469	163,069	123,208	170,125	133,717	101,031
2029	219,525	170,219	126,384	180,010	139,580	103,635
2030	231,943	177,511	129,592	190,193	145,559	106,265

SHC WATER CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	362,044					
2013	384,150					
2014	406,919					
2015	430,372					
2016	454,527	454,527	454,527	454,527	454,527	454,527
2017	479,408	471,114	462,821	325,998	320,357	314,718
2018	505,035	488,033	471,197	343,424	331,862	320,414
2019	531,430	505,290	479,658	361,372	343,597	326,168
2020	558,618	522,892	488,202	379,860	355,566	331,977
2021	586,621	540,847	496,833	398,902	367,776	337,847
2022	615,464	559,160	505,549	418,515	380,229	343,773
2023	645,173	577,840	514,353	438,718	392,931	349,760
2024	675,772	596,893	523,244	459,525	405,887	355,806
2025	707,290	616,327	532,225	480,957	419,102	361,913
2026	739,754	636,150	541,296	503,033	432,582	368,081
2027	773,191	656,369	550,457	525,770	446,331	374,311
2028	807,631	676,993	559,709	549,189	460,355	380,602
2029	843,105	698,029	569,055	573,311	474,660	386,957
2030	879,642	719,486	578,494	598,156	489,250	393,376

PHF WATER CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	7,343					
2013	7,843					
2014	8,363					
2015	8,903					
2016	9,466	9,466	9,466	9,466	9,466	9,466
2017	10,051	9,716	9,591	9,046	8,745	8,632
2018	10,659	9,971	9,718	9,593	8,974	8,746
2019	11,292	10,231	9,845	10,162	9,208	8,861
2020	11,950	10,497	9,974	10,755	9,447	8,976
2021	12,634	10,767	10,104	11,371	9,691	9,094
2022	13,346	11,043	10,235	12,011	9,939	9,212
2023	14,086	11,325	10,368	12,677	10,192	9,331
2024	14,855	11,612	10,502	13,370	10,451	9,452
2025	15,656	11,905	10,637	14,090	10,714	9,574
2026	16,489	12,204	10,774	14,840	10,983	9,697
2027	17,354	12,508	10,912	15,619	11,258	9,821
2028	18,255	12,819	11,052	16,429	11,537	9,946
2029	19,191	13,136	11,192	17,272	11,823	10,073
2030	20,165	13,460	11,335	18,149	12,114	10,201

OB WATER CONSUMPTION

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	12,577					
2013	13,795					
2014	15,050					
2015	16,342					
2016	17,673	17,673	17,673	17,673	17,673	17,673
2017	19,044	18,485	18,079	17,141	16,637	16,271
2018	20,456	19,313	18,489	18,411	17,382	16,640
2019	21,910	20,158	18,903	19,720	18,142	17,013
2020	23,408	21,020	19,322	21,068	18,918	17,390
2021	24,951	21,899	19,744	22,457	19,709	17,770
2022	26,540	22,795	20,171	23,887	20,516	18,154
2023	28,177	23,710	20,602	25,360	21,339	18,542
2024	29,863	24,643	21,037	26,878	22,178	18,933
2025	31,600	25,594	21,477	28,441	23,035	19,329
2026	33,388	26,564	21,921	30,050	23,908	19,729
2027	35,231	27,554	22,369	31,709	24,799	20,132
2028	37,128	28,564	22,822	33,416	25,707	20,540
2029	39,083	29,594	23,280	35,176	26,634	20,952
2030	41,096	30,644	23,742	36,987	27,580	21,368

PHC CO2e EMISSIONS

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	11,446					
2013	12,481					
2014	13,547					
2015	14,645					
2016	15,887	15,887	15,887	15,887	15,887	15,887
2017	17,052	16,664	16,275	6,247	6,101	5,952
2018	18,252	17,456	16,668	6,707	6,404	6,102
2019	19,488	18,264	17,064	7,180	6,714	6,254
2020	20,761	19,088	17,464	7,668	7,029	6,407
2021	22,073	19,929	17,868	8,170	7,351	6,562
2022	23,423	20,787	18,276	8,687	7,680	6,718
2023	24,815	21,661	18,688	9,220	8,015	6,876
2024	26,248	22,554	19,105	9,769	8,356	7,036
2025	27,724	23,464	19,525	10,334	8,705	7,197
2026	29,244	24,392	19,950	10,916	9,060	7,359
2027	30,810	25,339	20,379	11,516	9,423	7,524
2028	32,422	26,305	20,812	12,133	9,793	7,690
2029	34,084	27,290	21,250	12,769	10,170	7,857
2030	35,795	28,295	21,692	13,425	10,555	8,026

PHC CO2e EMISSIONS

Time (Year)	TM - BAU	TM - ARRM - 2%	TM - ARRM - 1%	TMTP - BAU	TMTP - ARRM-2%	TMTP - ARRM-1%
2012						
2013						
2014						
2015						
2016	15,887	15,887	15,887	15,887	15,887	15,887
2017	17,402	16,897	16,392	6,383	6,190	5,997
2018	18,962	17,927	16,902	6,981	6,584	6,192
2019	20,569	18,977	17,417	7,596	6,987	6,389
2020	22,224	20,049	17,937	8,230	7,397	6,588
2021	23,928	21,142	18,462	8,883	7,816	6,790
2022	25,684	22,257	18,993	9,555	8,243	6,993
2023	27,493	23,394	19,529	10,248	8,678	7,198
2024	29,356	24,554	20,070	10,961	9,122	7,405
2025	31,274	25,737	20,617	11,696	9,575	7,615
2026	33,251	26,944	21,169	12,453	10,037	7,826
2027	35,286	28,175	21,727	13,232	10,509	8,040
2028	37,383	29,430	22,290	14,035	10,990	8,255
2029	39,543	30,711	22,859	14,862	11,480	8,473
2030	41,767	32,017	23,434	15,714	11,980	8,693

SHC CO2e EMISSIONS

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	49,946					
2013	52,967					
2014	56,078					
2015	59,282					
2016	62,894	62,894	62,894	62,894	62,894	62,894
2017	66,293	65,160	64,027	23,761	23,349	22,926
2018	69,795	67,472	65,171	25,068	24,211	23,353
2019	73,401	69,830	66,327	26,414	25,091	23,784
2020	77,116	72,235	67,495	27,801	25,989	24,220
2021	80,942	74,688	68,674	29,229	26,905	24,660
2022	84,883	77,190	69,865	30,700	27,839	25,105
2023	88,942	79,742	71,068	32,215	28,791	25,554
2024	93,123	82,345	72,283	33,775	29,763	26,007
2025	97,429	85,001	73,510	35,383	30,754	26,465
2026	101,865	87,709	74,749	37,038	31,765	26,928
2027	106,433	90,472	76,001	38,743	32,796	27,395
2028	111,139	93,290	77,265	40,499	33,848	27,867
2029	115,986	96,164	78,542	42,309	34,921	28,343
2030	120,978	99,096	79,832	44,172	36,015	28,825

PHF CO2e EMISSIONS

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	690					
2013	737					
2014	786					
2015	836					
2016	889	889	889	889	889	889
2017	944	913	901	383	370	365
2018	1,001	937	913	406	380	370
2019	1,061	961	925	430	390	375
2020	1,123	986	937	455	400	380
2021	1,187	1,011	949	481	410	385
2022	1,254	1,037	961	508	421	390
2023	1,323	1,064	974	537	431	395
2024	1,396	1,091	987	566	442	400
2025	1,471	1,118	999	596	453	405
2026	1,549	1,146	1,012	628	465	410
2027	1,630	1,175	1,025	661	476	416
2028	1,715	1,204	1,038	695	488	421
2029	1,803	1,234	1,051	731	500	426
2030	1,894	1,264	1,065	768	513	432

OB CO2e EMISSIONS

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	2,463					
2013	2,701					
2014	2,947					
2015	3,200					
2016	3,460	3,460	3,460	3,460	3,460	3,460
2017	3,729	3,619	3,540	1,477	1,434	1,402
2018	4,005	3,782	3,620	1,587	1,498	1,434
2019	4,290	3,947	3,701	1,699	1,564	1,466
2020	4,583	4,116	3,783	1,816	1,630	1,499
2021	4,885	4,288	3,866	1,935	1,699	1,531
2022	5,197	4,463	3,949	2,059	1,768	1,565
2023	5,517	4,642	4,034	2,186	1,839	1,598
2024	5,847	4,825	4,119	2,316	1,911	1,632
2025	6,187	5,011	4,205	2,451	1,985	1,666
2026	6,537	5,201	4,292	2,590	2,060	1,700
2027	6,898	5,395	4,380	2,733	2,137	1,735
2028	7,270	5,593	4,469	2,880	2,216	1,770
2029	7,652	5,794	4,558	3,031	2,295	1,806
2030	8,047	6,000	4,649	3,188	2,377	1,842

PHC UTILITIES EXPENDITURES

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	419,145					
2013	452,495					
2014	486,845					
2015	522,225					
2016	558,668	558,668	558,668	558,668	558,668	558,668
2017	596,203	583,690	571,179	278,438	273,036	267,576
2018	634,864	609,214	583,815	295,310	284,176	273,091
2019	674,686	635,249	596,579	312,690	295,538	278,662
2020	715,702	661,804	609,470	330,591	307,127	284,288
2021	757,948	688,891	622,490	349,028	318,949	289,970
2022	801,463	716,518	635,639	368,020	331,007	295,709
2023	846,281	744,699	648,921	387,578	343,304	301,506
2024	892,445	773,444	662,336	407,726	355,851	307,360
2025	939,994	802,763	675,884	428,478	368,646	313,273
2026	988,969	832,668	689,567	449,852	381,697	319,244
2027	1,039,413	863,172	703,389	471,868	395,010	325,277
2028	1,091,371	894,285	717,348	494,543	408,589	331,369
2029	1,144,888	926,021	731,447	517,899	422,439	337,522
2030	1,200,013	958,391	745,686	541,959	436,566	343,736

PHC UTILITIES EXPENDITURES

Time (Year)	TM - BAU	TM - ARRM - 2%	TM - ARRM - 1%	TMTP - BAU	TMTP - ARRM- 2%	TMTP - ARRM-1%
2012						
2013						
2014						
2015						
2016	558,668	558,668	558,668	558,668	558,668	558,668
2017	607,463	591,198	574,932	283,412	276,313	269,214
2018	657,723	624,379	591,361	305,347	290,795	276,385
2019	709,490	658,223	607,952	327,939	305,565	283,626
2020	762,811	692,745	624,711	351,210	320,631	290,939
2021	817,731	727,958	641,636	375,178	336,000	298,326
2022	874,299	763,873	658,731	399,866	351,673	305,786
2023	932,564	800,509	675,997	425,295	367,662	313,322
2024	992,577	837,877	693,436	451,487	383,970	320,933
2025	1,054,391	875,991	711,049	478,464	400,605	328,620
2026	1,118,058	914,868	728,838	506,249	417,572	336,383
2027	1,183,636	954,523	746,805	534,870	434,878	344,225
2028	1,251,185	994,971	764,952	564,352	452,530	352,145
2029	1,320,751	1,036,228	783,279	594,709	470,537	360,142
2030	1,392,411	1,078,309	801,792	625,984	488,902	368,222

SHC UTILITIES EXPENDITURES

Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM- 2%	TP & ARRM- 1%
2012	1,873,226					
2013	1,975,804					
2014	2,081,468					
2015	2,190,295					
2016	2,302,382	2,302,382	2,302,382	2,302,382	2,302,382	2,302,382
2017	2,417,836	2,379,323	2,340,839	1,149,239	1,132,233	1,114,946
2018	2,536,755	2,457,837	2,379,712	1,202,646	1,167,493	1,132,404
2019	2,659,248	2,537,918	2,418,974	1,257,658	1,203,454	1,150,044
2020	2,785,403	2,619,594	2,458,616	1,314,310	1,240,135	1,167,845
2021	2,915,351	2,702,910	2,498,668	1,372,665	1,277,550	1,185,826
2022	3,049,190	2,787,892	2,539,112	1,432,767	1,315,712	1,203,991
2023	3,187,054	2,874,576	2,579,967	1,494,685	1,354,644	1,222,339
2024	3,329,051	2,962,988	2,621,234	1,558,452	1,394,344	1,240,879
2025	3,475,305	3,053,174	2,662,906	1,624,133	1,434,855	1,259,583
2026	3,625,948	3,145,160	2,704,991	1,691,788	1,476,160	1,278,483
2027	3,781,113	3,238,983	2,747,510	1,761,470	1,518,295	1,297,585
2028	3,940,926	3,334,689	2,790,445	1,833,241	1,561,275	1,316,864
2029	4,105,539	3,432,305	2,833,806	1,907,166	1,605,113	1,336,329
2030	4,275,091	3,531,868	2,877,605	1,983,306	1,649,817	1,356,001

PHF UTILITIES EXPENDITURES

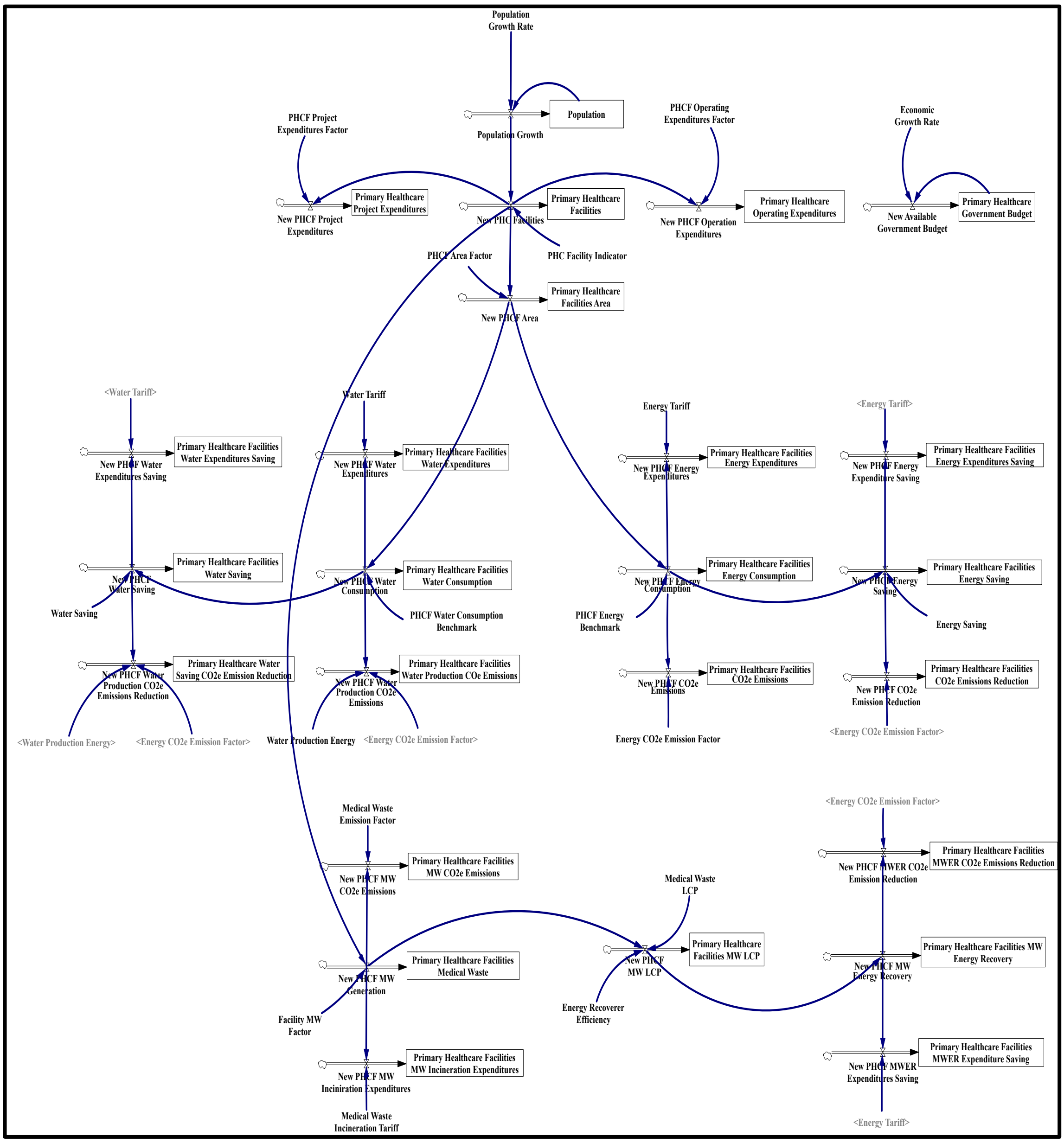
Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	21,563					
2013	23,032					
2014	24,559					
2015	26,147					
2016	27,799	27,799	27,799	27,799	27,799	27,799
2017	29,517	28,535	28,168	12,983	12,551	12,390
2018	31,303	29,284	28,538	13,769	12,880	12,553
2019	33,161	30,047	28,913	14,586	13,216	12,717
2020	35,094	30,827	29,291	15,436	13,559	12,884
2021	37,103	31,621	29,673	16,320	13,909	13,052
2022	39,193	32,432	30,059	17,239	14,265	13,222
2023	41,367	33,259	30,449	18,195	14,629	13,393
2024	43,627	34,102	30,842	19,190	15,000	13,566
2025	45,978	34,962	31,240	20,224	15,378	13,741
2026	48,423	35,840	31,641	21,299	15,764	13,917
2027	50,966	36,735	32,047	22,418	16,158	14,096
2028	53,611	37,648	32,456	23,581	16,560	14,276
2029	56,361	38,579	32,870	24,791	16,969	14,458
2030	59,221	39,529	33,288	26,049	17,387	14,642

OB UTILITIES EXPENDITURES

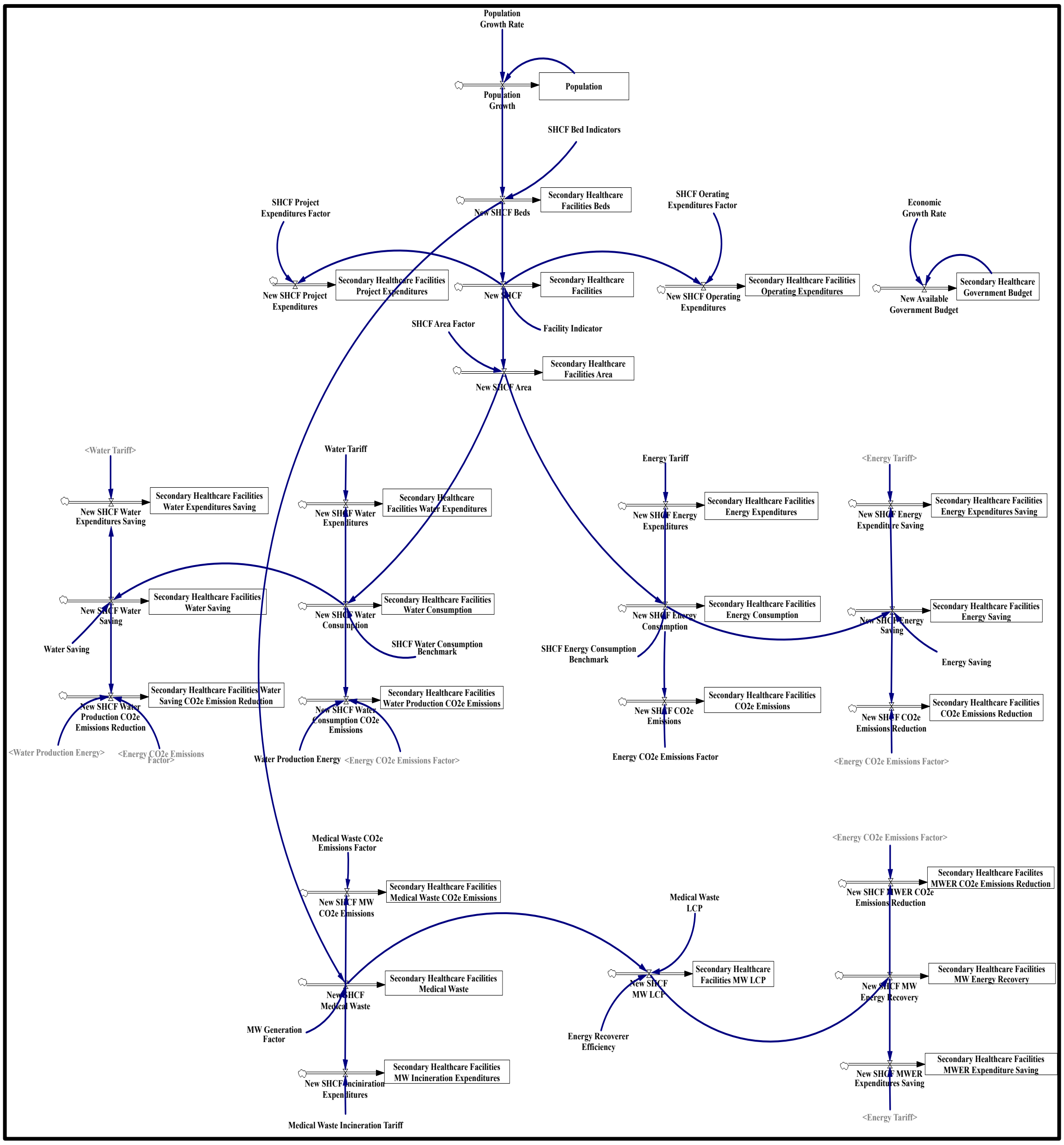
Time (Year)	BAU - 3%	ARRM - 2%	ARRM - 1%	TP & BAU	TP & ARRM-2%	TP & ARRM-1%
2012	74,206					
2013	81,392					
2014	88,794					
2015	96,418					
2016	104,270	104,270	104,270	104,270	104,270	104,270
2017	112,358	109,063	106,667	46,467	45,104	44,113
2018	120,690	113,949	109,087	49,913	47,125	45,114
2019	129,270	118,933	111,530	53,461	49,186	46,124
2020	138,108	124,018	113,999	57,116	51,289	47,145
2021	147,211	129,204	116,490	60,881	53,434	48,175
2022	156,588	134,493	119,008	64,759	55,621	49,217
2023	166,245	139,888	121,551	68,752	57,852	50,268
2024	176,193	145,391	124,119	72,866	60,128	51,331
2025	186,439	151,004	126,713	77,104	62,449	52,403
2026	196,992	156,729	129,333	81,469	64,817	53,487
2027	207,861	162,569	131,979	85,962	67,232	54,581
2028	219,058	168,526	134,652	90,594	69,695	55,687
2029	230,589	174,602	137,351	95,363	72,208	56,803
2030	242,467	180,799	140,077	100,274	74,771	57,930

Appendix O: Full Vensim Models

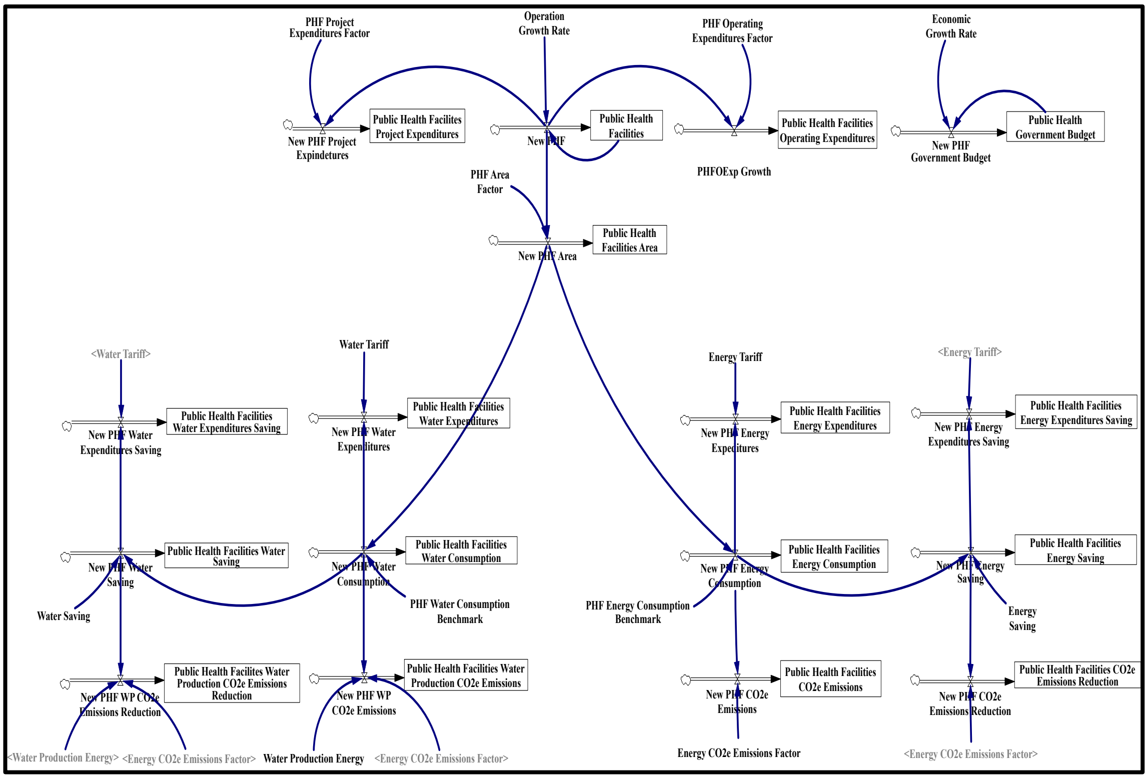
O1- Primary Healthcare Facilities Model:



O2- Secondary Healthcare Facilities Model:



O3- Public Health Facilities Model:



O4- Office Buildings Model: