The Development of a Measurement System for Water-Energy-Food (WEF) Security Nexus in Malaysia: Wellbeing, Sectoral Balance and Sustainable Development

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Thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy

June 2018

Abstract

It is undeniable that activities and events within the water, energy, and food (WEF) security nexus are inextricably linked and their relationships numerous and substantial. Complexity increases when factors governing the daily lives of humanity namely social, technology advancement, environment, economic, and policies (STEEP) adds upon the difficulty in addressing the relationships. It is thus paramount to address the problems from a holistic and systematic approach to maximise benefits as well as to minimize the negative impacts upon one another. However, there exists little to zero means of measuring their performance, whether qualitatively or quantitatively, within the context of a nexus. Moreover, minimal understanding exists regarding the relationships between the WEF securities in Malaysia, an emerging economy rich in natural resources, which envisions to be a developed nation.

This research sought to establish a measurement system for the WEF security nexus in Malaysia within the context of resource security wellbeing, sectoral balance, and sustainable development using a System Dynamics (SD) approach. This entailed an extensive literature review and qualitative interview with key stakeholders from the industrial sectors. The front end of the SD process is concerned with obtaining important and relevant information from literature and interviews, which are then used to construct causal loop diagrams (CLD). The back end of the SD is concerned with converting the CLDs into a stock and flow diagram (SFD), which provides a platform for quantitative simulation of different well-designed scenarios.

Key findings from this research can be highlighted; these include: renewables are necessary for the long-term energy plan of Malaysia, nuclear power is necessary to keep electricity tariff low, water tariff of supply and services are severely low, increasing self-sufficiency level (SSL) of Malaysia’s staple food is important, under-utilised crops are efficient in meeting nutrient requirements, and cash crops imposed systemic stresses upon the water sector more than the energy sector. Consequently, recommendations for policy makers are suggested accordingly to achieve a reasonable proportion of RE penetration, providing education on nuclear benefits, centralising and streamlining water governance, socio-economic improvement of water economics, increase SSL of staple food, embark upon widespread adoption of local under-utilized crops, and controlling land use of non-food crops.

The outcome of this research forms a vital and novel contribution to knowledge, when it is a pioneering work to address the WEF security nexus for Malaysia; especially in considering their securities for the country as a system rather than unaffected individual entities. This work will contribute towards spearheading the awareness and, hopefully, trigger further and more in-depth work in transdisciplinary resource and technology management. As a pioneering effort, this research has nonetheless provided the foundation and the fundamental understanding to an integrative and inclusive cross-sectoral national resource backbone - The WEF security nexus measurement system of Malaysia.

Nexus rerum universalis

-Johann Christoph Gatterer (1727-1799)

Acknowledgement

My PhD journey has been thoroughly fulfilling, which has not only been intellectually enhancing but character building as well. There are a number of people whom I would like to thank for making this endeavour possible.

Firstly, I would like to thank my principal supervisor, Dr Eng Hwa Yap, irrefutably the best mentor in my life. His consistent and tireless efforts in providing me guidance have nonetheless ensured the successful completion of this research. His patience and understanding of my constant visits to his office showed that he deeply cared about the welfare of my progress. It has certainly been my privilege to be working for, by, and with him.

Secondly, I would also like to thank Dr Yousif Abdalla Abakr, my secondary supervisor, who has also contributed valuable insights and constructive criticism into the research. His patience and wisdom will always be remembered.

I would like to thank my funders, BHP Billiton and UCL, and in particular Dr Simon Banks, for providing me the scholarship and stipend. Dr Simon Banks has indeed went out of his way to oversee my smooth transition from UCL Australia to The University of Nottingham Malaysia Campus, which undeniably plays a pivotal role in the continuation of this PhD.

On top of that, I would like to thank important individuals from UCL Australia, Dr Ady James and Jason Dow. Dr Ady James, being my secondary supervisor during my time in UCL Australia, was unselfish with sharing his vast knowledge and experience within and beyond the scope of the PhD that has enhanced my understanding of the research, especially during the initial stages. Jason’s ever-obliging support and unending friendship have indeed made this journey a joyful one.

I would also like to thank my family, who were all unconditionally supportive of my undertaking of this PhD research. Their sincere encouragements have thus allowed me to carry out this research with unquestioning fortitude.

Finally, I would like to thank Janice, who has always been there for me through thick and thins, from beginning to the end. Her overflowing morale support and endless inspiration have undoubtedly provided the motivations that I so leveraged upon to carry out this research through to completion.

Statement of Originality

I hereby certify that, to the best of my knowledge, the work contained in this thesis has not been previously submitted for a degree, masters, or PhD, to any another higher academic institution. I also certify that the work and intellectual property of this thesis is solely my own, and any form of techniques and knowledge adoption/adaptation has been properly acknowledged and referenced.

Signed

……………………………… 25th June 2018

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Definitions

Nexus	A connection or series of connections linking two or more entities.
Water Security	The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.
Energy Security	The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance.
Food Security	Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.
Composite Index	A composite index is a grouping of equities, indexes or other factors combined in a standardized way, providing a useful statistical measure of overall market or sector performance over time, and it is also known simply as a "composite."
Indicator	A measurable factor, metric, or fact to represent the state or level of subject of interest.

Abbreviations

CAPEX	Capital Expenditure
CLD	Causal Loop Diagram
EIU	Economist Intelligence Unit
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GNI	Gross National Income
GNP	Gross National Product
HDI	Human Development Index
ICIMOD	The International Centre for Integrated Mountain Development
IEA	International Energy Agency
IISD	The International Institute for Sustainable Development
KeTTHA	Ministry of Energy, Green Technology and Water
LNG	Liquefied natural gas
MDG	Millennium Development Goals
NWRC	National Water Resource Council
OPEC	Organization of the Petroleum Exporting Countries
OPEX	Operational Expenditure
PETRONAS	Petroliam Nasional Berhad
PO	Palm oil
RM	Ringgit Malaysia
RWH	Rainwater harvesting
SCORE	Sarawak Corridor of Renewable Energy
SD	System Dynamics
SDG	Sustainable Development Goals
SEDA	Sustainable Energy Development Authority Malaysia
SESCO	Sarawak Electricity Supply Corporation

SESB	Sabah Electricity Sendirian Berhad
SFD	Stock and Flow Diagram
STI	Science, Technology and Innovation
TBL	Triple Bottom Line
TNB	Tenaga Nasional Berhad
UN	United Nations
UNMC	University of Nottingham Malaysia Campus
USD	US Dollar
WEF	Water-Energy-Food

Chapter 1 Introduction

1.1 Background and Motivation

Water and food are amongst the most important basic necessities to sustain human life. In this context, energy is also equally important as it is necessary to produce, process and transport the former two. About one-seventh of the world's population does not have access to secure water, energy and food supply. As the global population is set to reach 8.5 billion by 2030 [1], the challenges in managing scarcity and security of water, energy and food resources become increasingly pressing by the day. On top of that, urbanisation, globalisation, rising standard of living, overall increase in the demand of resources alongside trade-offs in climate change, and socio-economic sectors magnify the challenges in securing and safe-guarding those resources even further.

1.1.1 Water

"Water security is defined here as the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability". This was the definition of water security given by UN-Water [2]. From the definition, it is clear that water security is not just about securing water in acceptable quality and quantity, but to do so in a manner such that sustainability of all important aspects involving human, environment, economy as well as geo-politics is ensured.

Whilst civilisation and economic development are improving in many countries, much work still remains to be completed in improving the state of water issues globally. The current state of affairs of water security around the world is not optimistic, as shown by the following facts and figures:

- Water crises ranked #1 global risk by World Economic Forum [3].
- Projected 55% of global demand of water from 2000 to 2050 [4].
- 1.7 billion people living in areas where water use exceeds recharge [5].

- 1 in 10 people lack improved drinking water sources [6].
- 8 in 10 people lack access to improved drinking water and the number is increasing [6].
- 1.8 billion people use faecal-contaminated water [7].
- Millennium Development Goal (MDG) target for basic sanitation was missed by 700 million people [6].
- 1 in 3 people still lack improved sanitation facilities [6].
- 1 in 8 people practises open defecation [6].
- 1.5% of gross domestic product (GDP) of developing countries loss as a result of lack of access to improved water sanitation [8].
- Great variation in priorities given to public water expenditures [9].
- 1 in 3 developing countries unable to cover basic operation and management costs of water utilities [10].
- Freshwater withdrawals for energy production to increase by 20% through 2035 [11].
- Agriculture's share of water withdrawals is 70% [12].
- People living in river basins under severe water stress expected to increase from 1.6 billion in 2000 to 3.9 billion in 2050 [4].
- 57 countries without publicly available information to flows of wastewater generated, treated, or re-used [13].
- Average coverage of wastewater treatment rate are 70% in high-income countries, 33% in middle-income countries, and 8% in low-income countries [13].
- Nitrogen and phosphorus effluents are expected to grow by 180% and 150% respectively between 2000 and 2050 globally [4].
- 4.2 billion people affected by floods, droughts, and storms between 1992 and 2012 [14].
- USD 1.3 trillion in economic losses from water-related disasters between 1992 and 2012 [14].
- Expected economic value of assets at risk to increase to USD 45 trillion by 2050 [4].

1.1.2 Energy

The world is faced with challenges of ensuring energy security, which is defined by IEA as "the uninterrupted availability of energy sources at an affordable price" [15]. Historically, non-renewable resources such as coal, oil, and natural gas have been used for power generation until recently where renewables are gaining bigger shares in the industry [16]. Recently, energy price shock and instability has been ranked in one of the top 10 global risks in terms of impact by the World Economic Forum [3,17–21]. Efforts looking into renewable and future energy systems are gaining huge momentum from around the world such as the recent "Affordable and Clean Energy" target set in Sustainable Development Goals [22]. Some facts and figures concerning energy issues worldwide:

- Demand of oil grows by 900 kb/day until 2020 and then to reach 103.5 million b/day in 2040 [23].
- Global energy demand to increase by 32% from 2013 to 2040 [23].
- Electricity consumption to grow by more than 70% to 2040, with 550 million people still without access to electricity [23].
- Projected 34.2 Gt in 2020 and 44.1 Gt of CO_2 emissions, if current policies scenario remains unchanged [23].
- World consumption of marketed energy to grow from 549 quadrillion Btu in 2012 to 629 quadrillion Btu in 2020 to 815 quadrillion Btu in 2040 (48% increase from 2012-2040) [24].
- World use of petroleum grows from 90 million b/d in 2012 to 100 million b/d in 2020 and 121 million b/d in 2040 [24].
- Share of energy used for power generation to increase from 42% to 45% by 2035 [25].

1.1.3 Food

Food, along with water, is a basic necessity to sustain life. World Food Summit of 1996 defined food security as "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" [26]. With an ever-increasing global population, ensuring food security will always be one of the main challenges as it is not only crucial for survival, it also plays a critical role in ensuring good health. In 2009 in the world food summit, the World Summit for Food Security stated the four pillars of food security, which are availability, access, utilisation, and stability [27]. The World Food Summit held in 2017 focused on key themes of better information, safer food, culinary diversity, and prevention of food waste [28]. Facts and figures concerning world hunger and food security:

- More than 1 billion people suffering from hunger and poverty [27].
- 1 in 7 people do not have sufficient protein and energy from their diet [29].
- Majority of hungry people live in developing countries where 12.9% of their populations are undernourished [30].
- Largest number of hungry people in Asia continent (largest hunger burden in Southern Asia: 281.4 million) [30–34].
- 3.1 million children per year die of poor nutrition causes [30].
- 16.6% of children are underweight in developing nations [30].
- 1 in 3 people are employed in Agriculture globally [35].
- Cereals yield have tripled over the last fifty years [36].
- Projections for business as usual scenario to 2030 will still leave 653 million people undernourished [36].
- 37% of global land area is agricultural land [37].

1.2 The Water-Energy-Food Security Nexus

Traditionally, key industrial players, not exclusive to the water, energy and food sectors, act independently of one another, treating external or other factors (or resource) separate from their own, otherwise known as silo-thinking [38,39]. Decisions involving investments and policies were often made in overlooked narrowly focused fashion. It was not until recently when diverse stakeholders, namely industrial experts from WEF sectors as well as policy makers, talk seriously about the inter-relationships of the water, energy and food sectors, the "water-energy-food (WEF) nexus" [40]. Researchers and policy-makers have acknowledged and emphasized the fact that the WEF security nexus interrelationships are indeed complex. However, it is also recognized that there is relatively minimal understanding on how to address these complex relationships.

It is undeniable that activities and events within the sectors of water, energy, and food are inextricably linked and their relationships are numerous and substantial. For example, water is used for mining, extracting, processing, and refining of fossil fuels, as well as generating steam for and cooling of power plants [41]. Energy production are also highly water intensive and polluting as returned water could increase surface water temperature and pollute the local water source, which disrupts the ecosystem. Besides that, energy is required in the water industry to treat, desalinate, supply, and distribute water through treatment plant, irrigation network and long chain of pipes [11]. In the food sector, the links are demonstrated through the withdrawals of water in the agricultural sector which accounts for 70% of all freshwater consumption as well as energy used during the irrigation, harvesting, and transporting of crops [42]. The energy-food link is also emphasized when the price of food increases quickly after the increase in global oil price [43].

It is important to consider and address the water, energy, and food resources holistically and systematically because it is evident that intrinsic relationships exist between them [40]. On top of that, complexity increases when factors governing the daily lives of humanity such as economy, social, technology advancement and policies adds upon the difficulty in addressing the relationships [40,44]. Since it became apparent that completely solving problems involving any one resource or factor in insolation to others is ineffective and counter-productive [45], it is paramount to address the problems from a holistic and systematic approach so as to maximise the benefits as well as to minimize the negative impacts on one another.

However, the system of WEF security nexus are different from one region to another, due to several factors such as geographical location, developmental history, culture, and etc. As such, a single generic WEF security nexus solution may not exist, and even if it did, it may not be effective for all countries. Consequently, a unique country such as Malaysia does possess its own unique WEF security nexus problems and solutions.

1.3 Water, Energy, and Food Security for Malaysia

Malaysia, with a population of 31 million [46], is a developing nation located in Southeast Asia, bordered by Singapore, Thailand, Indonesia, and Brunei. Having a landmass of 330 803 km^2 and being surrounded by the Straits of Malacca, South China Sea, and the Sulu Sea, Malaysia is blessed with an abundance of natural resources such as petroleum, natural gas, and various minerals. Malaysia, having one of the best economic record in Asia for almost 50 years have an annual GDP of approximately 6%, which was traditionally fuelled by natural resource exports, has recently expanded into sectors of manufacturing, science, tourism, services and commerce.

Malaysia's energy landscape is largely defined and controlled by Tenaga Nasional Berhad (TNB) in the peninsular, Sabah Electricity Sdn. Bhd. (SESB) in Sabah, and Sarawak Electricity Supply Corporation (SESCO) in Sarawak. With a total of 420 transmission substations, 11,000 km of transmission lines, and a total power capacity of 29,728 MW in 2013; total electricity generation was 140,985 GWh out of which 123,076 GWh was consumed [47]. The electricity fuel mix in Malaysia is largely based on natural gas, coal, and hydroelectric, with traces percentage of biomass, solar and diesel. The consumption of energy in Malaysia can largely be broken down into several sectors namely transport (43.3%), industrial (26.2%), residential and commercial (14.4%), non-energy use (14.1%), and agriculture and fishery (2.1%) [47]. During the Tenth Malaysia Plan, rural electricity coverage reached 97.6% [48].

Surrounded by a deep strait and two seas, and having a hot and wet season throughout the year, water resources in Malaysia are abundant and available. On top of that, Peninsular Malaysia is drenched by a vast network of rivers with the longest being the Pahang River (434 km), as well as Kelantan, Terengganu, Dungun, Endau, and Sedili rivers running into South China Sea [49]. In East Malaysia, the longest river is the Rajang River in Sarawak, which is 563 km, also running into South China Sea. Estimated at about 580 km^3/year, the water availability is equivalent to 3000 m^3 per capita per year.

The agricultural sector in Malaysia makes up 12% of the country's GDP and employs 16% of the population. The large scale agricultural products dominating agricultural exports from Malaysia consist of palm oil (PO), rubber, and cocoa. These commodities do not contribute towards addressing and ensuring food security for Malaysia directly or significantly, notwithstanding the fact that there are fruits being grown on small scales for the domestic market. Price and affordability has become a major factor in determining food security because Malaysia imports most of its staple food e.g. rice, sugar, wheat flour, and cooking oil [50]. Consequently, the strength of the Ringgit Malaysia (RM) against foreign currencies has become a factor in food security.

1.4 Problem statement

While we can measure and calculate the performances of each sector (water, energy, and food) individually, there is little to no means of measuring their performance holistically within the context of a nexus. Important parameters such as resource use efficiency and trade-offs between and within each sectors are not fully understood. On top of that, sectorial policies to run the water, energy, and food industries as well as national policies to propel a nation forward, which are supposed to improve the livelihoods of the people, are continuously being formed with the absence of this knowledge. As such, the policies formed may not be effective due to a lack of understanding. Consequently, side effects and negative impacts to the society, economy, and environment, which are not immediately apparent, may emerge over time due to the poorly developed policies. These problems arise because there is a lack of understanding of how each sector performs in relation to each other as well as holistically, and also a lack of means to simulate and measure, within the context of a nexus, the behaviours of key variables over time under different policy scenarios. The problems are very relevant and important to Malaysia, an emerging economy rich in natural resources which envisions to be a developed nation by 2020, because failure of addressing them in an effective and efficient manner could potentially hinder and cripple the country from achieving its aims.

1.5 Research Objectives

Upon establishing the problem statement, it is then possible to establish the research objectives for this research accordingly.

RO1. To investigate the intrinsic relationship between water, energy and food in a developing nation such as Malaysia and establish the definition for an optimum WEF security nexus.

RO2. To construct a causal loop diagram (CLD) for the WEF security nexus in Malaysia.

RO3. To construct stock and flow diagram (SFD) for the WEF security nexus in Malaysia.

RO4. To critically analyse the well-being of WEF security nexus on Malaysia, based upon inputs of interview and simulated results of SFD.

1.6 Research Questions

Upon forming the research objectives, the research questions can be derived accordingly. Research questions are necessary to provide the research with a guideline and direction to propel the research work. This section outlines and establishes the research questions.

1. What is the current state and intrinsic relationships between the water, energy and food (agriculture and land use) in a developing nation, such as Malaysia, within the context of a nexus?
2. What are the identifiable and measurable parameters, 'qualities' and 'quantities', in each sector and what are the interactions between them?
3. How do the values, behaviours, and relationships of the identified parameters represent the well-being of WEF security nexus of Malaysia?
4. What are the impacts of current activities in the nexus on the climate, socio-economics, and sustainable development of a geo-economic region such as Malaysia?

1.7 Thesis Outline

Chapter 1 provides a brief introduction, as well as facts and figures for water, energy, and food securities individually before supplementing a more holistic explanation of the WEF security nexus and its context for Malaysia. Subsequently, a problem statement is given with which aims, objectives and research questions are outlined.

Chapter 2 presents a critical literature review on past WEF security nexus works, by classifying them into types, scale, and themes of study. Types of study are divided into quantitative and qualitative, scale of studies into global and regional, and themes of study into technological, social, economic, environmental, and policy. The chapter also includes a review of WEF in other regions and techniques to measure WEF. This chapter proceeds to adopt generic definitions, by critical analysis of identified dimensions, for each respective resource security, namely water, energy, and food. The following sections look into the various development goals and plans globally as well as in Malaysia such as the Millennium Development Goals, Sustainable Development Goals, and national Malaysia plans. A brief comparison between developed and developing countries is then provided to enhance the understanding of WEF security nexus of a country. Subsequently, a review is conducted on the individual WEF security sectors of Malaysia in order to put forward the key attributes of each respective sectors.

Literature review on methodology used has also been conducted, namely systems thinking and system dynamics (SD).

Chapter 3 is the methodology chapter that begins by providing a research process flow which outlines all work done in the research. Upon identifying the need for a systemic method, a comparative analysis between different systemic approaches is given before the eventual selection of SD. Concepts of SD and the modelling process are then presented and discussed. Accompanying the SD method is an interview process used in the initial stages of the modelling process, which are also elaborated. Then, the chapter elaborates on the process of interview which includes interviewee screening and selection process, question design, and true/false questionnaire. Subsequently, selection of variables and indicators for CLD and SFD respectively were explained. The chapter concludes with an explanation of verification and validation plans, which are divided into three parts namely validation of causal loop diagram models, verification of stock and flow model, and validation of stock and flow model.

Chapter 4 starts out by presenting interview inputs and understanding into the WEF sectors of Malaysia. Subsequently, bi-sectoral relationships of resource sectors in Malaysia are provided. Consequently, the chapter provides a conceptual framework for the WEF security nexus of Malaysia. Moving on, measuring of resource securities are discussed, where key indicators of each respective sectors are put forward. The chapter then presents the final causal loop diagrams (CLD) constructed, alongside the justifications and rationale of each model. This part serves to provide an understanding into the qualitative relationships between variables, where their structures are result of literature review and interview efforts. Earlier iterations of the CLDs can be found in Appendix II.

Chapter 5 lays out the stock and flow diagrams (SFD) constructed for Vensim simulation. This chapter is divided into numerous sub-section which details the structure for each specific part, accompanied with their justification, rationale, and equations. The SFDs are constructed with guidance from the CLDs from chapter 5. Each equation is also associated with the units they are measured in. Before ending the chapter, a base case validation of SFD was carried out.

Chapter 6 provides the design of seven scenarios, with which consisting of more specific sub-scenarios. The scenarios are designed based upon the understanding acquired from chapters 2 - 4. The seventh scenario is designed as a result of combination of understandings from the results of previous six scenarios, which serves to illustrate the holistic understanding of WEF security nexus in Malaysia. After every design of scenario, each subsection presents the results of simulation of SFDs constructed. Each result is led by relevant graphs of key indicators, alongside accompanying discussion for each particular scenario. The chapter is concluded with the results and discussion of the seventh scenario

Chapter 7 concludes this research. The chapter first presents the research conclusions and fulfilment of research objectives, by elaborating on how they have been achieved. Then, a list of recommendations is provided to improve the WEF security nexus of Malaysia. Then it is followed by a description on the contributions of this research. Last but not least are the limitations of research and suggestion of further works.

Chapter 2 Literature Review

2.1 Introduction

The first part of this chapter provides a critical review on the WEF security nexus research efforts which have been carried out in the past. This is conducted by classifying the works into types of study, scale of study, and themes of study. The purposes of this review are to lay the groundwork for the understanding of WEF security nexus, to establish knowledge on WEF security nexus research status, and to provide a reference point from which WEF security nexus for Malaysia can commence. Subsequently, the WEF security nexus in other regions as well as techniques to measure WEF have been explored. Next, this chapter looks into the relevance and position of WEF security nexus within development goals, internationally as well as in Malaysia. International development goals consist of the Millennium Development Goals (MDG) and the Sustainable Development Goals (SDG). In Malaysia, the tenth and eleventh Malaysia plans are looked at. The third part of this chapter presents an understanding into the current status as well as past efforts into the individual sectors of WEF security in Malaysia, before advancing the key attributes of WEF security sectors and their relationships for Malaysia. A literature review has also been conducted on systems thinking and SD, which would be the methodology adopted for this research.

2.2 WEF Security Nexus

Water-Energy-Food (WEF) security nexus represents the relationships between water, energy, and food security sectors as well as the impacts, due to sectorial or inter-sectorial activities, any one sector has on another. The importance of the WEF security nexus stems from the fact that water, energy, and food are indeed basic necessities for human survival and to maintain quality of life, and the fact that the resources are undeniably inextricably linked.

2.3 Critical Analysis of WEF Security Nexus Research Efforts

Table 1 shows a critical summary, arranged chronologically, for the WEF security nexus research efforts conducted since 2011. The dimensions with which the studies are looked at, on top of their individual contribution, are types of study (qualitative or quantitative), scale of study (regional or global), and themes of study (technological, economics, social, environment, and policy).

Table 1: Comparative Analysis Table for WEF Security Nexus Works

Researcher / Author / Institution	**Year**	**Types of Study**		**Scale of Study**		**Themes of Study**				
		Qualitative	Quantitative	Global	Regional	Technical	Economics	Social	Environment/Ecosystem Services	Policy/Governance
SEI [40]	2011	✓		✓			✓	✓	✓	
World Economic Forum [17]	2011	✓		✓		✓	✓	✓	✓	✓
Bazilian et. al. [51]	2011	✓		✓			✓		✓	✓
Bach et. al. [52]	2012	✓		✓				✓	✓	✓
ICIMOD [53]	2012	✓			✓		✓	✓	✓	
Bizikova et. al. [54]	2013	✓		✓					✓	✓
Adnan [55]	2013	✓			✓					✓
FAO [56]	2014	✓	✓	✓	✓	✓	✓	✓	✓	✓
Finley and Seiber [45]	2014	✓	✓		✓	✓	✓		✓	
Benson et. al. [57]	2015	✓		✓						✓
Biba [58]	2015	✓			✓		✓	✓	✓	
Biggs et. al. [59]	2015	✓						✓	✓	✓
IRENA [60]	2015	✓		✓	✓	✓			✓	✓
Leese and Meisch [61]	2015	✓		✓			✓	✓		
Middleton et. al. [62]	2015	✓			✓			✓		✓
Mukuve and Fenner [63]	2015		✓		✓	✓	✓			
Rasul [64]	2015	✓			✓		✓	✓	✓	✓
Smajgl et. al. [65]	2015	✓		✓	✓			✓	✓	✓
Vanham [66]	2015	✓		✓		✓			✓	
Garcia and You [67]	2016	✓		✓		✓			✓	✓
Howarth and Monasterolo [68]	2016	✓			✓			✓	✓	✓
Sanders and Masri [69]	2016	✓		✓		✓				
WEC [70]	2016	✓	✓	✓		✓	✓		✓	
Martinez-Hernandez et. al. [71]	2017		✓		✓	✓			✓	
Siciliano et. al. [72]	2017	✓	✓		✓	✓			✓	
Franz et. al [73]	2017	✓		✓	✓			✓	✓	

Most of the WEF security nexus research work conducted was qualitative and of high-level discussion in nature, which cements the fact that research on this area is indeed at its infancy. Attempts to understand and portray the understanding of the fundamental WEF security nexus principles were carried out through developments of framework. The structure of most of the frameworks can be summarised as in Figure 1.

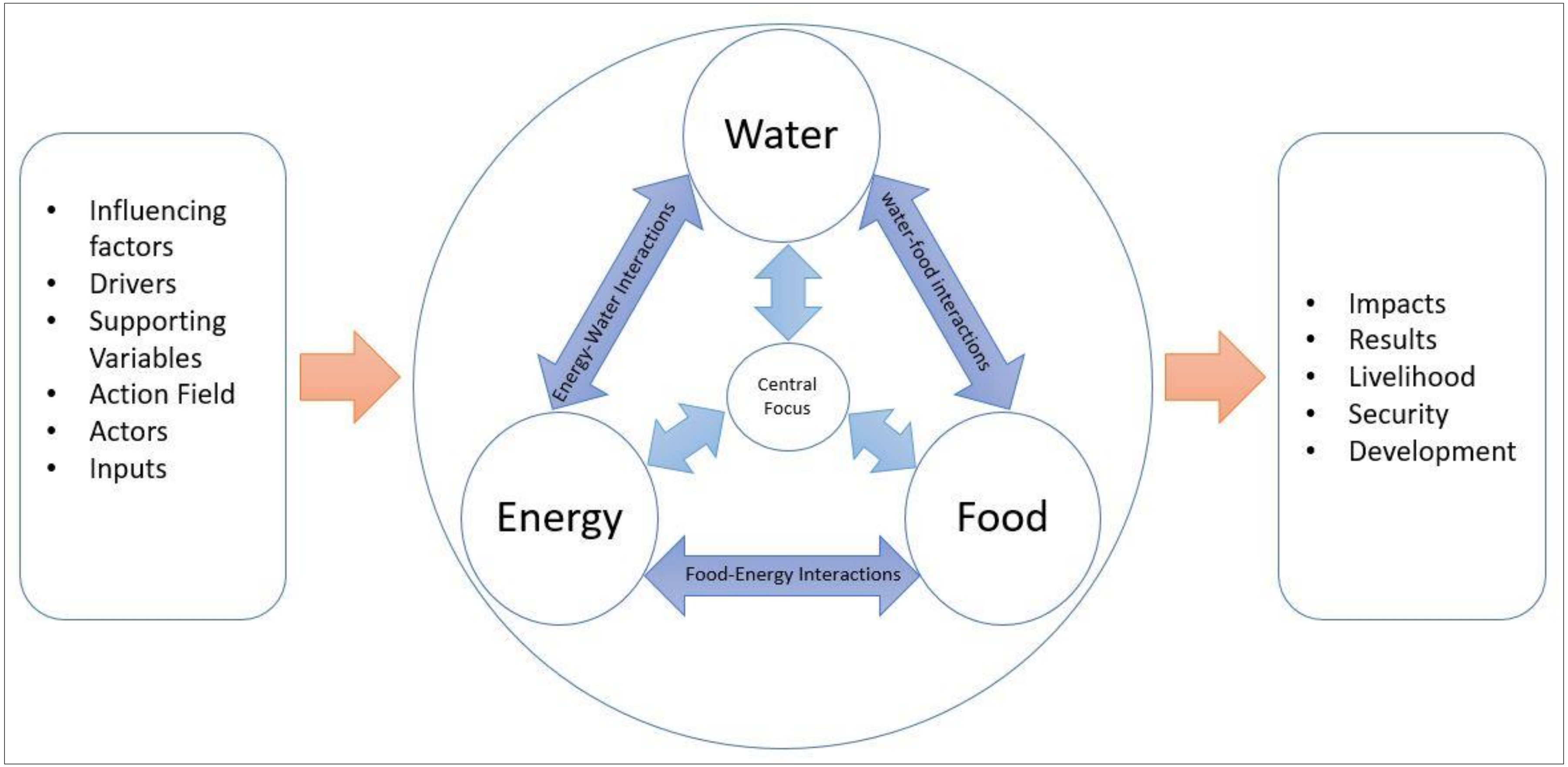

Figure 1: WEF Security Nexus Frameworks' Summary

From the framework, it can be seen that there are interactions between water and food, food and energy, as well as energy and water. The resource sectors and interactions revolves around a certain central theme, where it becomes the focus of the WEF nexus research. Outside the resource, interactions, and central circle lies factors (inputs) which influences the WEF nexus activities, which in turn result in impacts or results (outputs) such as livelihood, security, and sustainable developments.

2.3.1 Qualitative WEF Works and Framework Proposals

Hoff [40] initiated the global interest in WEF security nexus through his introductory discussion by showing a wealth of knowledge gap and listed the opportunities for improving the WEF through the nexus approach. Hoff also provided his framework by putting available water resources as the central focus, with action fields of society, economy, and environment as inputs to promote the outputs of resource security, equitable and sustainable growth, and resilient productive environment. One of the most popular discussion on the aspect of WEF nexus were its interactions and interrelatedness among the sectors i.e. the trade-offs and exchanges performed between the sectors. Hoff [40] used the term 'bloodstream' to describe water, which plays central role in the nexus and acting as control variable, as the connector between water supply, energy, and food security. World Economic Forum, in their annual activity of identifying global risks by listing and ranking risks through stakeholder engagement with council and survey of leaders, have named WEF security nexus as one of major global problem in 2016 [17]. This yearly event assess the direct and indirect impacts of the identified risks on governments, societies, and businesses. In addressing the identified risk of WEF security nexus, this body of professionals have provided a WEF framework which has similar inputs of population, economic growth, and environmental pressures to control the risks (outputs) of global governance failures, economic disparity, and geopolitical conflict. World Economic Forum [17], through their framework, explicitly showed that bi-directional relationship exist between water and energy security but only a one-way flow from water and energy security to food security. Bazilian et. al. [51] described and discussed some linkages of the WEF security nexus in a high-level aggregation, before which case studies were performed to provide directions in addressing the WEF. In his discussion, he highlighted the need to build institutional capacity to understand and act on complexity as well as to develop and apply modelling tool that support integrated decision making. Bach et. al [52], as a result of Mekong2Rio conference, presented a synthesis of information of WEF security nexus from the perspective of transboundary river management. Capitalising on the WEF security nexus knowledge obtained such as transboundary river challenges, local cultures, economy, and the ecosystem, improvement initiatives such as establishing policy coherence across nexus and promoting science-policy dialogue were suggested. In 2012, Rasul [53] studied the WEF security nexus of South Asia from the perspectives of agriculture and food production by understanding the interlinkages of WEF sectors in the region. As a result, Rasul proposed a framework where enhanced water, energy, and food security are put as the central focus and has ‘Himalayan ecosystem services’ (inputs), which consists of provisioning, regulation, supporting, and cultural factors, as the foundation for the nexus. Bizikova et. al [54] conducted a qualitative review on past and existing WEF frameworks and identified intervention points for WEF improvement namely engaging stakeholders, improving policy development, coordination, and harmonisation, resource planning, promoting innovation, and influencing policies on trade and investments in environment/climate. Consequently, the WEF framework proposed puts utilisation, access, and availability of water, energy, and food in the centre whilst expanding outwards into their influencing factors namely built and natural systems, as well as the larger scope of governance and management systems. Adnan [55] attempted to deepen the understanding of WEF security nexus in his discussion paper by reviewing and discussing on the policy and institutional dimensions of WEF, analysing the trends of resource security in Asia Pacific, and performing case studies in two regions namely Central Asia and Mekong River Basin. Benson et. al. [57] performed a qualitative comparative analysis between integrated water resource management (IWRM) and the WEF security nexus on key integrative features, such as integration of sectors, governance structure, scale, participation level, resource use, and sustainable development, and came to the conclusion that in order for the WEF security nexus concept to be significantly different from or replace IWRM, substantial work of detail remains to be expanded for the WEF security nexus concept to be widely accepted. Biba [58] in his article compares the theories of WEF security nexus concept with the reality on the ground, China and its southern periphery, and found that a glaring difference exist in terms of goals and achievements. Considering the challenges highlighted by Biba, namely food-energy tensions, human security threats, and ecological risks, ideas of achieving nexus goals such as rebalancing of nexus goals, concentrating on enabling factors by Hoff [40], and to factor in political dimensions in the nexus approach. Biggs et. al. [59], upon reviewing past frameworks of WEF, argues that sustainable livelihood has been neglected. By understanding and integrating the linkages between WEF security sectors and environmental livelihood security, Biggs et. al. introduced an integrated ELS-WEF framework by putting livelihoods as central focus with influencing factors acting from the outside in order to sustain the wellbeing of livelihood-WEF nexus. International Renewable Energy Agency (IRENA) [60] discussed the importance and opportunities for renewable energy intervention into the WEF security nexus by studying the important energy related links in the WEF security nexus, namely water-energy links and food-energy links. Leese and Meisch [61] provided a counterintuitive discussion to the necessity and sincerity of adopting the WEF concepts, arguing that the WEF security nexus is nothing but reframing from distributional justice to security of resources. Middleton et. al. [62] on the other hand argued that the nexus can be more effectively framed if environmental justice is introduced into its framework. Smajgl et. al. [65] explicitly emphasized that the bias has to be removed from any one sector as unequal weightage on any one resource would constrain analysis of the interactions of the entire nexus. As a result, Smajgl et. al. developed a framework that has population, income, ecosystem services, natural resources, and climate change as the central focus with entry points as energy and food security as well as water access. Vanham [66] investigated if the water footprint (WF) concept addresses the water-energy-food-ecosystem (WEFE) system, and found that WF only address agriculture, industry, and domestic water. Vanham suggests to add a host of relevant indicators to WF accounting in order to be coherent with the water-energy-food-ecosystem nexus. Garcia and You [67] discussed the research challenges of WEF security nexus and identified opportunities of improvement from a process engineering perspective. The difficulties faced by WEF security nexus researchers are such as the nature of WEF security nexus research being multi-scale, multi-temporal, and multi-spatial. Sanders and Masri [69] explored the use of remote sensing technologies in WEF security nexus, by first understanding their uses in each sectors respectively. Remote sensing technologies are able to address a few of the WEF security nexus management challenges such as fragmented expertise and institutions, mismatched spatial-temporal resolution, data management issues, cost and deployment issues, policy issues, and life cycle assessment considerations. In 2016, World Energy Council (WEC) [70] in their report of managing risk of the WEF security nexus around the globe reported key findings namely energy is the second largest freshwater user after agriculture, risks posed by WEF security nexus will become more significant, rising water demands and uncertainty of water availability, reduction in usable water capacity could impact power plants, lack of location-specific knowledge on water issues, risks posed by the WEF nexus are often exacerbated, and cross-border cooperation is an issue. Franz et. al. [73] investigated the potential of using global production network (GPN) approach to analyse socio-economic relations within the context of WEF security nexus. Utilising methods of case study, stakeholder interviews, and qualitative content analysis, it was found that the GPN approach can assist in filling the gap of having an analytical framework for addressing the complexities of WEF interrelationships as well as issues of globalisation.

2.3.2 Quantitative WEF Works

Despite the large number of qualitative analysis, a number of efforts to quantitatively analyse the WEF security nexus have been carried out.

Food and Agriculture Organization (FAO) [56] proposed a framework that has management of nexus, namely stakeholder’s dialogue on scenario development, evidence as well as response option, in the middle with drivers, which range from population growth to technology and innovation, as inputs to eventually result in the ultimate social, economic, and environmental goals and interests of water, energy, and food. FAO [56] suggested that upon identifying key indicators (readily obtainable from relevant international organizations or initiatives) from linkages matrices, either one of two quantification methods can be used, namely: (1) *detailed nexus assessment* which uses readily available key indicators collected by national authorities and (2) *Nexus rapid appraisal* where quantification is achieved through building of ad-hoc nexus indicators because lack of data is a key barrier. As depicted in Figure 2, FAO's quantitative assessment can be divided into four parts namely quantitative analysis, application of input/output tools, assessment of interventions, and comparison of interventions.

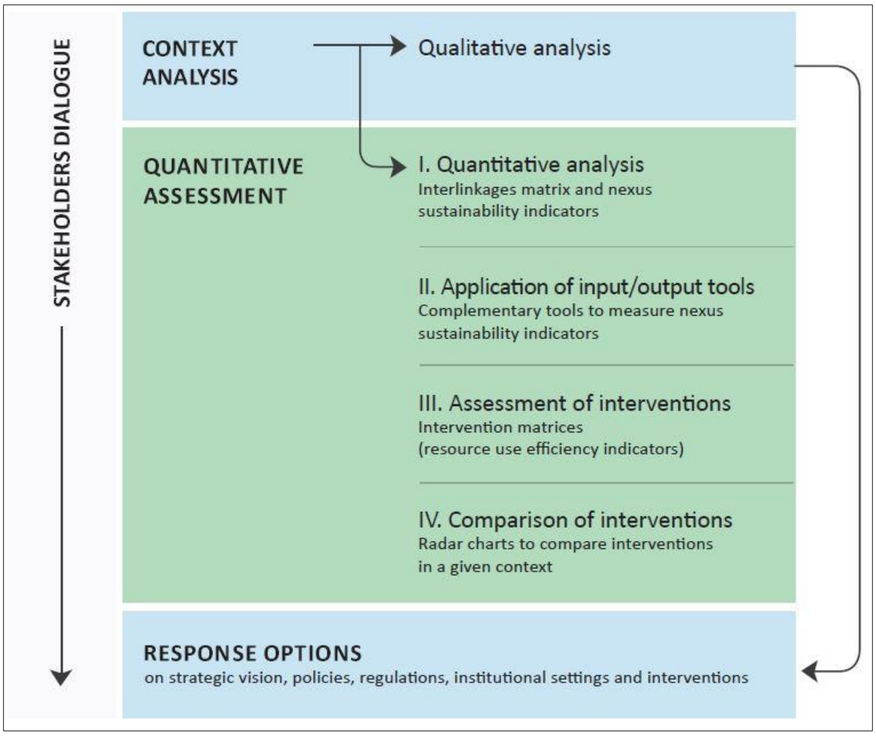

Figure 2: FAO Nexus Assessment [56]

Finley and Seiber [45] used quantitative data of important and relevant WEF indicators such as water withdrawal and consumption, average levelised cost of electricity (LCOE), CO_2 emissions, energy efficiency of food calories, and etc. to discuss on the interlinkages in the WEF security nexus. Mukuve and Fenner [63] performed a two-step quantitative analytical approach which involves geospatial analysis (which examines agricultural resource deficits and surpluses at different regional scale) of Uganda's resource limits and modelling resource interactions through various stages of food system (production, processing, distribution, and consumption). Through this method, Mukuve and Fenner managed to show, within the context of food system, graphically and numerically the constraints and interactions of water, land, and energy resources in Uganda region. Martinez-Hernandez et. al. [71] used the NexSym tool, which on a local scale models co-located technological and ecological processes, to simulate and analyse the effects of various components of a local nexus system in a UK eco-town. Figure 3 illustrates the technological and ecological interrelationships as investigated by Martinez-Hernandez et. al. [71].

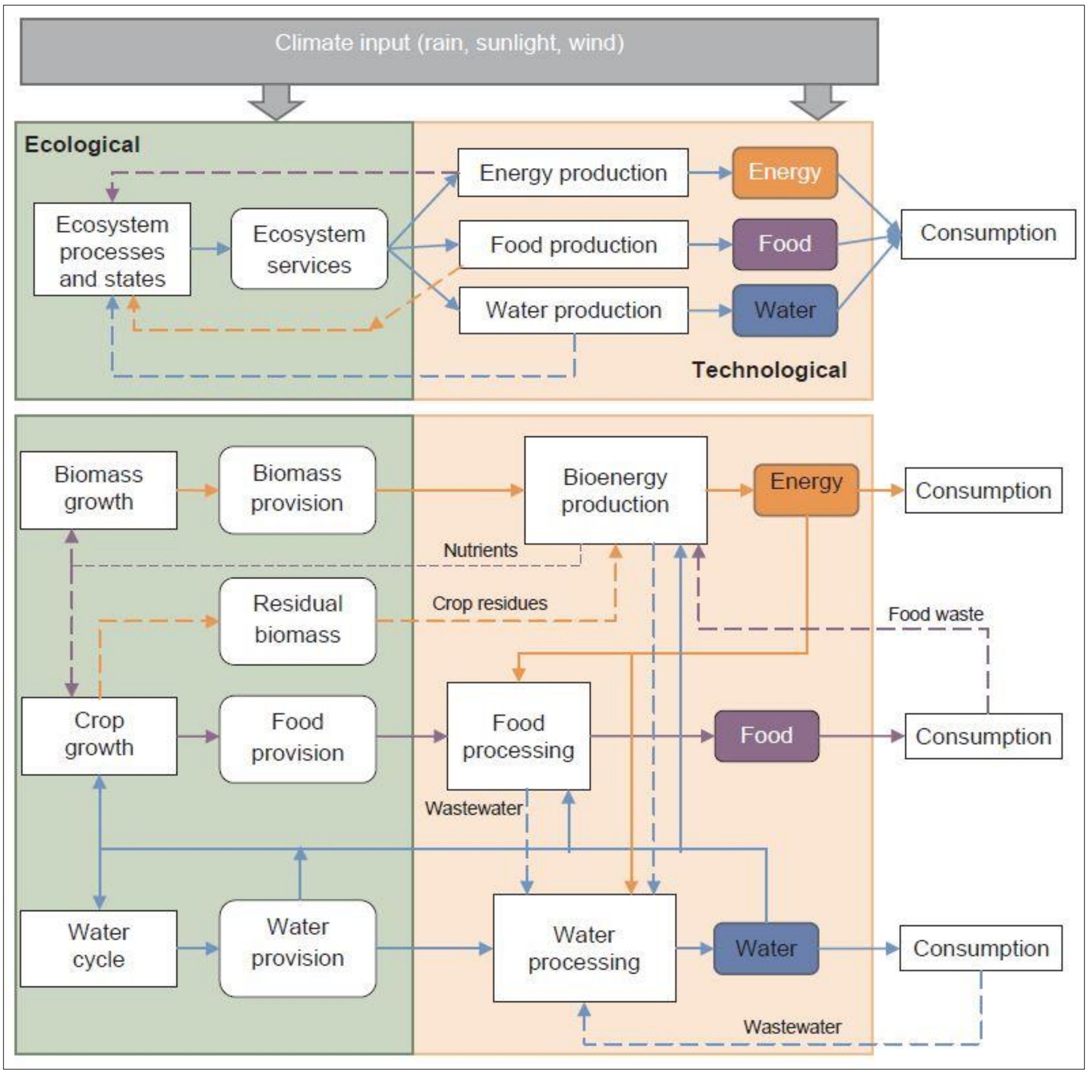

Figure 3: Techno-ecological Interactions in WEF by Martinez-Hernandez et. al. [71]

Siciliano et. al. [72] performed a resource assessment which evaluates linkages between land acquisition and availability of land and water in target countries. The analysis, which involves (i) estimation of land and water, (ii) analysis of competition of water, (iii) quantitative assessment of available water and land resources, and (iv) analysis of resource scarcity, showed that complex trade-offs exist between water, energy, and food resources.

2.4 WEF in Other Regions

Various WEF-security-nexus-related researches have been conducted in other regions. This section reviews the WEF security nexus researches in other regions, which vary in terms of scale, context, and sectors involved. However, it is necessary to understand works or WEF in other regions as it establishes a basis for comparison to that of Malaysia.

Hardy et. al. [74] assessed Spain's water-energy nexus by first taking into consideration other studies that analysed Spain's water-energy elements and then evaluate water needs in power plants. With an annual water withdrawal of 35000 Mm^3 and water-related energy consumption of 16500 GWh, energy per water use of Spain is estimated to be at 0.45 kWh/m^3. Agriculture in Spain, largest water user, uses 58 % of total water distributed. Spain's energy sector, excluding hydropower, accounts for 25 % of water-related energy use, where water use in generating technologies ranges from 684 m^3/GWh to 791676 m^3/GWh.

Keskinen et. al. [75] explored the WEF security nexus of Tonle Sap Lake, which is closely connected to the transboundary Mekong River. By defining two research components, namely (1) hydrology and water resources and (2) livelihoods and food security, WEF links in the area were understood and described. For the first analysis, it was discovered that climate change do impact the Mekong River and the Tonle Sap system by causing changes to rainfall and temperature in the area. For the second analysis, it was found that a strong link exists between livelihood and food security of the population of Tonle Sap because over 65 % of the workforce are either involved with agriculture or fishing. Additionally, simulation showed that the hydropower stations in Mekong would adversely affect the population of Tonle Sap, much more than climate change.

Spiegelberg et. al. [76] investigated the WEF relationships between upstream farmers and downstream fishermen at Dampalit sub-watershed of Laguna Lake, Philippines. By surveying 176 households and utilising a socio-ecological network, it was found that there are different livelihood profiles for the two groups, whilst there is no direct social links between them. Water-food links can be found in usage of surface water for irrigation of agroforestry and groundwater for production of food.

Yang et. al. [77] researched on the land and water requirements for biofuel, differentiated by feedstock of maize, cassava, sugarcane, sugarbeets, sweet potato, rapeseeds, and soybean, production in China. Utilising the water footprint concept and developing a similar method for land footprint, results vary from the minimum of sugarcane (1.47 m^3/L water footprint, 1.9 m^2/L land footprint) to the maximum of soybean (15.63 m^3/L water footprint, 28.40 m^2/L land footprint). Furthermore, 3.5-4 % of the country's annual maize production is consumed for the biofuel production.

Karatayev et. al. [78] presented key elements required to implement nexus-based resource management in Kazakhstan by identifying linkages between water resources, energy production, and agriculture. By understanding key WEF areas, such as water use in generating capacities, transboundary river water changes, and energy types, it was learned that if current practices of energy system remain the same, there will be significant water stress. Challenges highlighted were that the country is experiencing rapid population and economic growth as well as inefficient infrastructure and resource management which results in high water losses.

2.5 Techniques to Measure WEF

This subsection presents the techniques and literature review to measure and assess the WEF security nexus. There exist a number of works, performed by Semertzidis [79], Keairns [80], Endo et. al. [81] and Albrecht et. al. [82], where methods of measuring and assessing WEF security nexus have been reviewed.

Semertzidis [79] reviewed the suitability of adapting energy systems modelling tool for resource nexus type research, such as the WEF security nexus. Semertzidis divided the models into two categories, namely top-down and bottom-up. Top-down models are such as econometric models, computable general equilibrium (CGE) models, input-output models, and SD models. Bottom-up models include optimization models, simulation models, partial equilibrium models, and multi-agent models. Subsequently, Semertzidis suggested possibility of addressing the resource nexus by using modelling tools such as OSeMOSYS (Open Source Energy System Model), MARKAL/TIMES (Market Allocation/The Integrated MARKAL EFOM System), LEAP (Long-range Energy Alternatives Planning), GTAP (Global Trade Analysis Project), DynEMo (Dynamic Energy Model), POLES (Prospective Outlook on Long-term Energy Systems), PRIMES (Price-Induced Market Equilibrium System), and E3ME (Econometric Energy-Environment-Economy Model).

Endo et. al. [81] created teams to identify research problems and determine or create new methods to assess the WEF security nexus. Table 2 shows the classified methods, as created, in two main categories namely qualitative and quantitative. Questionnaire surveys is promising in terms of gathering pertinent information on the inter-relationships of different nexus resources. Ontology engineering is capable of creating a knowledgebase that computers can directly add metadata. Integrated maps can support implementation of synthesized policies between the land and the sea, on top of being capable of restoring and maintaining their interdependence. Physical models simulates reality systems using mathematical formalisation of the system's physical properties. Benefit-cost analysis facilitates comparison for an environmental-related project its economic benefits with its economic costs. Integrated indices allows for quantitative description and operationalisation of any system, regardless of complexity. Optimisation management models provides a method to optimise allocation of resource that is linked to many other resources that may also cross physical, political, and administrative boundaries.

Table 2: WEF methodology and taxonomy as adopted from Endo et. al. [81]

Type of Data		Functions	Interdisciplinary Research Approaches				Trans-Disciplinary
Primary	Secondary	Methods	Unification	Visualization	Evaluation	Simulation	Research Approaches
		Qualitative Methods					
√	√	Questionnaire Surveys	√	√	√	--	√
--	--	Ontology Engineering	√	√	√	√	√
√	√	Integrated Maps	√	√	√	√	√
		Quantitative Methods					
√	--	Physical Models	√	√	√	√	√
√	√	Benefit-Cost Analysis	√	√	√	--	√
√	√	Integrated Indices	√	√	√	√	√
√	√	Optimization Management Models	√	√	√	√	√

Albrecht et. al. [82] conducted a systemic review on methods for nexus assessment, by analysing past WEF security nexus researches. As a result, eleven categories of nexus methods were found, namely environmental management, economic, indicators, statistics, social science, integrated modelling, systems analysis, geospatial, hydrologic modelling, energy modelling, and food systems. Additionally, nexus analytical approaches can be summarised into four key features namely innovation, influence of context, collaboration, and implementation.

2.6 Defining Resource Security

Whilst it is important to address WEF security nexus as a whole, on top of addressing them separately, it is paramount to establish the definition of water security, energy security, and food security in the first place as it would build the foundation for determining the importance of any key indicators, factors or variables within and between each sectors respectively. As also demonstrated in a number of studies [83–88], precise definition of any particular subject is important for ensuing processes or procedures.

In the case for this research, establishing the definitions of water, energy, and food securities serves the following purposes:

1. To draw the boundary between what (factors, variables, key indicators, etc.) is categorized as water, energy, or food security related / relevant and what is not.
2. To allow critical analysis and discussion of identified key indicators with relation to the definition in terms of relevance and importance.

On selecting the definitions, identifying key dimensions which are complementary to the definitions are necessary to help in deciding which definitions to adopt. They form the selection criteria for which the various definitions will be compared. The default set of dimensions have been determined by the most comprehensive definitions available.

2.6.1 International Definition of Water Security

Throughout the years, numerous international organizations and academic researchers attempted to define or describe what they understand as 'water security'. Different definitions of water security have been coined owing to the context of which they were studied under as well as the evolving circumstances over time. On top of that, as opposed to energy or food security which could only be a problem due to insufficient quantity, water is unique in a sense that having too much can prove destructive [89]. Early definitions of water security which included terms such as productive life, ecosystems, and food production [89–92] showed grasp and understanding of water security as a multi-dimensional concept. Falkenmark's definition [91] mentioned the importance of hydro-solidarity between river's upstream and downstream living. The water security definitions grew increasingly concise and comprehensive in recent years as all of the dimensions of availability, affordability, accessibility, adequacy, quality, sustainability, and environment were included [93–95].

Table 3 shows a summary of the different definitions of water security developed by various institution / researchers and the dimensions of water security addressed by their respective definitions. For the purpose of this research, a comprehensive and relevant definition of water security is necessary to be adopted as the working definition i.e. the definition as given by UN-Water [2]:

"The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability."

Table 3: Definitions and Dimensions of Water Security

Author / Institution	*Year*	*Definition of Water Security*	*Dimensions of Water Security Looked at*							
			Availability	Affordability	Accessibility	Adequacy	Quality / Safety	Sustainability	Environment / Ecosystem	Others
UN-Water [2]	2013	The capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability.	✓	✓	✓	✓	✓	✓	✓	livelihood human well-being socio-economic development water-related disasters political stability
Norman et al. [94]	2010	Sustainable access, on a watershed basis, of adequate quantities of water, of acceptable quality, to ensure human and ecosystem health	✓		✓	✓	✓	✓	✓	human health
Savenjie and Van der Zaag [95]	2008	Water security implies ensuring that: Freshwater, coastal and related ecosystems are protected and improved; Sustainable development and political stability are promoted; Every person has access to enough safe water at an affordable cost to lead a healthy and productive life; and The vulnerable are protected from the risks of water-related hazards.	✓	✓	✓	✓	✓	✓	✓	political stability livelihood human well-being water-related hazards
Grey and Sadoff [89]	2007	The availability of an acceptable quantity and quality of water for health, livelihoods, ecosystems and production, coupled with an acceptable level of water-related risks to people, environments and economies	✓			✓	✓		✓	health livelihood water-related risks economy
de Loe et al. [90]	2007	Water security is a multi-dimensional concept that recognizes that sufficient good quality water is needed for social, economic and cultural uses while, at the same time, adequate water is required to sustain and enhance important ecosystem functions.	✓			✓	✓		✓	socio-economy cultural
Falkenmark [91]	2001	water security is linked to a safe water supply and sanitation, water for food production, hydro-solidarity between those living upstream and those living downstream in a river basin and water pollution avoidance so that the water in aquifers and rivers remains usable, i.e. not too polluted for use for water supply, industrial production, agricultural use or the protection of biodiversity, wetlands and aquatic ecosystems in rivers and coastal waters.	✓		✓		✓		✓	water sanitation water pollution
Global Water Partnership [92]	2000	Water security, at any level from the household to the global, means that every person has access to enough safe water at affordable cost to lead a clean, healthy and productive life, while ensuring that the natural environment is protected and enhanced.	✓	✓	✓	✓	✓		✓	livelihood

2.6.2 International Definition of Energy Security

The concept of energy security, as stated by Lesbirel [96], is a contestable concept similar to the definition of security. It first emerged in the 1970s where supply disruptions and price volatility caused the Organization of the Petroleum Exporting Countries' (OPEC) oil embargo in 1973 and Iranian revolution in 1979 [97]. The notions or definitions of energy security may vary from country to country depending on their respective energy profile or national conditions [98,99], or through time where it evolves and adapt as new dimensions such as supply of oil products, energy sources, and sustainability emerge as important factors of energy security [60]. Widely used measures of energy security are the 'four A's' of energy security namely availability, accessibility, affordability and acceptability [100]. Early definitions of energy security were specifically focused in nature such as to quickly recover from shocks to energy supply or infrastructure [101] or to have continuous uninterrupted availability [102]. APERC [100] included the economic performance while Sovacool and Brown [99] included the environmental dimension.

Table 4 shows a collection of energy definitions developed by various institution over time alongside the dimensions of energy security explicitly addressed. For the purpose of this research, one of the most recent and updated definitions, given by IEA [103], is adopted as the working definition for this research:

> *"The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance."*

Not only does this definition incorporate the necessary dimensions which evolved over time through other definitions, it also explicitly includes the notions of long-term and short-term aspects of energy security. For a case such as the WEF nexus in this research, where part of measuring security is predicting and analysing trends and behaviours of security dimensions, it is necessary to include the notion of time period.

Table 4: Definitions and Dimensions of Energy Security

Author / Institution	*Year*	*Definition / Description of Energy Security*	*Dimensions of Energy Security Looked at*						
			Availability	Affordability	Stability (no interruption)	Reliability (Responsiveness)	Economic	Environment	Others
IEA [103]	2014	The IEA defines energy security as the uninterrupted availability of energy sources at an affordable price. Energy security has many aspects: long-term energy security mainly deals with timely investments to supply energy in line with economic developments and environmental needs. On the other hand, short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance.	✓	✓	✓	✓	✓	✓	long-term aspects short-term aspects
Nuclear Energy Agency, OECD [104]	2010	Security of energy supply is the resilience of the energy system to unique and unforeseeable events that threaten the physical integrity of energy flows or that lead to discontinuous energy price rises, independent of economic fundamentals.		✓	✓	✓	✓		physical integrity
Sovacool and Brown [99]	2010	energy security should be based on the interconnected factors of availability, affordability, efficiency, and environmental stewardship.	✓	✓				✓	efficiency
Energy Research Centre of the Netherlands [102]	2007	A secure energy supply implies the continuous uninterrupted availability of energy at the consumer's site.	✓		✓				
APERC [100]	2007	energy security as the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy.	✓	✓		✓	✓		sustainability
Onamics [101]	2005	The ability of a country to protect itself from, or quickly recover from, sudden or prolonged shocks to the country's energy supply or infrastructure	✓		✓	✓			infrastructure

2.6.3 International Definition of Food Security

The official declaration of food security definition began as early as 1974 when the World Food Conference focused on food supply and defined food security as “Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices” [105]. Similar to water and energy security definitions, food security definition has evolved over time to include other dimensions such as access, food safety, nutrition, stability as well as preferences. This is due to the evolving nature of human needs and wants, as well as the improving quality of human lives. Maxwell [106] paid special attention to poor and vulnerable especially women and children when defining food security. Hamm and Bell [107] included social justice and cultural acceptability in his definition among many other dimensions.

Table 5 shows definitions and dimensions of food security developed by numerous authors / institutions. For the purpose of this research, the food security definition given by FAO in 2001 will be adopted as the working definition:

> *“Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.”*

Albeit it may not be the latest definition, it is most comprehensive compared to other definitions and is adopted by many other institutions and researchers. It is also the most comprehensive definitions compared to others.

Table 5: Definitions and Dimensions of Food Security

Author / Institution	*Year*	*Definition of Food Security*	*Dimensions of Food Security Looked at*									
			Availability	Economic Access	Social Access	Physical Access	Safety	Adequacy	Nutrition	Stability	Preferences	Others
Hamm and Bell [107]	2003	Food security is defined by a situation in which all community residents can obtain a safe, culturally acceptable, nutritionally adequate diet through a sustainable food system that maximizes self-reliance and social justice	✓				✓	✓	✓			cultural acceptability sustainable food system self-reliance social justice
FAO [108]	2001	Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life	✓	✓	✓	✓	✓	✓	✓	✓	✓	
USAID [109]	1999	When all people at all times have both physical and economic access to sufficient food to meet their dietary needs for a productive and healthy life.	✓	✓		✓		✓	✓			
FAO [26]	1996	Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.	✓	✓		✓	✓	✓	✓	✓	✓	
Maxwell [106]	1988	A country and people are food secure when their food system operates in such a way as to remove the fear that there will not be enough to eat. In particular, food security will be achieved when the poor and vulnerable, particularly women and children and those living in marginal areas, have secure access to the food they want		✓	✓	✓				✓	✓	food system
Reutlinger and Knapp [110]	1980	the probability of per capita consumption falling below a specified level										threshold

2.7 Millennium Development Goals (MDG)

At the turn of the millennium in 2000, leaders from around the world came to a consensus that fighting poverty in its many forms is necessary [111]. Amongst the goals erected by the agenda, two align well with the WEF security nexus interests such as:

- Goal 1: Eradicate poverty and hunger
- Goal 7: Ensure environmental sustainability

Goal 1 concerns closely with the affordability dimension of food suitability where the focus of the goal was to ensure that hunger was eliminated by means of ensuring population would not live on less than \$1.00 a day. Goal 7 is concerned with climate and resources, such as water and air pollution from human activities. Resource and environmental indicators such as population access to improved drinking water and sanitation as well as CO_2 emissions are very important factors in achieving goal 7. From goals 1 and 7 of Millennium Development Goals, it is seen that WEF security nexus ideals align well with it.

2.8 Sustainable Development Goals (SDG)

Upon expiry of MDG, Sustainable Development Goals (SDG) was setup to follow up with the MDG. The SDG, which runs from 2016-2030, improved from the MDG by having more goals (from 8 to 17) and is more inclusive and comprehensive. Of significant relevance to WEF security nexus are the following goals [22]:

- Goal 1: End poverty in all its form everywhere
- Goal 2: End hunger, achieve food security, and improved nutrition and promote sustainable agriculture
- Goal 6: Ensure availability and sustainable management of water and sanitation for all
- Goal 7: Ensure access to affordable, reliable, sustainable, and modern energy for all

The transition from MDG to SDG shows that the principles and goals as highlighted are in alignment with those from WEF security nexus.

2.9 Developed VS Developing Country

Understanding the meaning and differences between developed and developing countries will help the understanding of WEF security nexus in a few ways. First, criteria that differentiates a developing country from a developed one would provide a guide to relevant indicators necessary to be addressed in the WEF security nexus. Second, it provides an understanding to the current development level of Malaysia. As such, this section takes a brief look into a few criteria which forms the basis of comparison.

A developing country is a sovereign nation where its Human Development Index (HDI) is low and its industrial base is less developed [112] whilst the opposite is true for a developed country. Although there are no single set of agreed-upon criteria which differentiates the two types of countries [113], economic measures such as gross domestic product (GDP), gross national product (GNP), per capita income, standard of living, facilities, and etc. are among the criteria used for evaluation [114]. Table 6 shows a comparison in criteria between developed and developing countries, as compiled according to [114,115].

Table 6: Comparison of Developed and Developing Countries Criteria

Criteria	*Developed Countries*	*Developing Countries*
Human Development Index (HDI)	High	Low
Poverty	Low	High
Birth rate	Low	High
Death rate	Low	High
Infant mortality rate	Low	High
Life expectancy rate	High	Low
Per capita GDP	High	Low
Per capita income	High	Low
Standard of living	High	Low
Unemployment	Low	High
Education standards	High	Low
Healthcare standards	High	Low
Food security	High	Low
Water security	High	Low

2.10 Tenth and Eleventh Malaysia Plan

The Tenth Malaysia Plan has concluded as it ran from 2011 to 2015 [116]. The programs which were implemented in the tenth Malaysia Plan do have very close relevance to the WEF security nexus such as [116]:

- Focusing on key growth engines, which concerns around national key economic areas (NKEA). Of particular interest to the WEF security nexus are oil and gas, palm oil, electrical, and agriculture.
- Improving quality of life by providing efficient public utilities and services such as water and energy facilities.
- Enhancing environmental-friendly efforts by encouraging reduction of carbon footprint and promoting renewable energy.

Some major achievements of the Tenth Malaysia Plan of concern for the WEF security nexus are increases of rural electricity and water supply to 98 % and 94 % respectively, 95 % penetration for clean and treated water, and agricultural GDP contribution of RM 455 billion [117]. Subsequently, the next phase of national development plan is the Eleventh Malaysia Plan which runs from 2016 to 2020. In Eleventh Malaysia Plan, six strategic thrust were laid out, with which thrusts pertaining to WEF security nexus are:

- Pursuing green growth for sustainability and resilience
- Strengthening infrastructure to support economic expansion.
- Re-engineering economic growth for greater prosperity.

2.11 Review on the Status of Water, Energy, and Food in Malaysia

This section is to provide a review and understanding on the WEF sectors in Malaysia individually, looking into the general status can current efforts in each sector, as well as to present key attributes on each sector respectively. This is accomplished by a broad and expansive literature review into each respective sectors before examining each of them to necessary depth. The aim of doing so is to establish knowledge on the current state of affairs, problems, strengths, and weaknesses in each respective sector.

2.11.1 Water Resources, Supply, and Management in Malaysia

The water sector in Malaysia largely consists of two parts, namely water supply as well as water treatment and distribution. Prior to 2006, governing and managing the water sector were responsibilities of the federal government. As a result of a restructuring exercise in 2006, these responsibilities fell upon several bodies, namely the Ministry of Energy, Green Technology and Water (KeTTHA), which is responsible for setting water sector-related policies; state governments, which manages existing water basins and identifying new ones when required; the National Water Resource Council (NWRC), which coordinates with the state governments in water management issues; the National Water Services Commission, which is in charge of all regulatory matters based upon policies set by the federal government, and finally, the federal government, which is responsible for holistic policy-setting and direction. The change, alongside partial privatisation of water treatment plants, were positive as reflected in the increasing coverage and quality of water services provided in the country. In 2005, 13.2 km^3 of water was withdrawn in Malaysia, then divided into three similarly-sized constituents i.e. 36% for industries, 34% for agriculture, and 30% for municipalities [118]. Despite the lower water withdrawn proportioned for agriculture in Malaysia compared to the global statistics, it remains one of the major sectors requiring substantial amount of water. Out of the total water withdrawn, 96.94% was surface water, 3% was groundwater, and 0.06% was desalinated water.

In the 11th Malaysia Plan spanning the duration between 2016 to 2020, a framework of six strategic thrusts and six game-changers were outlined to propel Malaysia into a developed nation by 2020 [48]. One of the strategic thrusts, 'Strengthening infrastructure to support economic expansion', focuses on infrastructure investment in various industries, which includes the water and energy sectors. Under the section, key issues related to water nationally were highlighted i.e. high non-revenue water tariff, which resulted in unsustainable independent operation of water services, low water coverage in rural areas, and high operational costs. Consequently, four strategies were laid out – raising financial sustainability of the water industry, expansion through technology investments, optimizing water industry and operation services, as well as strengthening the regulatory framework, aimed to address and eliminate the issues in the coming five years.

Lee et. al. [119] in their investigation of rainwater harvesting (RWH) as an alternative water resource in Malaysia identified five challenges i.e. environment, policy, technological, social, and economic stand in the way of RWH development in Malaysia and came to the conclusion that inter-ministerial and multi-stakeholder co-operations are required in order to move forward.

Kim [120] conducted a study on the water sector reform in Malaysia looking into understanding the policy process of water sector reform, the extent at which the reform contributed to its objectives, and the improvements brought about by the reform in terms of operational efficiency and environmental effectiveness of water utilities. Some notable findings include the lack of and limited use of performance indicators in Malaysia's water industry, mixed results in the effectiveness of outputs of the reform, and the move to centralize water management within public was representative of global trend.

In 2013, Malek et. al. [121] looked into issues faced by the water sector in Malaysia and found that among the problems are water tariffs, pricing, sectorial water management and development of Science, Technology and Innovation (STI). It was also put forward that Malaysia is still in Water Supply Management (WSM) mode, a characteristic of a developing country, as opposed to Water Demand Management (WDM) mode, a characteristic of a developed country.

Apart from that, recent news proved that water security confidence in Malaysia has indeed been shaken. Malaysian industries were put in alarm for water crisis as El Nino hits the nation in the first half of 2016 [122,123]. Johnson's article [124] showed that Malaysians may not be on the same page as to what causes the water crisis and what is the most effective response for it. On top of that, the drought has also demonstrated the importance of water-food links in Malaysia as paddy farmers in Perlis did not manage to complete their first planting season [125]. More recently, the contamination of Semenyih water treatment plant on 22nd September 2016 [126], which left large parts of Selangor without clean water for days, enhances the fact that water security is indeed one of the most, if not the most, pressing concerns for Malaysia.

2.11.2 Energy Resources, Supply, and Demand in Malaysia

Malaysia is one of the world's exporter of liquefied natural gas (LNG) [127], and has based a large part of its revenues (40%) on oil exports. As of 2013, Malaysia has 98,315 trillion cubic feet (tcf) of proven natural gas reserves and 5.85 billion barrels of proven crude oil and condensate reserves [47]. Naturally, the country's electricity generation capacity is predominantly powered by gas (10,494.4 MW), followed by coal (8,066 MW), and hydro (2,149.1 MW) as of December 2015 [128]. The electricity sector is highly regulated and the national grid is operated by Tenaga Nasional Berhad (TNB) in Peninsular Malaysia, whilst two other grids are operated by Sabah Electricity Sdn Bhd (SESB) and Sarawak Energy Berhad (SEB) in Sabah and Sarawak respectively [129]. The Energy, Green Technology, and Water Ministry established three principal energy objectives in the National Energy Policy to guide the nation's development in the sector; the supply objective, which aims to ensure an adequate, reliable, high-quality and cost-effective supply of energy, the utilization objective, which aims to promote efficient utilization of energy, and the environmental objective, which aims to ensure that environmental sustainability is considered when producing and utilising energy [129].

In the 11th Malaysia Plan [48], the focus strategies related to the energy sector comprises of strengthening stakeholders' collaboration and coordination, ensuring and growing reliability and security of oil and gas supply sub-sector, managing supply diversity for electricity sub-sector, as well as improving its sustainability, efficiency and reliability. This came as no surprise as the issues highlighted in the energy sector were fragmented governance, security and reliability of supply, market distortion, lack of regulatory framework, and overdependence on fossil fuels [48].

Sharifuddin [130] presented a quantitative assessment on the energy security in Malaysia which conceptualizes energy security as having five core elements namely availability, stability, affordability, efficiency as well as environmental impact. The methodology utilises 35 indicators which were condensed from 400 indicators published by international institution. From his results it was found that Malaysia is performing well in terms of energy availability and affordability, whilst overall quite comparable to its Southeast Asian neighbours such as Indonesia, Thailand, Vietnam, and Philippines.

In 2011, Sovacool and Bulan [131] investigated on the drivers and challenges facing the Sarawak Corridor of Renewable Energy (SCORE) by performing interview and survey on selected representative sample of stakeholders in six categories namely technological, economic, political, legal, social, and environmental. A notable finding is that a holistic understanding of these dimensions is required to truly understand implementing projects like SCORE.

2.11.3 Food Supply, Security, and Agricultural Dynamics in Malaysia

One of the problem of the Malaysian agriculture contributing to its food security level is that Malaysia's agriculture largely produces cash crops as opposed to food crops [132]. The food security in Malaysia is mostly fulfilled by import, and that results in low self-sufficiency ratio for Malaysian food security. The major food imports are its staple food namely rice, wheat flour, cooking oil, and sugar [50]. 80% of Malaysia's rice requirement is produced locally while the rest has to be imported [133].

Bala et al. showed, through SD modelling of food security in Malaysia, that in order to improve Malaysia's self-sufficiency level in rice production, the best policies would be to prioritize bio-fertilizers over subsidies on agricultural input, to fund research and development of hybrid varieties, to explore the possibility of increasing cropping intensity, to adjust policy encouraging more support for improved rice production technologies, and to use up all available land for rice production before using them for high value cash crops [134].

Rezai et al. [135] investigated the potential of urban agriculture to address food security in Malaysia and has found that it is possible. However, special attention need to be given to the fact that different income groups perceive food security differently and that food security is highly correlated with earning power. This is because urban agriculture are more widely-adopted by middle to high income earners whilst the issue of food security are more prominent among low income earners.

Amin and Ahmed performed a 50-year time frame simulation on the impact of climate change on food security in Malaysia, alongside discussing Malaysia's readiness in facing climate change in terms of policy. Initially, it was found that Malaysia's food sustainability gap is 30-35% below the national target in 2015. Applying adaptation strategies ranging from management related instruments, infrastructure related instruments, and community initiated instruments showed that the gap can be closed considerably over time [136].

2.11.4 Key Attributes of Water, Energy, and Food in Malaysia

A variety of strengths and weaknesses can be found when looking across the sectors of water, energy, and food sectors in Malaysia which could have caused the apparent disconnect between the sectors existing today. This is because the focus of each sector is obviously different. While the water sector deals with the problems of economic sustainability as a result of high percentage of high-revenue water, the highly regulated energy industry looks into encouraging green development and renewable penetration by means of feed-in-tariffs programs. On the other hand, food security in Malaysia is highly vulnerable to the exchange rate of its Ringgit (RM) against the US Dollar (USD) as Malaysian imports most of their necessary daily food. Meanwhile, the strength of the Ringgit is susceptible to fluctuations (or weakening) due to the recent oil price plummet considering Malaysia is an oil-producing country.

2.12 Systems Thinking

2.12.1 Comparative Analysis of Systemic Approaches

Upon establishing the requirements for methodology, it is natural to look into potential methods that can be employed in this research. This sub-section looks into the various systemic or holistic approaches available, provides a comparative analysis of them, and finally selects the best suited method. Over the years, a number of system approaches stemming from the philosophy of systems thinking have been developed and employed both in the industry and academic research. Initially, systems thinking is concerned with thinking holistically about a problem whilst considering various factors together and then eventually coming up with a solution. However, different methodologies in approaching and performing systems studies emerged and were developed due to the different types of complexity and participants of problems at hand.

Before actually selecting the systems methodology to be used, it is rational to understand the nature of the research as well as the available methodologies developed. In 2003, Jackson proposed a comprehensive framework, system of system's methodology (SOSM) for systems methodology selection based upon the nature of the problem at hand which is the complexity of the system as well as considering the participants involved [137]. Due to its elaborate effort in systematically considering the dimensions of the problem, Jackson's framework will be employed in the methodology selection for this research.

Table 7: Jackson's System of System's Methodology

		Participants		
		Unitary	*Pluralist*	*Coercive*
Systems	*Simple*	Hard Systems Thinking	Soft Systems Thinking	Emancipatory Systems Thinking
	Complex	System Dynamics Organizational Cybernetics Complexity Theory	Soft Systems Thinking	Postmodern Systems Thinking

From Table 7, it can be seen that systems problem can be divided into two - simple and complex; while the participants can be divided into three - unitary, pluralist, and coercive. The elaboration of the terms used are given as:

- Simple system – consist of few interactions and are unaffected by other parts of system or external factors.
- Complex system – large number of subsystems with roughly defined interactions where meaningful parts adapt over time as a response to unpredictable and unstable environment.
- Unitary participants – participants that have similar values, interests, and beliefs as well as share a common agreed-upon objective.
- Pluralist participants – participants may have compatible basic interest but have different values or beliefs. Space for debate and conflict are required whilst accommodations and compromises can be found.
- Coercive participants – participants have few common interest but have conflicting values and beliefs. Compromise is not possible.

2.12.2 Comparison of Unitary Complex System Solutions

Consequently, it is important to classify this research into the categories stated above before a systems methodology can be adopted. From the descriptions, this research namely the WEF nexus, can be categorized as a complex system with unitary participants because:

- The WEF nexus is a complex system consisting of large subsystems, namely the water, energy, and food sectors, interacting with each other in terms of social, economics, and environmental factors.
- The participant is unitary because the participants, namely key stakeholders from the water, energy, and food sectors as well as the general public share common interest of having best resource use efficiency and performance, improve livelihood, and minimize environmental damage.

Hence, the classification for this research is established as complex system consisting of unitary participants and the methodologies have been narrowed down to SD, organizational cybernetics, and complexity theory. Table 8 provides a comparative analysis of the three methodologies:

Table 8: Comparative Analysis of Unitary Complex Solutions

Methodologies	Requirement									
	qualitative	quantitative	holistic	feedback	relationship	behaviour	analysis of delays	handle complexity	multi- and trans-disciplinary	policy analysis
System Dynamics	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Organizational Cybernetics	✓	✓	✓	✓	✓	✓		✓	✓	
Complexity Theory	✓	✓	✓	✓	✓	✓		✓	✓	

From the methodology requirement description, it can be seen that the WEF nexus is in fact a large complicated system in itself composing of subsystems, namely the water, energy, and food sectors, as well as technology, social, economics, and environment. As such, the SD methodology has been selected due to the following reasons:

- SD stems from the systems thinking philosophy which approaches problem in a holistic and systemic worldview.
- SD makes use of causal loop and stock flow diagram to exhibit the feedback nature of systems.
- SD take into account the time delays and non-linear relationships between variables which allows for analysing behaviours of key indicators in the WEF nexus over time.
- The causal loop diagrams are able to represent the relationships between the important key indicators of WEF nexus and thus able to provide a qualitative analysis platform.
- The stock and flow diagrams constructed from the understanding of causal loop diagrams are able to be simulated to give results in the form of values, tables, and graphs allow for quantitative analysis.
- SD have been used many times in the past in various multidisciplinary studies as well as in the resources and sustainability studies. Refer to Table 9.

2.13 System Dynamics (SD)

2.13.1 SD Background and Uses in WEF Relevant Areas

Prior to SD, the origins of SD can be traced back to the field of control theory [138]. SD was first introduced in mid-1950s by Forrester where he performed pencil and paper simulation on the dynamics between hiring and inventory decisions for General Electric [139]. In 1971, he demonstrated that within the context of a larger social system, efforts stemming from good intentions to improve the conditions of society and nation for a certain period of time could actually do more harm in the long term if the underlying principles for the well-being of society were not well understood [140]. Later on, Forrester, in an attempt to address the predicament of mankind, created WORLD1 and WORLD2 [141] which addresses the interrelationships between global population, industrial production, pollution, resource, and food. A famous model, based upon the previous WORLD2 model, was created in 1972 by Meadows et. al. [142] using SD method. Through the model, the authors attempted to explore and understand the behaviour of what contributes to sustainable feedback patterns. Since then, SD method has been employed in many studies and has also been acknowledged as a suitable and effective tool to understand complex problems [134,143,144]. SD method has also been used extensively in the field of resources, as illustrated in Table 9.

Table 9: System Dynamics Method adopted in WEF-related areas

Authors	***Year***	***Study Title***	***Field of Study***
Bala et. al. [134]	2014	Modelling of food security in Malaysia	Food security
Bala and Hossain [145]	2012	Modeling of Ecological Footprint and Climate Change Impacts on Food Security of the Hill Tracts of Chittagong in Bangladesh	Food security
Bala and Hossain [146]	2009	Modeling of food security and ecological footprint of coastal zone of Bangladesh	Food security
Chung et. al. [147]	2008	System Dynamics Modeling Approach to Water Supply System	Water supply
Feng et. al. [148]	2012	System dynamics modeling for urban energy consumption and CO_2 emissions: A case study of Beijing, China	Energy consumption
Ford [149]	1997	System Dynamics and the Electric Power Industry	Electric power
Holmes et. al. [150]	2014	Using System Dynamics to Explore the Water Supply and Demand Dilemmas of a Small South African Municipality	Water supply and demand
Hsu [151]	2012	Using a system dynamics model to assess the effects of capital subsidies and feed-in tariffs on solar PV installations	Electric power
Jiao et. al. [152]	2014	The effect of an SPR on the oil price in China: A system dynamics approach	Oil price

Naill [153]	1992	A system dynamics model for national energy policy planning	Energy policy
Ahmad [154]	2014	Using system dynamics to evaluate renewable electricity development in Malaysia	Renewable electricity
Samii and Teekasap [155]	2009	Energy Policy and Oil Prices: System Dynamics Approach to Modeling Oil Market	Energy policy and oil price
Akhtar et. al. [156]	2011	An Integrated System Dynamics Model for Analyzing Behaviour of the Social-Energy-Economic-Climatic System: Model Description	Social, energy, economic and climatic interactions
Davies and Simonovic [157]	2009	Energy Sector for the Integrated System Dynamics Model for Analyzing Behaviour of the Social-Economic-Climatic Model	Social, energy, economic and climatic interactions
Sun et. al. [158]	2016	Sustainable utilization of water resources in China: A system dynamics model	Water utilization
Vamvakeridou-Lyroudia and Savic [159]	2008	System Dynamics Modelling: The Kremikovtzi System	Water system
Xiao et. al. [160]	2016	Can China achieve its 2020 carbon intensity target? A scenario analysis based on system dynamics approach	Energy and emissions
Xi and Poh [161]	2013	Using system dynamics for sustainable water resources management in Singapore	Water Resource
Kotir et. al. [162]	2016	A system dynamics simulation model for sustainable water resources management and agricultural development in the Volta River Basin, Ghana	Water management and agricultural development

From the studies above, it can be seen that SD method has been widely used in a range of resource and sustainability studies. Most notably similar in terms of relation to the WEF nexus are Akhtar [156] and Davies' [157] works as they investigated on the social-energy-economic-climatic biosphere system which includes the water, energy, and food systems. Instead of analysing a particular system in isolation, SD emphasizes on the interfaces of sectors and focuses on the interdisciplinary relationships. As such, it is natural that SD deal with the broad behaviour of the system, as stated by Coyle [163]. Sterman described the link from natural to social science by stating that SD draws on socio-economics sciences because tools such as nonlinear dynamics and feedback control, which are derivatives from the development of mathematics, physics, and engineering, are applied to the behaviour of human [164]. It is a method to simulate dynamics of complex problems where insights can be generated to aid improving the overall system behaviour by formation of appropriate policies [165,166].

Apart from the listed studies above, SD method has also been used in various different type of studies such as electronic and electrical waste management [167], technological innovation systems [168], biodiesel policy analysis [169], drainage enterprise study [170], industry-academia and education quality relations [171], sustainability of low-income housing [172], and many others. This goes to show that SD method is indeed a versatile tool in terms of discipline and type of study.

2.13.2 Review of SD Modelling Processes

As SD methodology began, grew, and was adopted in many researches over the years, its modelling process, or sometimes known as SD process, has also been developed and evolved accordingly. From the SD researches, varying degrees of attention given to the modelling process can be seen. While SD' researches adopted a familiar framework as given by Sterman [164], a few did in fact presented alternative modelling process. Considering the various different scopes, boundaries, and depth of different SD research, it is natural that the modelling process is modified or innovated according to the research needs. An obvious similarity between all the modelling processes used is that they are all iterative in nature.

Forrester [173] provided a six step iterative modelling process from describing the system to implementing changes in policies and structures. Coyle [163] described the SD process (1. Problem definition 2. System description 3. Simulation model 4. Policy design) with relation to the results at each stage, with which they form an iteration opportunity to the previous steps. Lee et. al. [174] used a slight variation to the process where he combined 'triple bottom line (TBL)' methodology as the conceptual framework part with SD modelling process as the measurement tool. Espinoza [169] divided the methodology into three main categories of: (1) articulation of problem and conceptualization, (2) dynamic hypothesis formulation and (3) testing and analysis, with which it can be elaborated in 8 specific steps. Ha et. al. [175] provided a seven-step iterative systemic framework, which starts from developing understanding and ends with reflecting, that involves addressing stakeholders' mental models, systems structure as well as patterns and relationships. Jiao et. al. [152] constructed the modelling process in four general steps namely: (1) boundary setting, (2) CLD and SFD constructing as well as qualitative analysis, (3) equations constructing, and (4) theory and history simulation testing. Similarly, Lu et. al. [176] characterized the modelling process, as given by Jiao et. al. [152], into three categories instead of four: (1) model conceptualization, (2) model analysis and (3) model evaluation. Vamvakeridou-Lyroudia and Savic [159] used an 8-step iterative cycle starting from defining boundaries to testing alternative policies. Hosseini [177] developed a seven step modelling process sequencing from literature review, problem definition, conceptual modelling, mathematical modelling, model validation, model simulation, to scenario analysis. It can be seen that the modelling process generally consists of:

- Boundary selection / problem definition / model conceptualization
- Hypothesis formulation

- Equation settings
- Theory and history simulation
- Testing of model
- Policy and scenario evaluation

Sterman's [164] modelling process which consist of iterative steps of: (1) Problem articulation (2) dynamic hypothesis (3) formulation (4) testing and (5) policy formulation and evaluation; does largely include all of the elements mentioned above (other researches) and is conceptually concise. This modelling process has also been adopted readily in other researches such as [158,162,172,178].

2.14 Chapter Summary

From the analysis, it is evident that the knowledge base and understanding about and around the WEF security nexus is still at its infancy. With gaps in terms of measuring and comparing the performance of inter-resource efficiency, management, and synergies, the need to establish a measurement system from a new perspective is elaborated.

From Table 1, it can be concluded that previous WEF security nexus works were more qualitative in nature, have fair share of global and regional study, and range from themes of technological, economic, social, environment, to policy. From the qualitative frameworks that have been proposed for the different WEF security nexus context of study, they follow a similar pattern with which the three resources sectors surrounds a central focus, and has inputs in the forms of actors which results in outputs such as impacts, as illustrated in Figure 1. However, little has been achieved on the quantitative side especially when dynamics between the WEF security sectors are concerned, which shows that the state of WEF security nexus knowledgebase, at least in terms of quantification, is at its infancy. Whilst qualitative WEF nexus framework could demonstrate contextual inter-sectorial relationships on a high level and encompass necessary important elements, a lack of qualitative analysis on detailed-levels as well as quantitative follow up in most cases do not do justice to the high-level qualitative frameworks proposed. Besides that, there is also no established measurement for the wellbeing of WEF security nexus as a whole.

Malaysia on the other hand, has unique and different issues to deal with in each resource sector of the WEF, on top of being an emerging economy. No work has also been accomplished holistically on the WEF security nexus of Malaysia. Therefore, little empirical understanding exists regarding the relationships between water, energy, and food security in Malaysia. As such, it is highlighted here that there exists a glaring knowledge gap in the detailed-qualitative and quantitative analysis of WEF security nexus in Malaysia.

Chapter 3 Methodology

3.1 Introduction

Upon understanding the nature of WEF nexus' complexity, the knowledge gap, the research objectives of this research as well as the crucial topics surrounding the securities' issues, it is then possible to develop a methodology to establish a measurement system for the well-being of WEF nexus in Malaysia. This chapter first provides the research process flow, which would be a high-level representation of all works and steps performed for this research. Subsequently, this chapter provide detailed explanation on the two main methodologies involved, namely SD and stakeholder interview. Then, this chapter will discuss on the process of selecting indicators to be used in the construction of CLD and SFD. Finally, this chapter will also explain the verification and validation steps adopted in this research.

3.2 Research Process Flow

A research process flow provides a step-by-step illustration on all works performed in the research. Figure 4 shows the research process flow characterised by four distinct categories, namely literature and knowledge, modelling and simulation, verification and validation, and interview and stakeholder engagement. Additional details at every process step can be found at their respective subsection, as stated in each of their box.

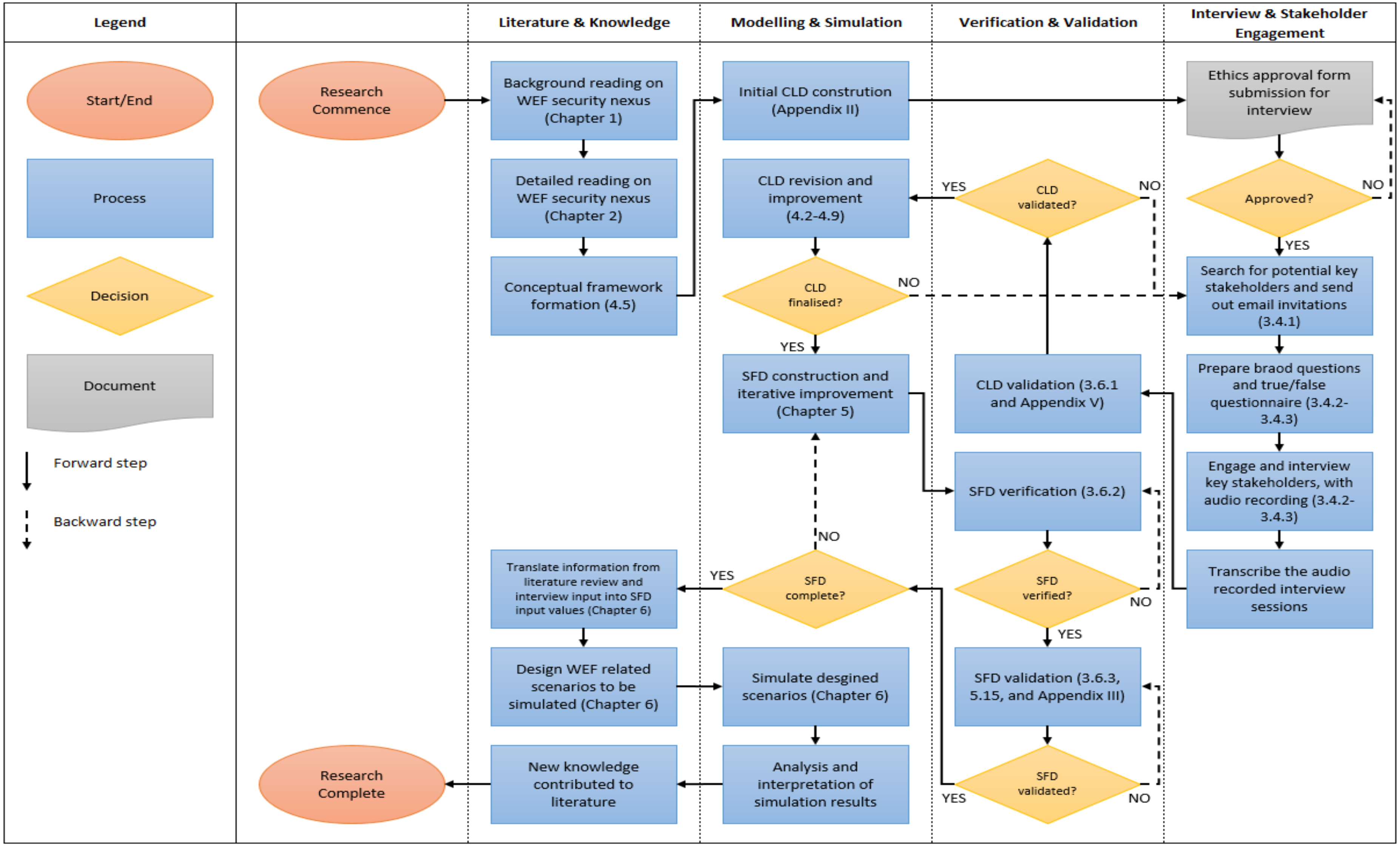

Figure 4: Research Process Flow

3.3 Components of System Dynamics

Before delving into the intricacies of the WEF nexus SD model, it is necessary for the basics and principles of SD to be established and well-understood. This sub-section elaborates the basic building blocks of SD model which would be inherent in the WEF nexus model.

3.3.1 Causal Loop Diagram (CLD)

A causal loop diagram (CLD) is a hypothetical representation of the dynamics of the system in study. It consists of the most important variables linked by arrows, which represents causal influences from cause to effect, with polarities attached at the head (+ or -) to denote the nature of the relation. A '+' sign means an increase in the cause will result in an increase in the effect while a '-' means an increase in the cause will result in a decrease in the effect. When the variables form a loop i.e. a variable causes a series of influence which eventually returns back on itself, an identifier can be labelled to denote if the loop is either positive feedback or negative feedback, and is usually positioned in the middle of the loop. Albeit many ways to represent the nature of these loops exist, a conventional way to identify them is a clockwise or anticlockwise (depending on the direction the loop is constructed) arrow circling either 'R', which represents reinforcing (positive) feedback, or 'B', which represents balancing (negative) feedback. As an example, consider the illustration of population CLD in Figure 5 below:

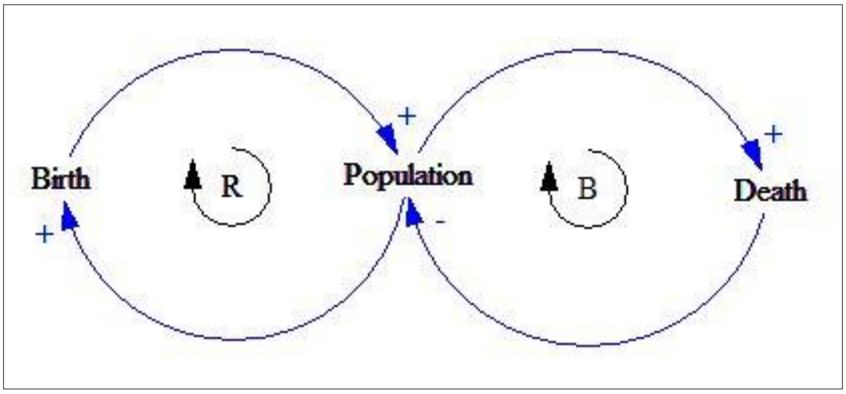

Figure 5: CLD of Population Model

Three variables were used to construct the CLD, namely birth, population, and death. Arrows (or causal links) exist from birth to population and vice versa, as well as from population to death and vice versa. On the left side of the CLD, a positive link exists from birth to population and from population to birth. This means that increasing birth will increase population, increasing population will in turn increase birth which will eventually result in even more increase in population, and so on so forth. Hence, population and birth form a reinforcing loop. On the right side of the CLD, a positive link exists from birth to population while a negative link exists from death to population. This means that increasing population will increase death, increasing death will however decrease population. It follows that decreasing population will decrease death and decreasing death will in turn increase population. Hence, population and death forms a balancing loop.

3.3.2 Stock and Flow Diagram (SFD)

From the population CLD in the previous sub-section, one may argue either population will grow exponentially out of control or reaches a certain stable state. This cannot be determined unless the model is converted into stock and flow diagram (SFD) and simulated with the corresponding numerical values. Stocks, as the term might imply, are anything than can accumulate over time be it material stock, information, and etc. Stock variables are represented in a box, as it signifies the 'container' that they are in. Flows, either inflow or outflow, are rates at which material or information are accumulating in or leaving the stock variable. As an illustration, consider Figure 6 below:

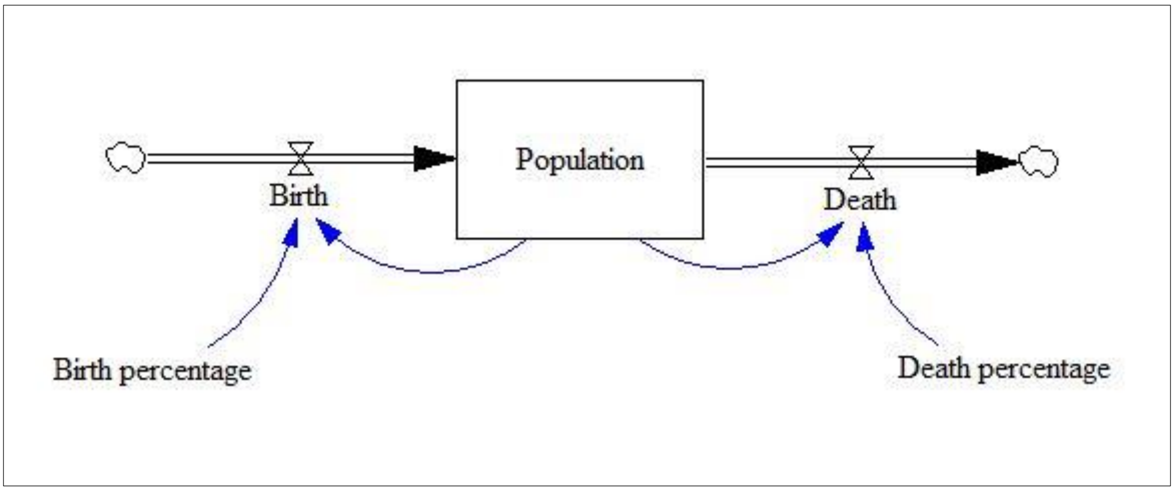

Figure 6: SFD of Population Model

From Figure 5, the population CLD can be converted to the SFD as shown in Figure 6. Population is a stock with birth as an inflow into population and death as an outflow from population. On top of that, variables birth percentage and death percentage has been introduced in the SFD while they were not in CLD. This is because for the SFD simulation to run, all necessary variables which make up the mathematical formulation required for calculating must be included. The mathematical equations for the population SFD can be given as:

$$\mathrm{Population(t)} = \left(\int_{t_0}^{t} \mathrm{birth(t)} - \mathrm{death(t)dt} \right) + \mathrm{Population(t_0)} \tag{1}$$

where Population(t_0) is the initial population

birth(t) = population(t) x birth percentage

death(t) = population(t) x death percentage

In general, the mathematical equation for all stock variables can be generalised as:

$$\mathrm{Stock(t)} = \left(\int_{t_0}^{t} \mathrm{Inflows(t)} - \mathrm{Outflows(t)\ dt} \right) + \mathrm{Stock(t_0)} \tag{2}$$

3.3.3 Delays Representations

Delay is defined as 'make (someone or something) late or slow' [179]. In SD, delays play intrinsic role in determining the behaviour and dynamics of the system and can be represented in several forms. For example, time variable and intermediate stocks are forms of delay. As an illustration, consider the following:

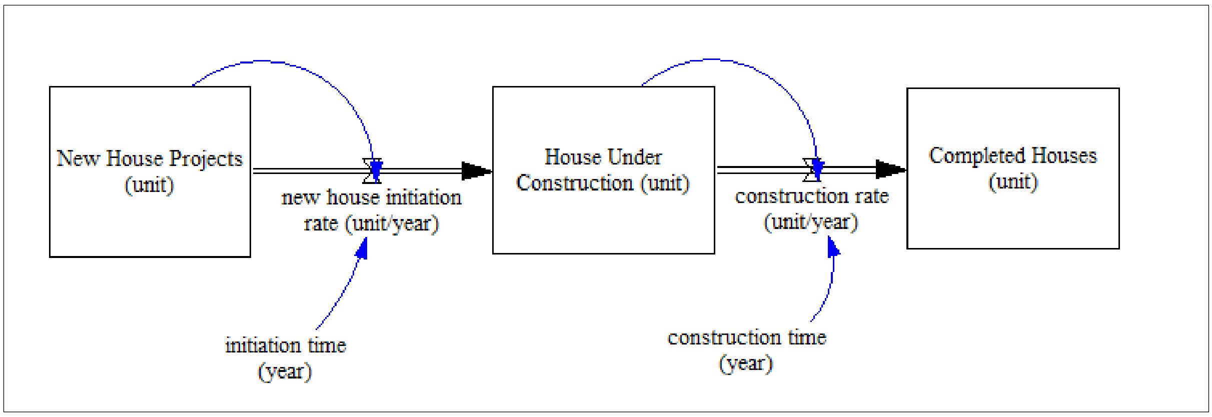

Figure 7: House Construction SFD

Figure 7 shows an SFD for new house construction. Before new house projects can become completed houses, they have to be constructed. One delay is the intermediate stock introduced, named as ‘House Under Construction (unit)’, to capture the amount of houses that are being constructed. Other delays are the two time variables namely initiation time and construction time. These two variables determine the speed at which ‘New House Projects’ becomes ‘House Under Construction’ and subsequently ‘Completed House’.

3.3.4 Minimum Values

In some cases, it is necessary to set a minimum value to variables to ensure that they stay within meaningful range. This is especially important in stock variables where it is highly likely that their level can be zero, or near zero. As an example, it would be impossible to continue to have a net positive drainage of water from an empty beaker, as illustrated in the Figure 8 below:

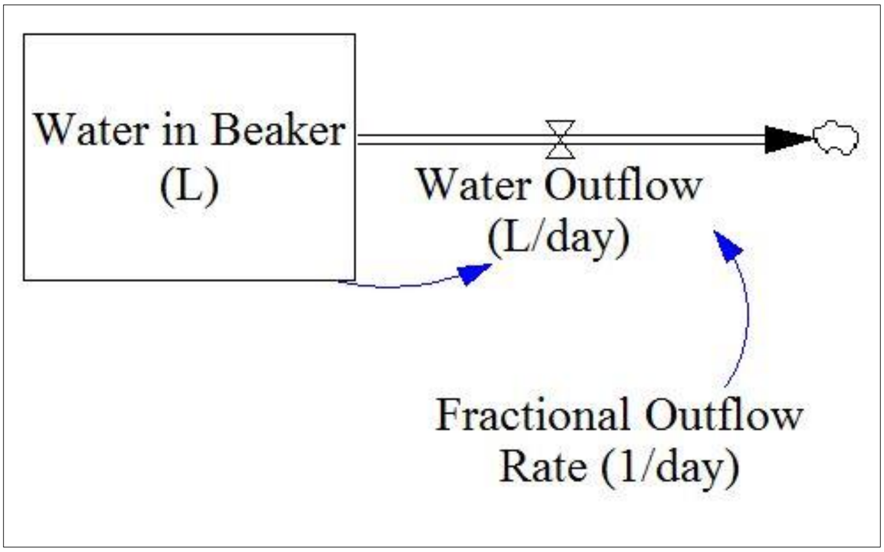

Figure 8: Minimum Values

Consider the SFD in Figure 8 where the stock “water in beaker” is continually being drained by the flow “water outflow”. When the level of water in “water in beaker” reaches zero, the “water outflow” variable should theoretically be zero. As such, an illustration of equation to set the minimum value of “water outflow” to zero is:

$$\text{Water Outflow} = \text{IF THEN ELSE(Water in Beaker} <= 0, 0, \text{Water in Beaker} * \text{Fractional Outflow Rate)} \tag{3}$$

3.3.5 Comparative Analysis of Software for System Dynamics

Although it is possible to model the entire CLD with pen and paper, it would be nearly impossible to calculate all the dynamics in the SFD using this method. Computer aided simulation is hence necessary as a moderate to large sized model, as expected of a WEF security nexus model, would incorporate plentiful of equations and data to be dealt with. A number of software that could perform SD are available. The aspects that have been taken into account when selecting software are:

- Computing power requirement
- Licensing fee of software
- Ability to perform Monte Carlo analysis
- Availability of software training
- Ease of use

Two notable software stands out, Vensim and Stella, in terms of computing power requirement, licensing fee, and ease of use. Both software are fairly similar in a sense that they require minimal computing power, reasonably low educational licensing fee, and are fairly user-friendly in their graphical user interface. Vensim has been picked over Stella because of the availability of software training in Vensim, which are in abundance throughout the internet.

3.3.6 The Modelling Process

Sterman's modelling process would be adopted and slightly revised for specifications for the purpose of this research (WEF Security Nexus), as illustrated in Figure 9:

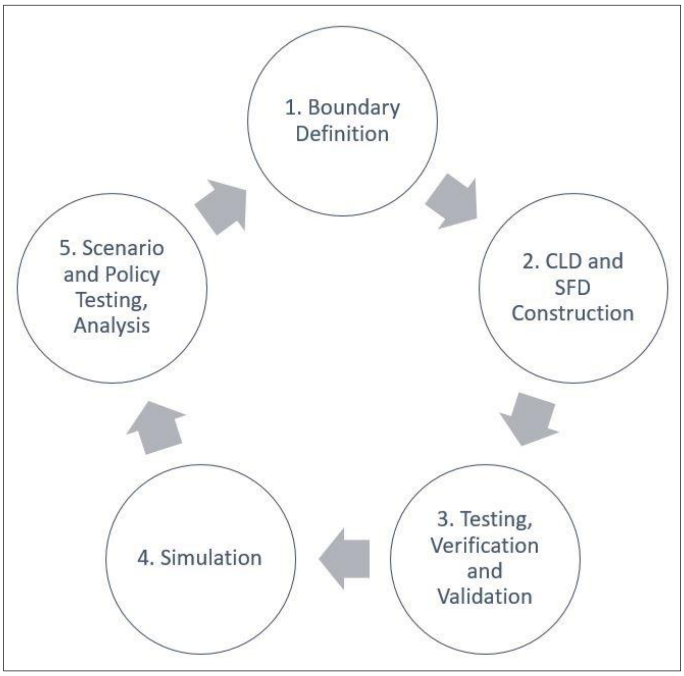

Figure 9: Modelling Process

The modelling process starts out with the (1) boundary definition. The term ‘Problem articulation’ has been used in Sterman’s model where stating the purpose of the model and identifying the problem becomes the first step. In the case of this research, a more specific step, namely resource security definition, has been initiated in section 2.6 where the problem of the study is addressed by setting the boundary of WEF nexus, by means of defining water, energy, and food security. This replacement of term from the original Sterman’s one is justified by the fact that the boundary defining process sets a selection criterion for the indices or indicators which are required by a WEF security nexus model which acts as a purpose of the model.

The second step is construction of causal loop diagram (CLD) and stock and flow diagram (SFD). The relationships formed in CLD and the structure of SFD are constructed from the variables identified. However, the CLD and SFD constructed remains a hypothesis until further tested, verified, and validated in step 3.

Steps 3 and 4 are slightly revised from Sterman’s original model in a sense that for this study, the author recognizes the need to test, verify, and validate the constructed CLD and SFD before running simulations of real cases in step 4. This is because the relationships formed between the identified indices or indicators of WEF security sectors, as exhibited in CLD and SFD, should mimic as real as possible to the reality before it is being simulated for real results in step 4.

Step 5 is the final step of the modelling process for which scenarios, policy testing and analysis provides suggestion of improvement for the WEF security nexus case for the system and in Malaysia. Although the modelling process has been sequenced from 1 to 5, it is iterative in nature meaning: at any one point where it is necessary to move back at or to any one step, then it is executed. This is because new data and understanding can be obtained from subsequent steps, which could inform on a better previous step. As an example:

1. The CLD is constructed (step 2) consisting of variables of A -> B -> C -> D -> A.
2. Validation steps in the form of interviews with professional in step 3 shows that variable C is not important and can be excluded.
3. The CLD is reconstructed (step 2) to be A -> B -> D -> A.

3.4 The Interview Process

A series of interviews were conducted with key stakeholders in Malaysia for the purpose of: (1) understanding the current status and problems of WEF sectors in Malaysia; (2) identifying key indicators for the WEF security nexus of Malaysia, and (3) as inputs to the construction of CLD and SFD. Information from the interviews will be used in several parts of the thesis namely in defining and understanding the resource security for Malaysia, identifying key indicators to model the WEF security nexus of Malaysia, scenario making and analysis, and discussion of results.

While section 3.3.6 details the entire system dynamic modelling process, specific methods, such as the carrying out interviews in step 3, within the process exists. This section provides more details on the specific steps to be taken during the interview processes.

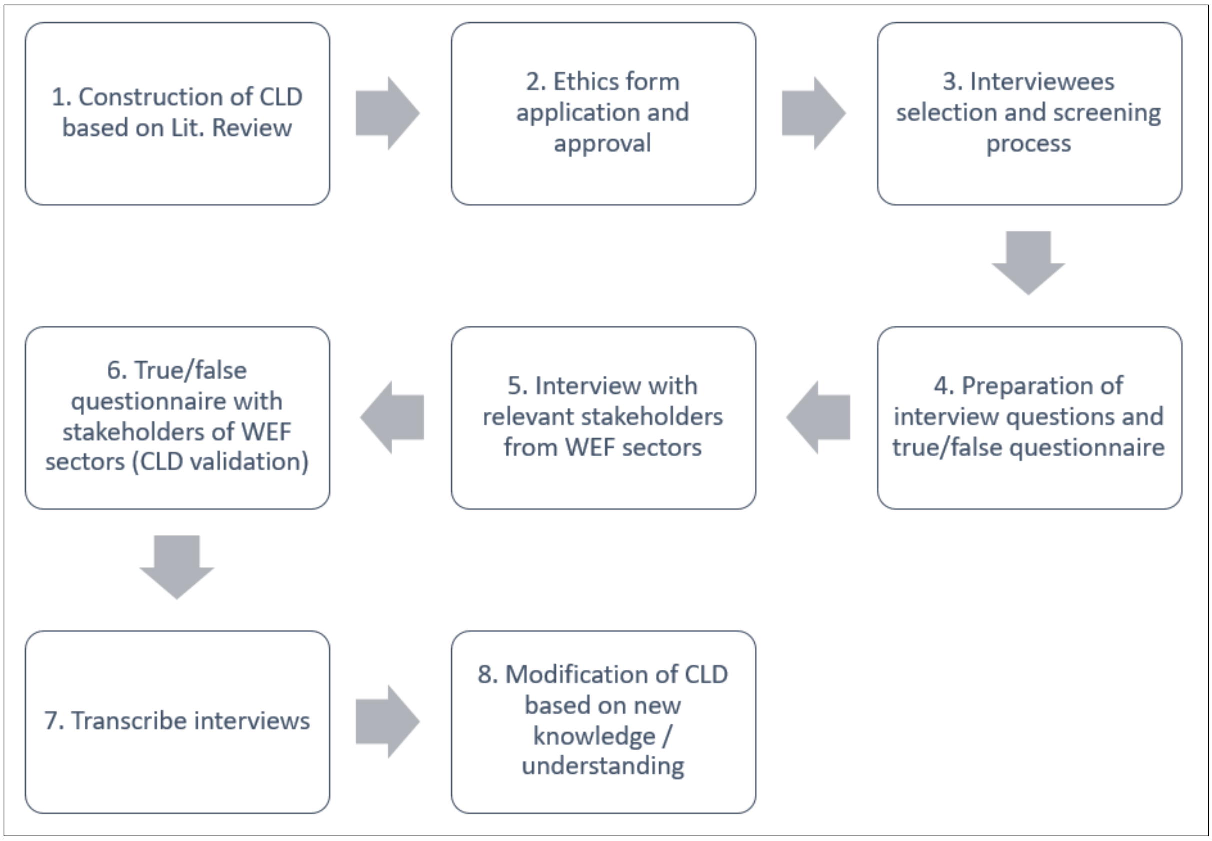

Figure 10: Interview Process

Figure 10 shows the interview process in constructing the CLD, SFD, and validating data. The entire process begins in step 1, namely constructing of the CLD based on Literature Review. This is necessary because:

- It provides a starting point for discussion during the interview
- It provides a background understanding to the interviewee, which could accelerate the learning curve of the interviewee which would
- Improve the quality of response from the interviewees

Upon completion of initial CLD construction, the ethics form is submitted to the university for approval. This is necessary because the research now involves interaction between representative of the university and external participants. This is a screening procedure as required by the university to assess the risks involved, to all the parties involved, namely the researcher, the external participant, and the university.

Interviewees selection process (step 3), preparations of interview questions (step 4), and true/false questionnaire procedure (step 6) are explained in the following subsections of 3.4.1, 3.4.2, and 3.4.3 respectively.

Step 7 is a transcription process where the audio-recorded interview sessions are being documented into text files. This is a manual process, where it allows for further re-examination of the interview sessions and for extraction of any information.

Step 8 is the modification of the CLD based upon new knowledge and understanding which were obtained in step 5 and step 6. As such, once the CLD has been modified, improved, and finalised, construction of SFD can begin.

3.4.1 Interviewees and Screening Process

Selecting correct interviewees is important, as they possess information relevant to the understanding of WEF security nexus and construction of the model. Therefore, this subsection explains the interviewees' selection and screening process.

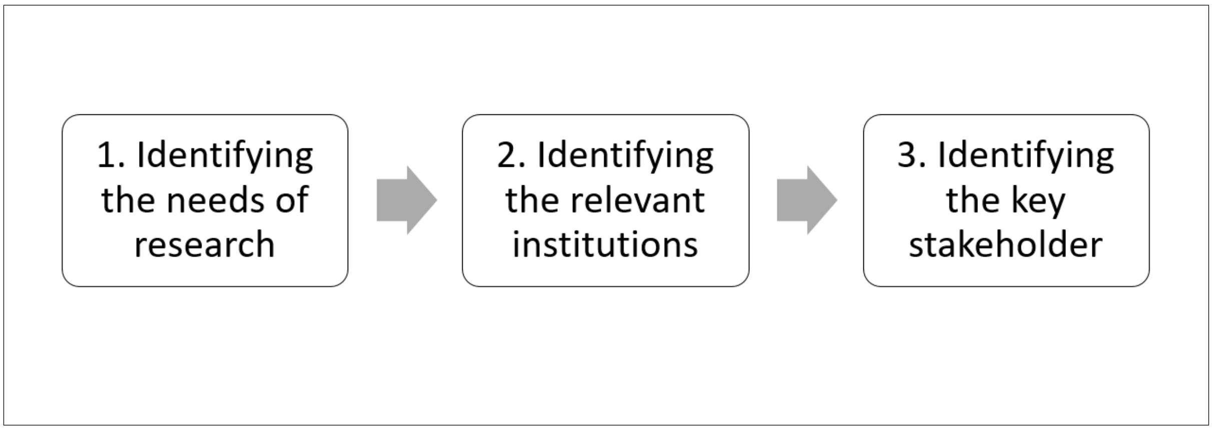

Figure 11: Interviewee Selection Process

Figure 11 shows the interviewees' selection process which consist of three steps, namely (1) identifying the needs of research, (2) identifying the relevant institutions, and (3) identifying the key stakeholder. Firstly, understanding the needs of the research, from the understanding acquired in literature review, would narrow down the search area of relevant institution. For this case, the research needs are framed as the WEF security nexus. As such, the second step allows for the identification of institution based upon the water, energy, and food sectors. Search of relevant institutes are done by searching the internet using the resource name followed by keywords such as ‘Malaysia’, ‘organisation’, ‘institute’, ‘department’, etc. Upon finding suitable websites of relevant institutes, search of key stakeholders is conducted by visiting their respective pages of personnel and peoples. Consequently, key stakeholders are selected based on their profile and positions as listed in the websites. Table 10 shows the list of key stakeholder interviews conducted, alongside their institutions and sectors involved.

Table 10: List of Interviews Conducted

Institution/Organisation	Key Stakeholders Interviewed	Sector
The Ministry of Energy, Green Technology and Water (KeTTHA)	(W1) Director-General	Water
The Ministry of Energy, Green Technology and Water (KeTTHA)	(W2) Director	Water
National Hydraulic Research Institute of Malaysia (NAHRIM)	(W3) Senior Researcher	Water
Economic Planning Unit (EPU)	(E1) Principal Assistant Director	Energy
Economic Planning Unit (EPU)	(E2) Special Officer from TNB	Energy
Crops for the Future (CFF)	(F1) Business Development Advisor	Food
Crops for the Future (CFF)	(F2) Chief Executive Officer	Food

3.4.2 Interview Questions Design

As the purpose of the interview is to obtain information that would be useful to the understanding of the research problem as well as to the construction of the model, the interview questions are designed with a few purposes in mind:

- to understand the status (problems, strengths, weaknesses) and definition of each resource
- to understand how each resource are related to each other
- to understand the importance and relevance of WEF within Malaysia’s governance and industry

As such, the interview questions, taking an example from energy sector, were designed and tailored to fulfil the following purposes:

To understand the status (problems, strengths, weaknesses) and definition of each resource

1. How would you define energy security?
2. How can we measure energy security?
3. What do you think of the energy security in Malaysia?

4. What are the strengths and weaknesses of energy security in Malaysia?

To understand how each resource are related to each other

5. What are the energy-water relationships that you know of?

6. What are the important elements in the energy-water nexus?

7. Do the Causal Loop Diagrams constructed represent the relationships between energy and water security in Malaysia accurately?

8. Are there additional elements which you think should be added to the CLD to show the relationships between energy and water security in Malaysia?

9. What are the energy-food relationships that you know of?

10. What are the important elements in the energy-food nexus?

11. Do the Causal Loop Diagrams constructed represent the relationships between energy and food security in Malaysia accurately?

12. Are there additional elements which you think should be added to the CLD to show the relationships between energy and food security in Malaysia?

To understand the importance and relevance of WEF within Malaysia's governance and industry

13. Have you heard of or have any understanding of the Water-Energy-Food Security Nexus before this interview?

14. Do you think that having a holistic understanding on the performance of the WEF Security Nexus in Malaysia is important? Why and Why not?

15. If yes, what do you think are important areas to look at when looking into the performance of WEF Security Nexus in Malaysia?

Consequently, depending on the responses received, individually tailored follow-up questions are then put forward to extract as much information as possible. The full list of questions, including water and food sector, are attached in Appendix IV.

3.4.3 True/False Questionnaire

There are two purposes of true/false questionnaire, i.e. to validate the constructed initial CLD and to identify errors in the CLD, such as additional/missing important variables and wrong connections. On top of that, interviewees are given the option to include their comments, which in hopes would lead to additional information on any particular causal link. This activity is performed on every link constructed in the CLD. A template of the questionnaire can be found in Appendix IV. An illustration on the construction of the true/false questionnaire is given below:

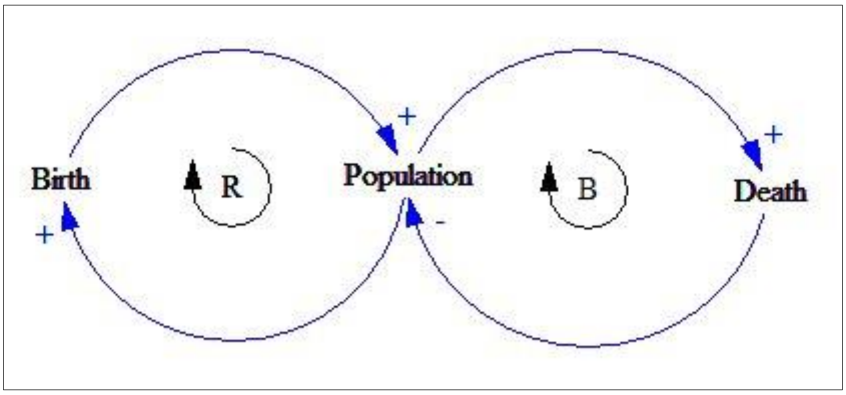

Figure 12: Population CLD

Figure 12 shows the population CLD from the model, which consist of four links, namely birth to population, population to birth, population to death, and death to population. As such, there will be four true/false validation required by the interviewee, as provided to them in a table form as illustrated in Table 11. Appendix IV contains the entire true/false questionnaire used in the research while Appendix V contains the completed questionnaire by the interviewees.

Table 11: Population True/False Validation

Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Population	increase in Birth				
increase in Population	increase in Death				
increase in Birth	increase in Population				
increase in Death	decrease in Population				

3.5 On Identifying, Selecting, and Linking Variables and Key Indicators

WEF security nexus is a broad topic and is expected to have many variables. However, a few variables (CLD) and key indicators (SFD) should be used to represent the wellbeing, sectoral balance, and sustainability of the system. This subsection outlines the process in identifying, selecting, and linking variables in both the CLD and SFD.

3.5.1 Variables Identification for CLD

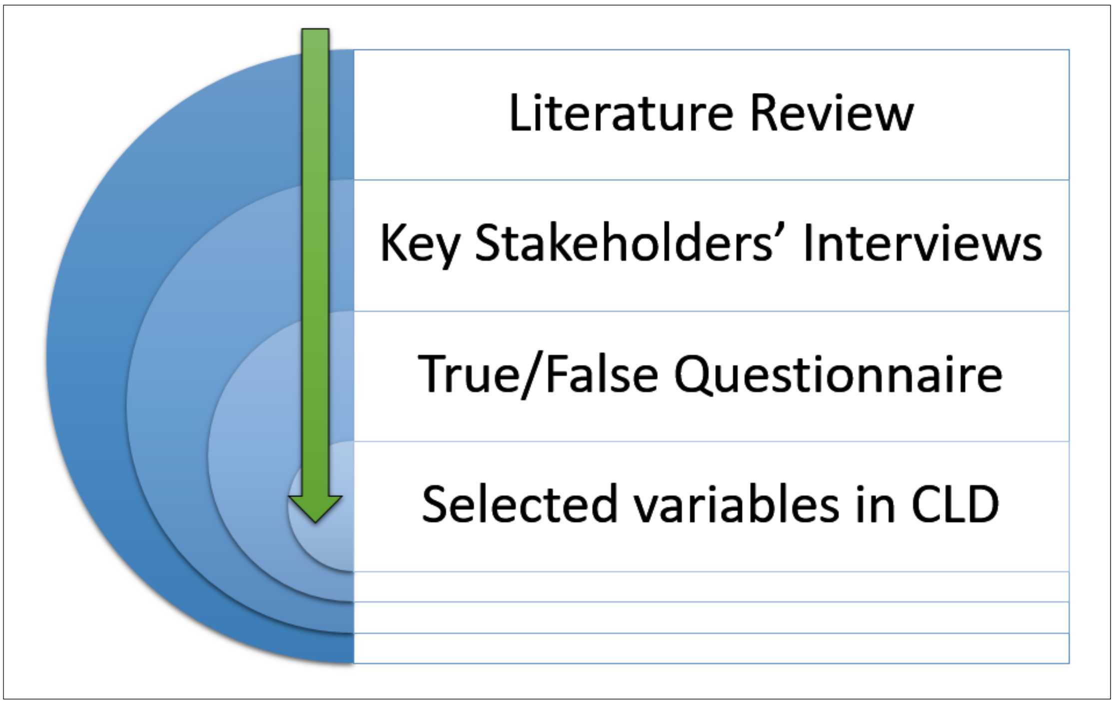

Figure 13: Variables for CLD

Figure 13 shows the variables selection process, where the variables are eventually constructed into CLD. The process begins with literature review and background reading into the area of interest, namely WEF security nexus, which would result in a large vocabulary of indicators. As the reading and understanding becomes more focused, such as into Malaysian WEF problems, the number of indicators that remain would be reduced. Interview with key stakeholders would cut down even more indicators, as the experts are able to provide a much clearer and updated information on the current status of Malaysian WEF. Subsequently, the key stakeholders helped by answering the true/false questionnaire provided clarity and improvement onto the initial CLD. Finally, the CLD is finalised with the selected variables in it. As an illustration of the process, consider the water supply, treatment, demand, and tariff loop. Initial reading into water sector showed that important factors of water security are such as adequacy, livelihood, water pollution, water-related disaster, socio-economic development, groundwater hydrology, surface water, and many others. A more targeted reading into Malaysia water issues revealed the problems of disconnect in governance and financial issues. An initial CLD on the sector was formed in Figure 126 in Appendix II, which improved into a more accurate and complete CLD in Figure 18 because of key stakeholder interviews and true/false questionnaire.

3.5.2 Key Indicators for SFD

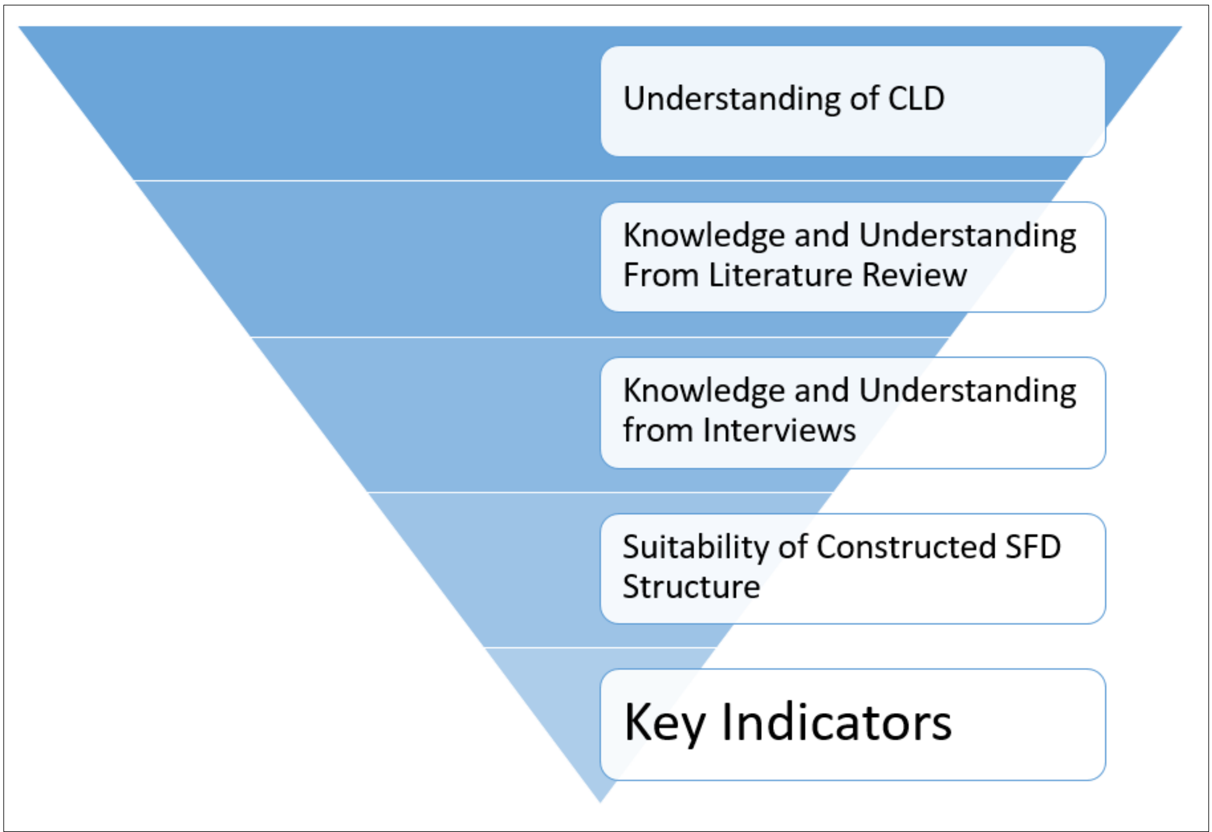

Figure 14: Key Indicators for SFD

Figure 14 shows the process for which the key indicators were identified. As opposed to the identification process of variables in CLD, identification of key indicators that can be simulated in the SFD begins with first understanding the constructed CLD. This is important because CLD, which maps the mental models onto a graphical representation, demonstrates and describe the research problem currently at hand while keeping the modeller within acceptable guidelines that have already been decided. For example, water-related disaster key indicators are left out regardless of how important they are elsewhere in the world because the CLD does not capture variables related to water-related disaster. Subsequently, similar to the identification of variables in CLD, the narrowing down of variables by knowledge and understanding follow the order from literature review to interview inputs. Finally, recognising and adapting to the suitability of constructed SFD structure while selecting key indicators is important. This means that the key indicator selected or created should fit in with the SFD variables, especially in terms of dimensional consistency. For example, if the constructed SFD contains variable of "electricity used per year (kWh/year)" and "water treated per year (L/year)", a potential suitable indicator to be added could be "electricity used per L water treated (kWh/L)" instead of "mass of coal burnt per L water treated (kg/L)".

3.6 Verification and Validation

Whilst verification is concerned with building the model right, validation is about building the right model [180]. For the case of SD, verification would mean the model constructed correctly from a technical viewpoint such as obeying physical laws, dimensionally consistent, having correct equations, and etc. On the other hand, validation would mean the model constructed represents reality as much as possible. Albeit the differences, the purpose of verification and validation is to provide confidence to the user, audience, and modeller.

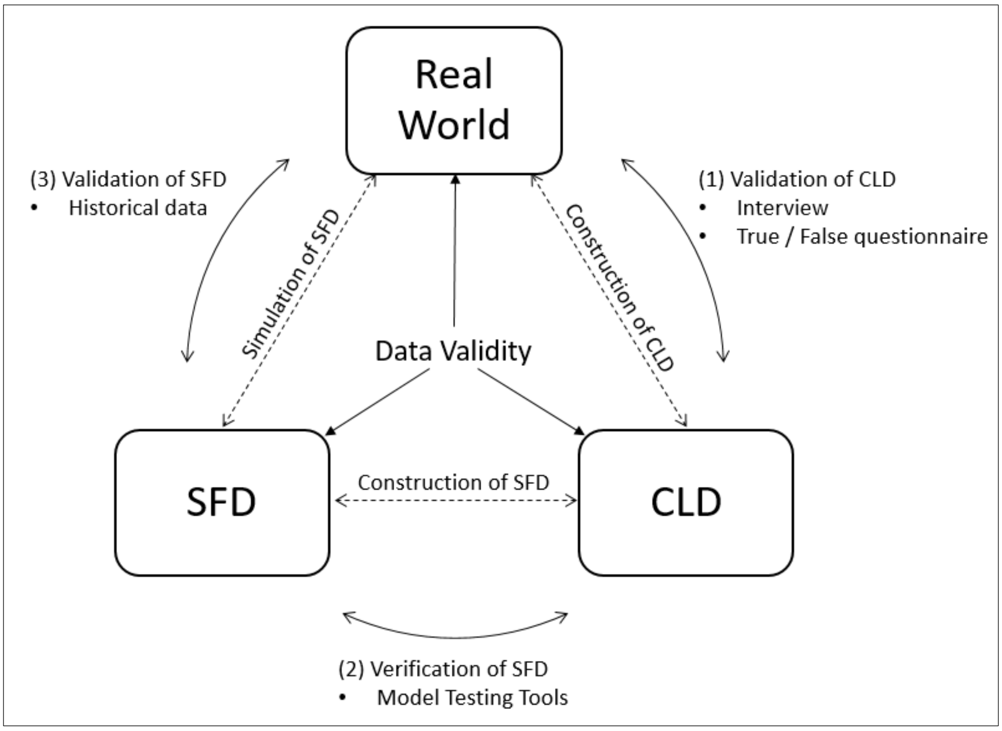

Figure 15: V&V Model

Despite many modellers claiming to have fully verified and validated their model, it has been noted multiple times, by experts in SD and simulation, that fully verifying and validating a model may not be feasible. Sterman [164] deems verification and validation of SD model, or modelling in general, to be impossible. Instead he described that a model should be 'fit for purpose' [164]. Coyle [163] similarly noted that it is inappropriate to use the term 'validation' as it implies the model would become real and true, and preferred to regard it as 'well suited to a purpose and soundly constructed'. Barlas [181] argued that it is impossible to provide validation of a model without discussing about its purpose. Similarly, Sargent [182] proclaims that model validation should be determined with respect to its purpose. Also as Forrester and Senge [183] put it - 'Validity is also relative in the sense that it can only be properly assessed relative to a particular purpose.’ However, model verification and validation is necessary and important, even in SD, as it provides a level of confidence the built model is meaningful.

Figure 15 illustrates the verification and validation plan as adapted from Sargent [182] and Martis [184]. Data validity means to ensure that the data involved at every stage of the modelling process is accurate and correct [182]. Verification and validation for this research is divided into three parts namely - (1) validation of CLD models; (2) Verification of SFD models; and (3) Validation of SFD model. The details of these procedures will be elaborated in the ensuing subsections (3.6.1-3.6.3).

3.6.1 Validation of CLD Models

The validation of CLD is perform using two steps namely interview with key stakeholders, as listed in Table 10, in relevant field, and a true / false questionnaire on all the relationships formed in the CLD. The interview provides a high-level top down approach on validating and understanding the relationships within the WEF nexus on top of helping to identify key indicators important in the WEF nexus. Upon completion of the interviews, a more concrete analysis on the CLD where the interviewees were given a series of true / false questionnaire for every relationship constructed in the CLD. As such, not only are broad understanding and high-level perspective were obtained, but detailed information and specificities at intricate levels were understood as well.

3.6.2 Verification (Testing) of SFD Models

For verification of SFD models, model testing tools as provided by Sterman [164] were adopted. The model testing tools are boundary adequacy, dimensional consistency, parameter assessment, extreme condition, and integration error. Whilst verification for this section may take place anywhere and anytime throughout the entire modelling process, majority of the verification happens when constructing the SFD.

Boundary Adequacy

Boundary adequacy is concerned with if the key indicators identified are enough and substantial to describe the system, as well as if any key indicators should or should not be endogenous to the model. Whilst literature review and interview did help to identify key indicators, additional steps of including and excluding variables before and during construction and simulation of the SFD were performed and their results observed. For example, a conceptual framework, given by Figure 16, is established to capture all factors and issues relevant to the WEF security nexus of Malaysia, where definitions of resource security were used in its construction.

Dimensional Consistency

Dimensional consistency test ensures that the units of every variable are consistent, especially when their relationships are described and processed through equations during simulation. Vensim's built-in function of 'Units check' performs this verification well. The 'Units check' function is a reliable tool that investigates the entire model and provides a list of errors in the form of missing units and units mismatch. This ensures that all variables have been inputted with units and they are consistent with each other based on the equations constructed. On top of that, a list of variables, units and equations are provided during the construction of SFD in chapter 6. This allows an additional step of validation, through manual inspection.

Parameter Assessment

Parameter Assessment deals with the estimation of numerical values of variables and ensure that they are consistent with reality. Four techniques have been employed for this research namely extensive literature review, partial model tests, disaggregate model test, and judgemental estimation. Partial model tests are used to calibrate the subsystems before the final model is complete while disaggregate model tests are used exclusively to validate a single subsystem or stock and flow structure, as discussed in section 3.11.3. Judgemental estimation, on top of being a result of extensive literature review, is based upon the interviews conducted as well as the author's knowledge and experience.

Extreme Conditions

Extreme conditions is when the model is subjected to extreme values entered into the variables. The model should perform realistically even under extreme conditions. However, only values to the extent of minimum and maximum within the theoretical and physical possibility is tested, as testing values outside this boundary is meaningless. For example, under normal values of per capita electricity requirement, it can be seen that initiation rates of electricity generation capacity would not be too high. However, subjecting per capita electricity requirement to have an abnormal increase results in a noticeable increase in initiation of generation capacities. As such, extreme conditions test for this part of the model would have been verified.

Integration Error

Integration error is concerned with the time step used when simulating SFDs. The choice of time step should not affect the results of simulation. As such, this step is performed by testing the model using different time steps. For example, the model is first run with a 0.125 years time step. The model is then run again at lower time step, namely 0.0625 years. The model passes the verification test as there are no difference in the results obtained.

3.6.3 Validation of SFD Models

For the results to be meaningful and deemed to be ‘correct’ there has to be certain crosscheck where results obtained can be compared to real world case. Despite the difficulty of obtaining real world data for every variable, simulating using historical data and crosschecking with actual data is performed wherever possible. However, it is impossible to thoroughly validate the entire SFD due to several reasons namely:

- Scarcity and unavailability of data.
- Simulation is into the future while data are historical.
- SFD structure is built based upon current understanding and situation, which may not represent the past.

As such, for this research, validation of results will be conducted on the disaggregated SFDs, otherwise known as disaggregate model tests [164], for selected variables where it is based upon the current and previous WEF conditions of Malaysia, and to the extent that the author deems sufficient and necessary to provide substantial confidence to the SFD. This is achieved by isolating a part of the SFD, simulate, and validate against published data, upon which a fit to data assessment, namely behaviour reproduction test, is performed.

Upon validation of SFD model, the behaviour reproduction test can be conducted. Three types of behaviour reproduction test are adopted for this research, namely Mean Absolute Percent Error (MAPE), MAE/Mean (Mean Absolute Error as a fraction of the mean), and percentage error.

Firstly, MAPE has been selected as one of the fit to data assessments because it is straightforward numerical way of determining differences between patterns, which is not subjected to the weakness of R^2 method that measures correlation where information on error could be lost, especially in exponential functions [164]. Secondly, MAE/Mean is included because this research simulation has data which passes through 0, and MAPE cannot be used in such cases. Thirdly, percentage difference is included for data which are too limited, where only one data point can be found. As have pointed out before by Forrester and Senge [183], part of behaviour reproduction test is to reproduce the pattern or values that have been seen before in the past (history). Example of other SD research, which utilises historical fit for validation, are such as Feng et. al.'s [148] study on urban energy and CO_2 emissions, Holmes et. al.'s [150] work on water supply and demand dilemma, Hsu's [151] research on capital subsidies and feed-in-tariff for solar photovoltaics, and Cheng's [215] investigation on container terminals.

These are tests which assess the ability of the model to reproduce the historical results. MAPE is used for variables where none of their points are zero or close to zero, otherwise, MAE/Mean is used. For variables that only has a single point, the percentage error is used. Whilst these test may produce numerical values of error percentage of simulated from real values, there exist no formal definition to the threshold between acceptable and unacceptable percentage errors. As such, these tests merely provide a guideline to the level of confidence for the particular part of model under test.

3.7 Chapter Summary

This chapter explained the methodologies used in this research, namely SD and interview. Selecting a suitable methodology and establishing a modelling process are necessary and important, especially for a complicated context such as the WEF security nexus, because they provide clarity on the nature of how the research would be conducted. Understanding SD is also vital as it serves as an important philosophy for the model construction: positive and negative feedback loops in CLD as well as identifying and constructing stock and flows in the SFD. Whilst SD help in developing the model, it is used with accompanying methods of interview to further strengthen the usefulness of the model. Key stakeholder engagements are also necessary as they provide valuable insights into the status of reality. Translating knowledge, through the identification of variables and indicators, into model values forms an important bridge from reality into simulation world, which was also explained in this chapter. Verification and validation steps are also important as it provides confidence to the built model and simulated results and thus a thorough series of steps are provided in section 3.6.

Chapter 4 Interview Inputs, Conceptual Framework, and WEF CLD Model Construction

4.1 Introduction

This chapter presents the interview inputs and information obtained from the interview sessions. From there, bi-sectoral links are also discussed. As a result, this chapter subsequently discusses the sectoral key indicators used to guide the construction of CLDs. Upon establishing the modelling process in the previous chapter, this chapter presents the construction, justification and rationale for the WEF causal loop diagram (CLD) models.

4.2 Interview Inputs

This subsection provides the interview inputs from experts of WEF sectors. There were seven interviewees - three from water, two from energy, and two from food. The list of interviewees can be found in Table 10 in section 3.4.1. The interviewees were from a range of important organisations and they have relevant information of their respective industrial sectors. The purpose of the interview is to provide understanding into each of the respective WEF sectors, while attempting to narrow down on key indicators to be used in the construction of CLD and SFD.

4.2.1 Water Security and Its Meaning for Malaysia

According to W1 and W2, water security in Malaysia means being able to supply water of sufficient quality and quantity to consumers from categories of domestic, industry, and commercial. Some vulnerabilities can be seen in Malaysia's water security namely extreme flood in east coast in 2014 (W3), in alignment with Grey's description [89] of having too much of water may prove destructive. Apart from that, safety of supply sources are also important (W1).

Quantitative indicators to measure the water security for Malaysia are such as reserve margin, non-revenue water (W1, W2). Reserve margin essentially means how much (in %) do we have in capacity for a said period after deducting the demand. Addressing water security is not solely from the supply side point of view, but water demand management is equally important (W2). This is because there are limited amount of space for us to build dams and water facilities and as such, building based upon demand without demand management is unrealistic due to their exponential growth. A few ways to manage water demand are such as policy implementation, technology control, and tariff setting (W2). For the longer period, education of public is necessary. Besides that, water stress index, a configuration from water resources and water demand, is also being worked on by National Hydraulic Research Institute of Malaysia (NAHRIM) (W3).

Malaysia strengths in water sector lies in having a large quantity of water, despite most of which goes to sea (W2). Improved water sector efforts in the past 5 years (W3) and regulation in terms of regulatory acts such as the Water Supply Industrial Act 2006 (WSIA) and existence of regulatory bodies such as National Water Regulator are forms of strengths (W1). Centralising water management is thus seen as a strength of the water sector, in alignment with Kim's research [120], as it represents the current global trend.

The primary weakness of Malaysia's water sector lies in the disconnect of governance where the federal is in charge of water supply and services while the state governments are in charge of water resources (W1, W2, W3). In addition, the extensive water regulatory acts cover only the water supply and services and not the water resources (river, seas, lakes, etc.), which resulted in poor water quality on the resources. Consequently, this leads to extra efforts and cost in water supply treatment by the federal government (W2). Insufficient revenue or income due to non-revenue water (NRW) and below-cost tariff [120] have also caused problems for the water sector (W2). A vicious cycle is inherent in the situation - Insufficient funding to improve water system because NRW is high, NRW is high because of insufficient funding to improve water system (W2). As such, the water security in Malaysia revolves around the following characteristics:

- To supply water of sufficient quality and quantity to consumers from domestic, industry, and commercial.
- Quantitative measures are addressed in a two ways namely from the supply side, where reserve margin, dam capacity, NRW, and etc. are looked at, and from the demand side, where water demand is managed through policies, technologies, tariff setting, and education.
- Disconnect in governance as the state government is in charge of water resources (lakes, river, sea, etc.) while the federal government is in charge of water supply and services.

- Below-cost water tariff that could not cover the costs of water sector.

4.2.2 Energy Security and Its Meaning for Malaysia

Energy security for Malaysia emphasised on having undisrupted electricity and its generating fuel (E1) in order to commit to Malaysian's daily use (E2). Not only does Malaysia have indigenous resources, cooperation with peers and other countries that ensures continuity of supply ensures security (E1). Besides that, adequacy, flexibility, and diversity of using resources without detrimental effects to other subsystem or ecosystem are also important (E2).

In terms of governance, the Economic Planning Unit (EPU), an organ of the Prime Minister's office, sets the overarching policies for the energy industry (E1). The EPU looks into setting long-term goals and policies, as erected and defined in the various Malaysia Plans, which are then followed through by the line ministries such as the KeTTHA and oil companies such as Petroliam Nasional Berhad (PETRONAS) (E1). Whilst KeTTHA, alongside its subsidiaries such as the Sustainable Energy Development Authority Malaysia (SEDA) are main stakeholders in overlooking the electricity industry, PETRONAS is the custodian of oil and gas resources that reports directly to the Prime Minister (E1).

Several dimensions of measurement exist for energy security such as production cost, electricity penetration, number of days a country has supply of electricity before total cut off (E1), resource reserve, total interruptions per year, occurrence of system breakdown, and many others (E2). Also, the indicators should be measure across the value chain of production, importation, storage, and retail site (E1). The current fuel mix in Malaysia's electricity sector are predominantly coal and gas as of 2016 (E1) [185]. Hydropower in Malaysia are only used for peak load and not baseload, as otherwise there will not be enough water in the dam (E2). For gas resource, there are three healthy supply of gasification terminal, which imports LNG into peninsular Malaysia (E1). As for petroleum, key stakeholders are namely PETRONAS. SHELL, and BHP (E1).

Malaysia learnt from the mistake of over depending on a single fuel source. Previously, Malaysia was heavily dependent on oil (60-70%) as a fuel input to electricity generation. As such, during the oil embargo in 1970s, Malaysia faced problems in securing enough oil resources, which eventually resulted in heavy monetary loss for the government, as they needed to subsidise (E1). Currently, oil power plants are mostly reserve for black start as the country moved away from dependence on oil fuel (E2).

Strengths in energy sector lies in having low energy fuel price especially to the generators because there exists a healthy competition between resource suppliers (E1, E2). Not only does Malaysia has long-term fuel supply contract with multiple countries which ensures continuity of fuel input, there exist numerous suppliers of fuel suppliers from every country. In addition to having indigenous resources, the national grid is also connected with Thailand and Singapore (E1).

The weakness of Malaysia's energy sector is describe primarily by low RE penetration (E1). Besides that, the electricity industry is also highly centralized as opposed to developed countries. However, Malaysia is transiting towards a decentralized model as introducing the single-buyer managed market model marks the first step in that direction (E2). As such, the energy security in Malaysia revolves around the following characteristics:

- Prioritised on having undisrupted electricity and fuel supply such that requirements of adequacy, flexibility, diversity, and environment are met.
- Major energy sectors are electricity and primary fuel where governance and management are distributed among entities of EPU, KeTTHA, PETRONAS, and SEDA.
- Quantitative measure for energy security can be categorized into capacities, costs, and fuel input.
- Energy type for electricity generation is predominantly non-renewables. Higher renewable energy penetration have always been part of Malaysia's national plan.

4.2.3 Food Security and Its Meaning for Malaysia

To address food security for any particular geo-economic region, it is important to look at its staple food. For the case of Malaysia, rice becomes the staple food, as it is the dominant delicacy across all races. As such, food security has unfortunately been addressed in an overly narrow fashion on rice only (F1). However, Malaysia is only at 70% self-sufficiency level (SSL) for rice only as the other 30% are imported (F1). 100% SSL for milk is not economically feasible in Malaysia (F1). Besides that, food security is defined by a multitude of factors such as the people's ever-changing diet, wastage along the entire value chain, appearance of food, attitude of people, cold chain, storage, and chemical usage during production (F1).

A number of measurement exists for measuring food security such as SSL, food kilometre, carbon footprint, import cost, nutrition security, GDP, gross national income (GNI), income breakdown, proportion to spend on food, per capita measures, calorie intake per person, nutrition loss in processing of food, and etc. (F1, F2). Apart from that, agricultural sustainability index, which currently do not exist, could probably help understand the state of food security in Malaysia (F2).

The strength in Malaysia's food sector is having large amount of palm oil to export, which is also an economic strength that helps in countering the country's high food import bills (F1). Malaysia also has a rich biodiversity that becomes the nation's comparative advantage (F2). The island of Borneo is a treasure trove that holds 5% of world's biodiversity (F2). That means 1 in 20 plants in the world comes from Malaysia (F2). In addition, Malaysia has 6 million hectares of marginal land where local and marginal crops can be grown (F2). Apart from that, Malaysians generally has good food safety awareness (F1).

The weaknesses of Malaysia's food security are multipronged. One of it lies in the fact that the staple food is rice, and rice causes diabetes (F1). Secondly, too much emphasis was given to growing palm oil, which are essentially grown for cash and does not address food security (F1). Besides, the import bill for food is high at RM45.4 billion, a 100% increase from RM23 billion in 2012 (F1, F2). On top of that, the weakening currency of Malaysian Ringgit (MYR) only increases the problem further (F2). Overdependence on food importation will also weaken Malaysia's food security because of food sovereignty, where the grower of the crops gets to choose whether to export or sell their products (F2). In addition, Malaysians' diets are rich in carbohydrate but poor in micronutrient, leading to poor nutrition security (F1, F2). Despite having many local food and fruits, the market for them is quite poor due to problems from both side of the business spectrum namely poor marketing knowledge and skills of the farmers and poor awareness from the general public (F1). As such, the food security in Malaysia revolves around the following characteristics:

- Rice has been the staple food of Malaysia apart from other major food such as wheat, sugar, and cooking oil.
- Malaysia is vulnerable in ensuring supply of rice as only 70% SSL in rice is achieved.
- Malaysia has a rich biodiversity and 6 million hectares of marginal land to be utilised.
- Import bill is very high (RM45.4 billion - a 100% increase over 5 years) and as such, the currency strength MYR plays a pivotal role.

4.2.4 Water-Energy Links for Malaysia

An apparent link in the energy use for water manifest itself in the form of production cost, as reportedly 40% of production cost is from energy (W1). It is in future plans of KeTTHA to put in efforts in being energy efficient when producing water on top of addressing construction material and carbon emissions (W1).

The most apparent water for energy link is the power plant generations where water is withdrawn for the operation and cooling of power plants (E2). Dams are also constructed for hydropower use during peak hours (W2, W3). However, when the dams were constructed, minimal attention were given to water requirement (W2). Flood and drought has also been known to cause problem on power generation (W3).

4.2.5 Food-Water Links for Malaysia

Water-Food links for Malaysia can be seen in the agriculture sector, particularly in the palm oil industry (W2). A problem which palm oil industry causes is the drying of catchment areas during dry seasons (W2). Apart from that, water for food links is demonstrated by irrigation of agriculture, and crop yield based on water usage, otherwise known as drop per crop (W3).

Water-use efficiency, otherwise known as crop per drop, is used to measure the amount of water used in order to produce the amount of food in weight (F1, F2). For example, palm oil is relatively inefficient because 0.6 tonnes of water is needed for 1 tonne of fresh fruit branch (FFB) (F1). Thousands of grams of water is also needed for one gram of biomass crop (F2).

4.2.6 Energy-Food Links for Malaysia

Food-energy links are prominent in land allocation (F1, F2). There exists a competition between the two sectors on the crops to grow - food crops or energy crops (F2). From the food sector perspective, energy must not compete with food in terms of land allocation (F1). That is to say, if the land is suitable for growing crops, then grow crops, and instead use agricultural waste to generate energy (F1). Besides that, energy use can also be found everywhere along the food value chain namely tractors, cold room, food distribution, transport and business packaging (F1, F2). Agriculture is also a net user of energy -

more kJ put in from energy than kJ content in food produced, essentially a conversion from inedible chemical energy of crude oil into edible forms of food (F2).

4.3 Malaysia WEF Security Nexus Conceptual Framework

From the understanding of Malaysian WEF security scenario, a framework to represent the Malaysia WEF security nexus is proposed in Figure 16. The skeleton of the framework is derived from the idea that WEF security nexus conceptual frameworks largely consist of the three sectors namely water, energy, and food circling around a central focus, with influencing factors affecting activities in the nexus to obtain a certain set of results, as illustrated in Figure 1. For the case of Malaysia, the influencing factors for WEF are issues related to the WEF sectors such as economic sustainability, high non-revenue water, development of green and renewable energy, the strength of the ringgit etc. The influencing factors affects and is affected by the activities and initiatives in the WEF sectors which consist of the three large water, energy, and food sectors which encircle the five important elements of study namely technology, environment, social, economy, and policy. Similar to the summary of WEF nexus frameworks in Figure 1, there is a core focus in the middle of the framework. However, instead of focusing on a very specific element, this framework puts the balance of technology, policy, social, environment, and economy in the middle. For the individual sectors, the boundaries of what is considered to be sector-related or not is formed from the established definitions of the respective resources as discussed in sections 4.2 and 4.4. The core of these sectors are the current problems faced by Malaysia WEF sectors. The output from the activities in the WEF security nexus gives results in alignment with Malaysia's vision towards a developed nation. They are such as sustainable development of the country, wellbeing of the WEF sectors, sectoral balance, and overall improvement in the livelihood in Malaysia. On top of that, there exists feedbacks from the results into the activities in the nexus, and back to the influencing factors as well. This is important as feedbacks from the current state and results provide relevant information for adjusting actions and improvements.

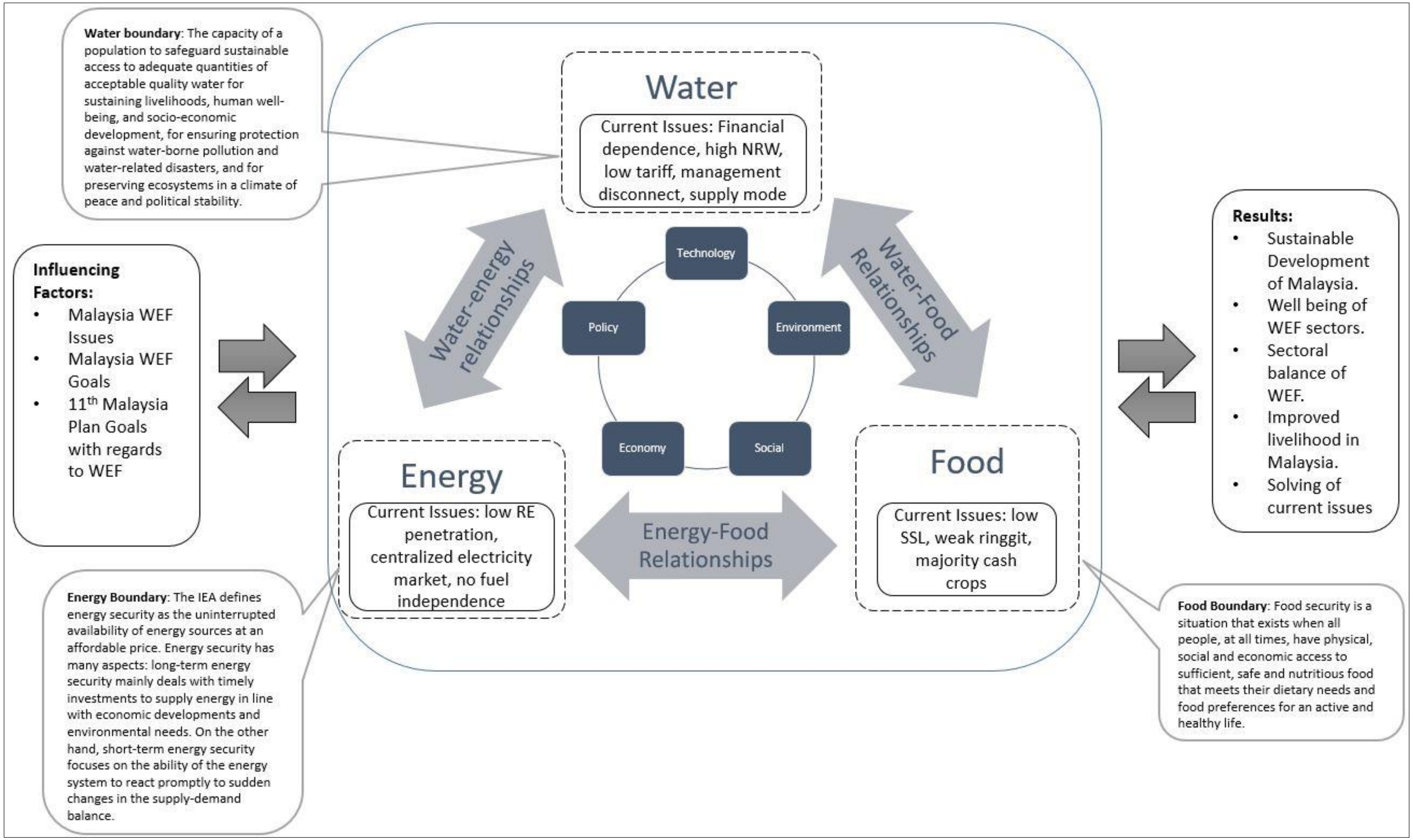

Figure 16: WEF Security Nexus Framework for Malaysia

4.4 Measuring Resource Securities

Upon establishing the working definitions, it is important to look at how the securities are measured. The measures of how good, bad, high, low, healthy, unhealthy, etc. of such dimensions are thus called 'performance'. Performance measurements are yardsticks to gauge how well and how close are individuals or organizations are doing in relation to their set goals and objectives [186]. They are forms of feedbacks which aid in making decisions, moving forward, and improving from any current to desired states on top of building confidence in decisions [187].

Securities of resources, be it availability, accessibility, affordability, and etc., are forms of performance measures. Examples of performance measures for such dimensions are amount of resource quantity in existence for use, ease of obtaining and safeguarding resources, price/cost per unit resource, and etc. Albeit some of the performance measures mentioned in this context may not be results of human activities, they still serve by providing information such that better decisions can be made. In cases such as the WEF security nexus, the measurements allow for *country self-assessment, progress tracking, scenario analysis, and cross-country comparisons* [188].

Various institutions, organizations, and individual researchers make use of indices and key indicators to measure such performances. The use of indicators, its build up, and its constituents varies according to different types of target audience, depending on the needs, such as general public, policy makers, or technical experts [189]. Previous studies and established measurements of water, energy, and food security indices as well as key indicators are critically analysed to form the foundation for which this research can build upon.

4.4.1 Water Security Key Indicators

Numerous works have attempted to measure water security in the past and have endeavoured by either aggregating a few metrics to form a composite index or measuring a few key indicators. Albeit they may be assigned different weightage (and hence importance) in some measurements, the sheer number of composite index and indicators proves the many different aspects that need to be addressed when addressing water security. A list of the indicators have been compiled in Table 35 in Appendix I [11,56,186,190–193]. This list has been used as a starting point to further narrow down to relevant key indicators for Malaysia.

The level of specificity of the composite index or key indicators varies from study to study depending on the scale of study, region, or context. While some are just ratings given by qualitative deduction from observation of the water condition of any specific state, some could provide a quantitative certainty as they are calculated from specific data. As an example, the Asian Development Bank [190] used a scale of 1-5, from hazardous to model stage, to rate its five key dimension of national water security index. On the other hand, Jiang [191] used specific quantities of 'population', 'arable land (ha)', 'per capita water resource (m3)', and 'per hectare water resource (m^3)' to perform the analysis.

From the adopted definition of water security in this research, as presented in section 2.6.1, and from the understanding of Malaysian water security sector, the key indicators for Malaysia's water security that are of primary concern are:

- Availability and Adequacy:
  - Reserve margin
  - Water demand management
- Quality and water-borne pollution:
  - Water supply treatment
  - Wastewater treatment
- Socio-economic development:
  - Water tariff
  - NRW
  - Cost
  - Water sector revenue
- Governance:
  - Disconnect of governance
  - Water regulatory acts

4.4.2 Energy Security Key Indicators

Energy security indices and indicators have been a very active research area in recent years and as such, there exists a wealth of literature on energy security index and indicators looking into many different aspects of energy security. Ang et. al. [188] provided a comprehensive comparative analysis on various types of energy index and indicator studies. Table 36 in Appendix I provides a list of energy security index and indicators being considered [130,194–198]. This list has been used as a starting point to further narrow down to relevant key indicators for Malaysia.

As opposed to water security index and indicators, there exists a larger range of index and indicator because of the diverse energy types and forms that are available. Energy security can be studied in terms of its primary supply (fossil fuels such as coal and oil, or renewable resource such as wind and solar) and secondary supply (electricity). On top of that, many of the energy indicators are related to environment, as the energy industry is a major contributor to emissions and air pollutants.

While Ang et. al. [188] may have used terms such as energy prices, environment, and societal effects in his second table to compile energy security index and indicator works, it can be seen that many of the energy security quantification revolves around the concept of '4As' which is: availability, accessibility, acceptability, and affordability. Yao and Chang [198] used this '4As' concept to identify the indicators required to quantitatively analyse energy policy implications in China. Sharifuddin [130], by using a similar method of selectively choosing indicators of energy security based upon the aspects of availability, stability, affordability, efficiency, and environmental impact, attempted to quantify the energy security for Malaysia. Some of the indicators used were such as primary energy supply per capita, proved reserves-to-production ratios, transport sector energy consumption per capita-kilometre, and etc.

From the adopted definition of energy security in this research, as presented in section 2.6.2, and from the understanding of Malaysian energy security sector, the key indicators for Malaysia's energy security that are of primary concern are:

- Reliability:
  - Undisrupted electricity supply
  - Undisrupted fuel supply

- Availability and supply:
  - Resource reserve
  - Resource import
  - Electricity production
  - Fuel type
  - Diversity of resources
  - Cooperation with other countries
- Affordability:
  - Production cost
  - Electricity tariff
- Economic development and supply-demand management:
  - Decentralizing electricity sector
- Environment:
  - Emissions
  - Renewable energy penetration

4.4.3 Food Security Key Indicators

Unlike water and energy security, fewer works have been completed on food security indices and indicators. However, a number of studies on food security index and indicators are available to present on what is important when measuring food security, as compiled in Table 37 in Appendix I [56,199–201]. This list has been used as a starting point to further narrow down to relevant key indicators for Malaysia.

When measuring food security, it can be seen that it is closely related to human health and well-being. Factors such as hunger, poverty, and content of micronutrient in daily diet are important indicators of food security in a country. The Economist Intelligence Unit (EIU) [200] in an attempt to establish global food security index, made use of variables such as prevalence of undernourishment, percentage of children stunted, percentage of children underweight, intensity of food deprivation, human development index, global gender gap index, EIU democracy index, and prevalence of obesity, to rank food security of numerous countries. Masters [199] made use of the pillars of food security (availability, access, utilisation, and stability) to identify key indicators such as food crop diversity, sufficiency of household food consumption, percentage household expenditure on food, and etc.

From the adopted definition of water security in this research, as presented in section 2.6.3, and from the understanding of Malaysian water security sector, the key indicators for Malaysia's water security that are of primary concern are:

- Population and attitude:
  - Wastage
- Physical, social, and economic accessibility:
  - Import cost
  - Strength of MYR
  - Proportion to spend on food
  - GDP
  - GNI
- Adequacy:
  - Self-sufficiency level (SSL)
  - Agricultural land
  - Marginal land
- Safety:
  - Cold chain
  - Storage
  - Chemical usage
- Nutritious and dietary needs:
  - Staple food: Rice, wheat, sugar, livestock
  - Nutrition security
- Food preference:
  - Appearance of food
  - Diet

- Environment:
  - Carbon footprint

4.5 Construction of CLD

This subsection provides the construction of the CLDs are a result of extensive literature review and interview with key stakeholders from the WEF industry. The manner in which the CLDs are presented is by addressing each loop that exists in the entire CLD, accompanied by a brief explanation on the model and the reasoning behind their structures. The purposes of CLDs are multipronged. They are to provide a high level understanding of the relationships between variables in the WEF security nexus, to act as a starting point for the construction of SFD, and to capture and provide qualitative understanding that would otherwise be unobvious in SFD. Considering that the building of CLDs are an iterative process, as discussed in the SD process in section 3.3.6, earlier iterations of the CLDs exist and can be found in Appendix II.

4.5.1 Electric Type, Demand, and Tariff Loops

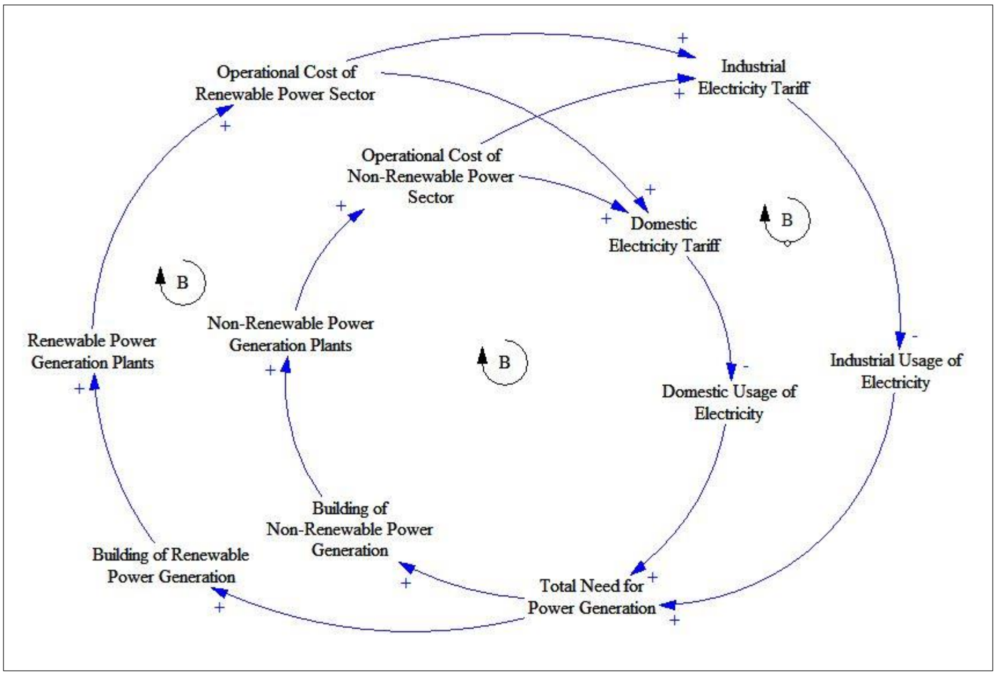

Figure 17: Electric Type, Demand, and Tariff Loops

Figure 17 shows four balancing loops that involves electricity type, demand, and tariff for both domestic and industry. The logic behind the loop is that electricity demand will increase electricity tariff, due to the higher operational costs of maintaining more generation plants. This model forms an important junction and interface of the energy sector to other sectors, as energy usage from other sectors would determine the industrial usage of electricity. The building of new power plants is driven by the prediction of power generation needs from current usage. However, the magnitude of whether renewables or non-renewables will cause tariff to increase in the long run is to be determined by SFD.

4.5.2 Water Supply, Treatment, Demand, and Tariff Loops

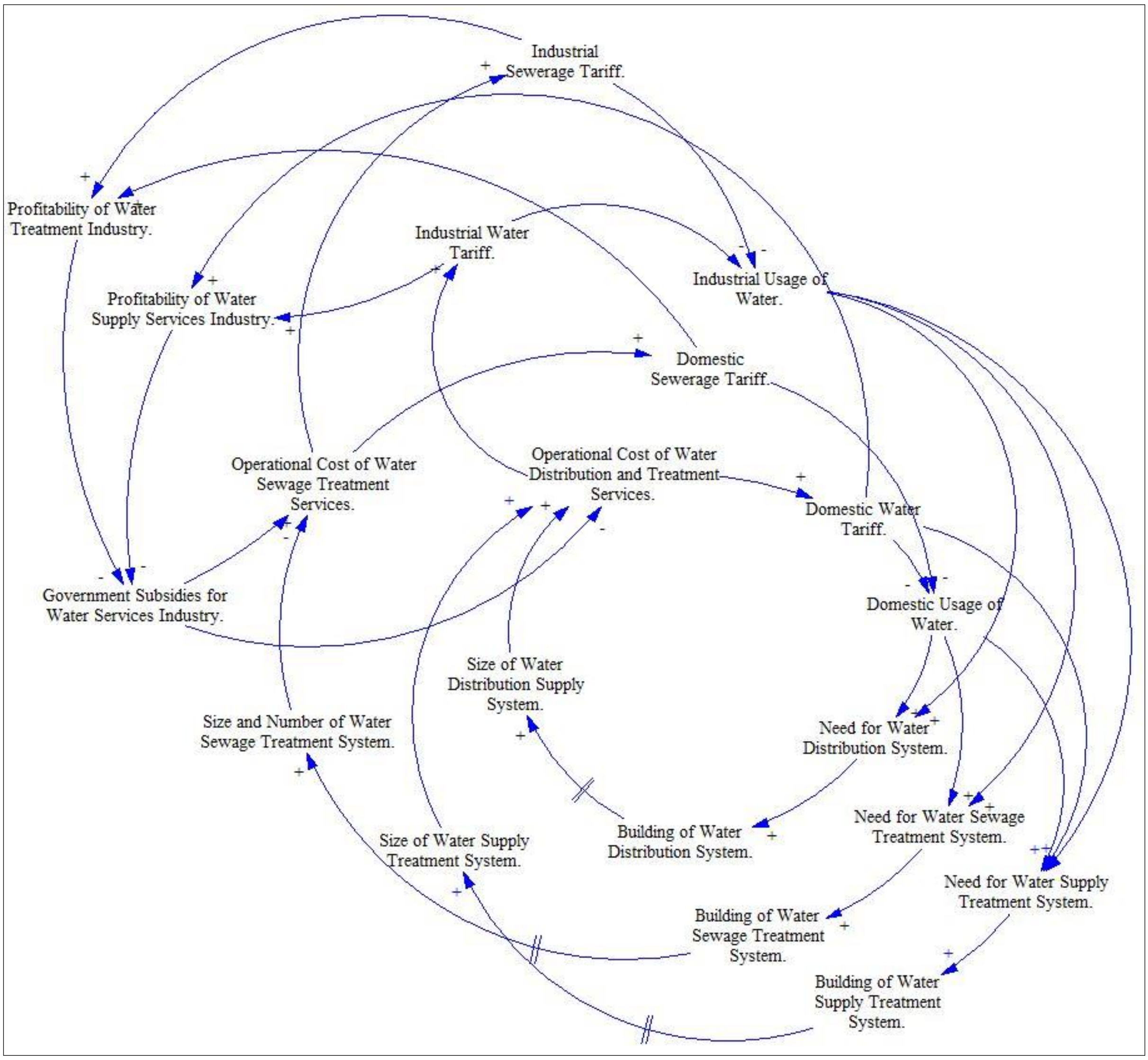

Figure 18: Water Supply, Treatment, Demand, and Tariff Loops

Figure 18 shows the domestic and industrial loops for water supply, treatment, and tariff. It portrays similarities and differences to the energy demand and supply loop. It is similar in a sense that the usage acts as an interface to other sectors as water usage from other sectors would feed into domestic and industrial usage of water. The difference is shown in the fact that water services in Malaysia is divided into supply and treatment.

4.5.3 Water Demand Management

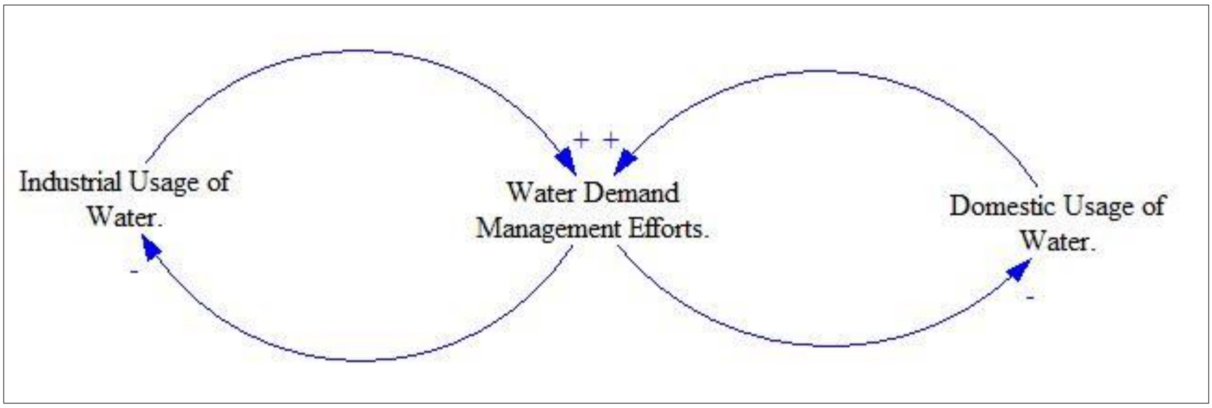

Figure 19: Water Demand Management CLD

Figure 19 shows the CLD for water demand management, which seeks to control the domestic and industrial usage of water. Water demand management are carried out in the form of tariff control and through technological and policies implementation. For example, in the past, water tanks in toilet systems are as large as 12 L (W2). Recent policy changes have compelled the size to be reduced to between 3 L and 6 L (W2).

4.5.4 Food Demand, Affordability, Availability, and Land Use Loops

Figure 20 shows a CLD of factors concerning food and agriculture. An important and highly relevant variable to food sector is available land and its usage. This is because land can be converted into area for growing crops and farming livestock to satisfy food requirements, as well as to grow cash crops such as rubber, cocoa, and palm oil. The conversion of land into these three areas forms three balancing loop with available land.

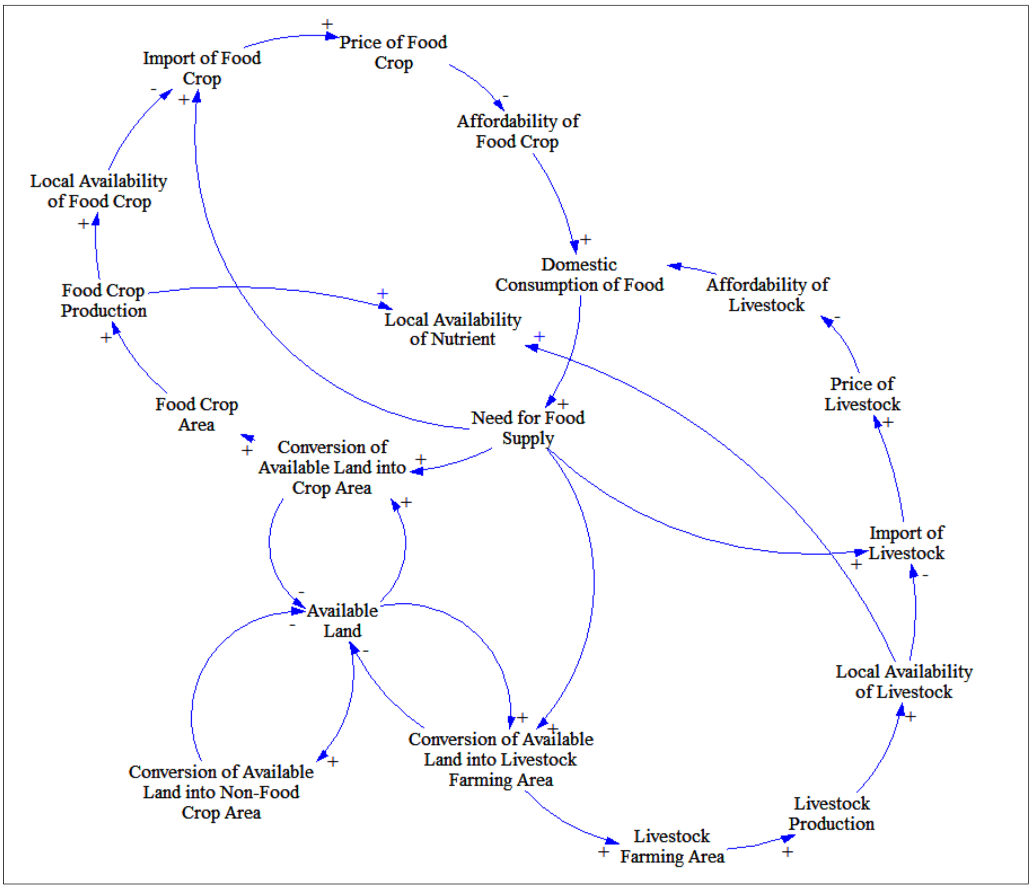

Figure 20: Food Demand, Affordability, Availability, and Land Use Loops

On the affordability of food, whether its crop, meat, or poultry, the price of food is usually determined by local availability. The less food we can produce on local soil, the more we need to import, the higher the average price of food, and hence the lower the affordability of food. While it is debatable on whether a person would cut down on food intake significantly based on affordability, affordability does play a major role in ensuring food adequacy and eventually human well-being. This is enhanced by the fact that UN pays much attention on reducing and eliminating poverty in Millennium Development Goals and Sustainable Development Goals [22,111].

4.5.5 Population as Drivers of Demand Loop

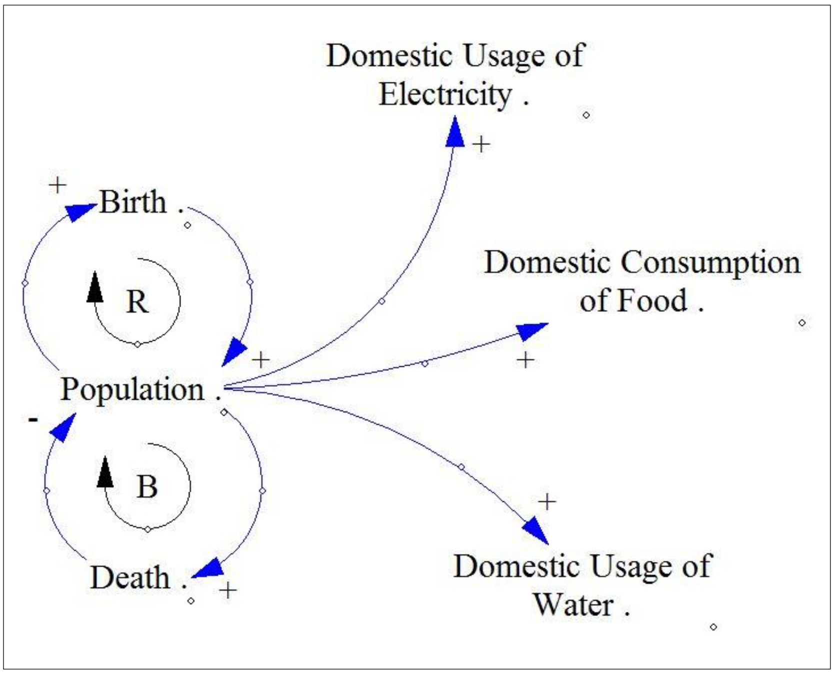

Figure 21: Population as Demand Loops

Figure 21 shows a basic loop to determine domestic demand for all three sectors namely water, energy, and food. The projection of population can be calculated with the reinforcing loop that population forms with birth, and balancing loop that it forms with death. Considering the average resource consumption per capita would be given by a particular value, the total domestic consumption of resources would increase or decrease in tandem with the change of the country's population.

4.5.6 Power Plant Operational Hours and Emissions Loop

Figure 22 shows other dominant factors of energy sector apart from electricity demand and tariff i.e. number of non-renewable power plants, power plant operational hours, emissions, and the need to reduce CO_2 emissions. The logic in constructing the reinforcing loop of operational hours of non-renewable and renewable power plants is that the energy service provider could opt to turn down power plants in the event of power surplus (as a result from power need forecast for any particular period). As such, for a constant amount of energy produced and consumed, more production from non-renewable power plant could result in less needed from renewables, and vice versa. The emissions loop in this case acts as a balancing check to prevent indefinite growth of non-renewable power as compared to renewables. This is because emissions condition may encourage environmental policies, which drive the building and use of renewable power plants.

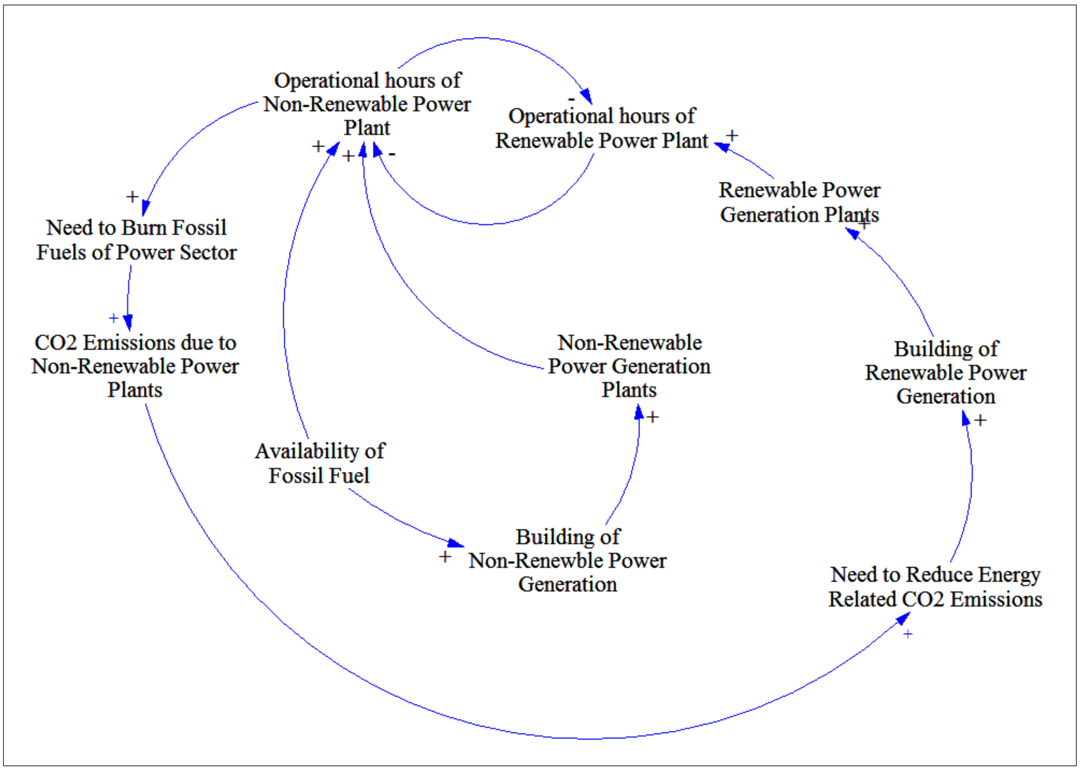

Figure 22: Power Plant Operational Hours, Fossil Fuel Mining, and Emissions Loop

4.5.7 Water-Energy Relationships

Figure 23 shows an elaborative water-energy relationship loop. The important links in forming these two closed reinforcing loop between water and energy lies in three important variables namely water withdrawal due to non-renewable power generation, water withdrawal due to renewable power generation, and power consumption due to water treatment. Water quality is a contributing factor to the need for water treatment, while power plants are a contributing factor to lower water quality. As power plants require water to cool the power plants, water treatment plant require power to treat the water.

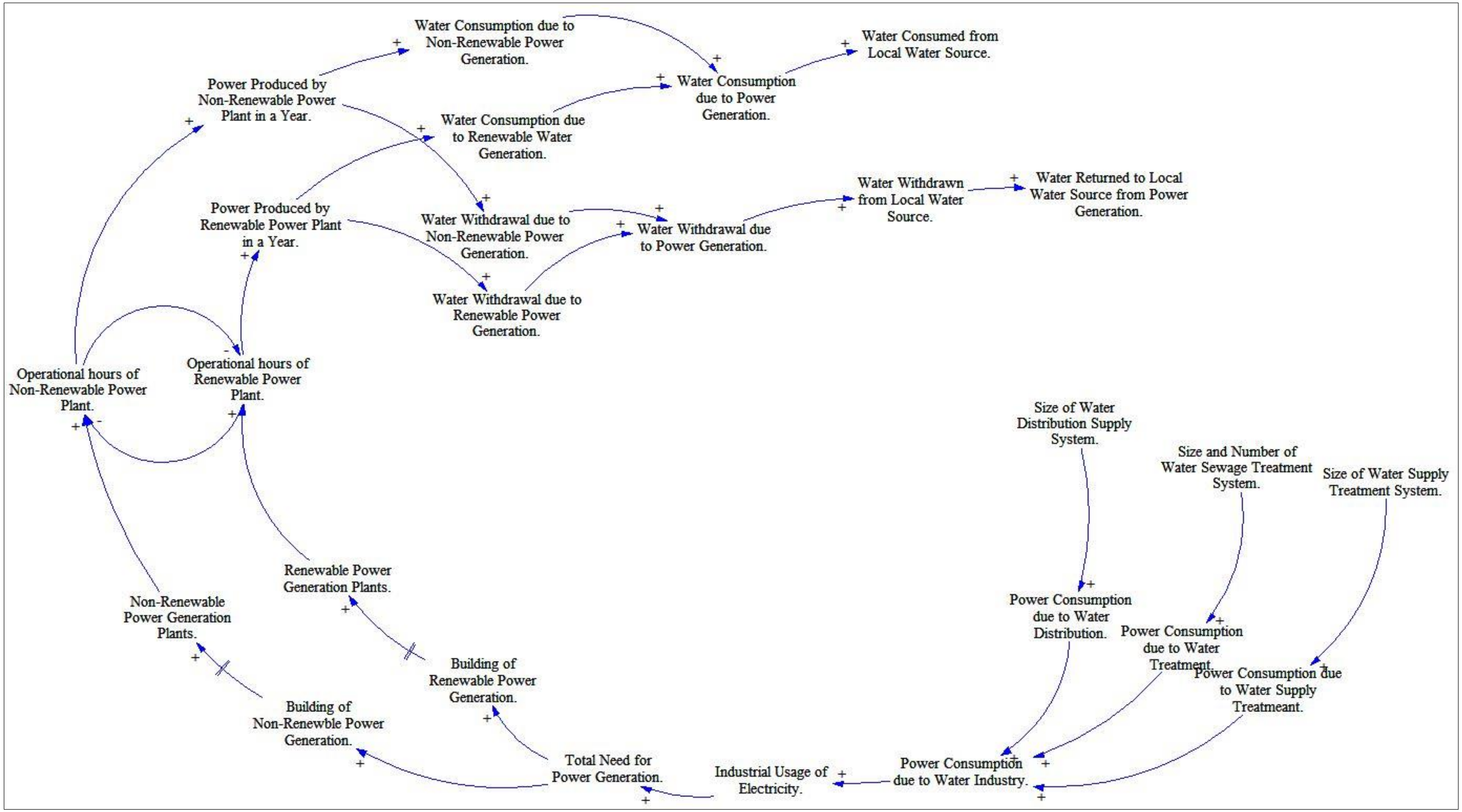

Figure 23: Water-Energy Relationships

4.5.8 Water and Energy for Food Relationships

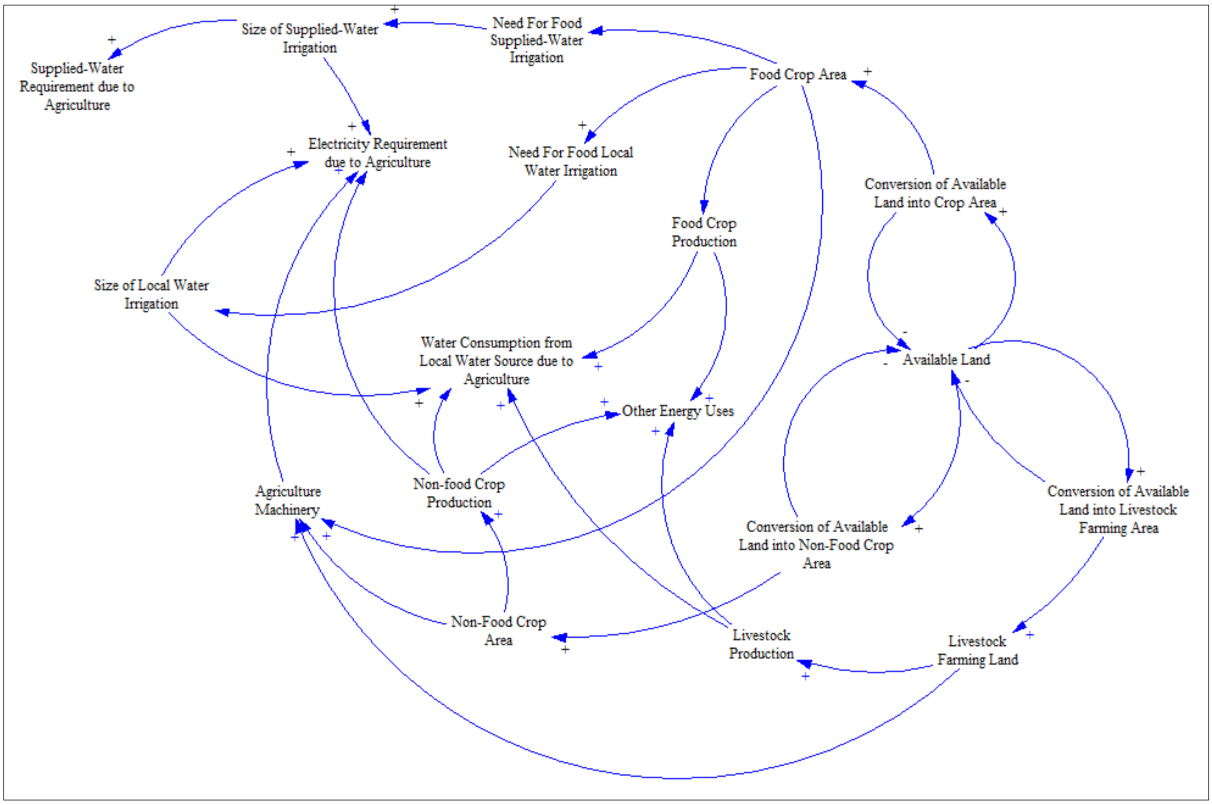

Figure 24: Food-Water Relationships Loop

Figure 24 shows water and energy requirements for food relationships loop. The important links which connects food sector to water sector is the need for food irrigation. Two types of irrigation exist, which are local water source irrigation and supplied water irrigation. As Malaysia’s agriculture are predominantly rain-fed (W2), the focus of this research is thus on local water source usage. From the figure, it can be seen that the more land we have (food crop, livestock, or non-food crop), the more production there will be, and consequently the higher the water consumption from local water source. On the other hand, energy for food links can be seen in the form of agricultural machinery, irrigation (which requires electricity), and other energy uses. Other energy uses are indirect energy such as pesticides used on crops and fuels.

4.5.9 Water-Energy-Food Security Nexus

Upon establishing the links of water-energy, water-food, and energy-food, it is then logical to establish that the three sectors, water, energy, and food are indeed interlinked with each other. While some variables form direct links between the sectors, such as water withdrawal due to power generation, some are indirect due to the presence of intermediate variables, such as land use and operational hours of generation capacities, in between the sectors.

4.6 Chapter Summary

From section 4.5, it was shown that the CLD of WEF nexus was constructed using relevant and important indicators. The indicators are obtained and understood from a combination of literature review and key stakeholders' input from highly relevant industry and organisations. The qualitative interrelationships from the loops have demonstrated that water, energy, and food sectors are indeed connected on a fundamental level. Qualitative validation of the established relationships have been performed via interviews with industry experts in the sectors. Upon consolidating the CLD, the next step would be to convert the CLD into SFD so that the behaviours of the variables can be simulated and analysed.

Chapter 5 Construction of Stock and Flow Diagram (SFD)

5.1 Introduction

From the CLDs constructed in previous chapter, Chapter 4, Stock and Flow Diagrams (SFD) are constructed in order to allow for data simulation and are discussed in this chapter. SFDs are specific numerical models, which allow for quantifying and simulating the ideas and relationships derived from CLDs. As opposed to CLDs, which are high-level representations on the understanding of WEF security nexus, SFDs are built with all relevant variables and constants that are necessary for the smooth simulation of model. In every subsection, SFDs are elaborated alongside its equations, rationale, and information obtained from interviews and extensive literature review. Whilst conversion of CLDs into SFDs differs on case-by-case basis, the general guideline for the transformation is first to understand the CLDs constructed in Chapter 4, and then to identify all necessary variables, which fall into categories of stock, flow, constant, and auxiliary. Upon successful representation of the variables in the form of SFDs, equations, values, and units are embedded into the variables. An SFD validation on the base case (S0) has been conducted to provide the SFDs with more confidence. As a result, the completed SFD model would be ready for simulating scenarios, as would be designed and presented in the following chapter.

5.2 Demand SFD

As discussed in section 4.5.5, population forms the demand of resources via domestic consumption. This subsection explores the dynamics of demand changes (6.2.1) and its translation into utilisation of resources (6.2.2). Whilst the specific demand needs may differ for different resources, as depicted by CLDs in sections 4.5.1, 4.5.2, and 4.5.4, the fundamental prerequisites for resource consumption are the per capita requirements, which derive from the population of the nation. SD research that employed the similar approach of considering population and per capita variables such as Ercan et. al.'s estimation of life expectancy [202], Hjorth and Bagheri's sustainable development study [203], as well as Azadeh and Arani's work on biodiesel supply chain [204].

5.2.1 Population Growth

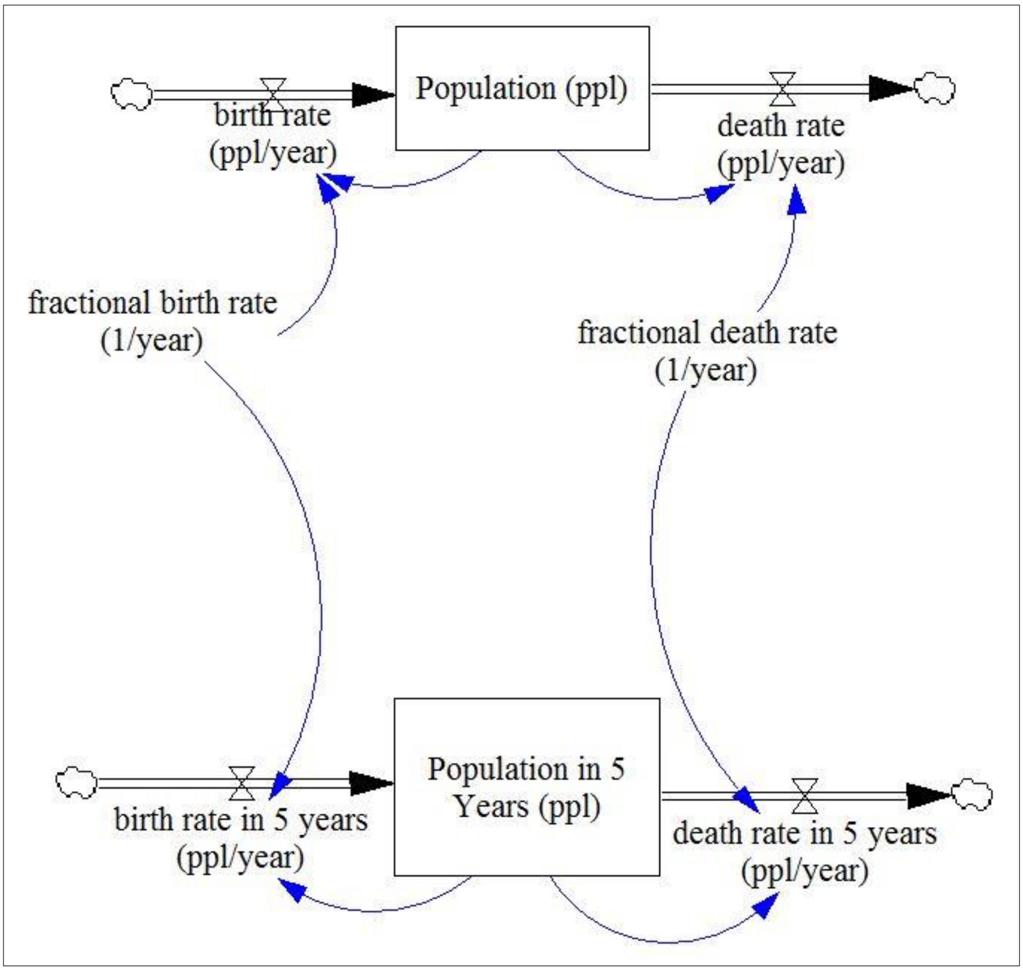

Figure 25: Population SFD

Population forms the primary group where their WEF securities are concerned. Whilst population may determine the usage of resources at any particular present time, the stock, ‘population in 5 years’, has been included in the model to provide a basis of forecast for the initiation of new land, new generation capacities, and water facilities. The duration of 5 years has been selected in alignment with Malaysia national plans which are usually developed and reviewed once every 5 years [205], thus showing that the planning is conducted by looking 5 years in advance on top of having a long term plan. The structure in Figure 25 has been seen several times in other studies [134,145,146,148,206].

Equations:

$$\text{Population} = \left(\int_{t_0}^{\text{t}} \text{birth rate} - \text{death rate dt} \right) + \text{Population}(\text{t}_0)\ \{\text{ppl}\} \qquad (4)$$

$$\text{birth rate} = \text{Population} * \text{fractional birth rate}\ \{\text{ppl/year}\} \qquad (5)$$

$$\text{death rate} = \text{Population} * \text{fractional death rate}\ \{\text{ppl/year}\} \qquad (6)$$

$$\text{fractional birth rate} = \text{input}\ \{1/\text{year}\} \qquad (7)$$

$$\text{fractional death rate} = \text{input}\ \{1/\text{year}\} \qquad (8)$$

$$\begin{aligned} &\text{Population in 5 years(t)} \\ &\qquad = \left(\int_{t_0}^{\text{t}} \text{birth rate in 5 years(t)} - \text{death rate in 5 years(t) dt} \right) \\ &\qquad + \text{Population in 5 years}(\text{t}_0)\ \{\text{ppl}\} \end{aligned} \qquad (9)$$

5.2.2 Population Demand (Basic Water, Energy, and Staple Food)

The estimation for total requirement and usage can be performed in the SFD as shown in Figure 26, by multiplying population with per capita requirement. Whilst energy and water are rather straightforward in resource identification, food has been broken down into four staple food namely rice, wheat, sugar, and livestock. As such, these six variables would be used as one of the inputs in determining subsequent resources (water, energy, and food) expansions, as detailed in subsequent subsections.

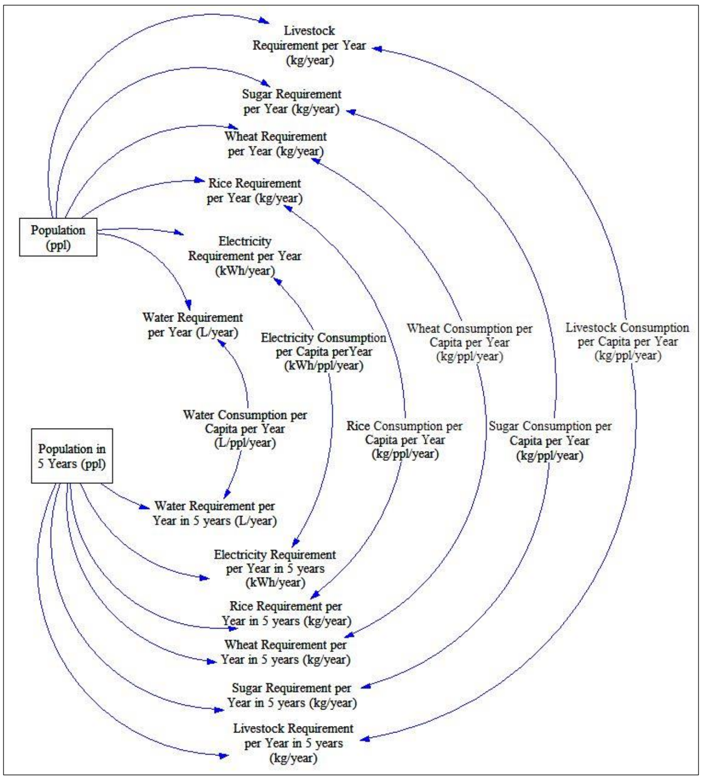

Figure 26: Demand SFD

Equations:

$$\begin{aligned}&\text{Water Requirement per Year}\\&\qquad = \text{Population} * \text{Water Consumption per Capita per Year } \{\text{L/year}\}\end{aligned} \tag{10}$$

$$\begin{aligned}&\text{Electricity Requirement per Year}\\&\qquad = \text{Population}\\&\qquad * \text{Electricity Consumption per Capita per Year } \{\text{kWh/year}\}\end{aligned} \tag{11}$$

$$\begin{aligned}&\text{Rice Requirement per Year}\\&\qquad = \text{Population} * \text{Rice Consumption per Capita per Year } \{\text{kg/year}\}\end{aligned} \tag{12}$$

$$\begin{aligned}&\text{Wheat Requirement per Year}\\&\qquad = \text{Population}\\&\qquad * \text{Wheat Consumption per Capita per Year } \{\text{kg/year}\}\end{aligned} \tag{13}$$

$$\text{Sugar Requirement per Year} \\ = \text{Population} \\ * \text{Sugar Consumption per Capita per Year } \{kg/year\} \tag{14}$$

$$\text{Livestock Requirement per Year} \\ = \text{Population} \\ * \text{Livestock Consumption per Capita per Year } \{kg/year\} \tag{15}$$

$$\text{Water Requirement per Year in 5 years} \\ = \text{Population in 5 years} \\ * \text{Water Consumption per Capita per Year } \{L/year\} \tag{16}$$

$$\text{Electricity Requirement per Year in 5 years} \\ = \text{Population in 5 years} \\ * \text{Electricity Consumption per Capita per Year } \{kWh/year\} \tag{17}$$

$$\text{Rice Requirement per Year in 5 years} \\ = \text{Population in 5 years} \\ * \text{Rice Consumption per Capita per Year } \{kg/year\} \tag{18}$$

$$\text{Wheat Requirement per Year in 5 years} \\ = \text{Population in 5 years} \\ * \text{Wheat Consumption per Capita per Year } \{kg/year\} \tag{19}$$

$$\text{Sugar Requirement per Year in 5 years} \\ = \text{Population in 5 years} \\ * \text{Sugar Consumption per Capita per Year } \{kg/year\} \tag{20}$$

$$\text{Livestock Requirement per Year in 5 years} \\ = \text{Population in 5 years} \\ * \text{Livestock Consumption per Capita per Year } \{kg/year\} \tag{21}$$

5.3 Electricity Generation Capacity SFD

5.3.1 Energy Capacities

Figure 27 shows a generic SFD for electricity generation capacity, which is the backbone for the generation of electricity. From the figure, TYPE refers to the different energy type used to generate electricity. They are:

- Five for Non-RE energy type:
    - Gas
    - Coal
    - Oil
    - Diesel
    - Nuclear
- Five for RE energy type:
    - Hydro
    - Solar
    - Bio + others
    - Marine
    - Wind

Similar structure is seen from previous works of Ford and Eker et. al. [149,207]. The structural idea has been adapted to suit the case of WEF where variables are further used to calculate important indicators in the WEF, such as the power produced yearly, the yearly CO_2 emissions, and subsequently the water used per power produced. In addition, to complete the loop of CLD from section 4.5.1, installed capacities and capacities under construction must also be used to consider and calculate the initiation of new power plants.

The initiation of new capacities is determined by the flow “initiation rate” whereby it is calculated from the forecast of future need, as discussed in section 5.3.3. Two main stocks exist in this SFD namely the installed capacity and the capacity under construction. Due to long construction time, as represented by the variable of average build time, capacity under construction is necessarily included as a delay element from a SD point of view. The rate at which the installed capacity decreases is determined by the retirement rate, which is calculated from knowing the average power plant lifespan.

On determining the total capacity for any energy type, it is important to consider the summation of both installed capacity and capacity under construction. This is to avoid over initiation of capacity based on demand projections, and would later be used in forecast of capacity requirement, as illustrated in section 5.3.3. As discussed in section 3.3.3, capacity under construction is a form of delay, which has to be considered to improve the accuracy of projection.

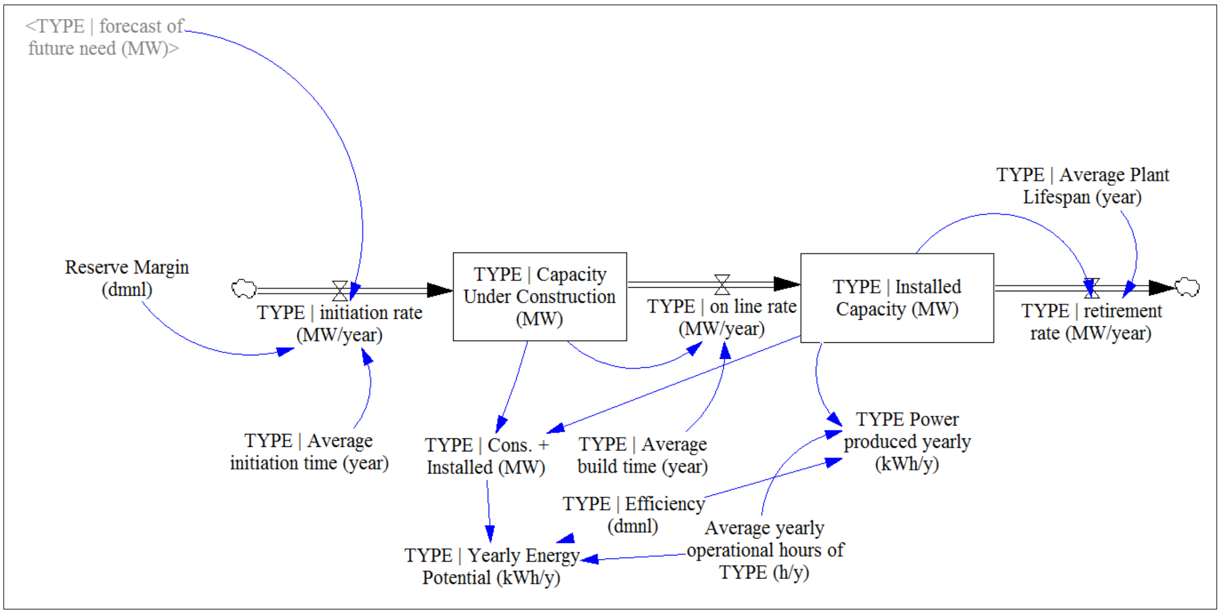

Figure 27: Electricity Generation SFD

Equations:

$$\text{TYPE | Capacity Under Construction} = \left(\int_{t_0}^{t} \text{TYPE | initiation rate } - \text{TYPE | on line rate dt} \right) + \text{TYPE | Capacity Under Construction}(\mathrm{t_0})\ \{\text{MW}\} \quad (22)$$

TYPE | Installed Capacity =

$$\left(\int_{t_0}^{t} \text{TYPE | on line rate} - \text{TYPE | retirement rate dt}\right) + \text{TYPE | Capacity Under Construction}(t_0)\ \{MW\} \tag{23}$$

TYPE | initiation rate =

TYPE | forecast of future need*(Reserve Margin+1)/TYPE | Average initiation time (year) {MW/year} (24)

TYPE | on line rate =

IF THEN ELSE(TYPE | Capacity Under Construction<=0, 0 , TYPE | Capacity Under Construction/TYPE | Average build time) {MW/year} (25)

TYPE | retirement rate =

TYPE | Installed Capacity/TYPE | Average Plant Lifespan {MW/year} (26)

TYPE | Cons. + Installed =

TYPE | Capacity Under Construction +TYPE | Installed Capacity {MW} (27)

TYPE | Power produced yearly =

TYPE | Installed Capacity*TYPE | Average yearly operational hours*1000*TYPE | Efficiency {kWh/year} (28)

TYPE | CO2 Emission per year =

TYPE | Average yearly operational hours*TYPE | CO2 Emission per Hour Operation {kT/y} (29)

$$\text{TYPE} \mid \text{Yearly Energy Potential} = \text{TYPE} \mid \text{Cons.} + \text{Installed}*\text{TYPE} \mid \text{Average yearly operational hours}*1000 \; \{\text{kWh/year}\} \tag{30}$$

$$\text{TYPE} \mid \text{Average initiation time} = \text{input} \; \{\text{year}\} \tag{31}$$

$$\text{TYPE} \mid \text{Average build time} = \text{input} \; \{\text{year}\} \tag{32}$$

$$\text{TYPE} \mid \text{Average Plant Lifespan} = \text{input} \; \{\text{year}\} \tag{33}$$

$$\text{TYPE} \mid \text{Average yearly operational hours} = \text{input} \; \{\text{year}\} \tag{34}$$

$$\text{TYPE} \mid \text{Efficiency} = \text{input} \; \{\text{dmnl}\} \tag{35}$$

5.3.2 Energy Economics

Figure 28 shows SFD to calculate the Levelised Cost of Electricity (LCOE), where it is the theoretical minimum of setting electricity tariff before losses are incurred. An average LCOE is calculated by considering the total cost and total electricity generated from all generation types. This follows the rationale that if there is only one electricity tariff which the users pay regardless of the source of electricity, then an average LCOE should be calculated before determining that tariff.

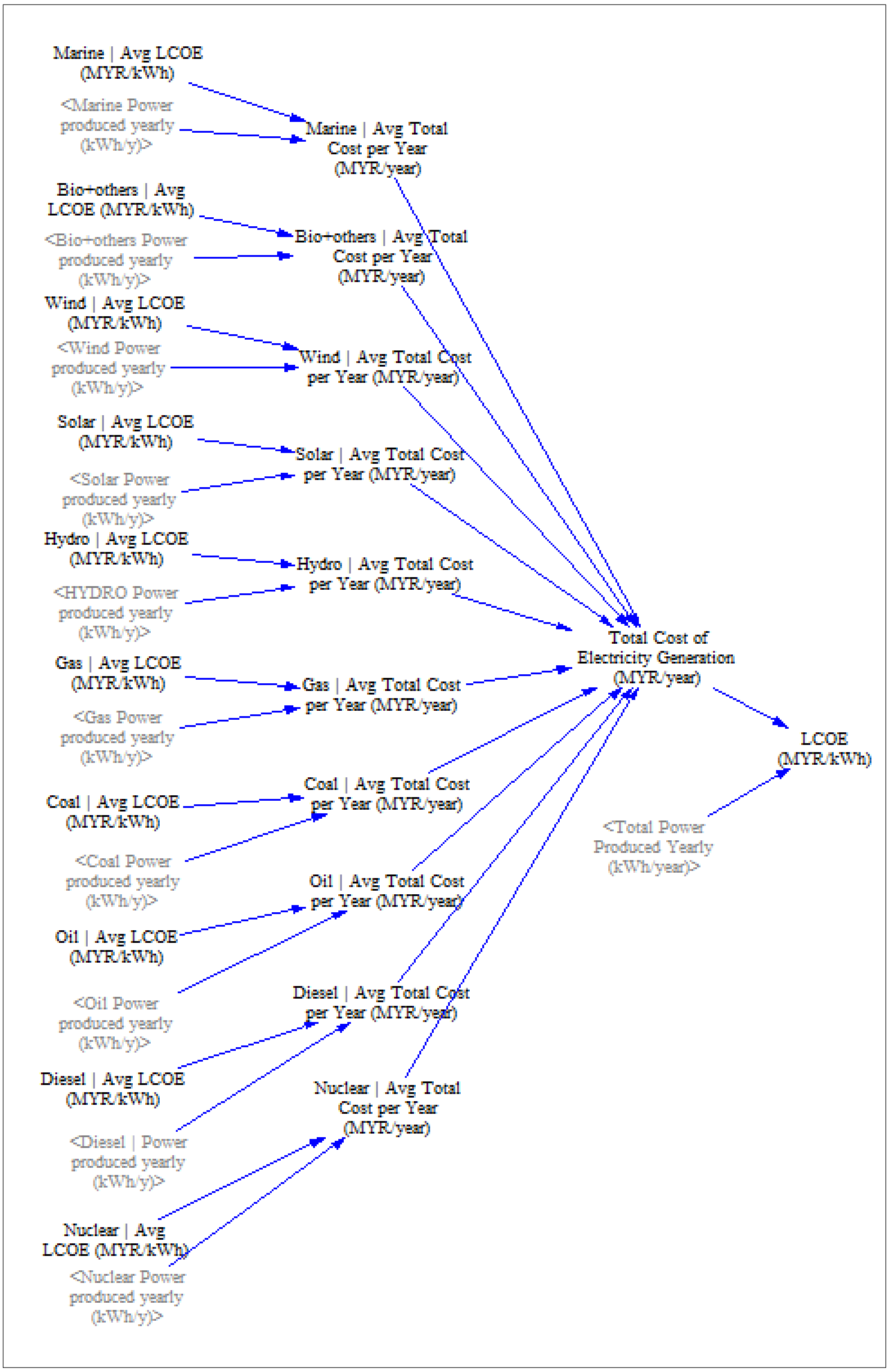

Figure 28: LCOE

Equations:

TYPE | Avg Total Cost per Year =

TYPE | AVG LCOE*TYPE Power produced yearly {MYR/year} (36)

Total Cost of Electricity Generation =

$$\sum_{\text{all types}} \text{TYPE | Avg Total Cost per Year} \tag{37}$$

{MYR/year}

LCOE =

Total Cost of Electricity Generation/Total Power Produced Yearly (38)

{MYR/kWh}

5.3.3 Forecast of Capacity Requirements

Figure 29 shows the entire sub-model for forecasting generation capacities, which subsequently lead to initiation of capacities. In order to determine how much electricity generation capacity to initiate, the gap of capacity requirement is calculated from considering the gap of electricity requirement per year and the average operational hours of different generation types. An important decision variable that needs to be considered is the desired renewable penetration. This subsequently results in a resulting desired non-renewable penetration. The specific forecast for each generation type is then determined by a further step of deciding the breakdown of the energy type share. Subsequently, the calculated forecast for each energy type would be used in the energy capacities SFD, as was illustrated in section 5.3.1.

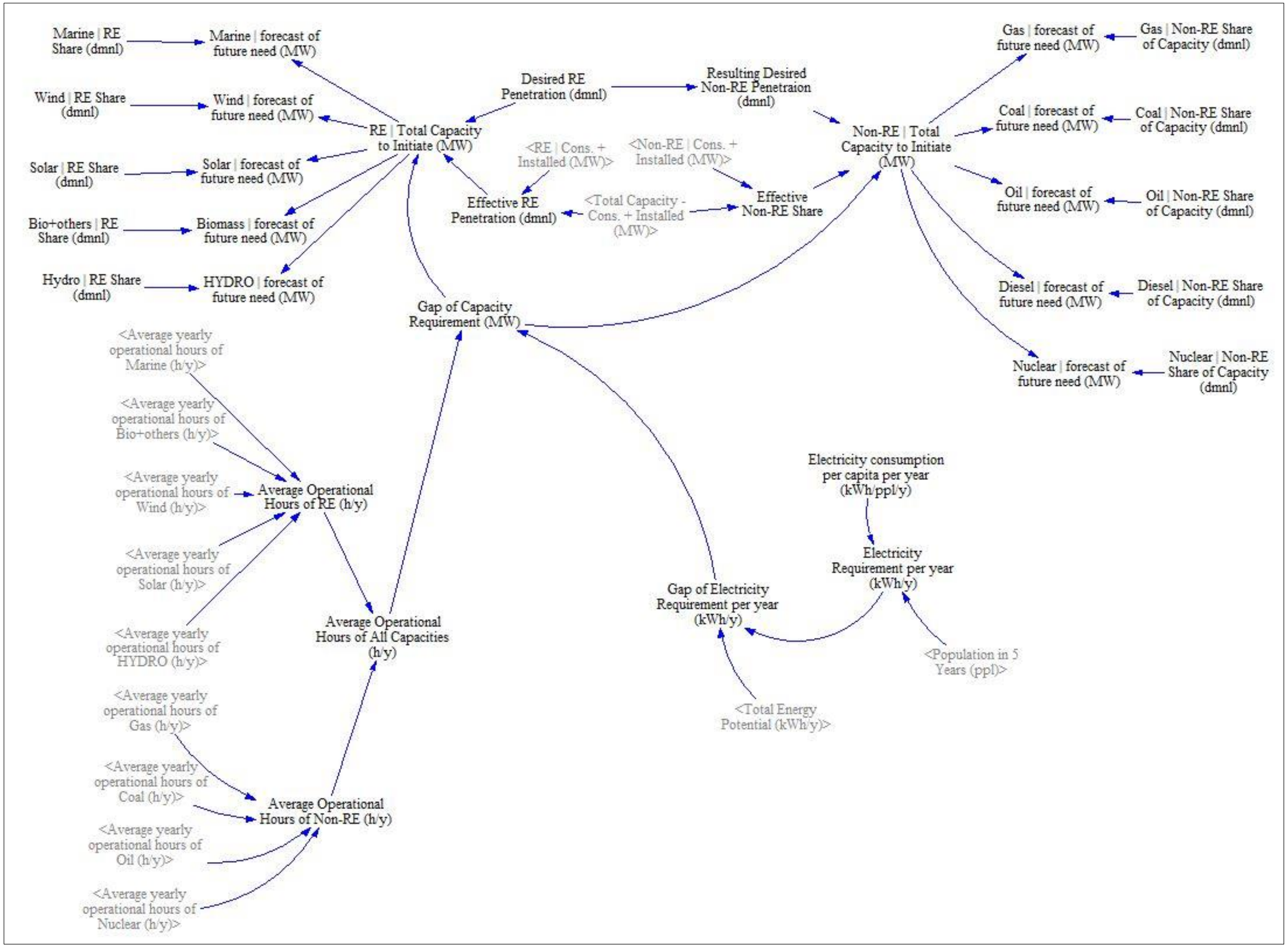

Figure 29: Forecast of Generation Capacity Needs

Equations:

RE | Cons + Installed =

$$\sum_{\text{all TYPES}} \text{RE Capacities}_{\text{installed and under construction}} \tag{39}$$

{MW}

Non-RE | Cons + Installed =

$$\sum_{\text{all TYPES}} \text{Non-RE Capacities}_{\text{installed and under construction}} \tag{40}$$

{MW}

Gap of Capacity Requirement =

Gap of Electricity Requirement per year / Average Operational Hours of All Capacities {MW} (41)

Gap of Electricity Requirement per year =

Total Energy Potential - Electricity Requirement per year {kWh/year} (42)

Average Operational Hours of RE =

$$\left(\sum_{\text{all RE TYPES}} \text{Average Operational Hours of TYPE}\right) \Big/ \text{number of RE types} \tag{43}$$

{hour}

Average Operational Hours of Non-RE =

$$\left(\sum_{\text{all Non}-\text{RE TYPES}} \text{Average Operational Hours of TYPE}\right) \Big/ \text{number of Non-RE types} \tag{44}$$

{hour}

RE | Total Capacity to Initiate =

$$\text{Desired RE Penetration*Gap of Capacity Requirement } \{MW\} \tag{45}$$

Non-RE | Total Capacity to Initiate =

$$\text{Resulting Desired Non-RE Penetration*Gap of Capacity Requirement } \{MW\} \tag{46}$$

Effective RE Penetration =

RE | Cons. + Installed / Total Capacity | Cons. + Installed {dmnl} (47)

Effective Non-RE Share =

Non-RE | Cons. + Installed / Total Capacity | Cons. + Installed {dmnl} (48)

RE TYPE | forecast of future need =

RE TYPE | RE Share* RE | Total Capacity to Initiate {MW} (49)

Non-RE TYPE | forecast of future need =

Non-RE TYPE | Non-RE Share of Capacity*Non-RE | Total Capacity to Initiate {MW} (50)

$$\text{RE TYPE} \mid \text{RE Share} = \text{input } \{\text{dmnl}\} \tag{51}$$

$$\text{Non-RE TYPE} \mid \text{Non} - \text{RE Share of Capacity} = \text{input } \{\text{dmnl}\} \tag{52}$$

$$\text{Desired RE Penetration} = \text{input } \{\text{dmnl}\} \tag{53}$$

$$\text{Resulting Desired Non} - \text{RE Penetration} = 1 - \text{Desired RE Penetration } \{\text{dmnl}\} \tag{54}$$

5.4 Water Use in Energy

5.4.1 Water Use in Power Production

Figure 30 shows the SFD to calculate the water used in electricity production. The water used in electricity production is calculated by first computing the amount of electricity generated in a year and then multiply it by the amount of water withdrawn per unit of electricity produced. As such, the size of generation capacity and operational hours are needed for this calculation. The water used per unit electricity generated thus varies accordingly to the energy type. Whilst most of the water used in the power plant are eventually returned to their local source, a small amount may be used up, or termed as consumed. As such, the fraction of water consumed because of electricity generation is added to the structure.

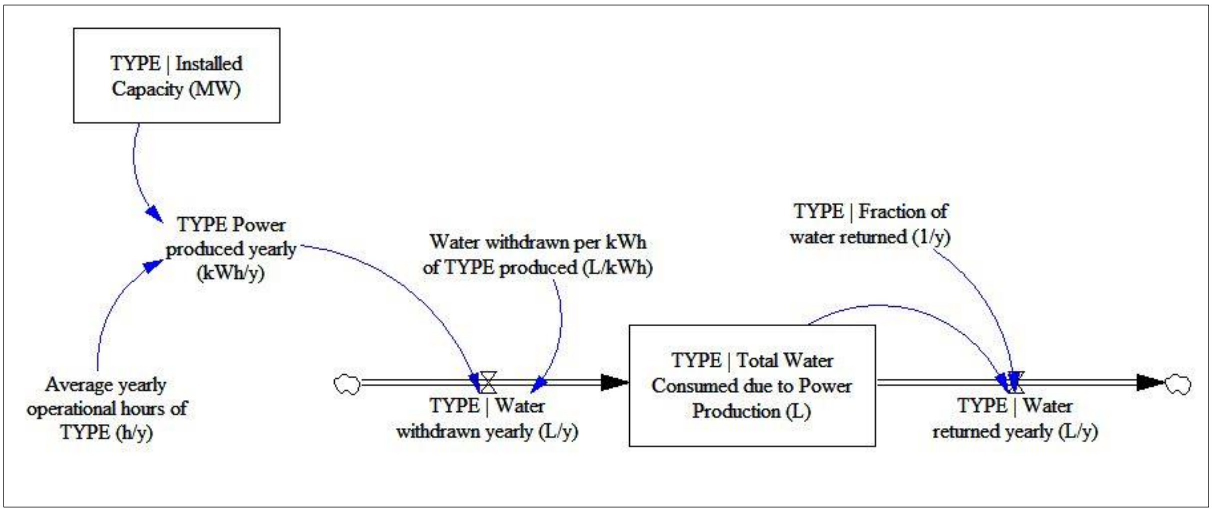

Figure 30: Water for Electricity SFD

Equations:

$$\begin{aligned}&\text{TYPE | Total Water Consumed due to Power Production} = \\ &\quad \left(\int_{t_0}^{t} \text{TYPE | Water withdrawn yearly} - \right. \\ &\quad \left. \text{TYPE | Water returned yearly dt} \right) + \\ &\quad \text{TYPE | Total Water Consumed due to Power Production}(\mathrm{t_0})\ \{\mathrm{L}\}\end{aligned} \tag{55}$$

$$\text{TYPE | Water withdrawn yearly} = \text{Water withdrawn per kWh of TYPE produced*TYPE Power produced yearly \{L/year\}} \tag{56}$$

$$\text{TYPE | Water returned yearly} = \text{IF THEN ELSE(TYPE | Total Water Consumed due to Power Production} <= 0, 0 \text{, TYPE | Total Water Consumed due to Power Production*TYPE | Fraction of water returned) \{L/year\}} \tag{57}$$

$$\text{Water withdrawn per kWh of TYPE produced} = \text{input \{L/kWh\}} \tag{58}$$

$$\text{TYPE | Fraction of water returned} = \text{input \{1/year\}} \tag{59}$$

5.5 Urban Water Cycle

The backbone of the water sector can be given by the urban water cycle [208,209] and can be illustrated by Figure 31. The urban water cycle is then converted into SFD form as depicted by Figure 32. The urban water cycle forms a closed loop starting from natural water resources, to water treatment and supply, usage by end users, disposal by end users, wastewater treatment, and finally back to natural water resources. As also emphasized by W2, two treatment exist in the urban water cycle i.e. the water supply treatment before distribution to users and the wastewater treatment after disposal from users.

Natural water resources are natural water bodies such as rivers, aquifers, lakes, etc. and are under the jurisdiction of the state governments in terms of management. They are represented by the stocks of Groundwater and Surface water in the SFD. Surface water in Malaysia is much greater than groundwater, 5.6 x 10^{14} L of surface water as compared to 6.4 x 10^{13} L of groundwater [210]. Seawater analysis has not been included in this study as desalination of water is non-existent in Malaysia due to overly high costs (E1, E2, W1, W2).

Next, the stage of water supply and services is represented by the stock of Treated water, and flows of groundwater treatment rate, surface water treatment rate, domestic water supply rate, and industrial/commercial water supply rate. In addition, the rate of supply water treatment is determined by the water supply treatment capacity units that we have in the country, as illustrated in section 6.6.2.

After treatment, water is supplied and distributed to users from categories of domestic and industrial/commercial. Essentially, treatment and distribution of supply water stems from the same place and as such, has been considered together in terms of per L water treated/distributed.

Usage and disposal of water have been represented by flows of Domestic water expel rate and industrial/commercial water expel rate. These flows determine the rate at which wastewater would accumulate before being treated in the wastewater treatment services stage, where it is represented by the stock of accumulated wastewater. The rate at which wastewater are treated is determined by the number of sewage treatment capacity, as discussed in section 5.5.2.

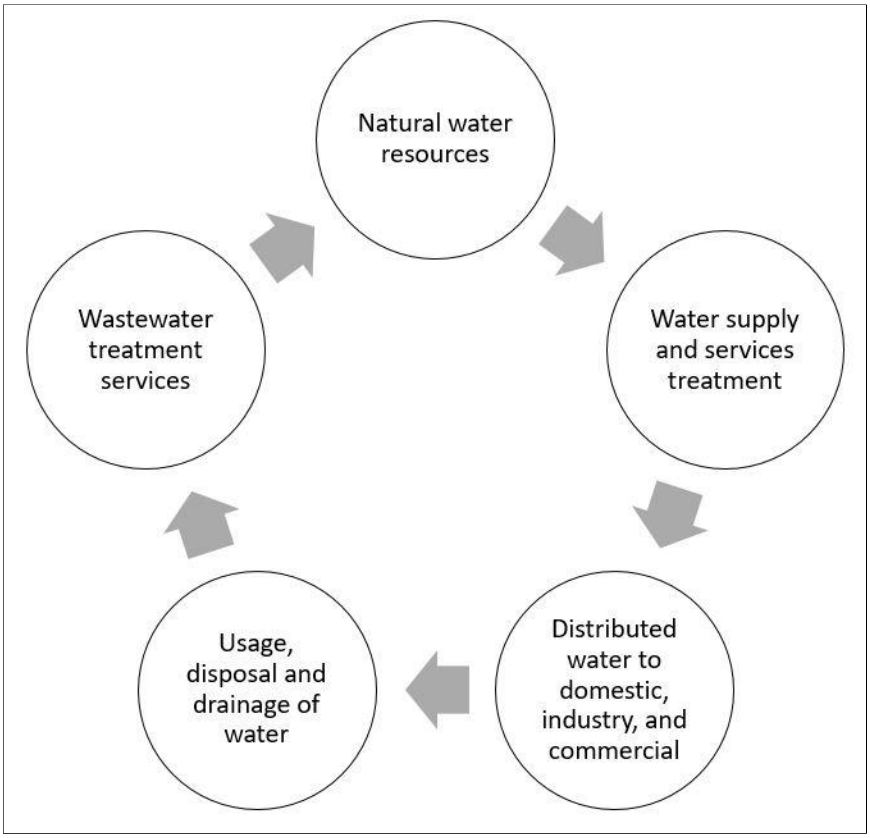

Figure 31: Urban Water Cycle

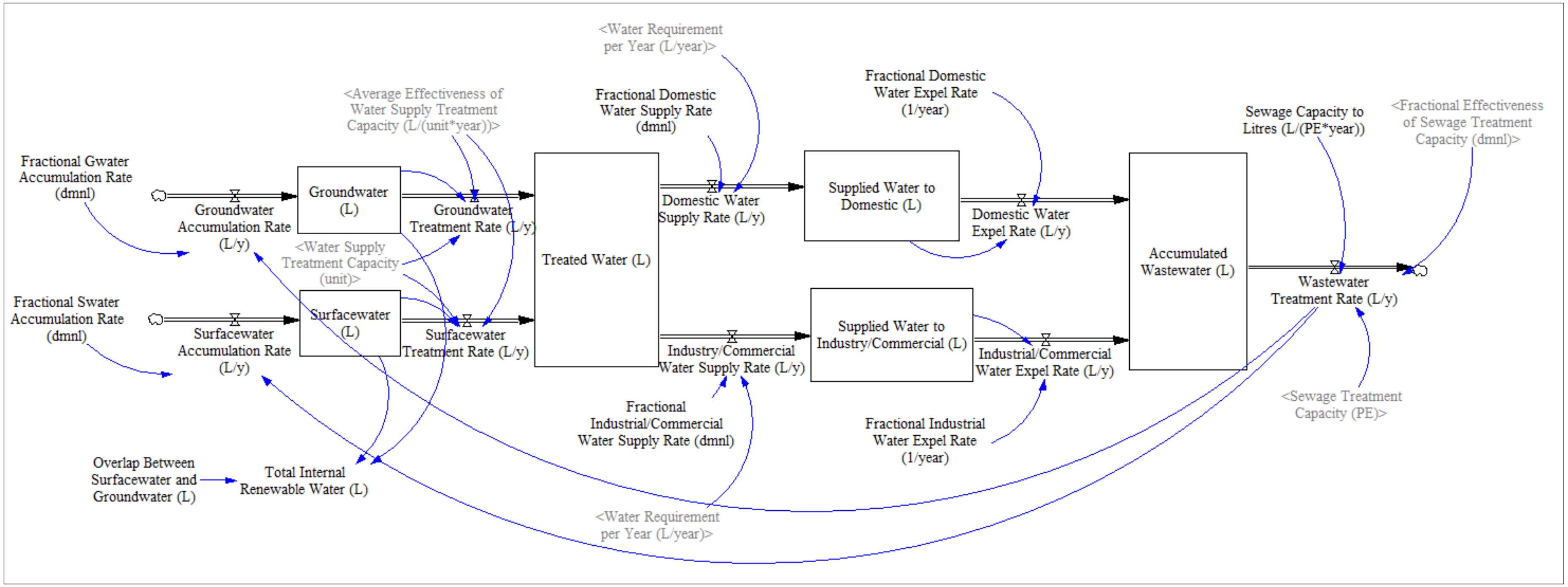

Figure 32: Urban Water Cycle SFD

Equations:

$$\text{Groundwater} = \left(\int_{t_0}^{\text{t}} \text{Groundwater Accumulation Rate } - \text{Groundwater Treatment Rate dt} \right) + \text{Groundwater}(\text{t}_0)\ \{\text{L}\} \quad (60)$$

$$\text{Surfacewater} = \left(\int_{t_0}^{\text{t}} \text{Surfacewater Accumulation Rate } - \text{Surfacewater Treatment Rate dt} \right) + \text{Surface}(\text{t}_0)\ \{\text{L}\} \quad (61)$$

$$\text{Treated Water} = \left(\int_{t_0}^{\text{t}} \text{Groundwater Treatment Rate} + \text{Surfacewater Treatment Rate} - \text{Domestic Water Supply Rate} - \text{Industry/Commercial Water Supply Rate dt} \right) + \text{Treated Water}(\text{t}_0)\ \{\text{L}\} \quad (62)$$

$$\text{Supplied Water to Domestic} = \left(\int_{t_0}^{\text{t}} \text{Domestic Water Supply Rate } - \text{Domestic Water Expel Rate dt} \right) + \text{Supplied Water to Domestic}(\text{t}_0)\ \{\text{L}\} \quad (63)$$

$$\text{Supplied Water to Industry/Commercial} = \left(\int_{t_0}^{\text{t}} \text{Industry/Commercial Supply Rate } - \text{Industry/Commercial Expel Rate dt} \right) + \text{Supplied Water to Industry/Commercial}(\text{t}_0)\ \{\text{L}\} \quad (64)$$

Accumulated Wastewater =

$$\left(\int_{t_0}^{t} \text{Domestic Water Expel Rate} + \text{Industry/Commercial Expel Rate} - \text{Wastewater Treatment Rate}\, dt \right) + \text{Accumulated Wastewater}(t_0)\ \{L\} \tag{65}$$

Groundwater Accumulation Rate =

Wastewater Treatment Rate*Fractional Gwater Accumulation Rate {L/year} (66)

Surfacewater Accumulation Rate =

Wastewater Treatment Rate*Fractional Swater Accumulation Rate {L/year} (67)

Groundwater Treatment Rate =

IF THEN ELSE(Groundwater<=0, 0 , Water Supply Treatment Capacity*Average Effectiveness of Water Supply Treatment Capacity) {L/year} (68)

Surfacewater Treatment Rate =

IF THEN ELSE(Surfacewater<=0, 0 , Water Supply Treatment Capacity*Average Effectiveness of Water Supply Treatment Capacity) {L/year} (69)

Domestic Water Supply Rate =

IF THEN ELSE(Treated water<=0, 0 , Treated Water*Fractional Domestic Water Supply Rate) {L/year} (70)

Industrial/Commercial Water Supply Rate =

IF THEN ELSE(Treated water<=0, 0 , Treated Water*Fractional Industrial/Commercial Water Supply Rate) {L/year} (71)

Domestic Water Expel Rate =

IF THEN ELSE(Supplied Water to Domestic<=0, 0 , Supplied Water to Domestic *Fractional Domestic Water Expel Rate) {L/year} (72)

Industry/Commercial Water Expel Rate =

IF THEN ELSE(Supplied Water to Industry/Commercial<=0, 0 , Supplied Water to Industry/Commercial *Fractional Industry/Commercial Water Expel Rate) {L/year} (73)

Wastewater Treatment Rate =

IF THEN ELSE(Accumulated Wastewater<=0, 0 , Sewage Capacity to Litres*"Sewage Treatment Capacity*Fractional Effectiveness of Sewage Treatment Capacity) {L/year} (74)

Fractional Groundwater Accumulation Rate = input {dmnl} (75)

Fractional Surfacewater Accumulation Rate = input {dmnl} (76)

Fractional Domestic Water Supply Rate = input {1/year} (77)

Fractional Industry/Commercial Water Supply Rate = input {1/year} (78)

Fractional Domestic Water Expel Rate = input {1/year} (79)

Fractional Industry/Commercial Water Expel Rate = input {1/year} (80)

Average Effectiveness of Water Supply Treatment Capacity

$$= \text{input } \{L/(\text{unit} * \text{year})\} \tag{81}$$

$$\text{Fractional Effectiveness of Sewage Treatment Capacity} = \text{input}\ \{\text{dmnl}\} \tag{82}$$

$$\text{Sewage Capacity to Litres} = \text{input}\ \{\text{L}/(\text{PE} * \text{year})\} \tag{83}$$

5.5.1 Water Supply Treatment

From the urban water cycle as depicted in section 6.6, the water supply treatment capacity is represented in this SFD (Figure 33). The water supply treatment is at the stage before distribution to users, where it is under the jurisdiction of federal government. Two main stocks exist in this SFD namely the water supply treatment capacity and the water supply treatment capacity under construction. Water supply treatment capacity under construction thus represents the delay for this section due to the long construction time. Based on the data available, the capacities are best measured in terms of units [210]. The number of water supply treatment capacity would then affect the rate at which groundwater and surface water is treated. The units for water supply capacity are set to be measured in L/year, as converted from the understanding of how water facilities are usually measured in, namely ML/day [211].

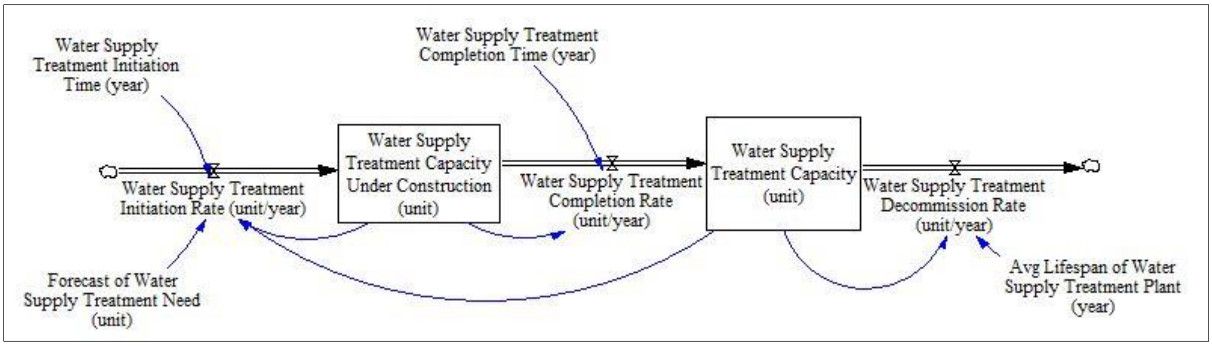

Figure 33: Water Supply and Services SFD

Equations:

$$\begin{aligned}&\text{Water Supply Treatment Capacity Under Construction} = \\ &\quad \left(\int_{t_0}^{t} \text{Water Supply Treatment Initiation Rate} - \right. \\ &\quad \left. \text{Water Supply Treatment Completion Rate dt} \right) + \\ &\quad \text{Water Supply Treatment Capacity Under Construction}(\text{t}_0)\ \{\text{unit}\}\end{aligned} \tag{84}$$

Water Supply Treatment Capacity =

$$\left(\int_{t_0}^{t} \text{Water Supply Treatment Completion Rate} - \text{Water Supply Treatment Decommision Rate}\, dt \right) + \text{Water Supply Treatment Capacity}(t_0)\ \{\text{unit}\} \tag{85}$$

Water Supply Treatment Initiation Rate =

IF THEN ELSE(Forecast of Water Supply Treatment Need<=(Water Supply Treatment Capacity Under Construction+ Water Supply Treatment Capacity), 0 , Forecast of Water Supply Treatment Need/Water Supply Treatment Initiation Time) {unit/year} (86)

Water Supply Treatment Completion Rate =

IF THEN ELSE(Water Supply Treatment Capacity Under Construction<=0, 0 , Water Supply Treatment Capacity Under Construction/Water Supply Treatment Completion Time) {unit/year} (87)

Water Supply Treatment Decommission Rate =

IF THEN ELSE(Water Supply Treatment Capacity<=0, 0 , Water Supply Treatment Capacity/Avg Lifespan of Water Supply Treatment Plant) {unit/year} (88)

Water Supply Treatment Initiation Time = input {year} (89)

Water Supply Treatment Completion Time = input {year} (90)

Avg Lifespan of Water Supply Treatment Plant = input {year} (91)

5.5.2 Water Sewage Treatment

The second treatment of water cycle is in the wastewater treatment, as depicted by the urban water cycle in Figure 31 and the SFD in Figure 32. This SFD is similar to the water supply treatment in terms of structure. However, the sewage treatment capacity in this case would only affect one rate i.e. the wastewater treatment rate as depicted in Figure 34. As opposed to water supply treatment, water sewage treatment capacity is measured in population equivalent (PE) [212].

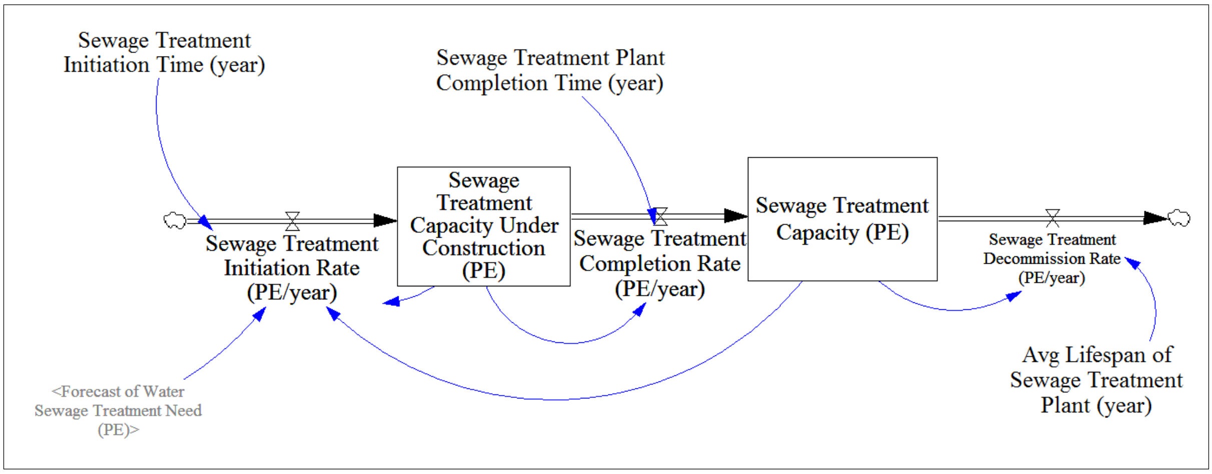

Figure 34: Water Sewage SFD

Equations:

$$\begin{aligned}&\text{Sewage Treatment Capacity Under Construction} = \\ &\quad \left(\int_{t_0}^{t} \text{Sewage Treatment Initiation Rate} - \right. \\ &\quad \left. \text{Sewage Treatment Completion Rate dt} \right) + \\ &\quad \text{Sewage Treatment Capacity Under Construction}(\mathrm{t_0})\ \{\text{PE}\}\end{aligned} \tag{92}$$

$$\begin{aligned}&\text{Sewage Treatment Capacity} = \\ &\quad \left(\int_{t_0}^{t} \text{Sewage Treatment Completion Rate} - \right. \\ &\quad \left. \text{Sewage Treatment Decommision Rate dt} \right) + \\ &\quad \text{Sewage Treatment Capacity}(\mathrm{t_0})\ \{\text{PE}\}\end{aligned} \tag{93}$$

Sewage Treatment Initiation Rate =

$$\text{IF THEN ELSE(Forecast of Water Sewage Treatment Need} <= \text{(Sewage Treatment Capacity Under Construction} + \text{Sewage Treatment Capacity), 0 , Forecast of Water Sewage Treatment Need/Sewage Treatment Initiation Time) \{PE/year\}} \tag{94}$$

Sewage Treatment Completion Rate =

$$\text{IF THEN ELSE(Sewage Treatment Capacity Under Construction} <= 0, 0 , \text{Sewage Treatment Capacity Under Construction/Sewage Treatment Completion Time) \{PE/year\}} \tag{95}$$

Sewage Treatment Decommission Rate =

$$\text{IF THEN ELSE(Sewage Treatment Capacity} <= 0, 0 , \text{Sewage Treatment Capacity/Avg Lifespan of Sewage Treatment Plant) \{PE/year\}} \tag{96}$$

$$\text{Sewage Treatment Initiation Time} = \text{input \{year\}} \tag{97}$$

$$\text{Sewage Treatment Completion Time} = \text{input \{year\}} \tag{98}$$

$$\text{Avg Lifespan of Sewage Treatment Plant} = \text{input \{year\}} \tag{99}$$

5.5.3 Water Economics

Whilst LCOE is well documented, thoroughly used, and practised in most energy capacity cost projections, the equivalent cost calculation for the water sector is less well documented and information on it is scarce. A few method of calculating the levelised cost of water exist [213,214]. However, to ease comparison with LCOE from section 5.3.2, the following equation to calculate unit cost of water production is adapted:

Unit cost of production$_{\text{supply and services}}$ =

$$\frac{\sum \text{Cost of Water Supply \& Services}}{\sum \text{Supply Water Produced}} \tag{100}$$

Similarly, for wastewater treatment as depicted in Figure 34, the unit cost of wastewater treated is given as:

Unit cost of production$_{\text{supply and services}}$ =

$$\frac{\sum \text{Cost of Water Sewage}}{\sum \text{Wastewater Treated}} \tag{101}$$

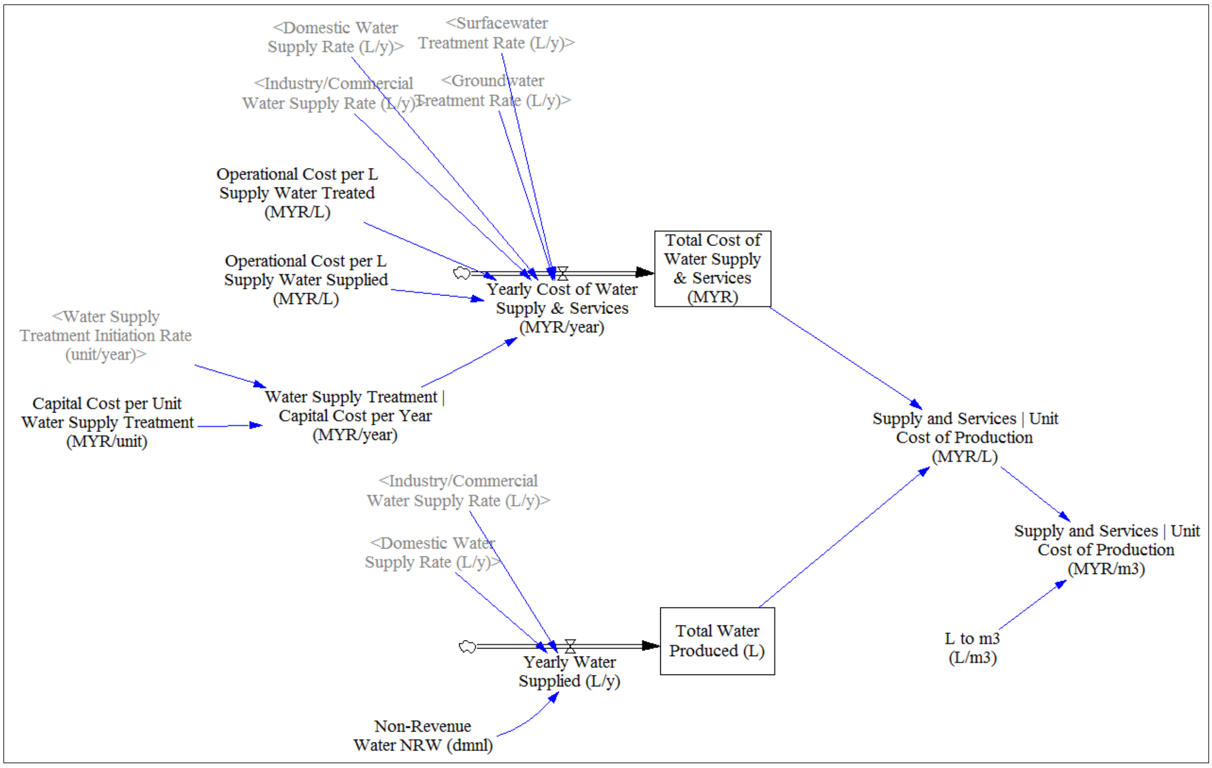

Figure 35: Unit Cost of Water Production for Water Supply and Services

Equations:

Supply and Services | Unit Cost of Production = (102)

Total Cost of Water Supply and Services/ Total Water Produced {MYR/L}

Supply and Services | Unit Cost of Production (in MYR/m3) =

Supply and Services | Unit Cost of Production*L to m3 {MYR/m3} (103)

Total Cost of Water Supply and Services =

$$\left(\int_{t_0}^{t} \text{Yearly Cost of Water Supply and Services dt} \right) + \text{Total Cost of Water Supply and Services}(t_0) \ \{\text{MYR}\} \quad (104)$$

Total Water Produced =

$$\left(\int_{t_0}^{t} \text{Yearly Water Supplied dt} \right) + \text{Total Water Produced}(t_0) \ \{\text{L}\} \quad (105)$$

Yearly Cost of Water Supply and Services =

(Operational Cost per L Supply Water Treated*(Surfacewater Treatment Rate + Groundwater Treatment Rate) + Operational Cost per L Supply Water Supplied*(Domestic Water Supply Rate + Industry/Commercial Water Supply Rate) + Water Supply Treatment | Capital Cost per year) {MYR/year} (106)

Yearly Water Supplied =

(Domestic Water Supply Rate + Industry/Commercial Water Supply Rate)*(1 - Non Revenue Water NRW) {L/year} (107)

Water Supply Treatment | Capital Cost per year =

Water Supply Treatment Initiation Rate*Capital Cost per Unit Water Supply Treatment {MYR/year} (108)

Operational Cost per L Supply Water Treated = input {MYR/L} (109)

$$\text{Operational Cost per L Supply Water Supplied} = \text{input} \{MYR/L\} \quad (110)$$

$$\text{Capital Cost per Unit Water Supply Treatment} = \text{input} \{MYR/unit\} \quad (111)$$

$$\text{Non-Revenue Water NRW} = \text{input} \{dmnl\} \quad (112)$$

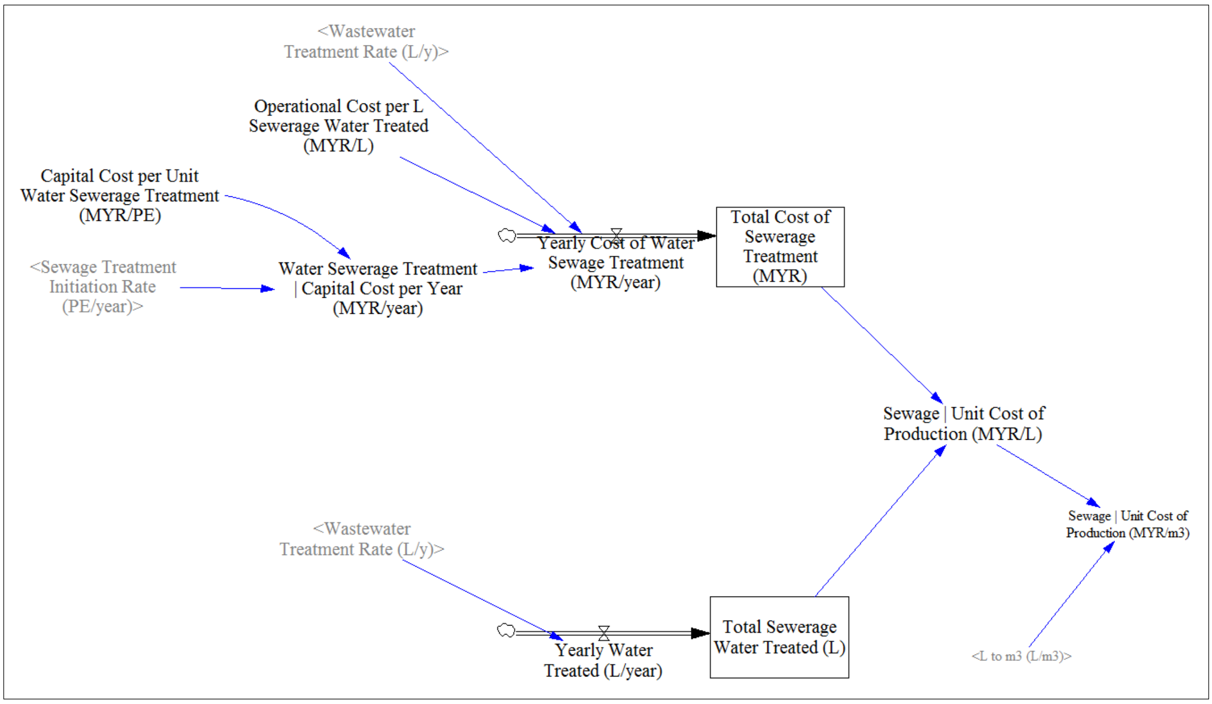

Figure 36: Unit Cost of Production for Wastewater Treatment

Equations:

Sewage | Unit Cost of Production =

Total Cost of Sewerage Treatment/ Total Sewerage Water Treated {MYR/L} (113)

Sewage | Unit Cost of Production (in MYR/m3) =

Sewage | Unit Cost of Production*L to m3 {MYR/m3} (114)

$$\text{Total Cost of Sewerage Treatment} = \left(\int_{t_0}^{t} \text{Yearly Cost of Water Sewage Treatment } dt \right) + \text{Total Cost of Sewerage Treatment}(t_0)\ \{MYR\} \quad (115)$$

$$\text{Total Sewerage Water Treated} = \left(\int_{t_0}^{t} \text{Yearly Water Treated } dt \right) + \text{Total Sewerage Water Treated}(t_0)\ \{L\} \quad (116)$$

$$\text{Yearly Cost of Water Treatment} =$$

(Operational Cost per L Supply Water Treated*Wastewater Treatment Rate + Water Sewerage Treatment | Capital Cost per Year) {MYR/year} (117)

$$\text{Yearly Water Treated} = \text{Wastewater Treatment Rate}\ \{L/year\} \quad (118)$$

Water Sewerage Treatment | Capital Cost per year =

Sewage Treatment Initiation Rate*Capital Cost per Unit Water Sewage Treatment {MYR/year} (119)

$$\text{Operational Cost per L Sewerage Water Treated} = \text{input}\ \{MYR/L\} \quad (120)$$

$$\text{Capital Cost per Unit Water Sewerage Treatment} = \text{input}\ \{MYR/PE\} \quad (121)$$

5.5.4 Forecast of Water Facility Requirements

Figure 37 shows the structure to forecast the requirement for water facilities - water supply treatment capacity and water sewage treatment capacity. Water supply and sewage treatment needs are predicted by considering the population number in 5 years, water requirement in 5 years, and the effectiveness of both water supply and sewage treatment capacities. These forecasted values are then used to initiate new projects as illustrated in sections 5.5.1 and 5.5.2.

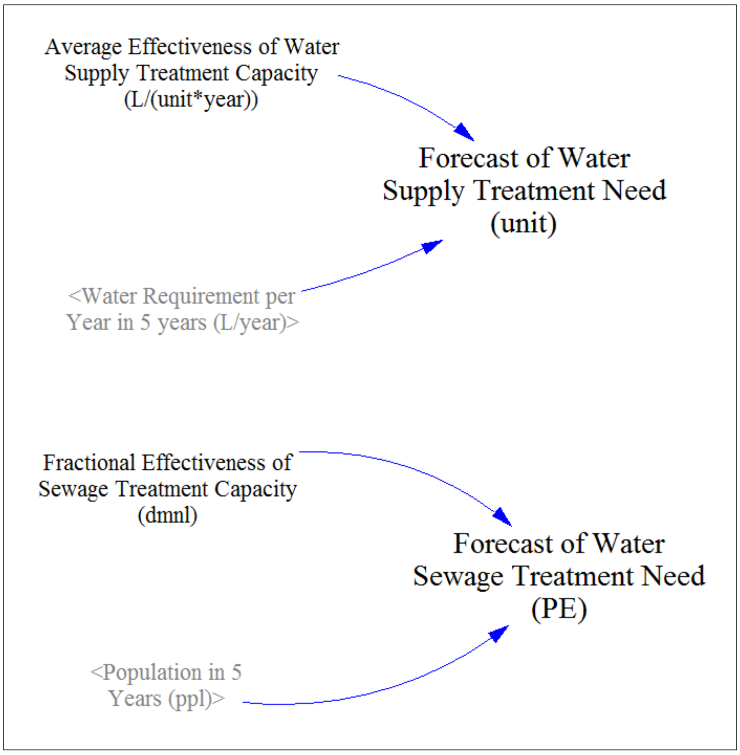

Figure 37: Forecast of Water Capacity Requirement

Equations:

Forecast of Water Supply Treatment Need =

Average Effectiveness of Water Supply Treatment Capacity/Water Requirement per Year in 5 Years {unit} (122)

Forecast of Water Sewage Treatment Need =

Population/Fractional Effectiveness of Water Supply Treatment Capacity {PE} (123)

5.6 Energy Use in Water

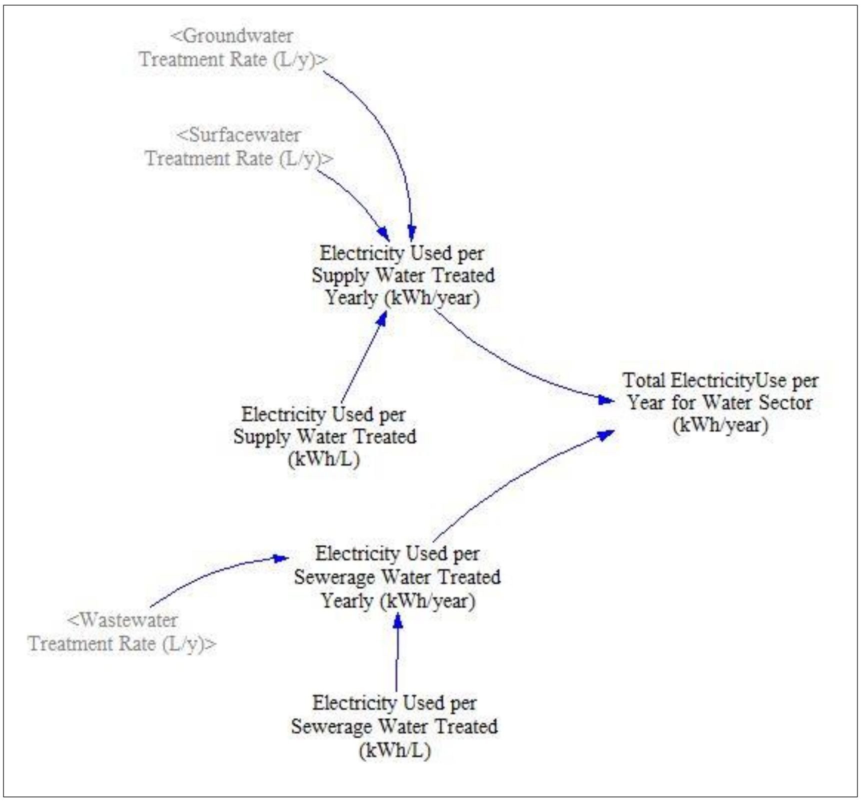

Figure 38: Electricity for Water

Figure 38 shows the relationships between electricity used and activity in the water sector. Electricity used in water sector can be found in the stages of water supply treatment, distribution, as well as wastewater treatment. In this case, the energy used in water distribution has been absorbed into water supply treatment.

Equations:

$$\text{Electricity Used per Supply Water Treated Yearly} = \\ (\text{Groundwater Treatment Rate} + \text{Surfacewater Treatment Rate}) * \\ \text{Electricity Used per Supply Water Treated } \{\text{kWh/year}\} \tag{124}$$

$$\text{Electricity Used per Sewage Water Treated Yearly} = \tag{125}$$

$$\text{Wastewater Treatment Rate} * \text{Electricity Used per Sewage Water Treated } \{\text{kWh/year}\}$$

$$\text{Total Electricity Used per Year for Water Sector} = \text{Electricity Used per Supply Water Treated Yearly} + \text{Electricity Used per Sewage Water Treated Yearly } \{\text{kWh/year}\} \quad (126)$$

$$\text{Electricity Used per Supply Water Treated} = \text{input } \{\text{kWh/L}\} \quad (127)$$

$$\text{Electricity Used per Sewage Water Treated} = \text{input } \{\text{kWh/L}\} \quad (128)$$

5.7 Economic Indicators

5.7.1 GNI and Affordability of Population on Resources

Figure 39 shows the SFD for gross national income (GNI). GNI is used to calculate the average per capita income, where together with is corresponding breakdown, can be used to calculate per capita affordability on each of the three resources. GNI is represented as stocks where its change (growth or decline) is affected by a yearly fractional change. Proportion of income to spend on WEF bills is the fraction of each people's income that the people are willing to spend on acquiring necessary water, energy, and food.

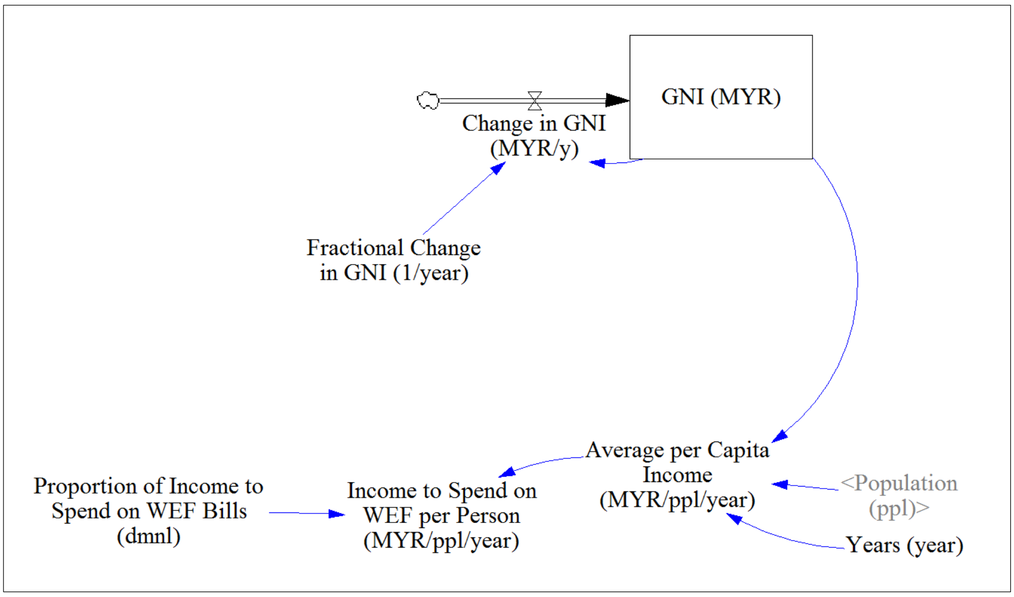

Figure 39: GNI SFD and Income to Spend on WEF Bills

Equations:

$$\text{GNI} = \left(\int_{t_0}^{t} \text{Change in GNI } dt \right) + \text{GNI}(t_0) \ \{\text{MYR}\} \tag{129}$$

$$\text{Change in GNI} = \text{GNI} * \text{Fractional Change in GNI} \ \{\text{MYR/year}\} \tag{130}$$

$$\text{Average per Capita Income} = \text{GNI/(Population*Years)} \ \{\text{MYR/(ppl*year)}\} \tag{131}$$

$$\text{Income to spend of WEF per Person} = \text{Proportion of Income to Spend on WEF Bills*Average per Capita Income} \tag{132}$$

$$\text{Fractional Change in GNI} = \text{input} \ \{1/\text{year}\} \tag{133}$$

5.8 Conventional Agriculture

5.8.1 Land Use of Staple Food

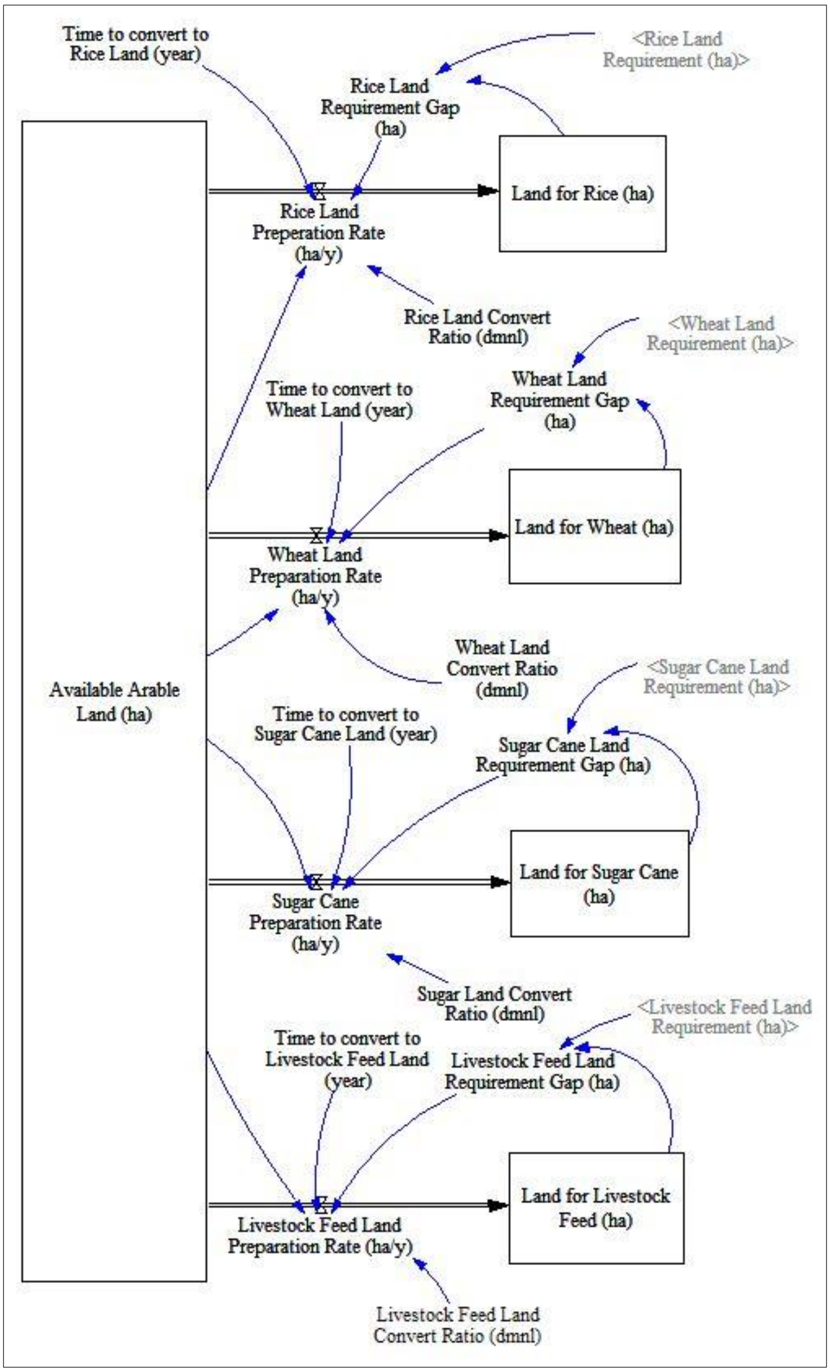

Figure 40: Land Use of Staple Food

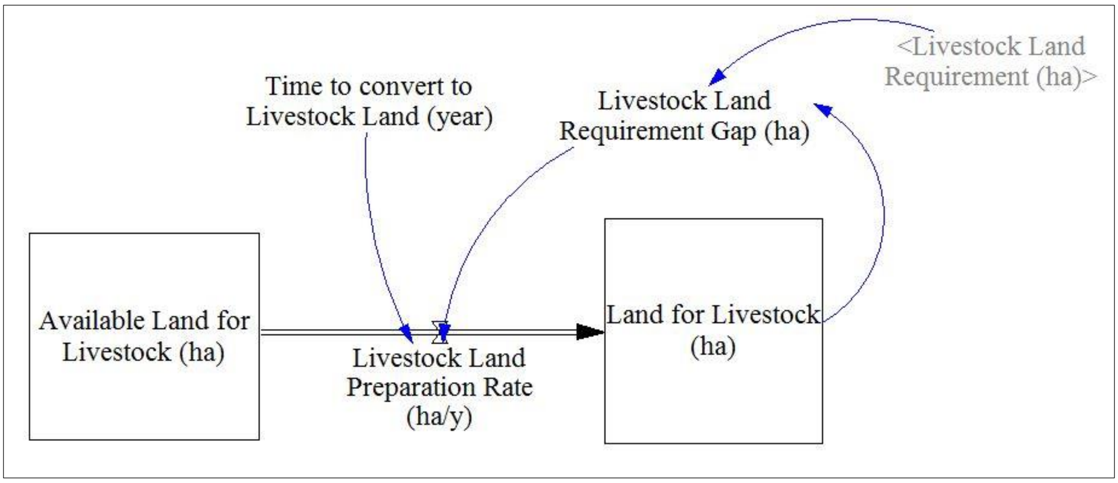

Figure 41: Land for Livestock

Figure 40 shows the SFD of land use for staple food. Four staple food namely rice, wheat, livestock, and sugar. Whilst rice and wheat are investigated directly based their own land usage, sugar and livestock are calculated differently.

Seven stocks exist in the SFD i.e. “available arable land”, “available land for livestock”, “land for rice”, “land for wheat”, “land for livestock feed”, “land for sugar cane”, “land for livestock”. “Available arable land” is a finite stock that represents the fertile land throughout Malaysia that are capable of being prepared for staple food growing. The rates at which lands are converted into land for staple food are determined by their respective land requirement gaps. Land requirement are then calculated from the population food demand as illustrated in section 5.2.2.

Likewise, “available land for livestock” is the amount of land that are suitable for livestock farming. If livestock are grown, there is also a need for livestock feed. As such, amount of homebred livestock, together with desired SSL for livestock feed, do affect the amount of livestock land required in Figure 40.

Equations:

$$\text{Available Arable Land} = \left(-\int_{t_0}^{t}(\sum \text{STAPLE FOOD TYPE Land Preparation Rate})\,dt\right) + \text{Available Arable Land}(t_0)\ \{ha\} \tag{134}$$

$$\text{Land for STAPLE FOOD TYPE} = \int_{t_0}^{t} \text{STAPLE FOOD TYPE Land Preparation Rate}\,dt + \text{Land for STAPLE FOOD TYPE}(t_0)\ \{ha\} \tag{135}$$

STAPLE FOOD TYPE Land Preparation Rate =

STAPLE FOOD TYPE Land Requirement Gap/Time to convert to STAPLE FOOD TYPE Land {ha/year} (136)

STAPLE FOOD TYPE Land Requirement Gap =

STAPLE FOOD TYPE Land Requirement - Land for STAPLE FOOD TYPE {ha} (137)

$$\text{STAPLE FOOD LAND Convert Ratio} = \text{input}\ \{dmnl\} \tag{138}$$

5.8.2 Staple Food Production

Figure 42 shows the food production SFD for staple food. The main stock is the food storage while four rates affect its change in level. The four rates are food production, food import, food consumption and food export. Food production is determined by the amount of land that is prepared to grow the food, together with food yield (measured in kg/ha) and food production time. Food consumption rate is assumed the same as food requirement per year, as depicted in section 5.2.2. Food export is determined by multiplying a factor, namely the fractional export rate, by the total amount of food in storage. Food import is required as effectively, Malaysia is not 100% self-sufficient in any of the staple food. However, Figure 42 only applies to rice, wheat, and livestock. An additional stage is needed for sugar, which is the processing from sugar cane into sugar, as depicted in Figure 43. From the sugar cane to sugar production, there may be losses in terms of mass. As a result, the variable of sugar cane to sugar ratio, which provides the ratio of mass equivalence from sugar cane to sugar, has been introduced.

The FOOD production variable from this section will be used later to calculate food links to energy and water in section 5.11.

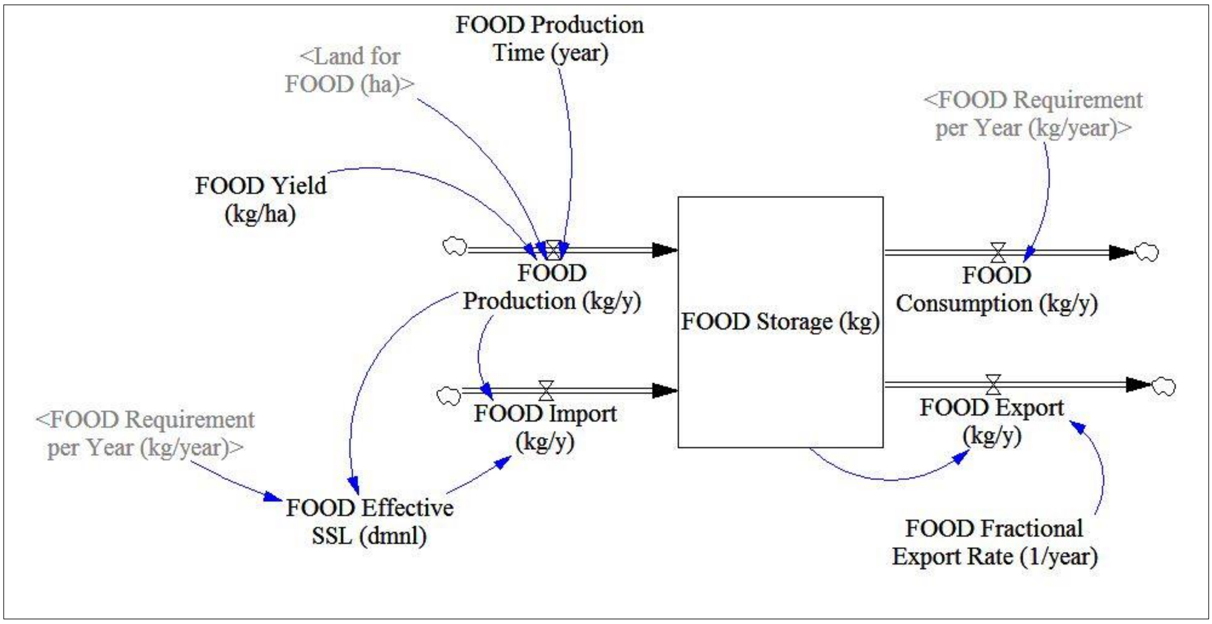

Figure 42: Food Production SFD

Equations:

$$\text{Food Storage} = \int_{t_0}^{t} (\text{FOOD Production} + \text{FOOD Import} - \text{FOOD Consumption} - \text{FOOD Export})\, dt + \text{FOOD Storage}(t_0)\ \{kg\} \quad (139)$$

FOOD Production =

FOOD Yield*Land for FOOD/FOOD Production Time {kg/year} (140)

FOOD Import =

(1-FOOD Effective SSL)*FOOD Production {kg/year} (141)

$$\text{FOOD Consumption} = \text{FOOD TYPE Land Requirement Gap } \{kg/year\} \tag{142}$$

$$\text{FOOD Export} = \text{FOOD Fractional Export Rate*FOOD Storage } \{kg/year\} \tag{143}$$

$$\text{FOOD Effective SSL} = \text{FOOD Production / Food Requirement per Year } \{dmnl\} \tag{144}$$

$$\text{FOOD Yield} = \text{input } \{kg/ha\} \tag{145}$$

$$\text{FOOD Production Time} = \text{input } \{year\} \tag{146}$$

$$\text{FOOD Fractional Export Rate} = \text{input } \{1/year\} \tag{147}$$

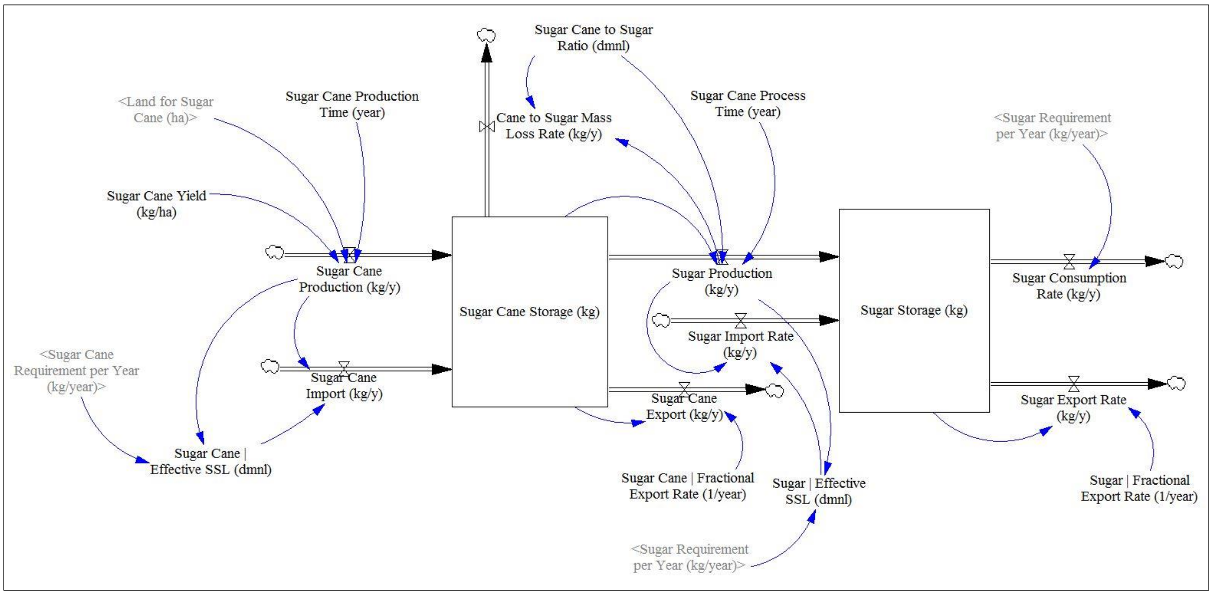

Figure 43: Sugar Production SFD

Equations:

Sugar Cane Storage =

$$\int_{t_0}^{t}(\text{Sugar Cane Production} + \text{Sugar Cane Import} - \text{Sugar Production} - \text{Sugar Cane Export} - \text{Cane to Sugar Mass Loss Rate})\, dt + \text{Sugar Cane Storage}(t_0)\ \{kg\} \quad (148)$$

Sugar Cane Production =

Sugar Cane Yield*Land for Sugar Cane/Sugar Cane Production Time {kg/year} (149)

Sugar Cane Import =

(1-Sugar Cane Effective SSL)*Sugar Cane Production {kg/year} (150)

Sugar Production =

IF THEN ELSE(Sugar Cane Storage<=0, 0, ((1/Sugar Cane to Sugar Ratio)*Sugar Cane Storage/Sugar Cane Process Time) {kg/year} (151)

Cane to Sugar Mass Loss Rate =

(1-(1/Sugar Cane to Sugar Ratio))*Sugar Production {kg/year} (152)

Sugar Cane Export =

IF THEN ELSE(Sugar Cane Storage<=0, 0, (Sugar Cane Fractional Export Rate*Sugar Cane Storage) {kg/year} (153)

Sugar Cane Effective SSL =

Sugar Cane Production / Sugar Cane Requirement per Year {dmnl} (154)

Sugar Consumption Rate = Sugar Requirement per Year {kg/year} (155)

Sugar Export Rate =

IF THEN ELSE(Sugar Storage<=0, 0, (Sugar | Fractional Export Rate*Sugar Storage)) {kg/year} (156)

Sugar Cane Yield = input {kg/ha} (157)

Sugar Cane Production Time = input {year} (158)

Sugar Cane Fractional Export Rate = input {1/year} (159)

5.8.3 Desired Self-Sufficiency Level (SSL) and Land Expansion of Staple Food

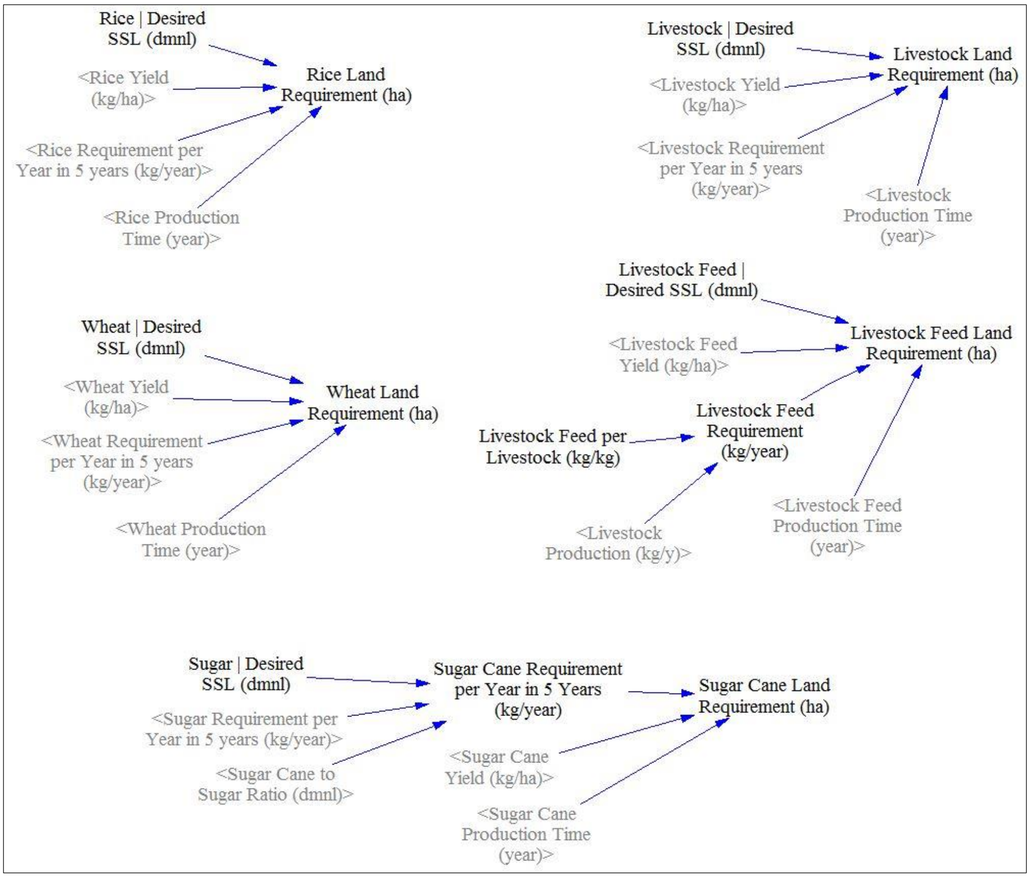

Figure 44: From Desired SSL to Land Requirement

Self-sufficiency level (SSL) for the food sector is a measure of total production of food by the country as a proportion of total requirement for the country for any selected food type. Whilst section 5.8.2 illustrated the effective SSL for any given time, this section illustrated the desired SSL where we hope to achieve. As such, desired SSL would be treated as an input into the model where we hope to achieve how much of SSL and subsequently calculate the amount of land that is required to be expanded to grow more food. Apart from SSL, other important variables to determine the amount of land required to achieve the desired SSL are each food's respective yield, requirement in 5 years, and production time. Since different food types would have their own separate SSL, it is thus necessary to have SSL values for different food types.

Equations:

FOOD Land Requirement =

FOOD | Desired SSL*FOOD Yield*FOOD Production Time/FOOD Requirement in 5 Years {ha} (160)

$$\text{FOOD} \mid \text{Desired SSL} \ = \ \text{input}\,\{\text{dmnl}\} \tag{161}$$

For sugar, an additional process step is required as before sugar is obtained, its sugar crop, sugar cane, has to be grown first before being processed into sugar. Considering the staple food of interest is sugar while its raw material is sugar cane, sugar cane land requirement is determined from the desired SSL of sugar. Thus, their computations are given by:

Sugar Cane Land Requirement =

Sugar Cane Requirement per Year in 5 Years* Sugar Cane Production Time/ Sugar Cane Yield {ha} (162)

Sugar Cane Requirement per Year in 5 Years =

Sugar | Desired SSL*Sugar Requirement per Year in 5 years*Sugar Cane to Sugar Ratio {kg/year} (163)

5.9 Non-Food Agriculture

5.9.1 Land Usage

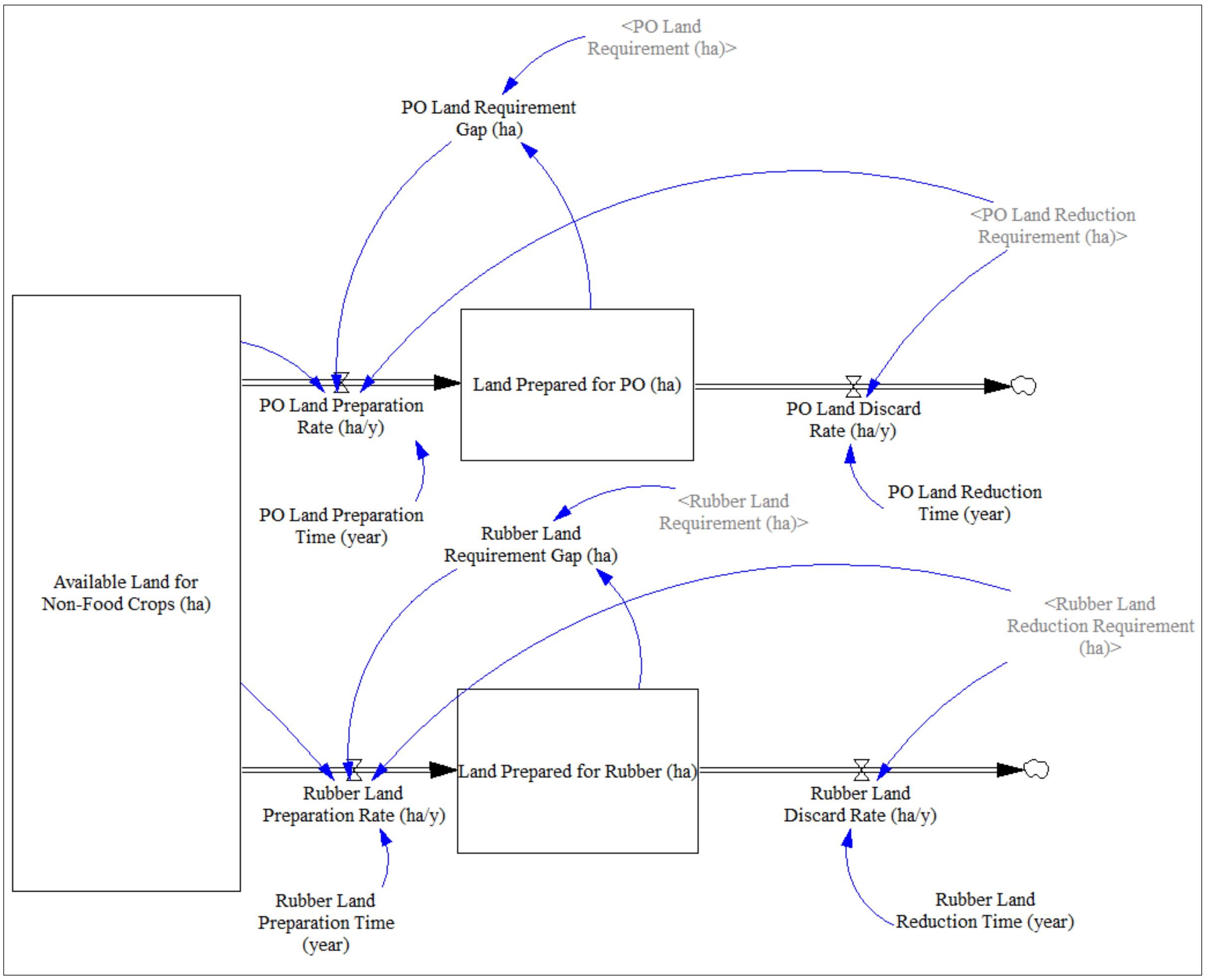

Figure 45: Non-food Land Use

Non-food agriculture, namely palm oil and rubber, contributes a large part of Malaysia's agriculture share. Similar to conventional staple food, non-food agriculture uses large amounts of land, and thus uses water and energy as well. As such, the SFD, as illustrated in Figure 45, shows the land use dynamics for the non-food agriculture. However, as opposed to staple food, the difference in non-food SFD is that desired SSL and effective SSL are not present because they do not address food security. This is because palm oil and rubber are mostly grown for economic purposes. As such, it is also important to consider the production and exports of palm oil rubber, as would be discussed in section 5.9.2, which become users of water and energy, as well as provider of national revenue.

Equations:

$$\text{Available Land for Non-Food Crops} =$$

$$\left(-\int_{t_0}^{t}(\sum \text{NON-FOOD TYPE Land Preparation Rate})\, dt\right) + \text{Available Land for Non-Food Crops}(t_0)\ \{ha\} \tag{164}$$

$$\text{Land Prepared for NON-FOOD TYPE} =$$

$$\int_{t_0}^{t} \text{NON-FOOD TYPE Land Preparation Rate}\, dt + \text{Land Prepared for NON-FOOD TYPE}(t_0)\ \{ha\} \tag{165}$$

$$\text{NON-FOOD TYPE Land Preparation Rate} =$$

$$\text{IF THEN ELSE(Available Land for Non-Food Crops} <= 0, 0, \text{NON-FOOD TYPE Land Requirement Gap} / \text{NON-FOOD TYPE Land Preparation Time})\ \{ha/year\} \tag{166}$$

$$\text{NON-FOOD TYPE Land Requirement Gap} =$$

$$\text{NON-FOOD TYPE Land Requirement - Land Prepared for NON-FOOD TYPE}\ \{ha\} \tag{167}$$

$$\text{NON} - \text{FOOD TYPE Land Preparation Time} = \text{input}\ \{year\} \tag{168}$$

5.9.2 Non-Food Crops Production

Non-food crops in Malaysia mainly consists of palm oil and rubber. For palm oil, the primary products are crude palm oil (CPO). Not only does growing palm oil require large amount of water, but processing fresh fruit branches (FFB) into CPO also requires large amount of water and energy (F1). Rubber industry has also started since the British colonization days in Malaysia. Similar to palm oil, rubber also uses large amount of land, and thus large amount of water and energy. Figure 46 shows the SFD for the production of non-food crops namely PO and rubber.

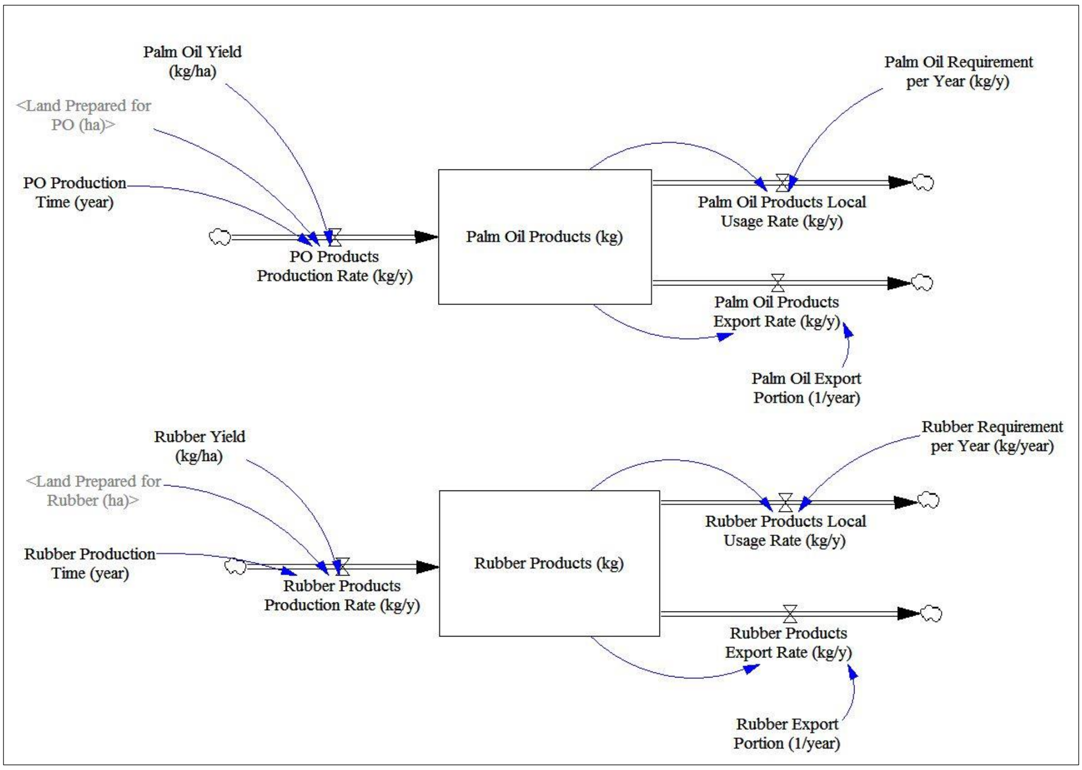

Figure 46: Non-Food Products

Equations:

NON-FOOD TYPE Products =

$$\int_{t_0}^{t} \text{NON-FOOD Products Production Rate} - \text{NON-FOOD TYPE Products Local Usage Rate} - \text{NON-FOOD Products Export Rate}\, dt + \text{NON-FOOD TYPE Products}(t_0) \quad \{\text{ha}\} \tag{169}$$

NON-FOOD Products Production Rate =

$$\text{NON-FOOD TYPE Yield} * \text{Land Prepared for NON-FOOD} / \text{NON-FOOD TYPE Production Time} \quad \{\text{kg/year}\} \tag{170}$$

NON-FOOD Products Local Usage Rate = (171)

IF THEN ELSE(NON-FOOD TYPE Products<=0, 0
, NON-FOOD TYPE Requirement per year) {ha/year}

NON-FOOD Products Export Rate =

$$\begin{gathered}\text{IF THEN ELSE(NON-FOOD TYPE Products<=0, 0} \\ \text{, NON-FOOD TYPE Products} * \text{NON-FOOD TYPE Export Portion)} \\ \text{\{ha/year\}}\end{gathered} \tag{172}$$

$$\text{NON} - \text{FOOD TYPE Production Time} = \text{input \{year\}} \tag{173}$$

$$\text{NON} - \text{FOOD TYPE Yield} = \text{input \{kg/ha\}} \tag{174}$$

$$\text{NON} - \text{FOOD TYPE Export Portion} = \text{input \{year\}} \tag{175}$$

5.10 Marginal Crops Agriculture

5.10.1 Land Use of Marginal Crops

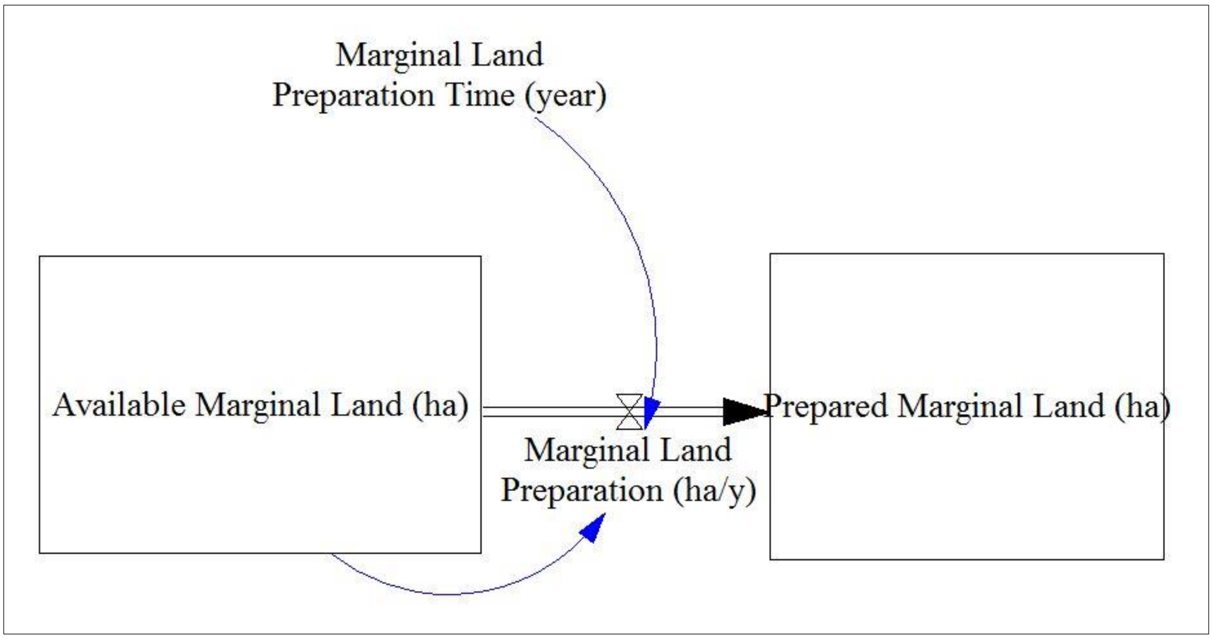

Figure 47: Marginal Land Use

Whilst the staple food section considers the main diet of Malaysians, Malaysia has more than 6 million hectares of marginal land that can be used to cultivate and farm under-utilised crops (F2). Example of under-utilised crops are such as moringa oleifera and bombara groundnuts (F1). Moringa oleifera and bombara groundnuts have nutritional values that are equal or at least better than that of typical staple food listed in previous subsections. As such, the dynamics of these under-utilized crops are included in the study, where their respective usage of land, water, and energy are also considered.

Equations:

$$\text{Available Marginal Land} = \left(-\int_{t_0}^{t} \text{Marginal Land Preparation dt}\right) + \text{Available Marginal Land}(t_0) \ \{\text{ha}\} \quad (176)$$

$$\text{Prepared Marginal Land} = \int_{t_0}^{t} \text{Marginal Land Preparation dt} + \text{Prepared Marginal Land}(t_0)\ \{\text{ha}\} \quad (177)$$

$$\text{Marginal Land Preparation} = \text{IF THEN ELSE(Available Marginal Land}<=0, 0, \text{Available Marginal Land}/\text{Marginal Land Preparation Time})\ \{\text{ha/year}\} \quad (178)$$

$$\text{Marginal Land Preparation Time Time} = \text{input}\ \{\text{year}\} \quad (179)$$

5.10.2 Marginal Crops Production

Figure shows the SFD for marginal crops production. Similar to the conventional staple food crops and non-food crops, knowing amount of land required from section 5.10.1 allows for calculation for yearly production of under-utilized crops via variables of land efficiency and production time. Subsequently, yearly production rate would be used to calculate yearly use of water and energy for marginal crop. On top of that, nutrients obtained per kg marginal crop can also be computed.

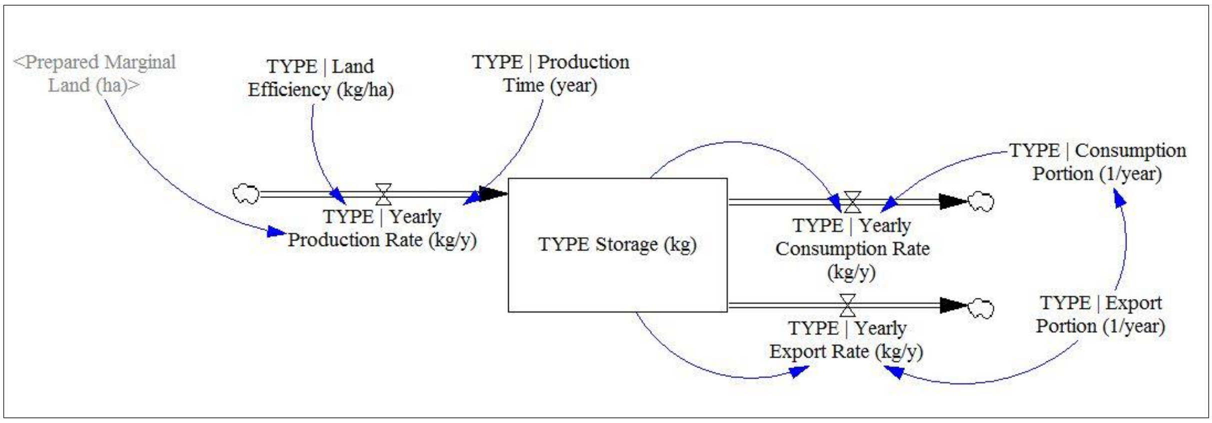

Figure 48: Marginal Crop Production

Equations:

$$\text{TYPE Storage} = \int_{t_0}^{t} \text{Marginal Land Preparation}\, dt + \text{TYPE Storage}(t_0)\ \{kg\} \tag{180}$$

TYPE | Yearly Production Rate =

Prepared Marginal Land*TYPE | Land Efficiency / TYPE | Production Time {kg/year} (181)

TYPE | Yearly Consumption Rate =

IF THEN ELSE(TYPE Storage<=0, 0 ,TYPE | Consumption Portion * TYPE | Storage) {kg/year} (182)

TYPE | Yearly Export Rate =

IF THEN ELSE(TYPE Storage<=0, 0 ,TYPE | Export Portion * TYPE | Storage) {kg/year} (183)

TYPE | Consumption Portion =

1 − TYPE | Export Portion {1/year} (184)

$$\text{TYPE} \mid \text{Export Portion} \;=\; \text{input}\,\{1/\text{year}\} \tag{185}$$

$$\text{TYPE} \mid \text{Production Time} \;=\; \text{input}\,\{\text{year}\} \tag{186}$$

$$\text{TYPE} \mid \text{Land Efficiency} \;=\; \text{input}\,\{\text{kg/ha}\} \tag{187}$$

5.11 Resource Use in Agriculture

5.11.1 Energy Use in Agriculture

Figure 49 shows an important food-energy link. Energy use from agriculture can be divided into two: electricity used per year and fuel used per year. They are calculated by taking the food production estimated from section 5.8.2 and multiplying with unit use of energy for each respective food type.

Similar to staple food, Figure 50 and Figure 51 shows energy use for non-food crops and marginal crops respectively. Likewise, energy use in these subsections of agriculture are also calculated by considering per unit use of energy and yearly production in mass kg.

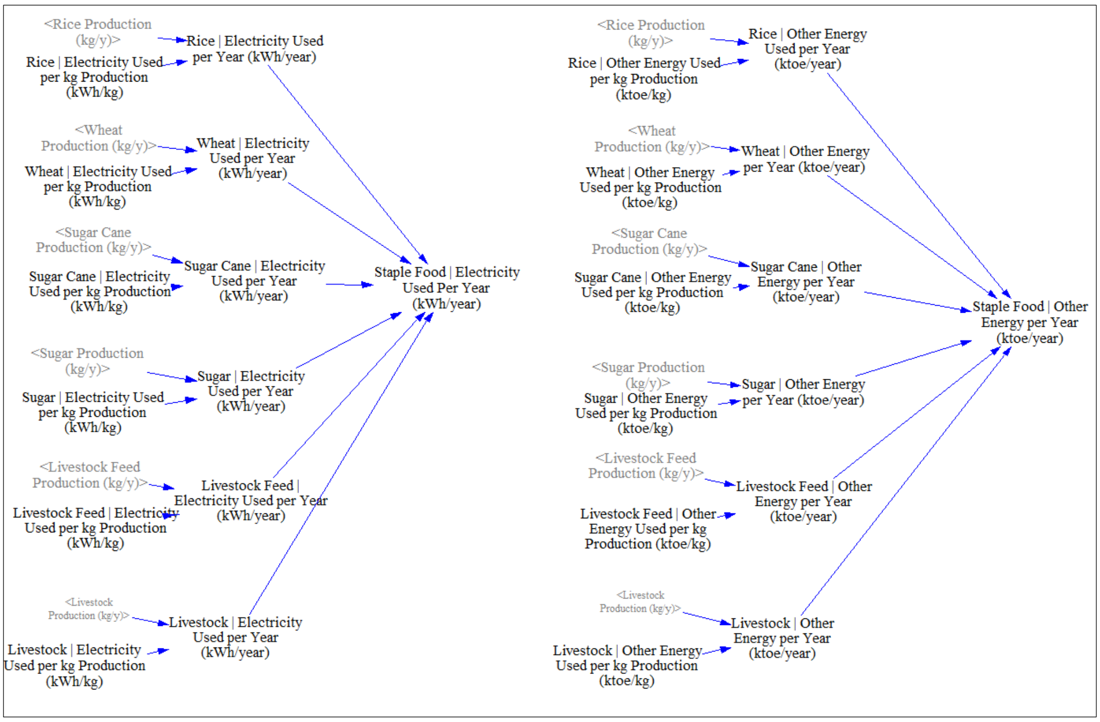

Figure 49: Energy Use in Agriculture

Equations:

$$\text{Staple Food | Electricity Used per Year} = \sum_{\text{all Staple Food TYPES}} \text{FOOD TYPE | Electricity used per Year} \quad \{\text{kWh/year}\} \tag{188}$$

$$\text{Staple Food | Fuel Used per Year} = \sum_{\text{all Staple Food TYPES}} \text{FOOD TYPE | Fuel used per Year} \quad \{\text{ktoe/year}\} \tag{189}$$

$$\text{FOOD TYPE | Electricity Used per Year} = \text{FOOD TYPE Production} * \text{FOOD TYPE | Electricity Used per kg Production } \{\text{kWh/year}\} \tag{190}$$

$$\text{FOOD TYPE | Fuel Used per Year} = \text{FOOD TYPE Production} * \text{FOOD TYPE | Fuel Used per kg Production } \{\text{ktoe/year}\} \tag{191}$$

$$\text{TYPE | Electricity Used per kg Production} = \text{input } \{\text{kWh/kg}\} \tag{192}$$

$$\text{TYPE | Fuel Used per kg Production} = \text{input } \{\text{ktoe/kg}\} \tag{193}$$

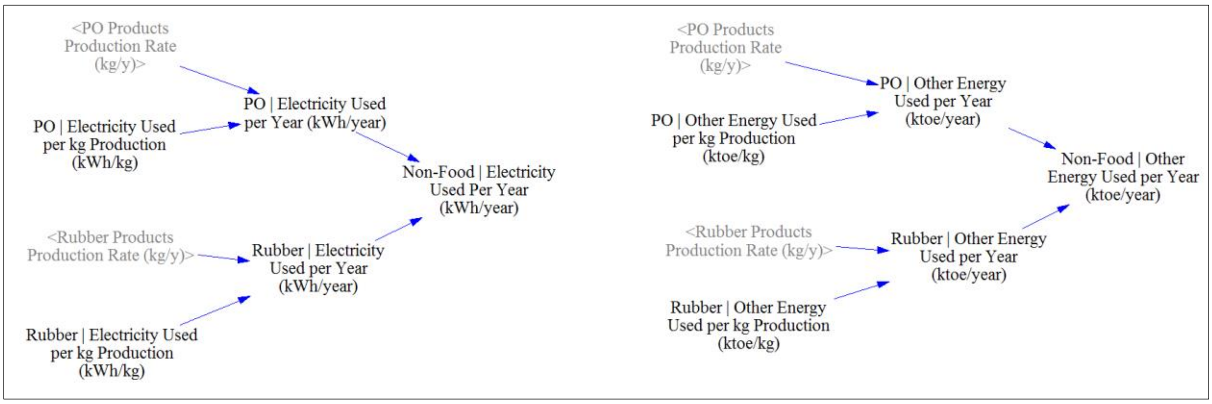

Figure 50: Energy Use in Non-Food Crop

Equations:

Non-Food | Electricity Used Per Year =

$$\sum_{\text{all Non-Food}} \text{TYPE | Electricity Use per Year} \tag{194}$$

{kWh/year}

Non-Food | Other Energy Used Per Year =

$$\sum_{\text{all Non-Food}} \text{TYPE | Other Energy Used Per Year} \tag{195}$$

{kWh/year}

NON-FOOD TYPE | Electricity Use per Year =

NON-FOOD TYPE Products Production Rate* NON-FOOD TYPE | Electricity Used per kg Production {kWh/year} (196)

NON-FOOD TYPE | Other Energy Used Per Year =

NON-FOOD TYPE Products Production Rate* NON-FOOD TYPE | Other Energy Used Per kg Production {ktoe/year} (197)

NON-FOOD TYPE | Electricity Used per kg Production = input {kWh/kg} (198)

$$\text{NON-FOOD TYPE | Other Energy Used per Year} = \text{input \{ktoe/kg\}} \tag{199}$$

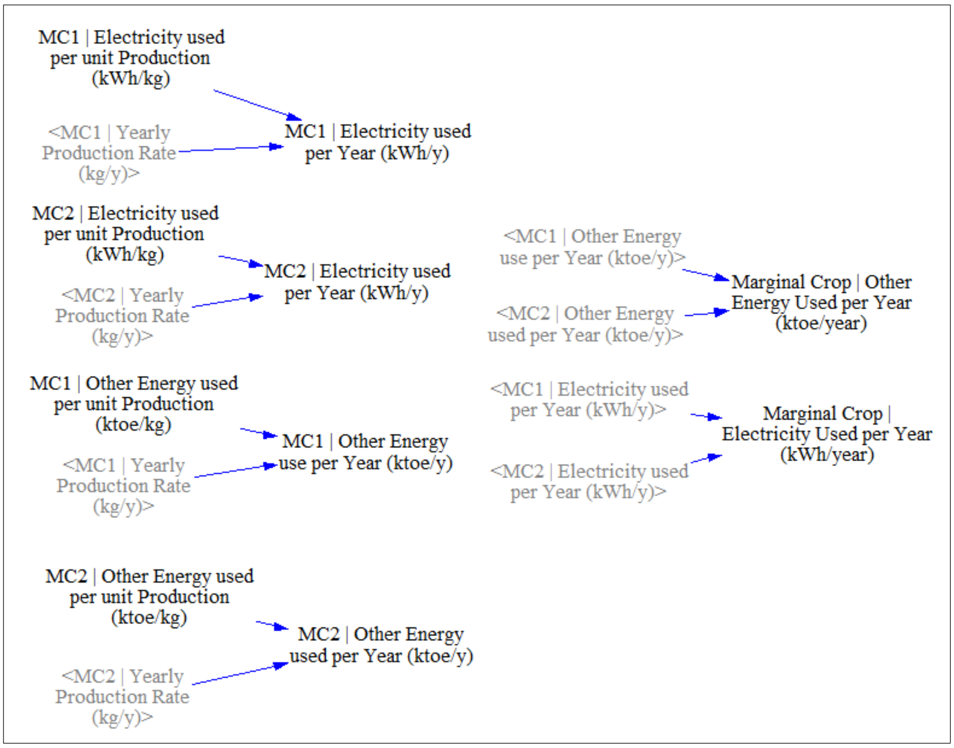

Figure 51: Energy Use in Marginal Crop

Equations:

$$\text{Marginal Crop | Electricity Used per Year} = \sum_{\text{all Marginal Crop TYPES}} \text{MARGINAL TYPE | Electricity used per Year} \quad \text{\{kWh/year\}} \tag{200}$$

$$\text{Marginal Crop | Other Energy Used per Year} = \sum_{\text{all Marginal Crop TYPES}} \text{MARGINAL TYPE | Other Energy used per Year} \quad \text{\{ktoe/year\}} \tag{201}$$

$$\text{MARGINAL TYPE | Electricity Used per Year} = \tag{202}$$

$$\text{MARGINAL TYPE } | \text{Electricity used per unit Production} \\ * \text{MARGINAL TYPE } | \text{Yearly Production Rate } \{kWh/y\}$$

MARGINAL TYPE | Other Energy Used per Year =

$$\text{MARGINAL TYPE } | \text{Other Energy Used per unit Production} \\ * \text{MARGINAL TYPE } | \text{Yearly Production Rate } \{ktoe/y\} \quad (203)$$

$$\text{MARGINAL TYPE} \, | \, \text{Electricity used per unit Production} = \text{input } \{kWh/kg\} \quad (204)$$

$$\text{MARGINAL TYPE} \, | \, \text{Other Energy used per unit Production} = \text{input } \{ktoe/kg\} \quad (205)$$

5.11.2 Water Use in Agriculture

As opposed to energy use in agriculture that is divided into electricity and fuel used, water use in producing staple food is mainly from water withdrawal only. Figure 52 shows the relationships of water use in producing staple food in a year. The water use for each staple food, namely rice, wheat, sugar, and livestock, is calculated by multiplying unit withdrawal per kg production by its corresponding yearly food production. The concept of water use calculation is also repeated in non-food crops and marginal crops, as depicted in Figure 53 and Figure 54.

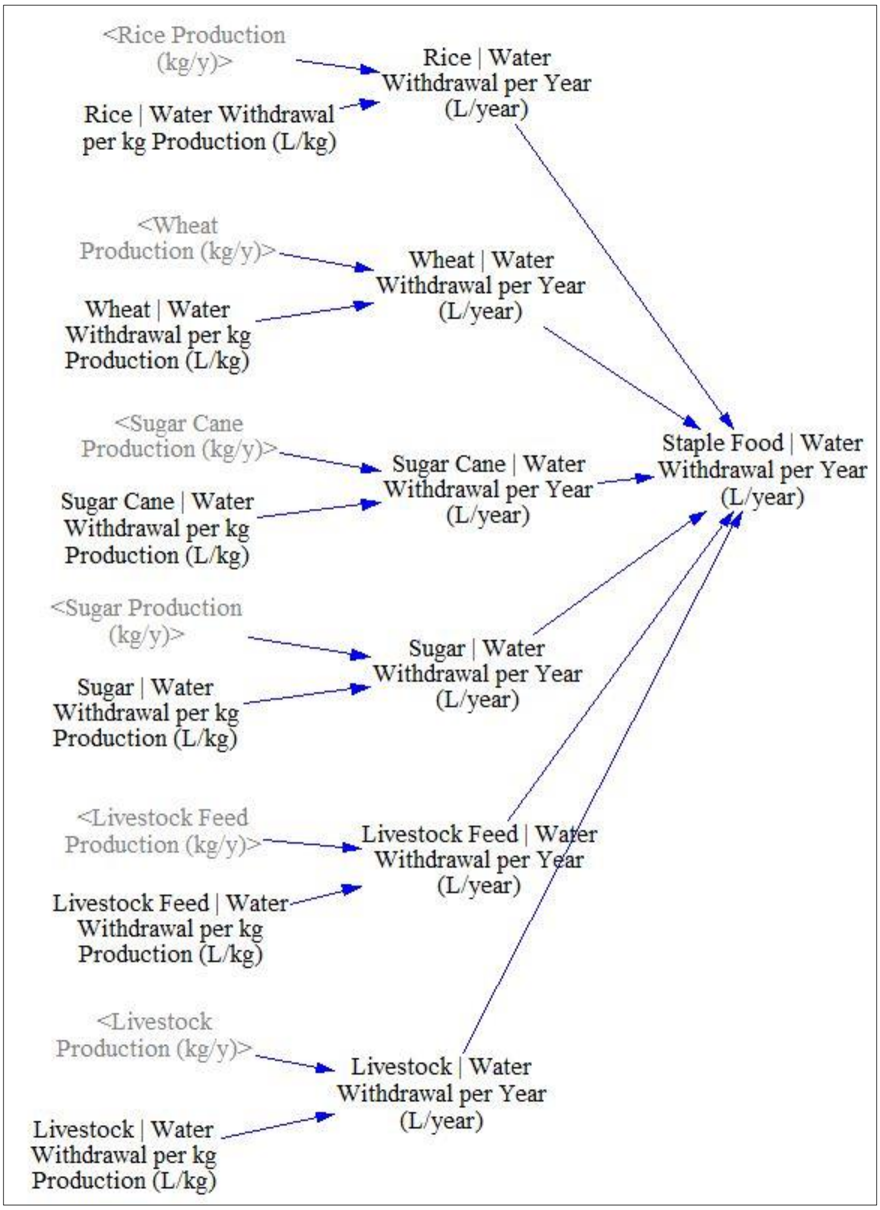

Figure 52: Water Use in Staple Food

Equations:

$$\text{Staple Food | Water Withdrawal per Year} = \sum_{\text{all Staple Food TYPES}} \text{TYPE | Water Withdrawal per Year} \quad (206)$$

{L/year}

$$\text{FOOD TYPE} \mid \text{Water Withdrawal per Year} =$$

$$\text{TYPE Production} * \text{TYPE} \mid \text{Water Withdrawal per kg Production} \tag{207}$$

$\{L/year\}$

$$\text{FOOD TYPE} \mid \text{Water Withdrawal per kg Production} = \text{input}\ \{L/kg\} \tag{208}$$

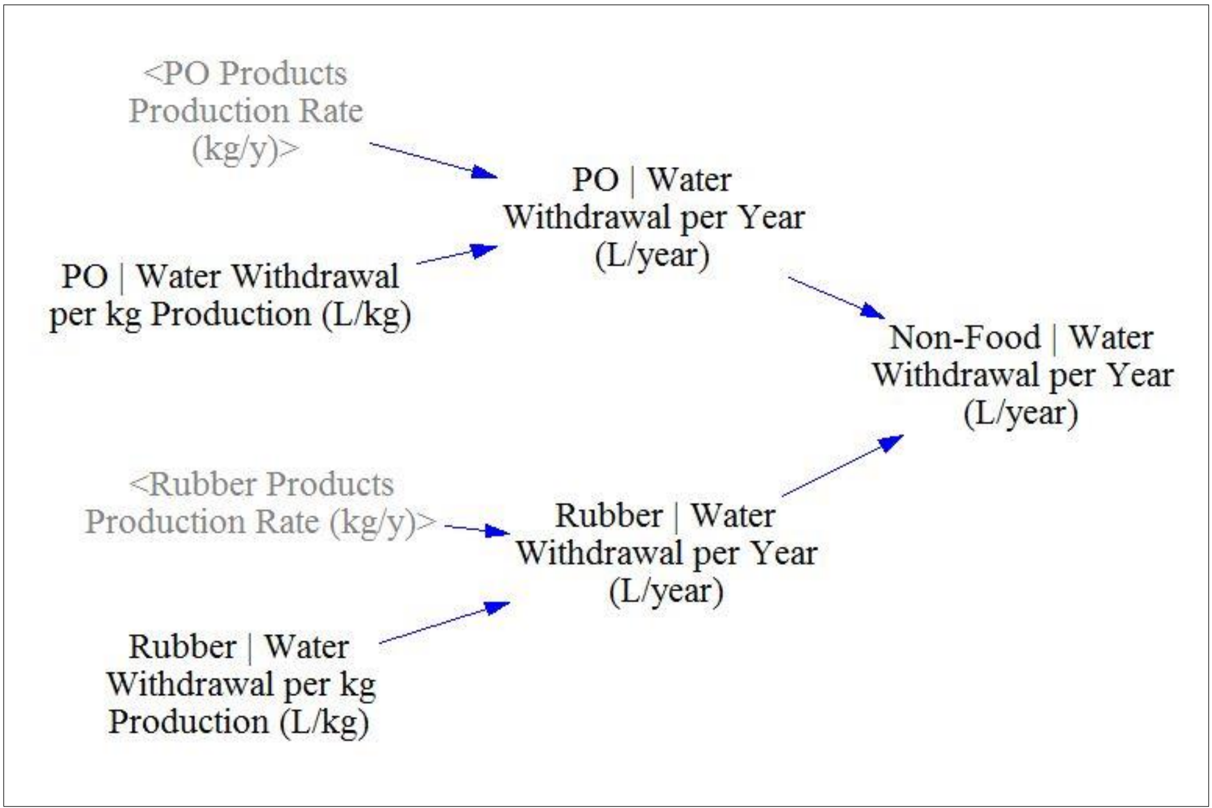

Figure 53: Water Use in Non-Food Crop

Equations:

$$\text{Non-Food} \mid \text{Water Withdrawal per Year} =$$

$$\sum_{\text{all Non-Food TYPES}} \text{TYPE} \mid \text{Water Withdrawal per Year} \tag{209}$$

$\{L/year\}$

$$\text{NON-FOOD TYPE} \mid \text{Water Withdrawal per Year} = \text{TYPE Production} * \text{TYPE} \mid \text{Water Withdrawal per kg Production} \quad \{\text{L/year}\} \tag{210}$$

$$\text{NON-FOOD TYPE} \mid \text{Water Withdrawal per kg Production} = \text{input } \{\text{L/kg}\} \tag{211}$$

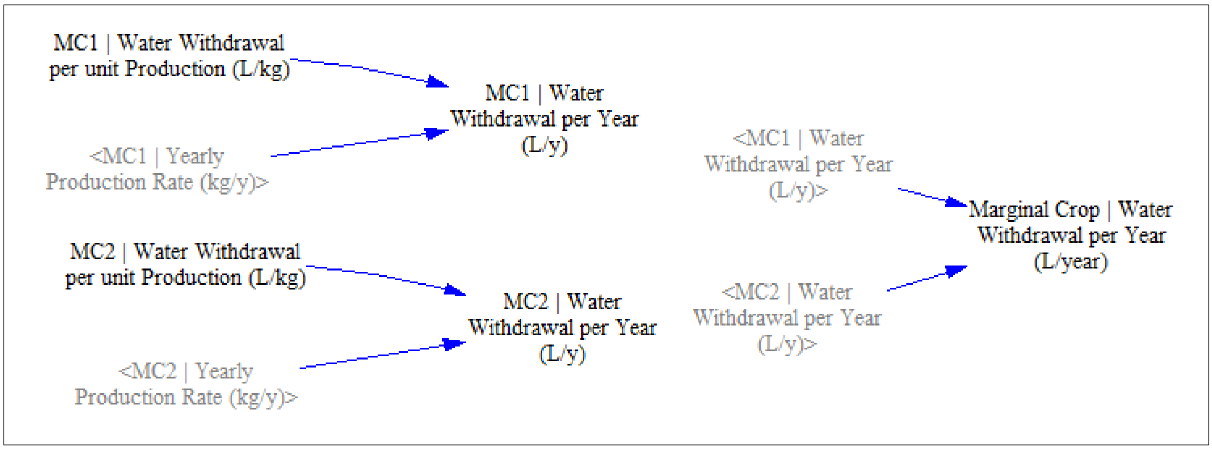

Figure 54: Water Use in Marginal Crop

Equations:

$$\text{Marginal Crop} \mid \text{Water Withdrawal per Year} = \sum_{\text{all Marginal Crop TYPES}} \text{TYPE} \mid \text{Water Withdrawal per Year} \quad \{\text{L/year}\} \tag{212}$$

$$\text{MARGINAL TYPE} \mid \text{Water Withdrawal per Year} = \text{TYPE} \mid \text{Water Withdrawal per unit Production} * \text{MARGINAL TYPE} \mid \text{Yearly Production Rate} \quad \{\text{L/year}\} \tag{213}$$

$$\text{MARGINAL TYPE} \mid \text{Water Withdrawal per unit Production} = \text{input } \{\text{L/kg}\} \tag{214}$$

5.12 Nutrition Security

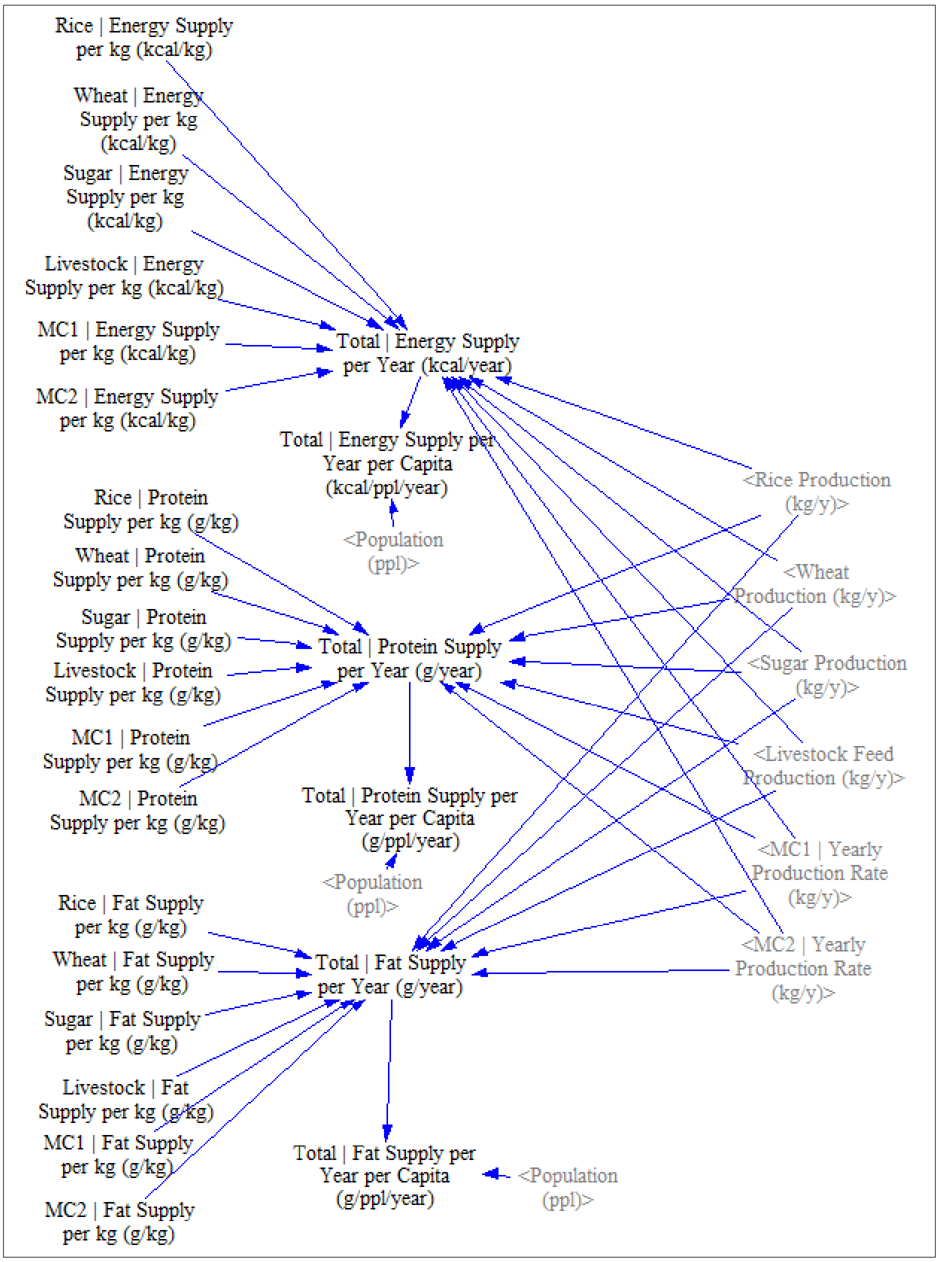

Figure 55: Nutrition Security From Food

Figure 55 shows the structure for calculating nutrition as obtained from staple foods and marginal crops. Three major nutrients are used to represent the nutrition security of food sector within the WEF security nexus, namely energy, protein, and fat respectively. The nutrition security calculation is used to determine how much nutrient the country can produce because of local food production. The calculation is performed by considering how much nutrients each of the food types contains together with yearly local production in kg/year, as calculated from section 5.8.2 and 5.10.2.

Equations:

$$\text{Total | Energy Supply per Year} = \sum_{\text{all Food TYPES}} \text{FOOD TYPE | Energy Supply per kg} * \text{FOOD TYPE Production} \quad \{\text{kcal/year}\} \tag{215}$$

$$\text{Total | Protein Supply per Year} = \sum_{\text{all Food TYPES}} \text{FOOD TYPE | Protein Supply per kg} * \text{FOOD TYPE Production} \quad \{\text{g/year}\} \tag{216}$$

$$\text{Total | Fat Supply per Year} = \sum_{\text{all Food TYPES}} \text{FOOD TYPE | Fat Supply per kg} * \text{FOOD TYPE Production} \quad \{\text{g/year}\} \tag{217}$$

$$\text{Total | Energy Supply per Year per Capita} = \text{Total | Energy Supply per Year/Population} \ \{\text{kcal/(ppl*year)}\} \tag{218}$$

$$\text{Total | Protein Supply per Year per Capita} = \text{Total | Protein Supply per Year/Population} \ \{\text{g/(ppl*year)}\} \tag{219}$$

$$\text{Total | Fat Supply per Year per Capita} = \text{Total | Fat Supply per Year/Population} \ \{\text{g/(ppl*year)}\} \tag{220}$$

5.13 Food Economics

5.13.1 Staple Food Import Cost

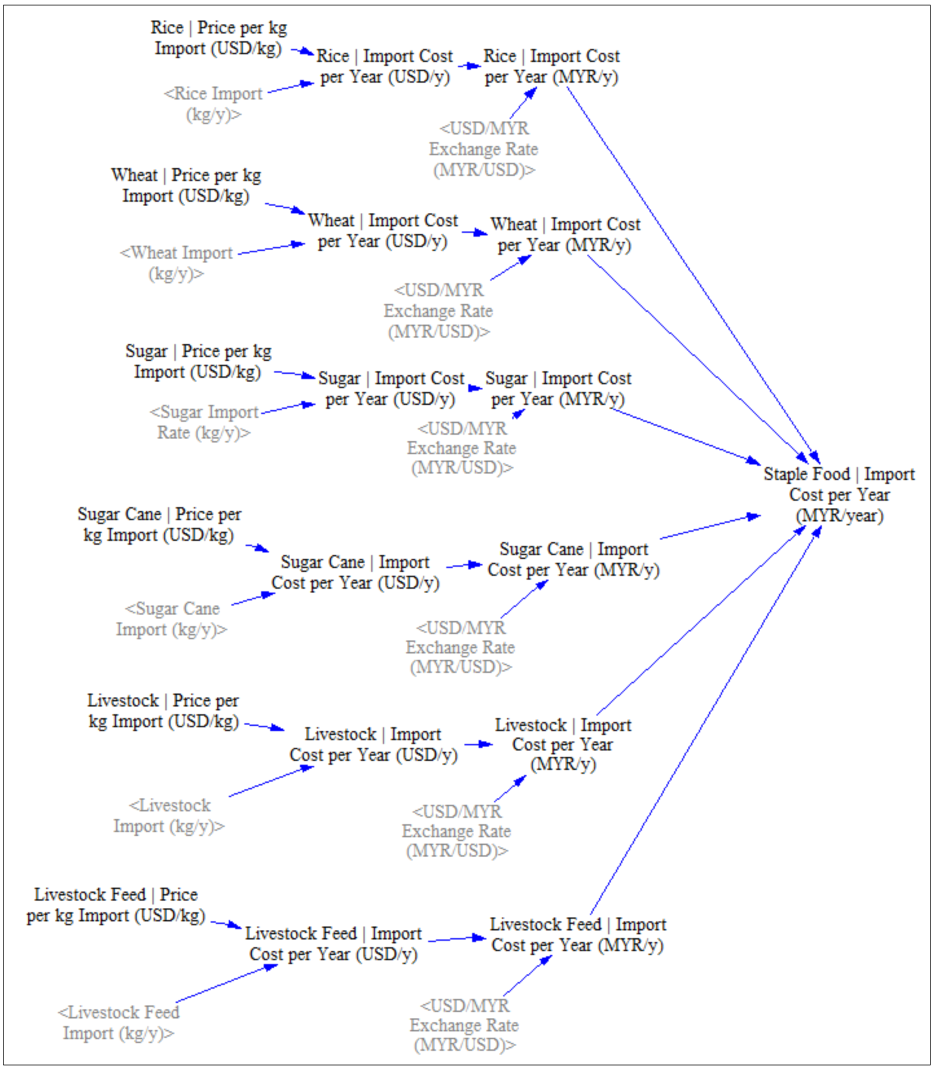

Figure 56: Staple Food Import Costs

Figure 56 shows the import cost of staple food. Import of food is necessary for Malaysia because Malaysia's SSL is not at 100 %. Considering that import involves international trade, the strength of the ringgit, represented by the USD/MYR exchange rate variable, is thus included here.

Equations:

Staple Food | Import Cost per Year = (221)

$$\sum_{\text{all STAPLE FOOD TYPE}} \text{STAPLE FOOD TYPE | Import Cost per Year}$$

{MYR/year}

STAPLE FOOD TYPE | Import Cost per Year =

STAPLE FOOD TYPE | Import Cost per Year (USD/year)*USD/MYR Exchange Rate {MYR/year} (222)

STAPLE FOOD TYPE | Import Cost per Year =

STAPLE FOOD TYPE | Price per kg Import*STAPLE FOOD TYPE Import {USD/year} (223)

STAPLE FOOD TYPE | Price per kg Import = input {USD/kg} (224)

5.13.2 Non-Food Crop Export Revenue

On the other hand, as non-food crops were grown mainly for its economic value, the export revenues of non-food crop products are studied, as structured in Figure 57. Similarly, USD/MYR exchange rate plays a role in determining the total export revenue for non-food crop industry.

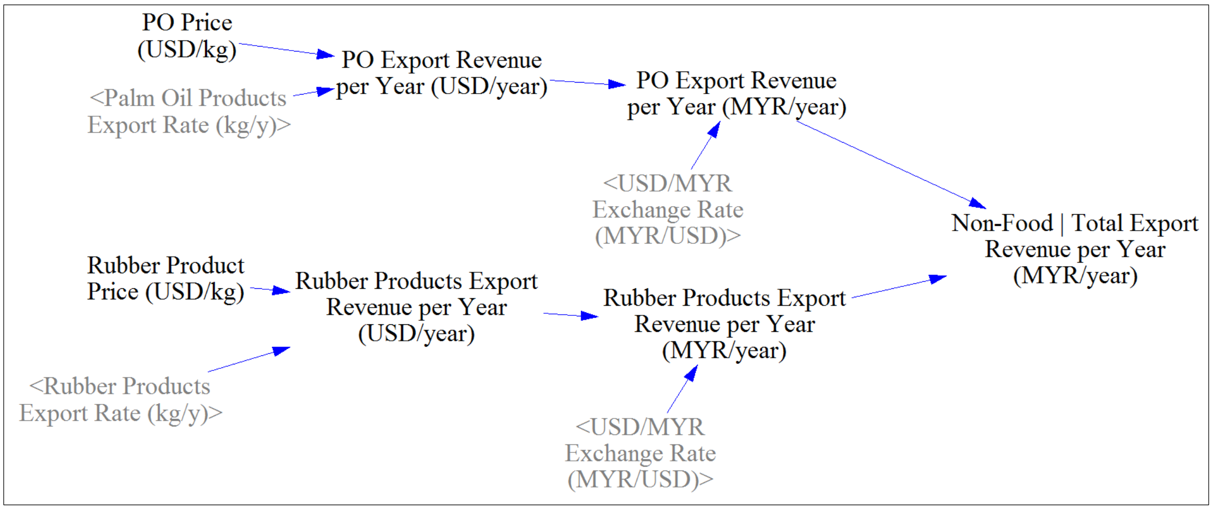

Figure 57: Non-Food Crop Export Revenue

Equations:

Non-Food | Total Exports Revenue per Year =

$$\sum_{\text{all NON-FOOD TYPE}} \text{NON-FOOD TYPE Export Revenue per Year} \quad (225)$$

{MYR/Year}

$\text{NON-FOOD TYPE Export Revenue per Year} =$

NON-FOOD TYPE Export Revenue per Year*USD/MYR Exchange Rate (226)
{MYR/year}

NON-FOOD TYPE Export Revenue per Year =

NON-FOOD TYPE Price*NON-FOOD TYPE Products Export Rate (227)
{USD/year}

$$\text{NON} - \text{FOOD TYPE Price} = \text{input} \{\text{USD/kg}\} \quad (228)$$

5.14 Emissions Indicators

5.14.1 Energy Emissions

Figure 58 shows the CO_2e emissions for each energy type while Figure 59 shows the total emissions for energy sector. CO_2e emissions for each energy type is calculated by considering the emissions per unit electricity production and the total production of electricity for each type. Consequently, the summation of CO_2e emissions is shown in Figure 59.

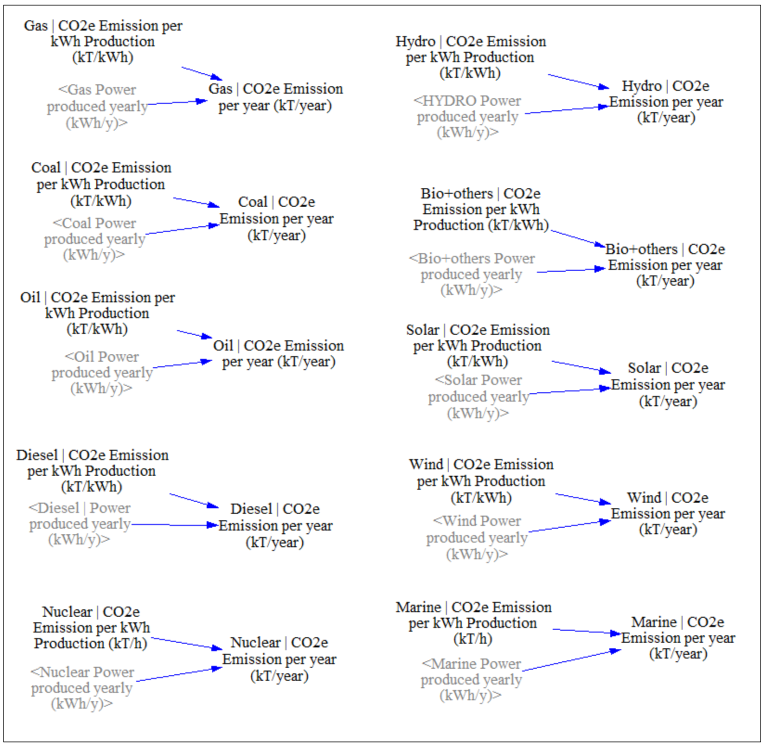

Figure 58: CO2e Emissions for Energy Types

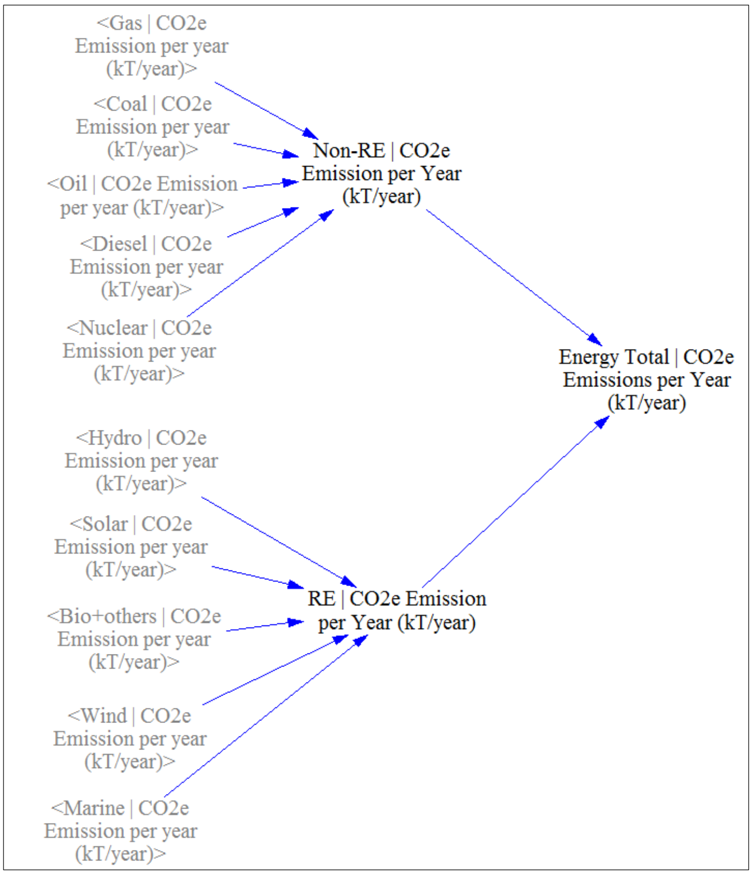

Figure 59: Energy Emissions

Equations:

ENERGY TYPE | CO_2e emissions per year =

$$\text{ENERGY TYPE | } CO_2\text{e Emissions per kWh Production*ENERGY TYPE Power produced yearly } \{kT/year\} \tag{229}$$

Non-RE | CO_2e Emissions per Year =

$$\sum_{\text{all Non-RE TYPES}} (\text{Average yearly operational hours of Non-RE TYPE} * \text{NON-RE TYPE} \mid \text{CO2e Emissions per Hour Operation}) \; \{kT/year\} \tag{230}$$

RE | CO2e Emissions per Year =

$$\sum_{\text{all RE TYPES}} (\text{Average yearly operational hours of RE TYPE} * \text{RE TYPE} \mid \text{CO2e Emissions per Hour Operation}) \; \{kT/year\} \tag{231}$$

Energy Total | CO2e Emission per Year =

$$\text{Non-RE | CO2e Emissions per Year + RE | CO2e Emissions per Year } \{kT/year\} \tag{232}$$

5.14.2 Water Emissions

Figure 60 shows the CO_2e emissions from the water supply & services sector and the sewage (wastewater) sector. CO_2e emissions for water supply & services sector is calculated by considering emissions from both unit treatment of groundwater and surface water while wastewater emissions considers unit treatment of wastewater as expelled by the end users.

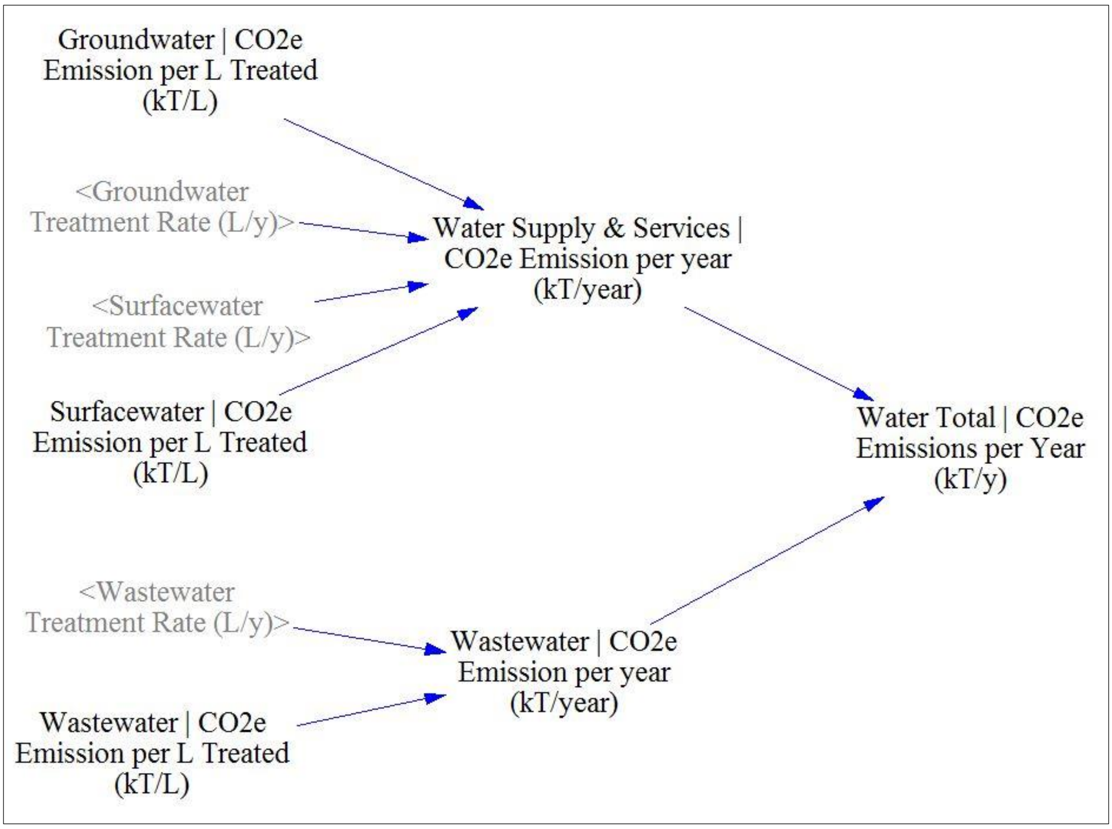

Figure 60: Water Sector Emissions

Equations:

Water Total | CO2e Emissions per Year =

Water Supply & Services | CO2e Emissions per Year + Wastewater | CO2e Emissions per year {kT/year} (233)

Water Supply & Services | CO2e Emissions per Year =

Groundwater | CO2e Emissions per L Water Treated*Groundwater Treatment Rate + Surface water | CO2e Emissions per L Water Treated*Surface water Treatment Rate {kT/year} (234)

Wastewater | CO2e Emissions per year =

Wastewater | CO2e Emissions per L Water Treated*Wastewater Treatment Rate {kT/year} (235)

5.14.3 Food Emissions

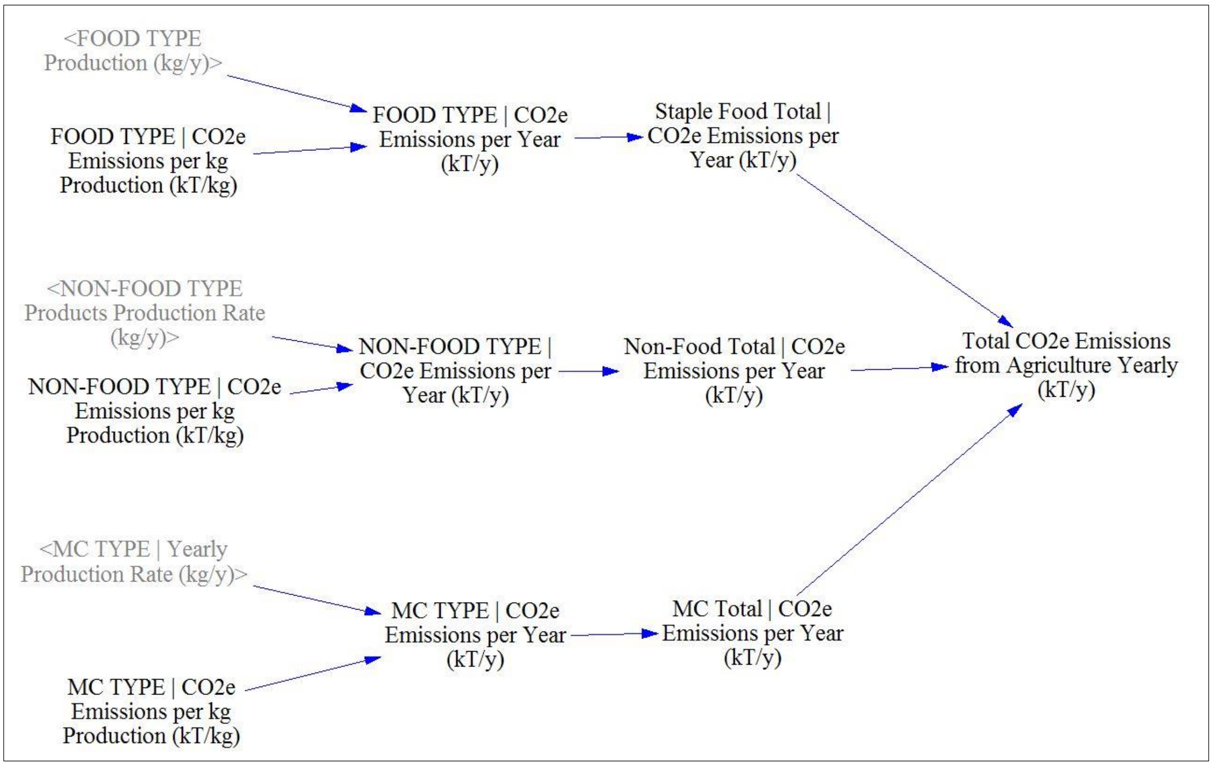

Figure 61: Food Sector Emissions

Figure 61 shows the CO_2e emissions for food sector, stemming from three sub-sectors of agriculture namely staple food, non-food, and marginal crop. Similar to energy and water emissions structures, total emissions from food sector is the sum of sub-sectoral emissions whilst sub-sectoral emissions are calculated from summation of emissions derived from emissions of unit food production.

Equations:

Total CO2e Emissions from Agriculture Yearly =

Staple Food Total | CO2e Emissions per Year + Non-Food Total | CO2e Emissions per Year + MC Total | CO2e Emissions per Year {kT/year} (236)

Staple Food Total | CO2e Emissions per Year = (237)

$$\sum_{\text{all FOOD TYPES}} \text{FOOD TYPE | CO2e Emissions per Year}$$

{kT/year}

Non-Food Total | CO2e Emissions per Year =

$$\sum_{\text{all NON-FOOD TYPES}} \text{NON-FOOD TYPE | CO2e Emissions per Year} \tag{238}$$

{kT/year}

MC Total | CO2e Emissions per Year =

$$\sum_{\text{all MC TYPES}} \text{MC TYPE | CO2e Emissions per Year} \tag{239}$$

{kT/year}

FOOD TYPE | CO2e Emissions per Year =

$$\sum_{\text{all FOOD TYPES}} \text{FOOD TYPE | CO2e Emissions per kg Production} \\ * \text{FOOD TYPE Production} \tag{240}$$

{kT/year}

NON-FOOD TYPE | CO2e Emissions per Year =

$$\sum_{\text{all NON}-\text{FOOD TYPES}} \text{NON-FOOD TYPE | CO2e Emissions per kg Production} \\ * \text{NON-FOOD TYPE Production} \tag{241}$$

{kT/year}

$$\text{MC TYPE | CO2e Emissions per Year} = \sum_{\text{all MC TYPES}} \text{MC TYPE | CO2e Emissions per kg Production} * \text{MC TYPE Production} \quad (242)$$

{kT/year}

5.14.4 WEF Total Emissions

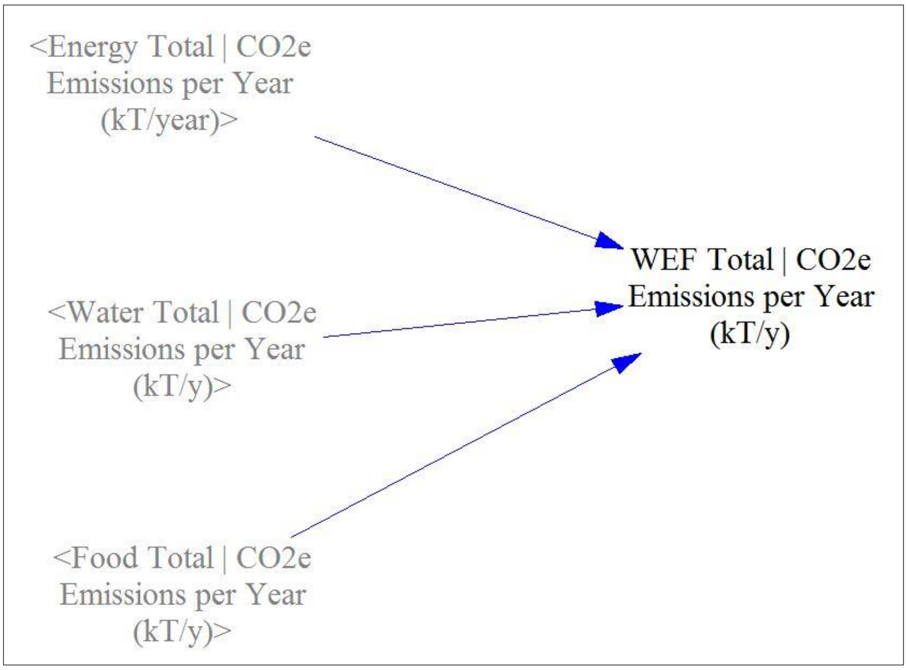

Figure 62: WEF Security Nexus Emissions

Using sectoral emissions from water, energy, and food, the total WEF security nexus CO_2e emissions can be computed by taking the sum of emissions from all three sectors, as depicted by Figure 62.

Equations:

WEF Total | CO2e Emissions per Year =

Energy Total | CO2e Emissions per Year + Water Total | CO2e Emissions per Year + Food Total | CO2e Emissions per Year {kT/year} (243)

5.15 Base Case (S0) Validation

Table 12 shows variables that have been validated with historical data, alongside their corresponding fit to data assessments, or otherwise known as behaviour reproduction test, of either mean absolute percentage error (MAPE), mean absolute error as a percent of mean (MAE/Mean), or percentage difference [164].

This validation, as discussed in section 3.6.3, is by no means an assertion of correctness of the results obtain, but instead a procedure to increase the confidence of the constructed model so that actual simulation can proceed. The graphs of validation are attached in Appendix III. For variable tests which used MAPE, the error ranges from a minimum 0.39 %, exhibited by installed dam capacity, to a maximum of 14.0 %, exhibited by diesel installed capacity. For MAE/Mean, oil installed capacity and land for sugar shows error of 0.33 and 1.19 respectively. The errors seen in diesel installed capacity and land for sugar are because of the large fluctuations in their real data, as compared to a smooth curve as simulated by the model. For oil installed capacity, the large error is due to Malaysia moving away and stop using oil as a fuel for generation, largely because of the 1970s oil embargo (E1,E2). As there were not much data that could be found on import cost for staple food, a single point data was used from interview with key stakeholder, which resulted in a 5 % prediction error.

Table 12: Validation Table

Variables	MAPE (%)	MAE/Mean	Percentage Difference (%)	Validation Data Source
Population	5.6	-	-	[216]
Population in 5 Years	6.2	-	-	[216]
Hydro Installed capacity	7.9	-	-	[185,217]
Gas Installed capacity	6.1	-	-	[185,217]
Coal Installed capacity	3.9	-	-	[185,217]
Oil Installed capacity	-	1.19	-	[185,217]
Diesel Installed capacity	14.0	-	-	[185,217]
Installed Dam Capacity	0.39	-	-	[210]
Land for Rice	12.3	-	-	[218]
Land for Sugar	-	0.33	-	[218]
Total Internal Renewable Water Resources	1.2	-	-	[210]
Staple Food | Import Cost per Year	-	-	5.0	(F1)

5.16 Chapter Summary

This chapter presented the SFDs to demonstrate the relationships in the WEF security nexus of Malaysia, constructed based upon high level understanding derived from the CLDs described in chapter 4. Whilst some CLD relationships were more obvious in SFDs, such as the population and capacities generation SFDs, some conversions were less obvious, such as water demand management where the changes in water demand are controlled via altering values of water requirement per capita. On top of that, some relationships were not converted, such as increase of profitability of water supply and sewage systems leading to reduction of government subsidies in water sector. This is because such relationships can be understood from the dynamics of other relevant parts, namely unit cost of water production and water tariff for this case, as well as from qualitative discussion of their simulation results. However, it is necessary to emphasize again on the importance and necessity of including such representations in the CLD, as was discussed and introduced in chapter 4, because of the need to establish the high level and qualitative understanding of these parts. Moreover, the non-numerical nature of certain parts of CLD increases the difficulty of conversion into SFD. However, wherever conversion into SFD is possible, conversion has been conducted, accompanied by their equations, justification, and rationale, described and discussed as thoroughly as possible. Validation of SFD have thus been conducted and explained in section 5.15. Errors were as low as 0.39 % (for installed dam capacity) and as high as 1.19 (for installed oil capacity). This high error is due to the total phasing out of oil capacity, where potential for errors increases for values that passes through zero. However, SD study is concerned primarily with the behaviour of the key indicators, and less emphasis should be place on numerical accuracy. As Sterman [164] puts it, a model is good enough when it is fit for purpose.

Chapter 6 Scenarios, Results, and Discussion

6.1 Introduction

This chapter describes the design of scenarios for the aim of simulating the SFDs constructed in chapter 5, and simulates for results. At every scenario design, they are discussed and reasoned alongside tables of relevant constants, scenario values, and key indicators. Each scenario is expressed and differentiated in terms of selected variables and their corresponding values, which are determined from the current status of Malaysia's WEF security nexus as understood from the previous chapters, i.e. works of extensive literature review, interviews, and CLDs. Every scenario will have a control sub-scenario, which is used to represent, as closely as possible, the reality of current Malaysia's WEF state. The purposes of having control sub-scenarios are to enact a reference point from which other sub-scenarios can be critically compared to. This would allow for meaningful analysis that subsequently leads to policy proposal. Subsequently, the results and discussion are presented after every scenario design subsection. Sub-scenarios within the scenarios are presented together to allow for meaningful comparative analysis and deductions. Accompanying scenario result is a discussion that infers from the graphs (results) presented. The discussions are expounded by considering the behaviours of key indicators of each sub-scenario, as well as by their relations and comparisons to other sub-scenarios. A final discussion, which combines all insights obtained, is provided after S7 is conducted to provide a holistic understanding on the SD of WEF security nexus in Malaysia. These comparative analysis, deductions, and understanding are important because they provide a grasp and realization on the consequences of actions and decision making, within and between, the WEF sectors.

6.2 Scenarios, Results, and Discussion

Whilst chapters 2, 4, and 5 provided knowledge and insights into the relationships between WEF sectors in Malaysia, the effects of actions on the wellbeing, sectoral balance, and sustainable development of the WEF security nexus in Malaysia as well as the behaviour of key indicators under different policies remain unknown without further investigation. The understanding of WEF security nexus in Malaysia can be completed with scenario design and simulation, where its dynamics can be profoundly studied. Scenario simulation is important because, just like many sciences, it allows for prediction of behaviours under different actions. In this case, it is also used for uncovering different factors of improving the WEF security nexus in Malaysia, which would otherwise be overlooked. On top of that, from practicality point of view, scenario simulation can serve as justification for policies formed before the actual implementation. As such, based upon the understanding of WEF security nexus in Malaysia accumulated thus far, the scenarios designed are renewable energy (without nuclear), energy scenario with nuclear, water demand management, increasing self-sufficiency levels of food, nutrition security and utilising marginal crops, variation in non-food crops, and combined scenarios.

6.2.1 Renewable Energy (Without Nuclear)

The first scenario to look at is an energy scenario where varying amounts of renewable energy penetration as well as energy type are investigated. In alignment with Malaysia's Eleventh Plan [48], Malaysia's response towards SDG [219], and goal 7 of the SDG [22], it is inevitable that RE penetration in the energy sector must increase in share. This is because as conventional electricity generation methods using gas, coal, and oil as fuel input are one of the major contributors to GHG emissions, aggressive initiation on RE capacities would be a prime candidate for the reduction of GHG emissions and increase in sustainability.

This scenario looks into the aggressive expansion of RE whereby if the effective RE penetration of RE is below the desired RE penetration (input), only RE capacities and none of Non-RE would be initiated. This means that at any one time when the RE penetration is not equal to the desired RE penetration, the model will only build RE capacities, based upon the respective RE share in Table 16. Four sub-scenarios are analysed namely S1A, S1B, S1C, and S1D where different values of RE penetration are studied (as a whole and their breakdowns). S1A is set as a control, where there is zero RE penetration. S1B and S1C are set at 20% RE penetration, where only hydro and solar type RE are considered. This is because under Malaysian natural geographical conditions, bio, wind, and marine type energies are not as favourable as solar and hydro. S1D has been set to assume the very aggressive scenario of RE penetration, 50%, and assume possible initiation capacities of bio, wind, and marine. This is to further understand how the dynamics of WEF would behave under extreme assumptions.

The impact of RE penetration on the WEF security nexus of Malaysia can be seen from several angle. As different energy types come with different fixed and operational costs, LCOE would thus be an important key indicator to consider in this scenario. Dynamics of water use from different energy types, which includes water use from conventional energy, are also included. Emissions, which are inseparable from the energy sector, are also an important indicator.

Table 13, Table 14, and Table 15 provide the list of relevant constants. Table 16 provides the list of scenario values and Table 17 provides the list of key indicators.

Table 13: LCOE by Type

Type	LCOE (MYR/kWh)	Source
Marine	1.80	[220]
Bio+others	0.52	[220]
Wind	0.80	[220]
Solar	0.52	[220]
Hydro	0.24	[220]
Gas	0.26	[220]
Coal	0.28	[220]
Oil	0.48	[221]
Diesel	1.59	[221]
Nuclear	0.36	[220]

Table 14: CO_2e Emissions by Type

Type	CO_2e (kT/kWh)	Source
Marine	0	-
Bio+others	4.50×10^{-8}	[222]
Wind	2.60×10^{-8}	[222]
Solar	8.50×10^{-8}	[222]
Hydro	2.60×10^{-8}	[222]
Gas	4.99×10^{-7}	[222]
Coal	8.88×10^{-7}	[222]
Oil	7.33×10^{-7}	[222]
Diesel	7.33×10^{-7}	[222]
Nuclear	2.90×10^{-8}	[222]

Table 15: Water Withdrawal by Type

Type	Water Withdrawal (L/kWh)	Source
Marine	0	
Bio+others	142.5	[41]
Wind	0	[41]
Solar	4	[41]
Hydro	70	[41]
Gas	142.5	[41]
Coal	142.5	[41]
Oil	142.5	[41]
Diesel	142.5	[41]
Nuclear	174.6	[41]

Table 16: Scenario 1 (S1)

Scenario: Energy Scenario - Renewable Energy (S1)	A	B	C	D	
Variable		**Values**			**Units**
Desired RE Penetration	0	0.2	0.2	0.5	dmnl
Hydro | RE Share	0	0.5	0.25	0.25	dmnl
Solar | RE Share	0	0.5	0.75	0.25	dmnl
Bio+others | RE Share	0	0	0	0.2	dmnl
Wind | RE Share	0	0	0	0.15	dmnl
Marine | RE Share	0	0	0	0.15	dmnl

Table 17: Key Indicators for S1

Key Indicators	Units
LCOE	MYR/kWh
Energy Total | CO_2e Emissions per Year	kT/year
Total Water Withdrawn Yearly due to Electricity Generation	L/year
Total Water Consumed due to Electricity Generation	L/year

Results and Discussion:

Figure 63 to Figure 67 show the results for scenario S1. Figure 63 show that for S1B, S1C, and S1D, LCOE would rise steadily, following an S-shaped curve, from approximately RM 0.27/kWh to RM 0.35 at 2050. Towards 2050, it is shown that LCOE for complete zero RE penetration would be in between S1B and S1C. This is natural as LCOE for solar is higher than for hydroelectric. It can be seen that S1A, the scenario of aggressive RE penetration, displays LCOE that is significantly higher than other scenarios, reaching RM 0.46/kWh towards 2050. Whilst the LCOE may double for aggressive RE penetration scenario, the selection of RE type plays a major role in determining the hike in LCOE. As opposed to S1B and S1C that also considers increasing RE share, the significant difference in the increase of LCOE is contributed by expansions in bio-energy, marine, and wind, which are difficult under Malaysia's geographical setting.

CO_2e emissions will be highest (S1A) if we continue on our current energy scenarios, reaching 110000 $kTCO_2$e/year in 2050, doubling from the value in 2015. S1B and S1C, moderate RE penetration scenarios of 20%, are lower at about 80000 $kTCO_2$/year. S1D shows the least CO_2e emissions per year at roughly 50% of business-as-usual, at 60000 $kTCO_2$e/year in 2050.

Water use per year from electricity generation are given by Figure 65 (withdrawal) and Figure 66 (consumption). The water withdrawal of electricity generation is a yearly value whilst the water consumption is the total water consumed up until 2050. It can be seen that water consumption of electricity generation is a very small amount as compared to its water withdrawal because the total water consumed up until 2050 is the same as a year of total water withdrawal, by comparing Figure 65 and Figure 66. By continuing the current energy policy plans (S1A), Malaysia would reach 25 TL of water withdrawal per year due to electricity generation. Moderate RE penetration scenarios (S1B and S1C) would have a slower rate of increase in water withdrawal to about 21 TL/year by 2050. On the contrary, an aggressive RE scenario (S1D) shows the slowest increase in water withdrawal for electricity generation, reaching only 17 TL/year. Water consumption of electricity generation follows the decreasing order of S1A, S1B, S1C, and S1D, from about 26 TL to 19 TL.

Figure 67 shows water withdrawn per unit of electricity produced measured in L/kWh. If Malaysia proceeds with the current energy scenario (S1A), the water withdrawal per unit of electricity produced would increase from about 127 L/kWh to 140 L/kWh. By having a moderate level of RE penetration, i.e. 20 %, water withdrawal per electricity produced can be reduced from 127 L/kWh to about 123 L/kWh as shown by scenarios S1B and S1C. On the extreme side, a 50 % RE penetration will result in 102 L/kWh water withdrawal per electricity produced in 2050.

From this set of results, it is thus a balance between environment control and socio-economy considerations. It is without a doubt that some level of RE penetration must be present for Malaysia because Figure 67 shows that water withdrawal per electricity produced will only increase if no changes are made to the current energy situation whilst all other levels of RE penetration (20-50 %) will result in a reduced water withdrawal per electricity produced. However, going to aggressive (50 %) may not favour the socio-economy side of things, as the LCOE will be almost double of the other scenarios.

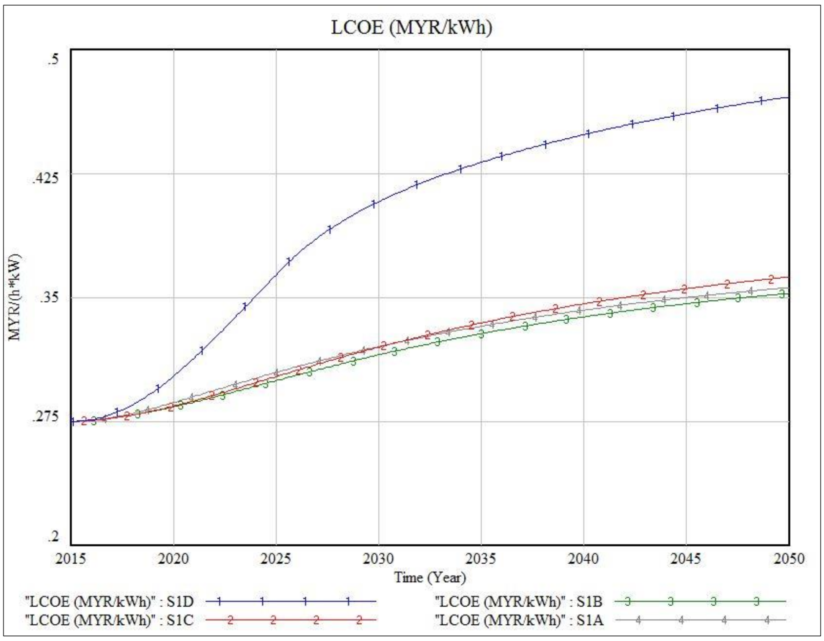

Figure 63: S1 - LCOE

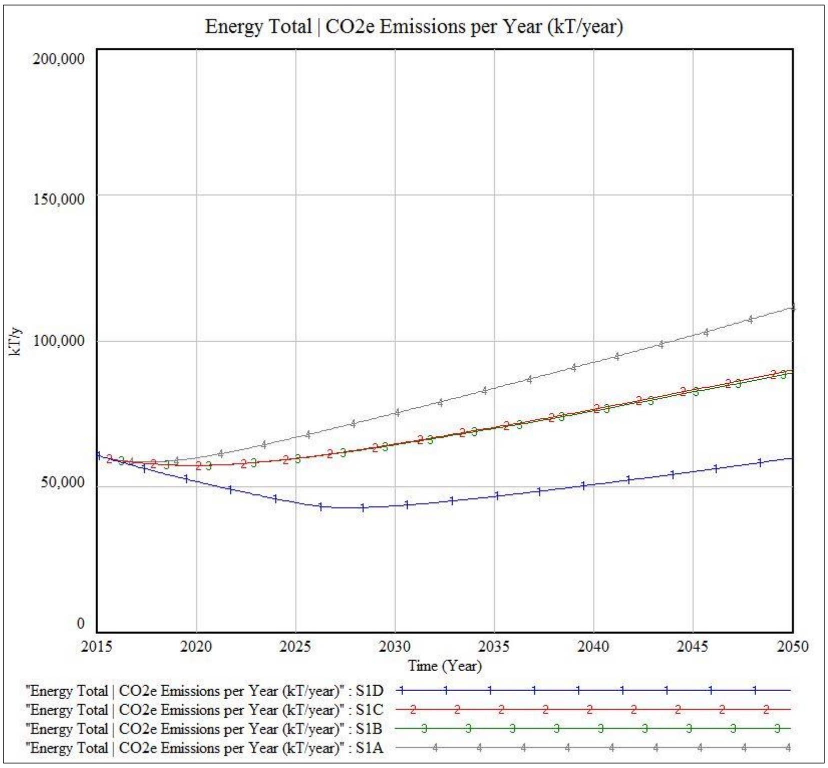

Figure 64: S1 - Energy Total | CO_2e Emissions per Year

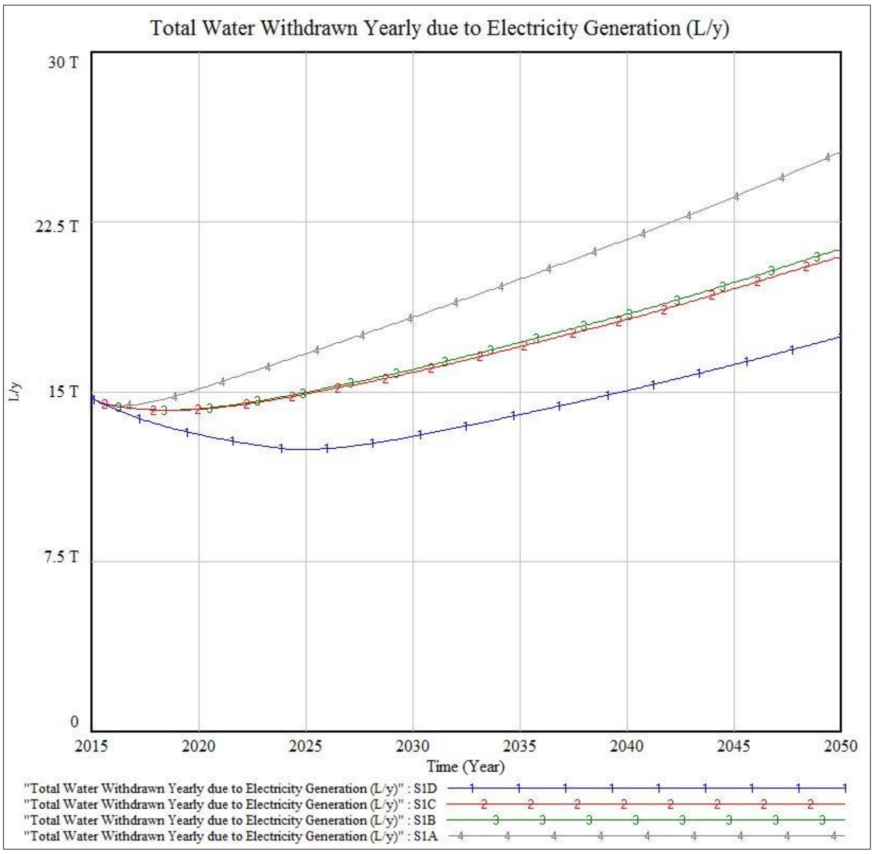

Figure 65: S1 - Total Water Withdrawn Yerly due to Electricity Generation

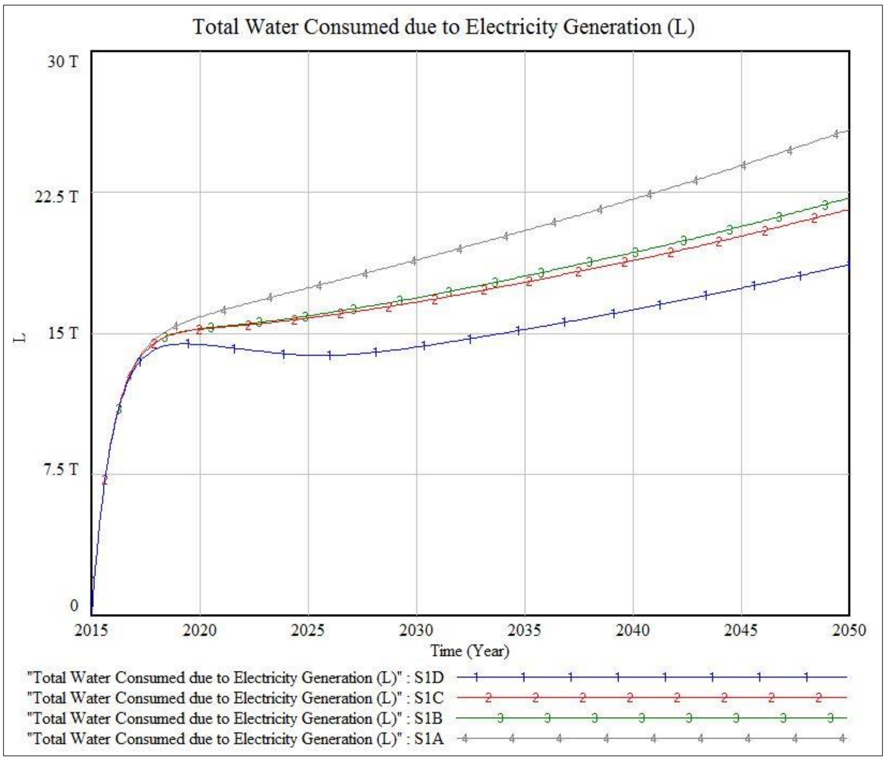

Figure 66: S1 - Total Water Consumed due to Electricity Generation

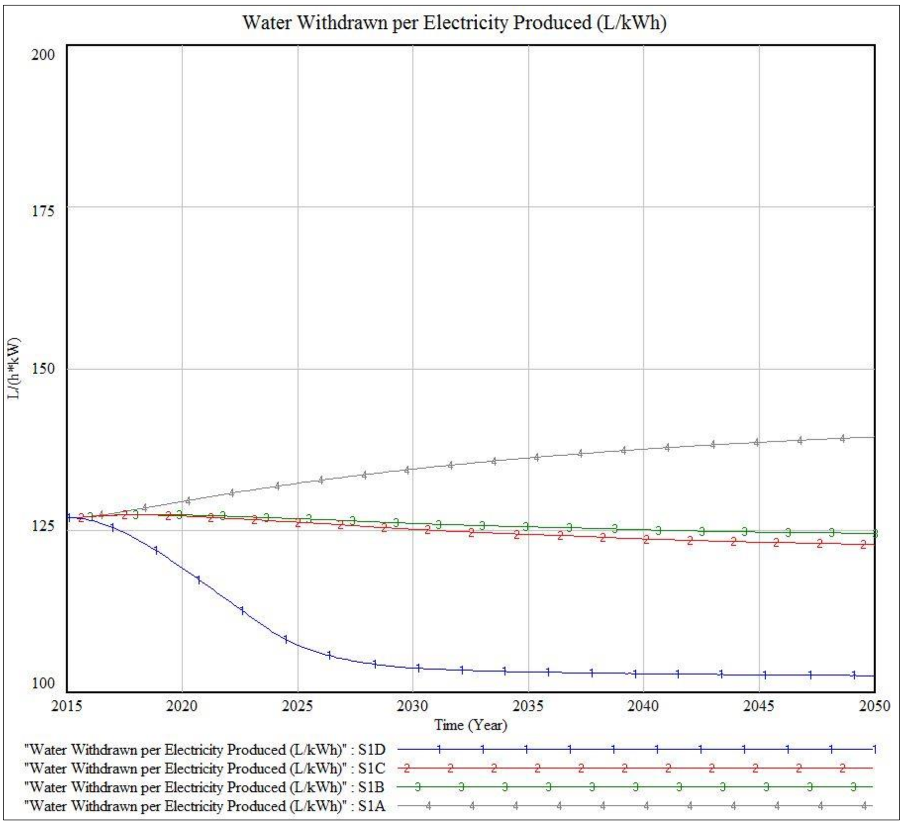

Figure 67: S1 - Water Withdrawn per Electricity Produced

6.2.2 Energy (With Nuclear)

Malaysia, being a member state of Integrated Nuclear Infrastructure Review Missions (INIR) and recently initiated an infrastructure review led by International Atomic Energy Agency (IAEA) [223], always has adoption of nuclear energy in the horizon [224]. Despite the challenges [225], such as uncertainty of ASEAN countries in adopting nuclear energy due to uncertainty of dealing with radioactive wastes as well as the economic competitiveness of nuclear energy, and the postponement of deployment plans [226], it is necessary, important, and interesting to consider the impacts of nuclear energy penetration upon the WEF security nexus in Malaysia.

This scenario considers the four sub-scenarios, two of which without nuclear penetration (S2A, S2B) and two with nuclear penetration (S2C, S2D). This is to include and look into the dynamics of expansion of conventional energy without aggressive RE penetration, as described by stakeholders (E1, E2) as the norm for Malaysia. As such, "desired RE penetration" has been set to 5% on all four sub-scenarios. In S2B, an equal amount of weightage has been given to gas, coal, oil, and diesel. However, in S2C and S2D, oil and diesel have been excluded entirely, as pointed out by the stakeholders that there are no plans to further expand them. Nuclear penetration has been set to 10% and 20% in S2C and S2D respectively, with corresponding equal weightage in gas and coal adjustments. Similar to the energy scenario in S1, important variables to look at are LCOE, total emissions per year, and total water withdrawn yearly due to electricity generation. Table 18 provides the list of scenario values and Table 19 provides the list of key indicators.

Table 18: Scenario S2

Scenario: Energy Scenario - Conventional and Nuclear (S2)	**A**	**B**	**C**	**D**	
Variable	**Values**				**Units**
Desired RE Penetration	0.05	0.05	0.05	0.05	dmnl
Resulting Desired Non-RE Penetration	0.95	0.95	0.95	0.95	dmnl
Nuclear | Non-RE Share	0	0	0.1	0.2	dmnl
Gas | Non-RE Share	0.45	0.25	0.45	0.4	dmnl
Coal | Non-RE Share	0.45	0.25	0.45	0.4	dmnl
Oil | Non-RE Share	0	0.25	0	0	dmnl
Diesel | Non-RE Share	0.1	0.25	0	0	dmnl

Table 19: Key Indicators for S2

Key Indicators	Units
LCOE	MYR/kWh
Energy Total | CO_2e Emissions per Year	kT/year
Total Water Withdrawn Yearly due to Electricity Generation	L/year
Total Water Consumed due to Electricity Generation	L/year

Results and Discussion:

Maintaining RE penetration at 5 % without any nuclear power would increase LCOE to RM 0.35/kWh (S2A) and RM 0.53/kWh (S2B) respectively. S2B is significantly higher because diesel has a high LCOE. On the other hand, LCOE would be maintain at RM 0.27/kWh if there is nuclear penetration, as depicted by S2C (10 %) and S2D (20 %). This is consistent with the fact that nuclear energy is considerably cheaper as compared to other energy types.

For CO_2e emissions per year, the projected values are roughly equal for all four sub-scenarios at 112000-114000 kTCO_2e/year. With nuclear adoption added to the mix of fossil fuel energies, without the expansion of RE as shown in S1, these CO_2e emissions are naturally higher. Albeit having very similar values of CO_2e emissions, it is noticeable that with the addition of nuclear energy, total CO_2e emissions per year will be slightly reduced.

Water withdrawal and consumption per year for all four sub-scenarios are 24 TL/year, and 24 TL respectively. These values are higher than when there are some RE penetration, which was in the range of 17 - 21 TL/year, as illustrated in the previous subsection. The water withdrawn per unit of electricity produced shows a similar growth rate across all four sub-scenarios until about 2045 where they stabilize at about 139 L/kWh. It is indeed natural that a mixture of fossil fuel energy and nuclear would have a higher value of water withdrawn per unit of electricity production as compared to a mixture with considerable RE penetration, which is observed to be in the region of 102 - 127 L/kWh.

Considering the LCOE, CO_2e emissions, and water use in energy production, nuclear energy can be recommended to be adopted into the Malaysian setting. However, beyond these key indicators, the feasibility of nuclear energy adoption in Malaysia must further be analysed with other factors, especially social acceptance and public perception. As pointed out by Misnon et. al [227], whilst the public may generally agree on the adoption of nuclear energy, few are well verse with the benefits of nuclear energy. Also, risks of nuclear power accidents, such as those experienced by Fukushima, Japan in 2011 [228], adds upon the complications of nuclear power adoption. On top of that, there are strong links between nuclear energy and nuclear power [229]. The possibility of nuclear weapon development, which might provoke wars, has to be well-controlled should nuclear energy be adopted. Consequently, the option of deregulating and liberalising of the energy market becomes more difficult if nuclear power comes into play because it is necessary that a central authority keeps the said risks in check.

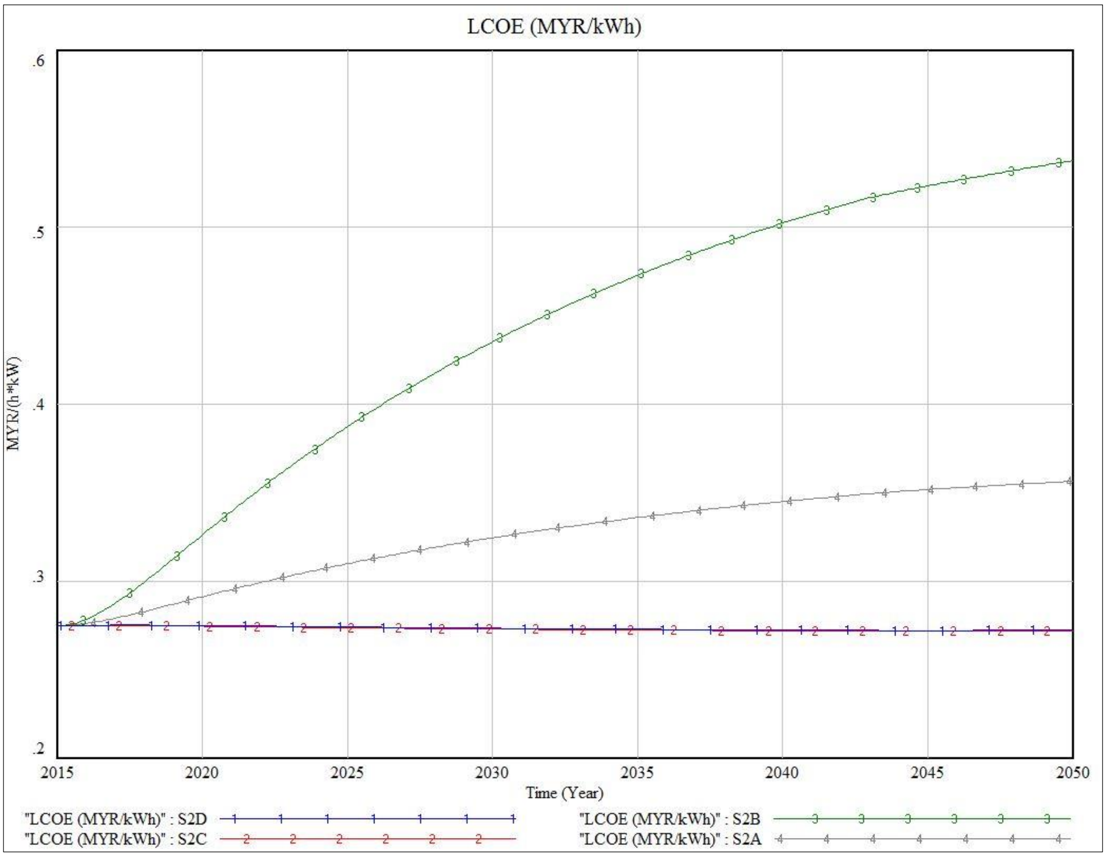

Figure 68: S2 - LCOE

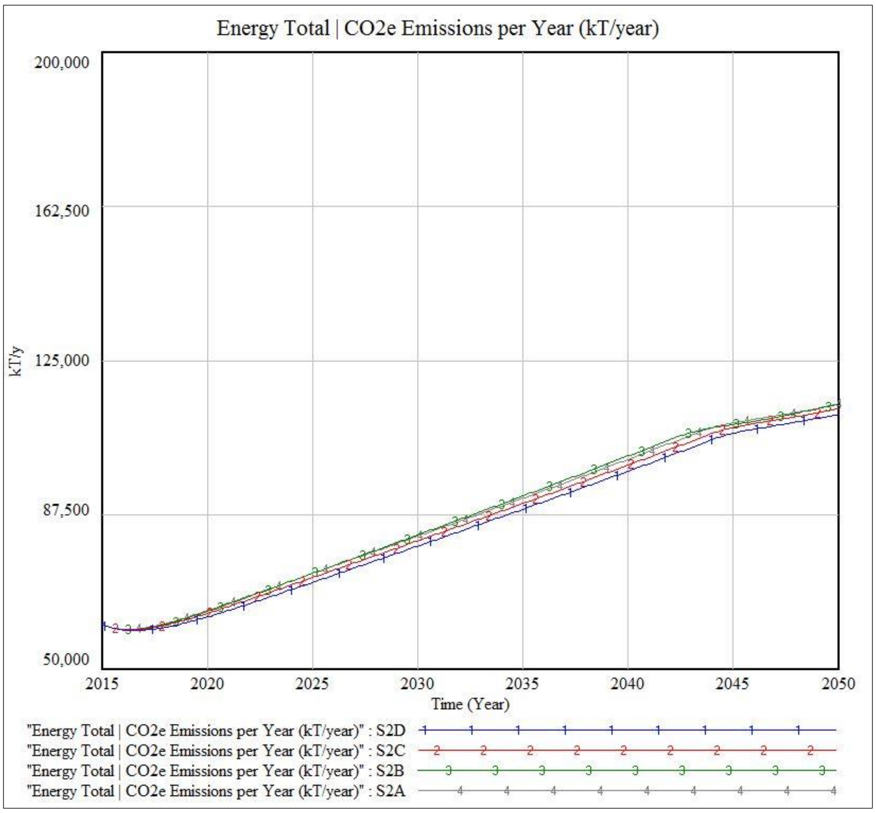

Figure 69: S2 - Energy Total | CO_2e Emissions per Year

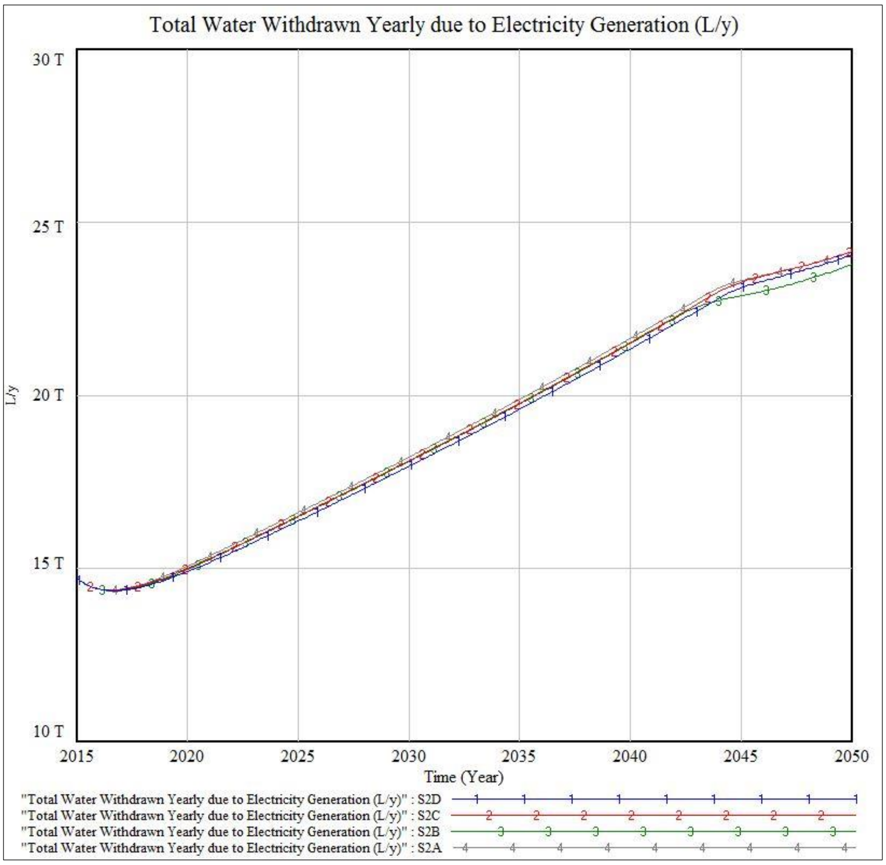

Figure 70: S2 - Total Water Withdrawn Yearly due to Electricity Generation

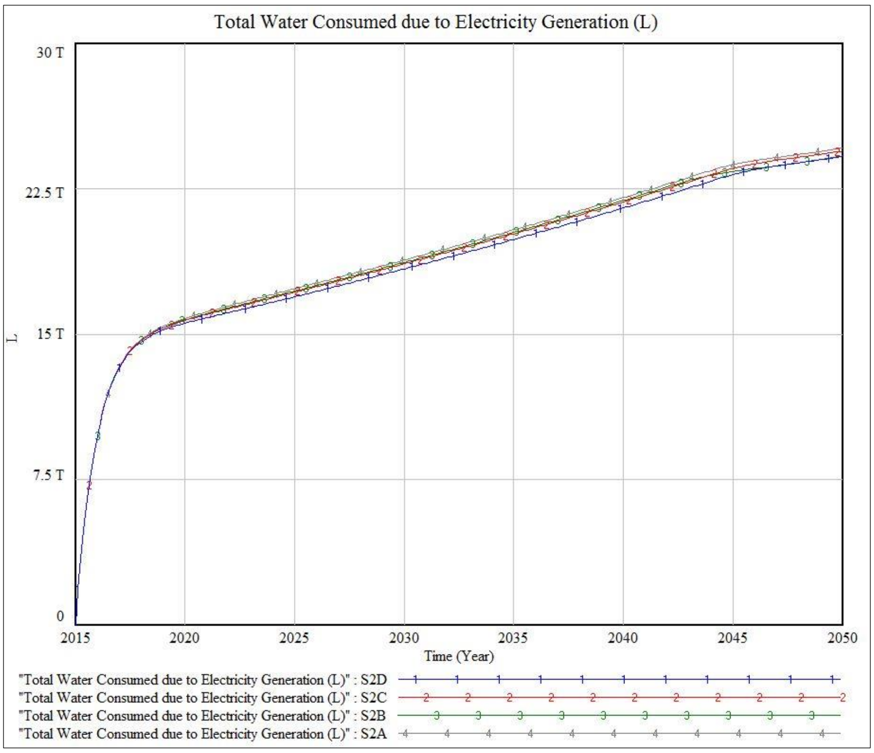

Figure 71: S2 - Total Water Consumed due to Electricity Generation

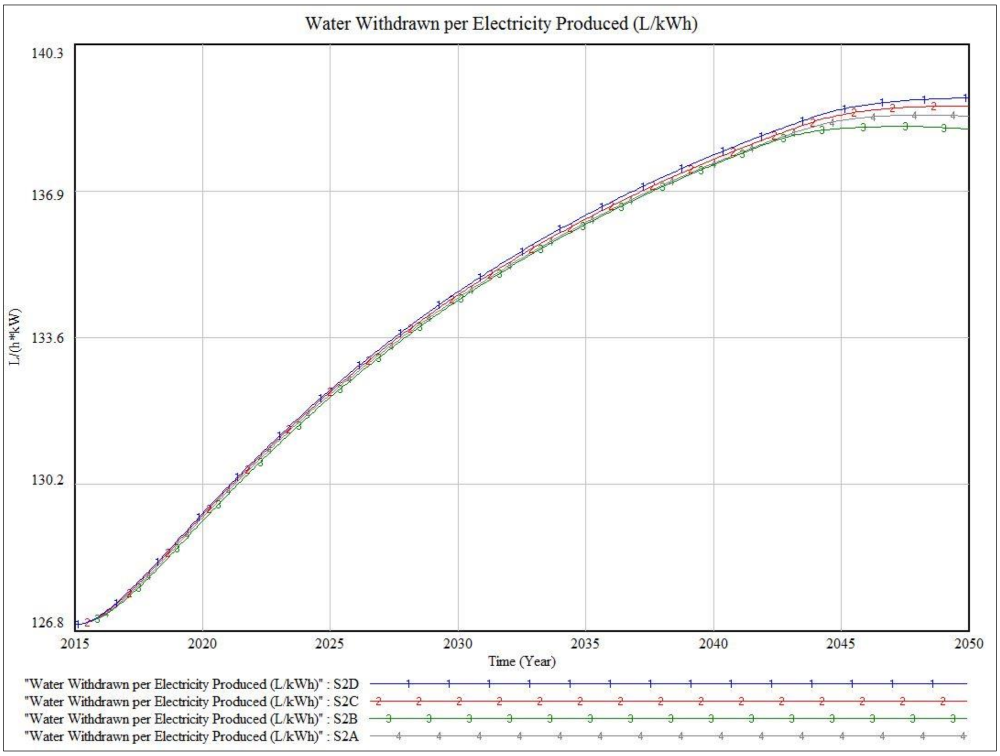

Figure 72: S2 - Water Withdrawn per unit of Electricity Produced

6.2.3 Water Demand Management (Tariff and Education)

Water sector in Malaysia revolves around the economic sustenance of water services, supply, and wastewater treatment. On top of that, the disconnect in governance between state and federal government contributes to one of the several problems of the water sector, namely the overly low water tariff. As pointed out by key stakeholders from the water sector, there are two main ways to control water demand management namely setting water tariff, and education of public.

This scenario is concerned with two very important variables namely "water tariff" and "water requirement per capita". Water tariff is important because it determines the affordability of the people to afford water, and the economic sustainability of the water service provider (e.g. water supply treatment and distribution, wastewater treatment). Water tariff can be divided into two, namely the domestic water tariff and industrial water tariff. Whilst the water tariff rates (both domestic and industrial) are different in every state, this study uses an average to represent the entire Malaysia. The domestic tariff rate starts at 0.0007 MYR/L for domestic and 0.0017 MYR/L for industrial/commercial [120]. Also, the current water consumption per capita per year for Malaysians is estimated at 120000 L/(ppl*year).

There are different ways to control water demand (W2). For example, through technological policies implementation, the maximum capacity of toilet flush was reduced from 12L to 3L (W2). The multiple of ways to control water demand can be reflected in "water consumption per capita per year" variable.

Key indicators are the revolved around the sustenance of water sector, namely financial indicators such as LCOW, water supply sector revenue, and yearly cost of water supply and services. On top of that, the energy-for-water indicator in this case is "total electricity used per year for water sector", which forms an important W-E link in the WEF security nexus. S3A provides a control for this scenario analysis, using current values of "water supply tariffs" and "water consumption per capita per year". S3B and S3C looks into doubling the water tariffs, and implementation of water demand management by reducing "water consumption per capita per year" by approximately 16.6% respectively. S3D looks into the combination of S3B and S3C. Table 20 provide the list of relevant constants. Table 21 provides the list of scenario values and Table 22 provides the list of key indicators.

Table 20: Relevant Constants for S3

Relevant Constants	Value	Units	Source
Average Effectiveness of Water Supply Treatment Capacity	0.85	L/(unit*year)	[211]
Fractional Effectiveness of Sewage Treatment Capacity	0.85	dmnl	[211]
Operational Cost per L Supply Water Treated	3.00×10^{-4}	MYR/L	[120]
Operational Cost per L Supply Water Supplied	3.00×10^{-4}	MYR/L	[120]
Capital Cost per Unit Water Supply Treatment	0.01	MYR/unit	[120]
Operational Cost per L Sewerage Water Treated	6.00×10^{-4}	MYR/L	[120]
Capital Cost per Unit Water Sewerage Treatment	1.00×10^{-9}	MYR/PE	[120]
Energy Used per Supply Water Treated	5.86×10^{-4}	kWh/L	[230]
Energy Used per Sewerage Water Treated	6.34×10^{-4}	kWh/L	[230]
Groundwater | CO_2e Emission per L Treated	2.90×10^{-10}	kT/L	[230]
Surface water | CO_2e Emission per L Treated	2.90×10^{-10}	kT/L	[230]
Wastewater | CO_2e Emission per L Treated	4.10×10^{-10}	kT/L	[230]

Table 21: Scenario S3

Scenario: Water Demand Management (S3)	A	B	C	D	
Variable	**Values**				**Units**
Domestic | Effective Water Supply Tariff	7.00×10^{-4}	1.40×10^{-3}	7.00×10^{-4}	1.40×10^{-3}	MYR/L
Industrial | Effective Water Supply Tariff	1.70×10^{-3}	3.40×10^{-3}	1.70×10^{-3}	3.40×10^{-3}	MYR/L
Water Consumption per Capita per Year	1.20×10^{5}	1.20×10^{5}	1.00×10^{5}	1.00×10^{5}	L/(ppl*year)

Table 22: Key Indicators for S3

Key Indicators	Units
Supply and Services | Unit Cost of Production	MYR/m^3
Sewage | Unit Cost of Production	MYR/ m^3
Total Electricity Use per Year for Water Sector	kWh/year
Water Supply Sector Revenue per Year	MYR/year
Yearly Cost of Water Supply & Services	MYR/year
Yearly Cost of Water Sewage Treatment	MYR/year

Results and Discussion:

Figure 73 shows the graph for unit cost of production for water supply and services as well as sewage. Considering the available data on Malaysian water facilities, and reserve margin, Malaysia do have enough facilities to cater for the projected demand. As such, the number of water facilities is seen to decrease through normal rate of retirement/decommission. However, as population rises again, new facilities would need to be constructed at around 2027, if water demand is left at 120000 L/(ppl/year), and to be constructed at 2033 if demand is controlled to 100000 L/(ppl/year). Despite that, the unit cost of production would stabilize towards 2050 at RM 1.80 for water supply and services, and RM 0.50 for sewage services.

Figure 74 shows the graph of cost and revenue for the water services and supply sector. From the graph, it can be seen that yearly cost for the sector remains above the revenue obtained from tariff for all four sub-scenarios. The hike in the yearly cost in 2027 and 2033 is due to new facilities being initiated where fresh capital costs are incurred. New facilities are initiated when the number of water treatment facilities can no longer meet the demand from the users. As such, it can be deduced that the water supply and services sector is not economically sustainable. On the other hand, Figure 75 shows the cost is below the revenue for the water sewage sector.

Energy used per year from treating and distributing water is shown in Figure 76. For all four sub-scenarios, the energy used is similar, increasing towards 12 B kWh/year for S3A and S3B, and 11 B kWh/year for S3C and S3D. These values are roughly 12 % from the total power generation projection of 175 B kWh/year at 2050. These values are accurate concerning surface water in Malaysia because surface water forms the primary water source for Malaysia. Should Malaysia attempt to tap into groundwater or adopt desalination, the numbers may increase significantly because processing these type of water are more difficult as compared to surface water [231]. Desalination and groundwater tapping are potential water supply alternatives with benefits of being unaffected by weather and sea water are abundance. However, the drawbacks are technological difficulty as well as higher economical and energy cost.

Figure 77 shows the CO_2e emissions per year for water sector is in the order of 6300 kT/year for S3A and S3B, and 5700 kT/year for S3C and S3D. This is about one order lower than that of the electricity production sector. As such, it is safe to say that the water sector plays minimal role in terms of environmental degradation. However, one must consider the energy use of water processing and production, where electricity use translates into energy production and consequently CO_2e emissions. The illusion of water sector impact on the environment is thus enhanced if energy intensive water producing technologies are utilised, such as the desalination of seawater and tapping of groundwater.

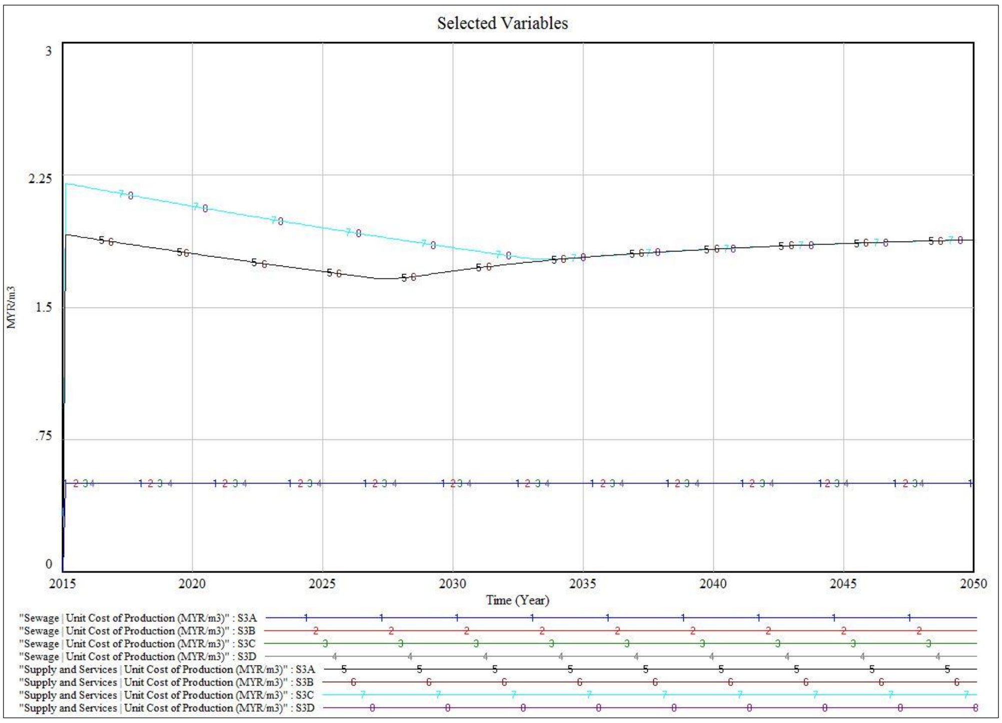

Figure 73: S3 - Unit Cost of Production

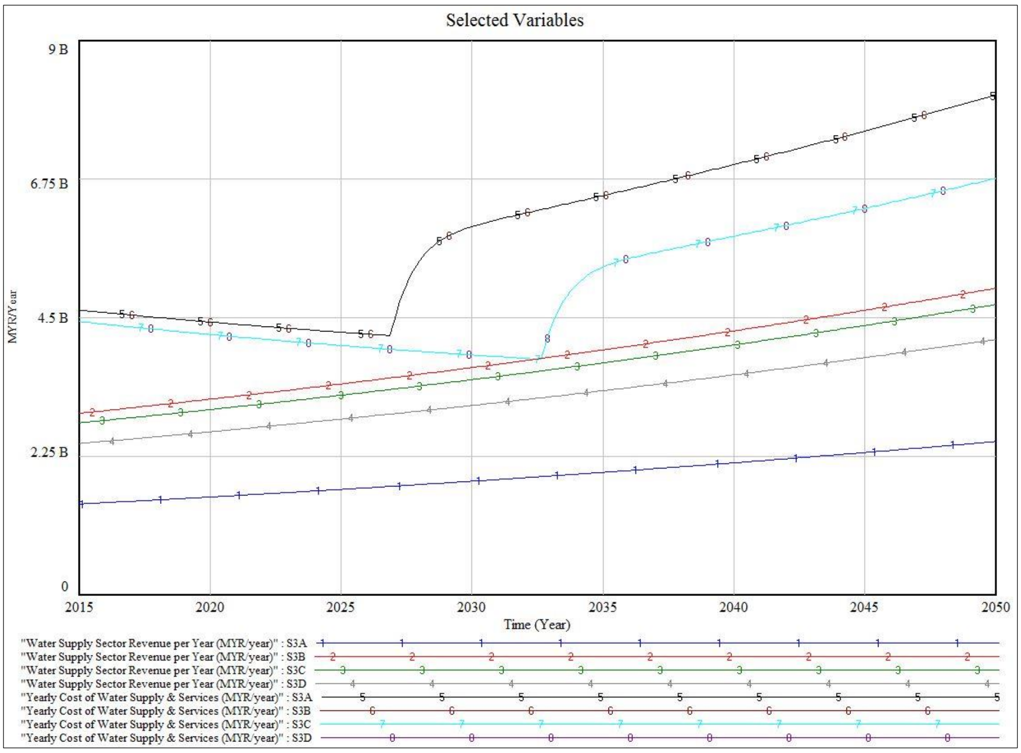

Figure 74: S3 - Water Supply and Services Cost and Revenue

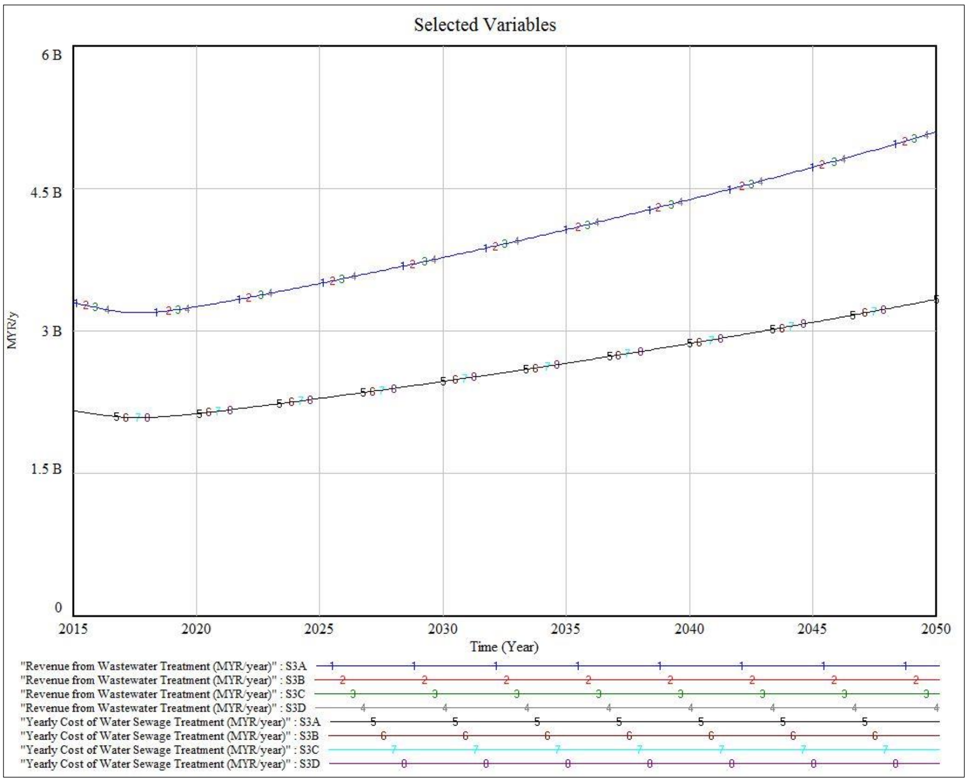

Figure 75: S3 - Sewage Cost and Revenue

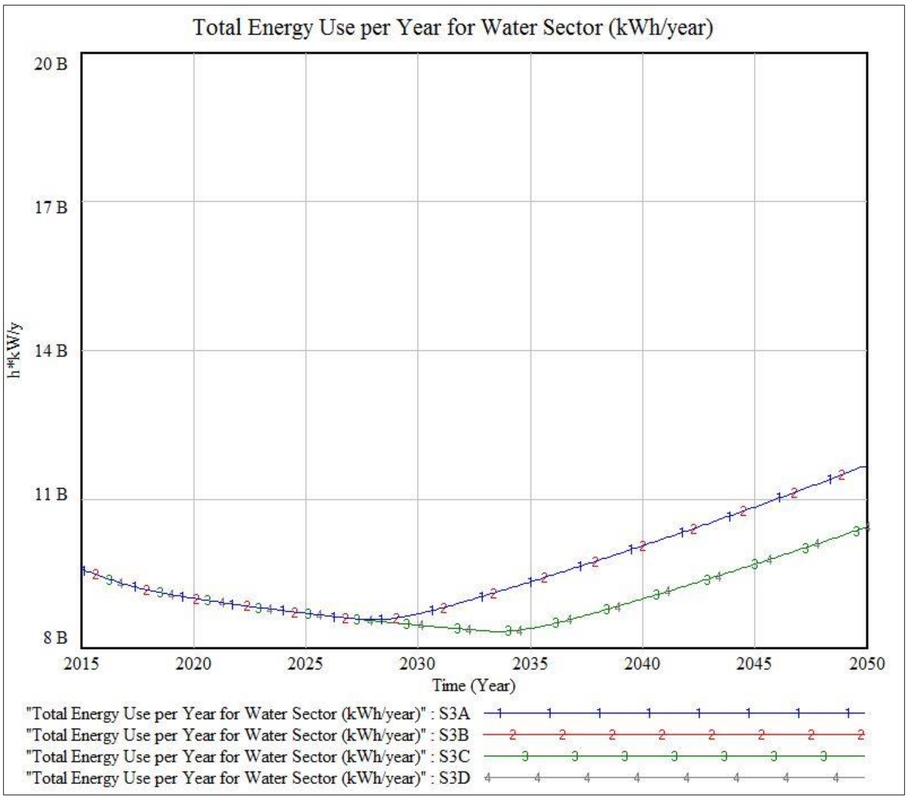

Figure 76: S3 - Energy Use per Year for Water Sector

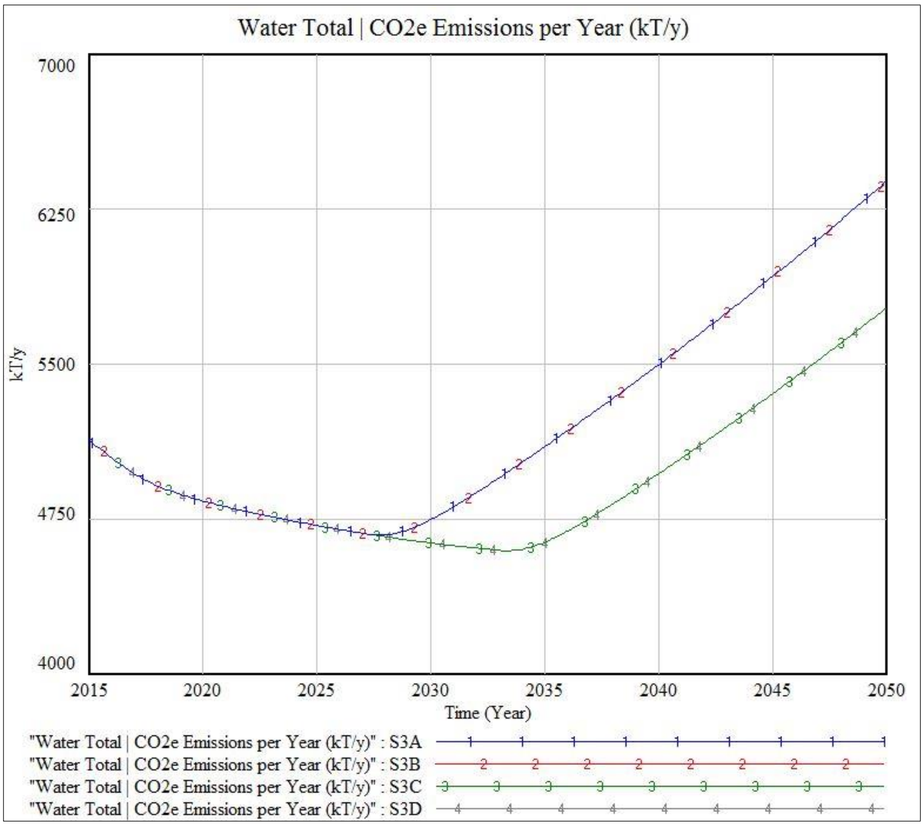

Figure 77: S3 - CO_2e Emissions per Year

6.2.4 Increasing Self-Sufficiency Levels (Food)

Food security has conventionally been addressed in an overly narrow fashion, which is to consider rice only, Malaysia's main staple diet (F1). As also pointed out by Halim [50], wheat and sugar are also equally important. Effective SSL and desired SSL are also important as it measures the portion of self-produce food from the total food requirement of the country. Consequently, with knowledge of land yield, the amount of land required to achieve each specific desired SSL can be calculated. From the WEF security nexus point of view, the amount of food production would provide the amount of energy and water needed to produce each food type.

Livestock has also been included in the study as a source of protein. Cattle has been chosen to represent livestock in the study as they utilise vast amount of land, water, energy, and livestock feed to breed. Energy use has been divided into two - electricity and other energy used. Electricity is estimated to cover 20% of the total energy use in each agriculture type [232]. The SSL for livestock involves two separate SSL namely the SSL for the livestock itself, and the SSL for its livestock feed.

This scenario examines five sub-scenarios. Considering that Malaysia is focused on rice when it comes to addressing food security (F1), S4A is a simplified base case, where SSL for rice is approximately 65% and the assumption that Malaysia do not produce other staple food products. S4B looks into increasing slightly the SSL of other staple food SSL to 20%, while keeping livestock feed at 0% SSL. S4C is the more aggressive scenario as compared to S4B, where Malaysia attempts to achieve 100% SSL in rice production on top of increasing their own livestock feed SSL. S4D tunes the values to more reasonable levels, where rice SSL is set at 80%, and 20% of livestock SSL are considered. S4D also acts as a reference point for S4E, where the USD/MYR exchange rate is raised from 4 to 4.5. This is important because the majority of import food bills originates from importing livestock feed.

A variety of key indicators is important for this set of scenarios. They are land use for food, yearly food production, import cost per year, and effective SSL. Of significance important to the WEF context, are the variables water withdrawal per year, electricity used per year, fuel used per year, and total emissions per year. Table 23 provide the list of relevant constants. Table 24 provides the list of scenario values and Table 25 provides the list of key indicators.

Table 23: Relevant Constants for S4

Relevant Constants	Value	Units	Source
Rice | Water Withdrawal per kg Production	2497	L/kg	[233]
Wheat | Water Withdrawal per kg Production	1500	L/kg	[233]
Sugar Cane | Water Withdrawal per kg Production	160	L/kg	[42]
Livestock | Water Withdrawal per kg Production	15414	L/kg	[233]
Livestock Feed | Water Withdrawal per kg Production	980	L/kg	[42]
Rice Yield	3835	kg/ha	[218]
Wheat Yield	3120	kg/ha	[234]
Livestock Yield	2000	kg/ha	[235]
Livestock Feed Yield	6097.5	kg/ha	[218]
Sugar Cane Yield	70000	kg/ha	[236]
Rice | Electricity Used per kg Production	0.16	kWh/kg	[237]
Wheat | Electricity Used per kg Production	0.16	kWh/kg	[237]
Sugar | Electricity Used per kg Production	0.16	kWh/kg	[237]
Sugar Cane | Electricity Used per kg Production	0.16	kWh/kg	[237]
Livestock | Electricity Used per kg Production	13.3	kWh/kg	[237]
Livestock Feed | Electricity Used per kg Production	0.16	kWh/kg	[237]
Rice | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	[237]
Wheat | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	[237]
Sugar | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	[237]
Sugar Cane | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	[237]
Livestock | Other Energy Used per kg Production	4.60×10^{-6}	ktoe/kg	[237]
Livestock Feed | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	[237]
Rice | CO_2e Emissions per kg Production	2.90×10^{-6}	kTCO_2e/kg	[238]
Wheat | CO_2e Emissions per kg Production	2.90×10^{-6}	kTCO_2e/kg	[238]
Sugar Cane | CO_2e Emissions per kg Production	2.90×10^{-6}	kTCO_2e/kg	[238]
Livestock | CO_2e Emissions per kg Production	34.6	kTCO_2e/kg	[238]
Livestock Feed | CO_2e Emissions per kg Production	2.90×10^{-6}	kTCO_2e/kg	[238]
Rice | Price per kg Import	0.4	USD/kg	[239]
Wheat | Price per kg Import	0.18	USD/kg	[239]
Sugar | Price per kg Import	0.32	USD/kg	[239]
Sugar Cane | Price per kg Import	0.0695	USD/kg	[239]
Livestock | Price per kg Import	4.16	USD/kg	[239]
Livestock Feed | Price per kg Import	0.147	USD/kg	[239]

Table 24: Scenario S4

Scenario: Increasing Food Self-Sufficiency Levels (S4)	A	B	C	D	E	
Variable			**Values**			**Units**
Rice | Desired SSL	0.65	0.65	1	0.8	0.8	dmnl
Wheat | Desired SSL	0	0.2	0.2	0	0	dmnl
Sugar | Desired SSL	0	0.2	0.2	0	0	dmnl

Livestock| Desired SSL	0	0.2	0.2	0.2	0.2	dmnl
Livestock Feed| Desired SSL	0	0	0.2	0.2	0.2	dmnl
USD/MYR Exchange Rate	4	4	4	4	4.5	MYR/USD

Table 25: Key Indicators for S4

Key Indicators	**Units**
Land for Rice	ha
Land for Wheat	ha
Land for Sugar Cane	ha
Land for Livestock	ha
Land for Livestock Feed	ha
Rice Production	kg/year
Wheat Production	kg/year
Sugar Production	kg/year
Livestock Production	kg/year
Livestock Feed Production	kg/year
Rice | Import Cost per Year	MYR/year
Wheat | Import Cost per Year	MYR/year
Sugar | Import Cost per Year	MYR/year
Livestock | Import Cost per Year	MYR/year
Livestock Feed | Import Cost per Year	MYR/year
Rice | Effective SSL	dmnl
Wheat | Effective SSL	dmnl
Sugar | Effective SSL	dmnl
Livestock | Effective SSL	dmnl
Livestock Feed | Effective SSL	dmnl
Staple Food | Water Withdrawal per Year	L/year
Staple Food | Electricity Used Per Year	kWh/year
Staple Food | Fuel Used per Year	ktoe/year
Staple Food | CO_2e Emissions per Year	kT/year

Results and Discussion:

Figure 78 shows the change in available arable land over time until 2050, which is dependent on the level of SSL Malaysia sets to achieve for its respective staple food crops. The amount of arable land available at 2050 follows the increasing order of scenarios S4C, S4D, S4E, S4B, and S4A. The amount of available arable land decreases over time because of the need to fulfil an ever-growing population under similar yield, SSL, and per capita consumptions.

From Figure 79, Figure 80, and Figure 81 its can be seen that water withdrawal per year, electricity used per year, and other energy used per year for scenario S5A are significantly lower than other scenarios because this scenario is where Malaysia do not focus on growing its own staple food, and imports a large part of them. This is not favourable for Malaysia in the long term because being food dependent puts Malaysia at the mercy of its exporting country. Coupled with the policy of food sovereignty, the declaration of Nyeleni [240] where communities take full control of the way their food is grown, produced, traded, and consumed, food security in Malaysia is further complicated.

Naturally, increasing SSL for staple food types increases each respective resource use. S4C, an aggressive SSL scenario where Malaysia seeks to achieve 100 % SSL in rice, and 20 % respectively in wheat, sugar, and livestock, results in the highest values of water withdrawal (20.9 TL/year), electricity use per year (9.5 TWh/year), and other energy used (3300 ktoe/year). On the other hand, this scenario loosens the import cost burden by having the lowest projected total import cost of RM 57 billion.

S4B, S4D, and S4E resulted in similar values of resource use i.e. 17 TL/year of water withdrawal, 9 TWh/year of electricity used, and 3200 ktoe/year of other energy used. All three indicators show a sharp rise in the first five years after 2015 and then slowly stabilizes towards 2050.

For food import cost per year, as depicted by Figure 82, total spent on food import per year when nearing towards 2050 follows the decreasing order of S4A, S4E, S4D, S4B, and lowest being S4C. Scenarios S4A and S4E reach significantly higher import cost than the other three at RM 72 billion and RM 68 billion respectively. During the first 5-7 years after 2015, the impact of the weak ringgit (S4E) on import cost is more apparent. However, after 5-7 years, the impact of having weak SSL takes over, as can be seen from Figure 82, where the import cost of S4A (weak SSL) overtakes the import cost of S4E (weak ringgit). This shows that whilst the strength of USD/MYR exchange rate is very important in the food cost of Malaysia, being independent in terms of food production (i.e. having a strong SSL) is still number one priority.

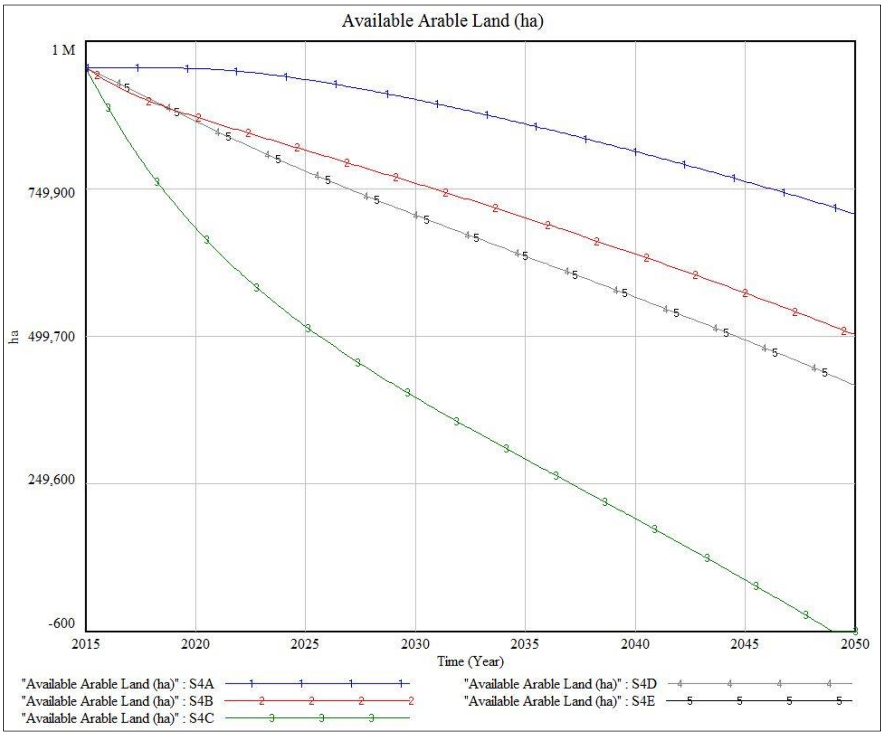

Figure 78: S4 - Available Arable Land

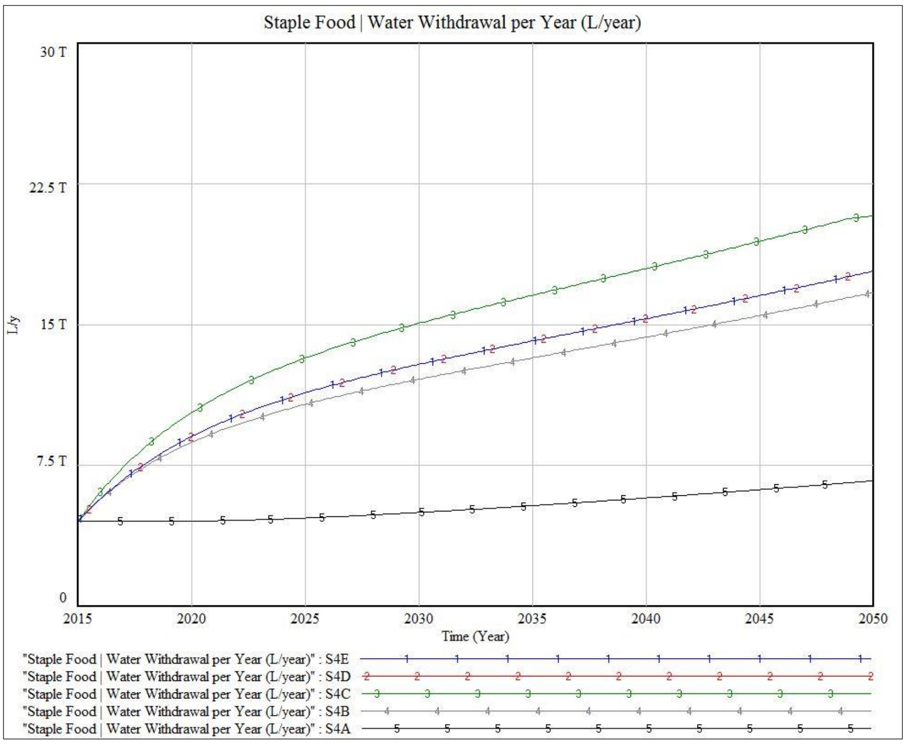

Figure 79: S4 - Staple Food | Water Withdrawal per Year

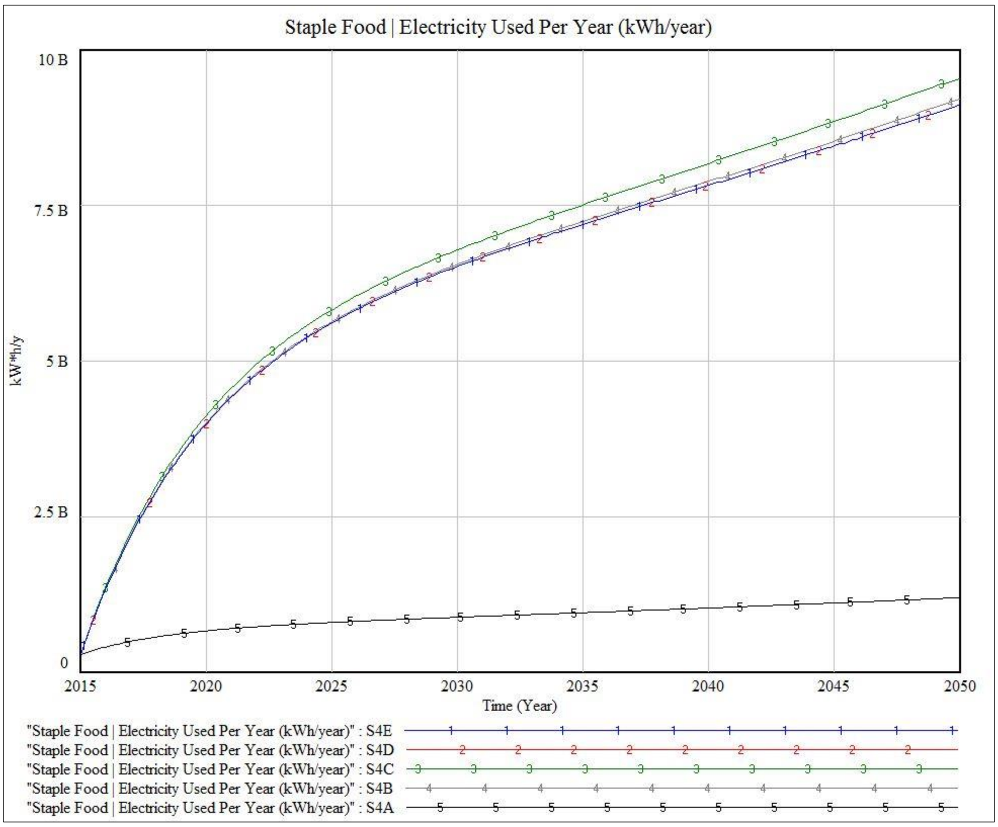

Figure 80: S4 - Staple Food | Electricity Used per Year

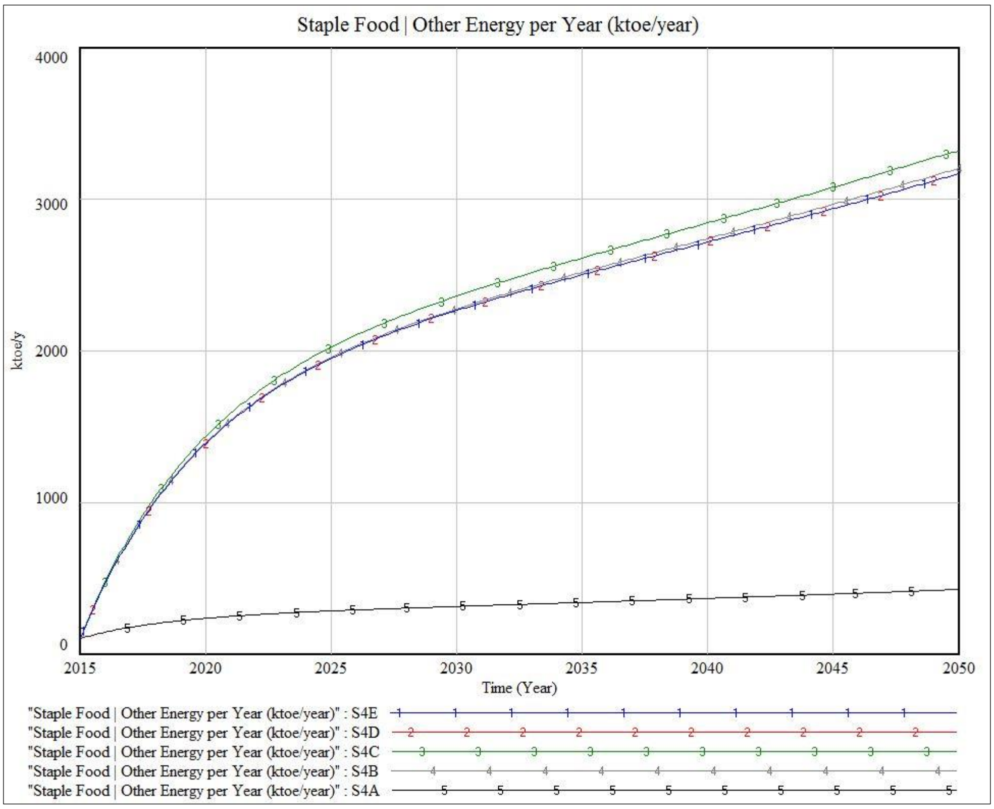

Figure 81: S4 - Staple Food | Other Energy Used per Year

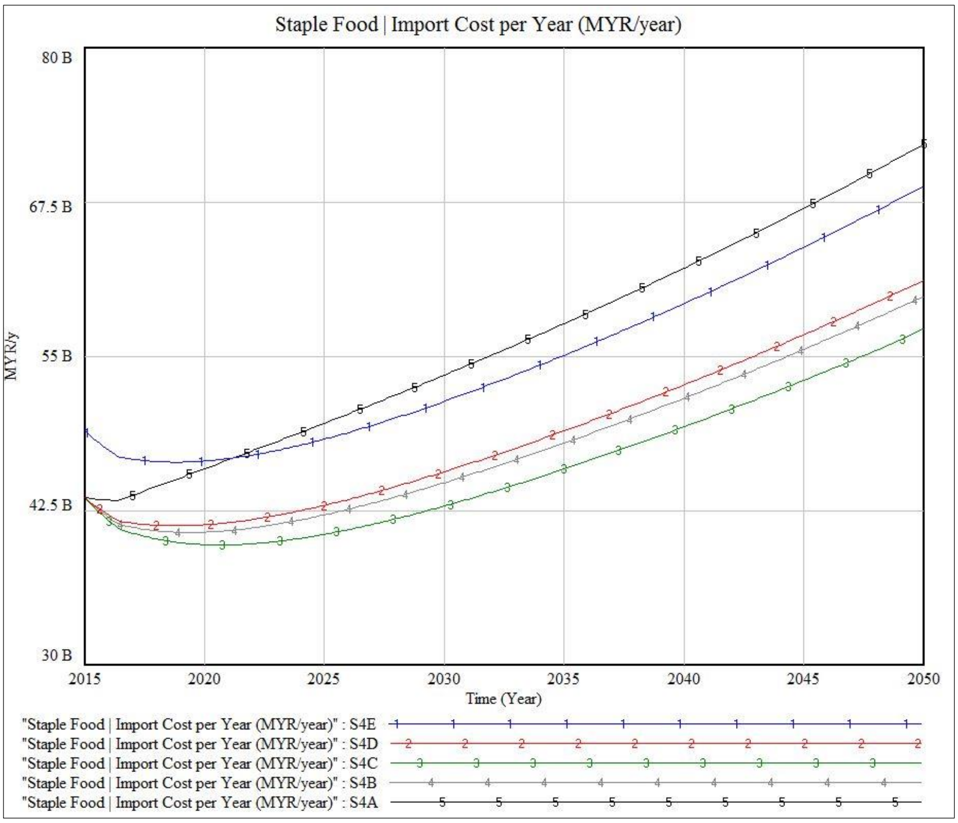

Figure 82: S4 - Staple Food | Import Cost pet Year

6.2.5 Nutrition Security and Utilising Marginal Crops

As understood from key stakeholders from the food industry (F1, F2), Malaysia has 6 million hectares of marginal land, and a variety of crops which are under-utilized known as marginal crops. Whilst they may not provide the mass as regular crops, they are far superior in nutrient contents (F2).

As opposed to S4 where different levels of SSL of staple food types are investigated, this scenario investigates the effect of equal penetration of different marginal crops under varied timescale for land preparation. This is because as conventional staple food are well established in term of mass production and knowledge in farming; marginal crops are not ready for mass production yet and are not yet socially acceptable to replace conventional staple food. As such, this scenario looks into the effects of speed in adoption of marginal crops into Malaysian's diet on the key indicators of WEF.

Considering that marginal crops are absorbed into Malaysian's diet, this scenario has to be accompanied by a corresponding decrease in staple food requirement per capita. S5A considers a slow transition towards marginal crop, setting the marginal crop preparation time at 35 years. For S5A, the original staple food per capita per year requirements are used. Subsequently for S5B, S5C, and S5D, the staple food requirements are reduces by 20% at every stage. Eventually staple food requirements in S5D is 50% of S5A.

This scenario provides insights into several important key indicators, which are affected by the balance between conventional staple food, and utilizing marginal crops. Pertaining to the inter-sectoral indicators are water withdrawal per year, electricity used per year, and fuel used per year for the marginal crops grown. For nutrient security, the dynamics of energy, protein and fat supply can also be analysed, considering that conventional staple food nutrient contents are different from those of marginal crops. Finally yet importantly are the economic and environmental factors such as CO_2e emissions per year and total costs per year. Table 26 and Table 27 provide the list of relevant constants. Table 28 provides the list of scenario values and Table 29 provides the list of key indicators.

Table 26: Nutrition Relevant Constants for S5

Relevant Constants - Nutrition	Value	Units	Source
Rice | Energy Supply per kg	1.29	kcal/kg	[241]
Wheat | Energy Supply per kg	3.39	kcal/kg	[241]
Sugar | Energy Supply per kg	3.87	kcal/kg	[241]

Lifestock | Energy Supply per kg	2.5	kcal/kg	[241]
MC1 | Energy Supply per kg	3.7	kcal/kg	[242]
MC2 | Energy Supply per kg	2	kcal/kg	[243]
Rice | Protein Supply per kg	27.4	g/kg	[241]
Wheat | Protein Supply per kg	140	g/kg	[241]
Sugar | Protein Supply per kg	0	g/kg	[241]
Lifestock | Protein Supply per kg	260	g/kg	[241]
MC1 | Protein Supply per kg	160	g/kg	[242]
MC2 | Protein Supply per kg	0	g/kg	[243]
Rice | Fat Supply per kg	3	g/kg	[241]
Wheat | Fat Supply per kg	25	g/kg	[241]
Sugar | Fat Supply per kg	0	g/kg	[241]
Lifestock | Fat Supply per kg	150	g/kg	[241]
MC1 | Fat Supply per kg	60	g/kg	[242]
MC2 | Fat Supply per kg	25	g/kg	[243]

Table 27: Resources Relevant Constants for S5

Relevant Constants - Resources	**Value**	**Units**	**Source**
MC1 | CO_2e Emissions per kg Production	1.50×10^{-6}	kT/kg	(F1,F2)
MC2 | CO_2e Emissions per kg Production	1.50×10^{-6}	kT/kg	(F1,F2)
MC1 | Water Withdrawal per unit Production	250	L/kg	(F1,F2)
MC2 | Water Withdrawal per unit Production	250	L/kg	(F1,F2)
MC1 | Electricity used per unit Production	0.08	kWh/kg	(F1,F2)
MC2 | Electricity used per unit Production	0.08	kWh/kg	(F1,F2)
MC1 | Other Energy used per unit Production	2.80×10^{-8}	ktoe/kg	(F1,F2)
MC2 | Other Energy used per unit Production	2.80×10^{-8}	ktoe/kg	(F1,F2)
MC1 | Land Efficiency	650	kg/ha	[242]
MC2 | Land Efficiency	3000	kg/ha	(F1,F2)

Table 28: Scenario S5

Scenario: Utilizing Marginal Crops (S5)	**A**	**B**	**C**	**D**	**E**	
Variable			**Values**			**Units**
Available Marginal Land (million)	0	6	6	6	6	
Marginal Land Preparation Time	-	35	25	15	5	year
Rice Consumption per Capita per Year	80	80	80	80	80	kg/(ppl*year)
Wheat Consumption per Capita per Year	60	60	60	60	60	kg/(ppl*year)
Sugar Consumption per Capita per Year	30	30	30	30	30	kg/(ppl*year)

Livestock Consumption per Capita per Year	60	60	60	60	60	kg/(ppl*year)
Rice | Desired SSL	0.8	0.8	0.8	0.8	0.8	dmnl
Wheat | Desired SSL	0.2	0.2	0.2	0.2	0.2	dmnl
Sugar | Desired SSL	0.2	0.2	0.2	0.2	0.2	dmnl
Livestock| Desired SSL	0.2	0.2	0.2	0.2	0.2	dmnl
Livestock Feed| Desired SSL	0.2	0.2	0.2	0.2	0.2	dmnl

Table 29: Key Indicators for S5

Key Indicators	Units
Food | Water Withdrawal per Year	L/year
Food | Electricity Used per Year	kWh/year
Food | Fuel Used per Year	ktoe/year
Total | Energy Supply per Year	kcal/year
Total | Protein Supply per Year	g/year
Total | Fat Supply per Year	g/year
Energy | Supply per Electricity Spent	kcal/kWh
Protein | Supply per Electricity Spent	g/kWh
Fat | Supply per Electricity Spent	g/kWh
Energy | Supply per Water Spent	kcal/L
Protein | Supply per Water Spent	g/L
Fat | Supply per Water Spent	g/L
Energy | Supply per Other Energy Spent	kcal/ktoe
Protein | Supply per Other Energy Spent	g/ktoe
Fat | Supply per Other Energy Spent	g/ktoe

Results and Discussion:

Figure 83, Figure 84, and Figure 85 show the total nutrients supply per year as a results of local production as calculated from the total food production whilst Figure 86, Figure 87, and Figure 88 show total resources use per year because of the food production. Consequently, Figure 89 to Figure 97 show the specific resource use for each nutrient type.

Since this scenario is concerned with how quickly marginal crops are being implemented into Malaysia's food sector, it is thus natural that the indicators improve in increasing order of S5A, S5B, S5C, S5D to S5E. It can be seen from the control case of S5A, that without any marginal crop adoption, total resource use (i.e. yearly electricity, water withdrawals, and other energy uses) is lowest among all sub-scenarios. Without marginal crop adoption (S5A), Malaysia is expected to produce 25 B kcal/year of food energy supply, 29.3 B g/year of fats, and 186.3 B g/year of protein. On the other hand, with the adoption of marginal crop, yearly production is at 57-75 B kcal/year for food energy supply, 462-712 B g/year for fats, and 581-809 B g/year for protein. These values however arises as a result on the assumption that all 6 million hectares of Malaysia's marginal land are converted to grow marginal crops.

However, the total nutrients supply per year for S5A is also lowest, on top of being significantly lower than the other four sub-scenarios. The three resources looked at were electricity, other energies, and water. The following illustrates the amount of nutrient obtain to its unit resource expenditure:

Without marginal crops:

- 1 kWh of electricity produces:
  - 2.506 kcal of energy
  - 2.926 g of fat
  - 18.59 g of protein
- 1 ktoe of other energies produces:
  - 7.21 M kcal of energy
  - 8.42 Mg of fat
  - 53.48 Mg of protein
- 1 L of water produces:
  - 0.0013 kcal of energy
  - 0.00151 g of fat
  - 0.00965 g of protein

With marginal crops:

- 1 kWh of electricity produces:
  - 5.1-6.4 kcal of energy
  - 41.5-60.5 g of fat
  - 52.2-68.8 g of protein
- 1 ktoe of other energies produces:
  - 14.7-18.4 M kcal of energy
  - 119-174 Mg of fat

- 150-198 Mg of protein

- 1 L of water produces:
    - 0.0025-0.0030 kcal of energy
    - 0.020-0.028 g of fat
    - 0.025-0.033 g of protein

Whilst marginal crops such as Bambara groundnut and Moringa leaves are by no means complete substitutes of Malaysian's staple food of rice, wheat, sugar, and beef, it can be seen that by including or increasing the share of marginal crop into Malaysia's diet, efficiency of resource use can be increased. By adopting marginal crops such as these, two main advantages can be obtained namely:

- Reduce the stress of obtaining basic nutrient requirements from the normal staple food, which thus reduces the stress on achieving a high SSL.
- Reduce the stress on electricity, water, and other energies.

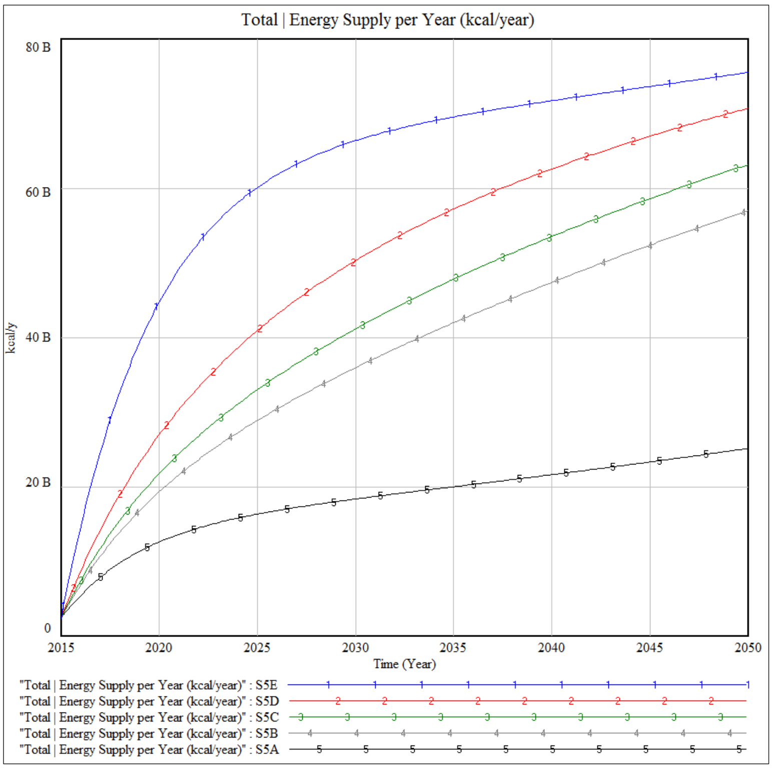

Figure 83: S5 - Total | Energy Supply per Year

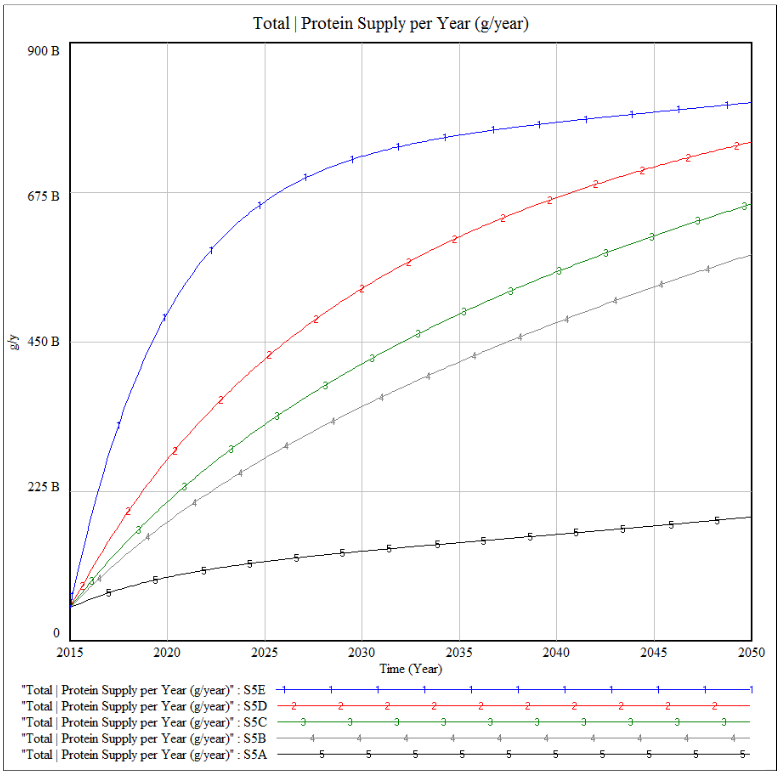

Figure 84: S5 - Total | Protein Supply per Year

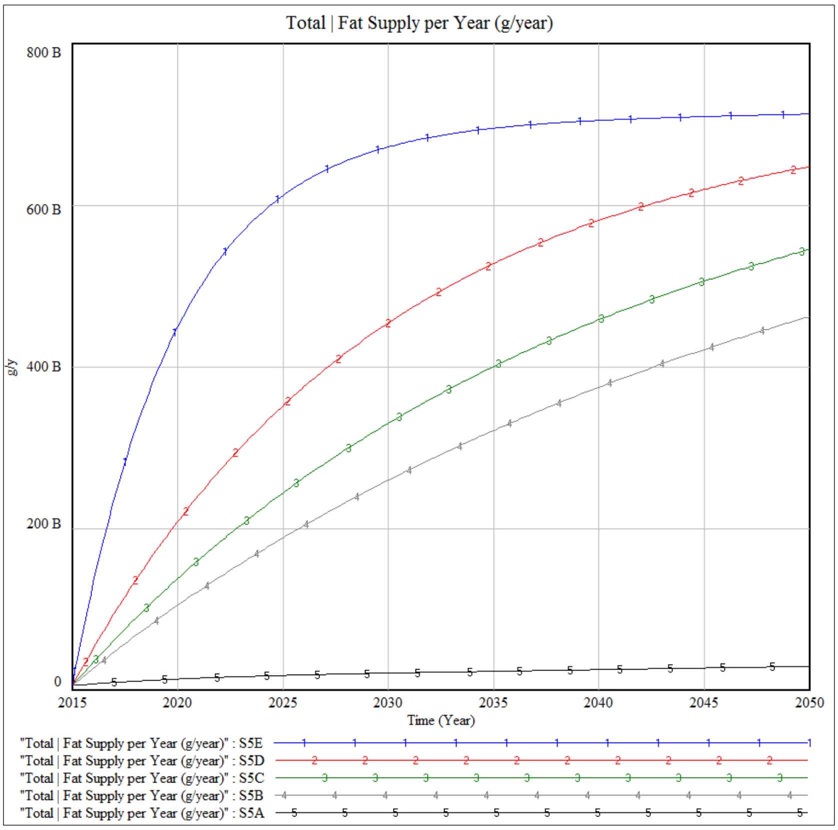

Figure 85: S5 - Total | Fat Supply per Year

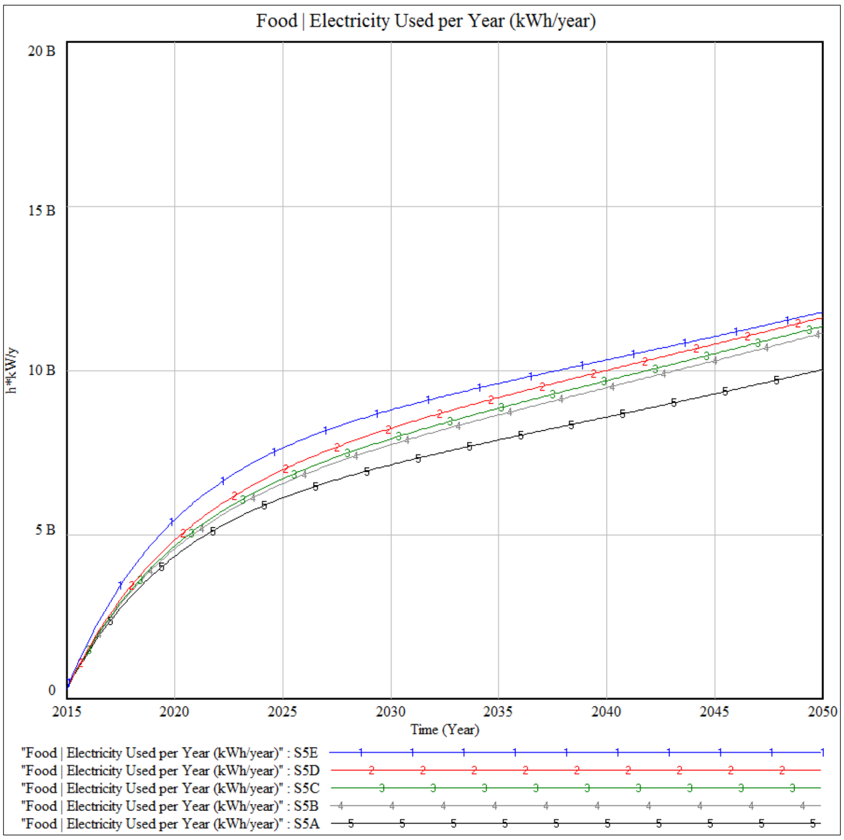

Figure 86: S5 - Food | Electricity Used per Year

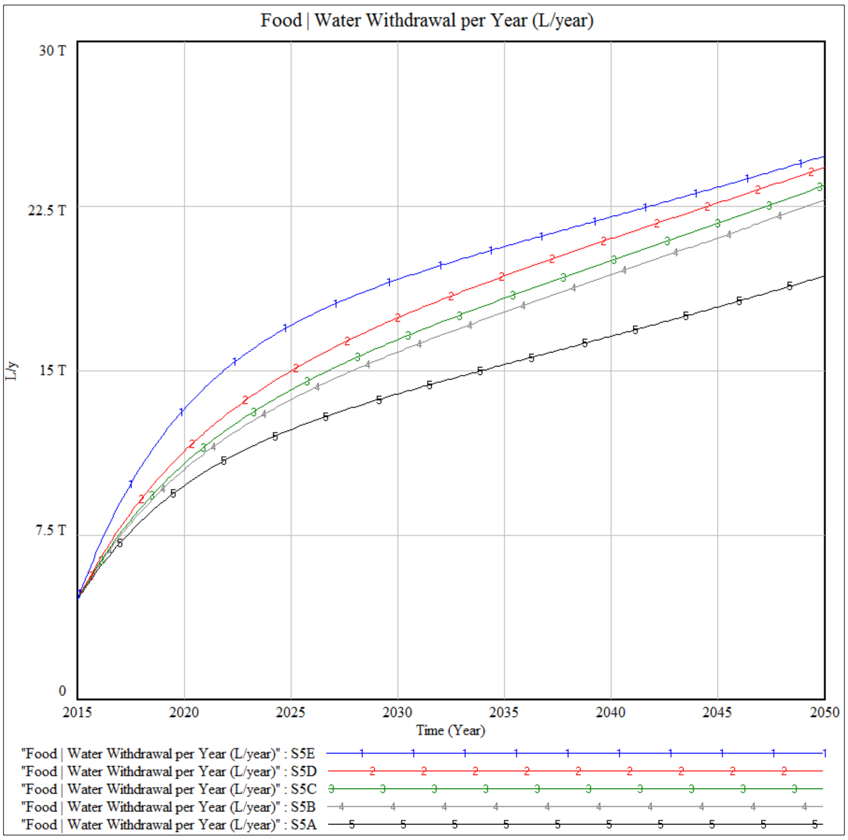

Figure 87: S5 - Food | Water Withdrawal per Year

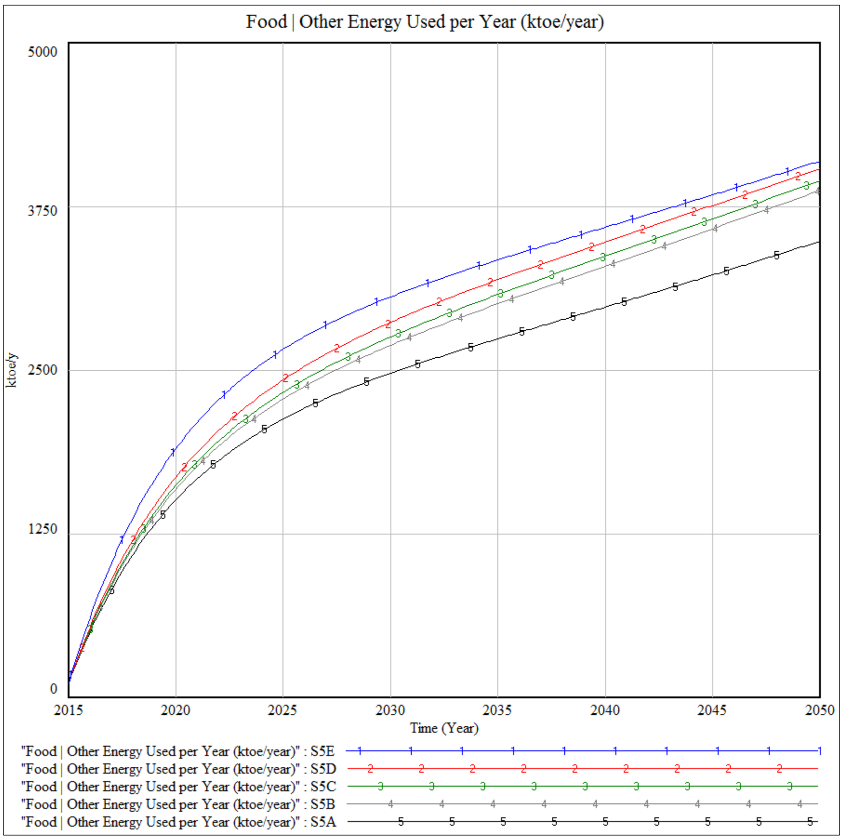

Figure 88: S5 - Food | Other Energy Used per Year

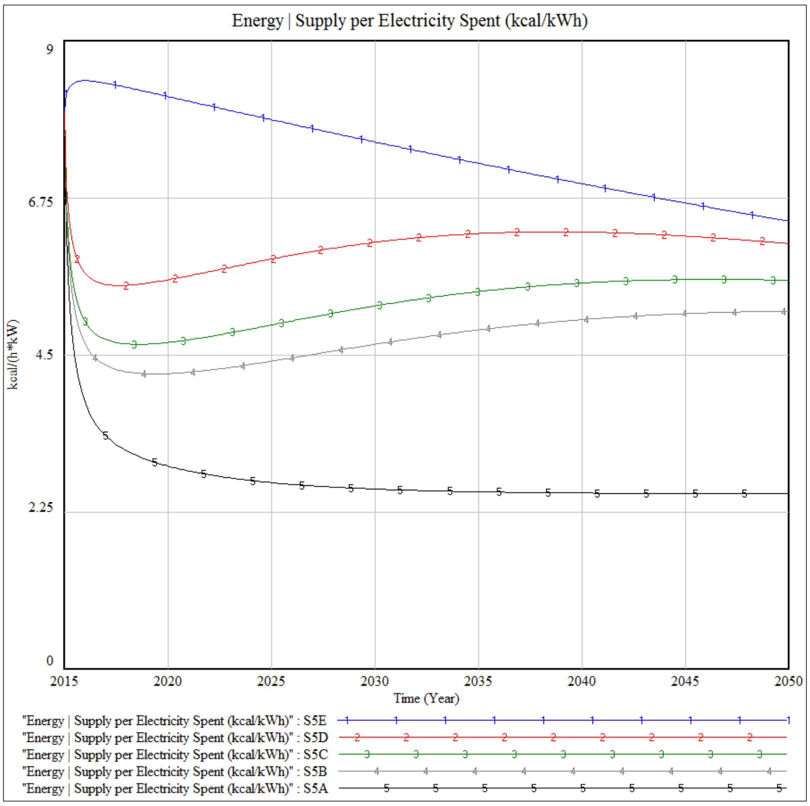

Figure 89: S5 - Energy | Supply per Electricity Spent

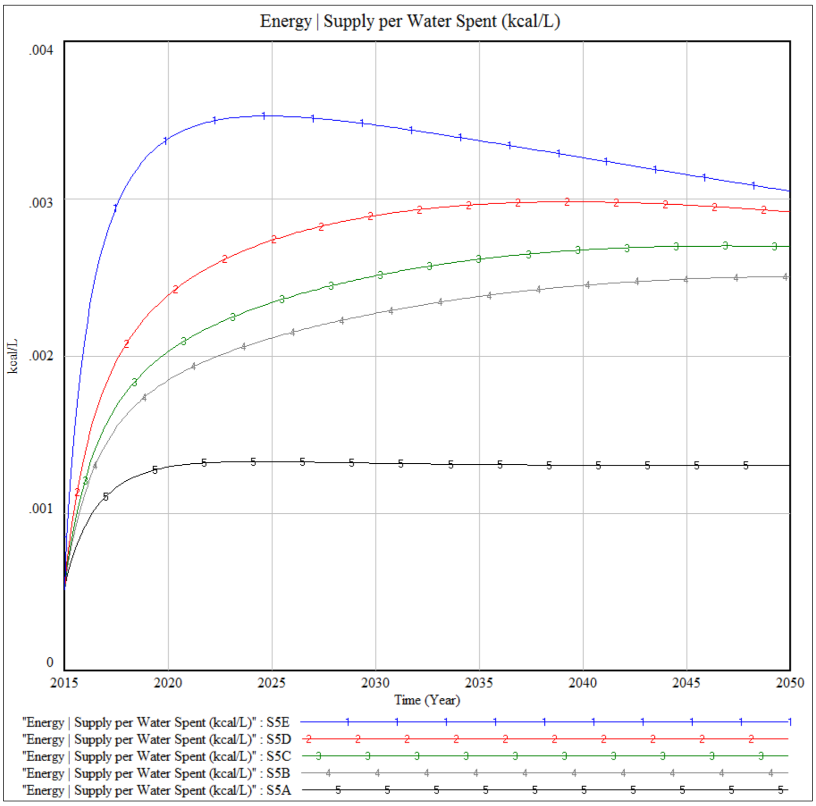

Figure 90: S5 - Energy | Supply per Water Spent

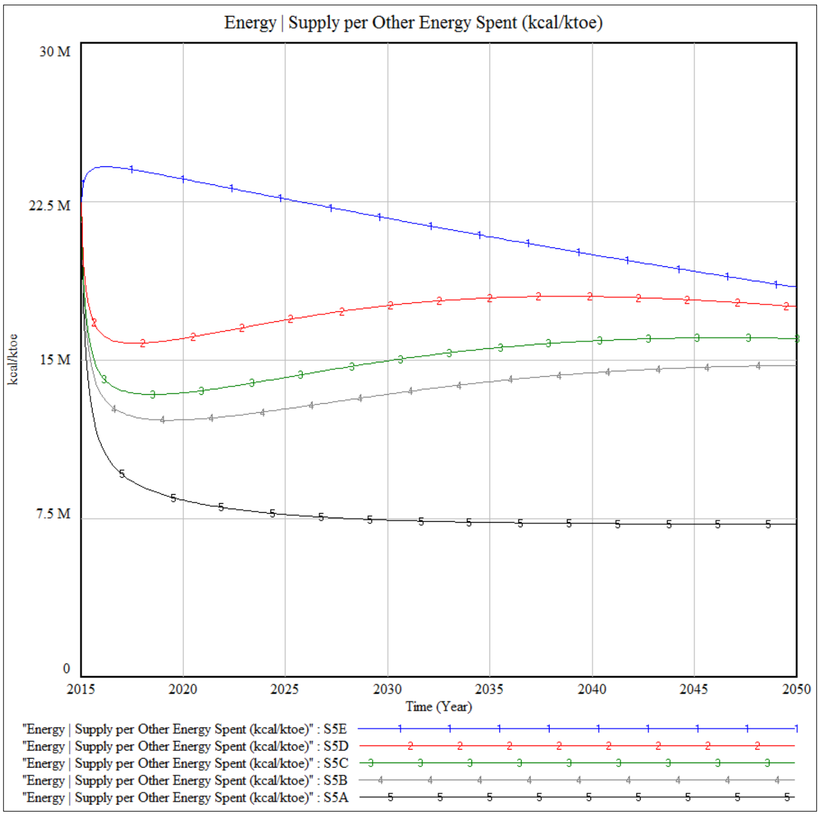

Figure 91: S5 - Energy | Supply per Other Energy Spent

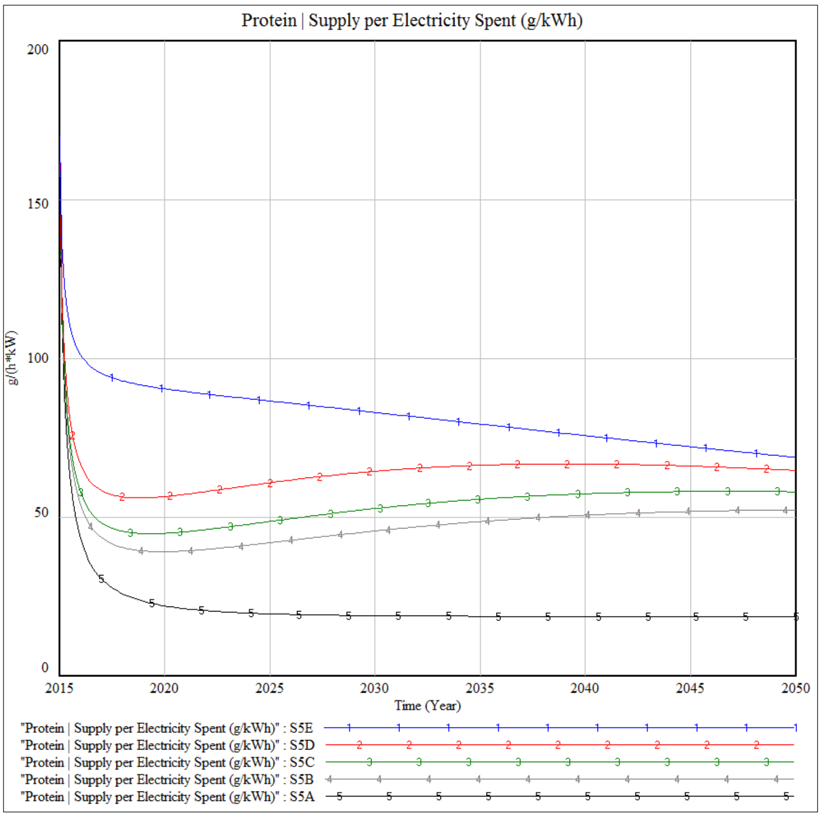

Figure 92: S5 - Protein | Supply per Electricity Spent

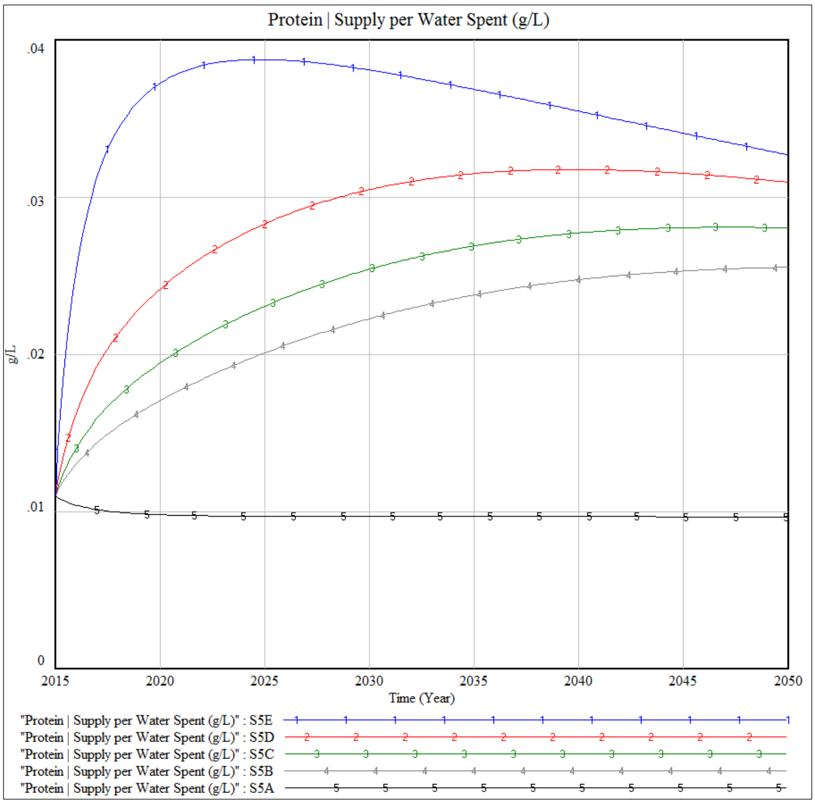

Figure 93: S5 - Protein | Supply per Water Spent

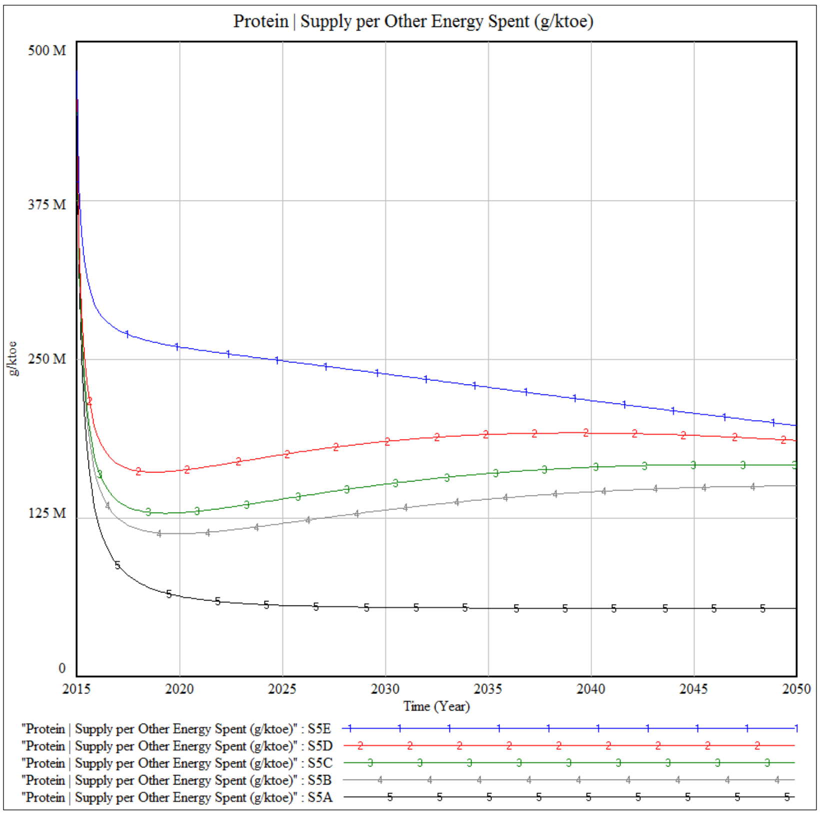

Figure 94: S5 - Protein | Supply per Other Energy Spent

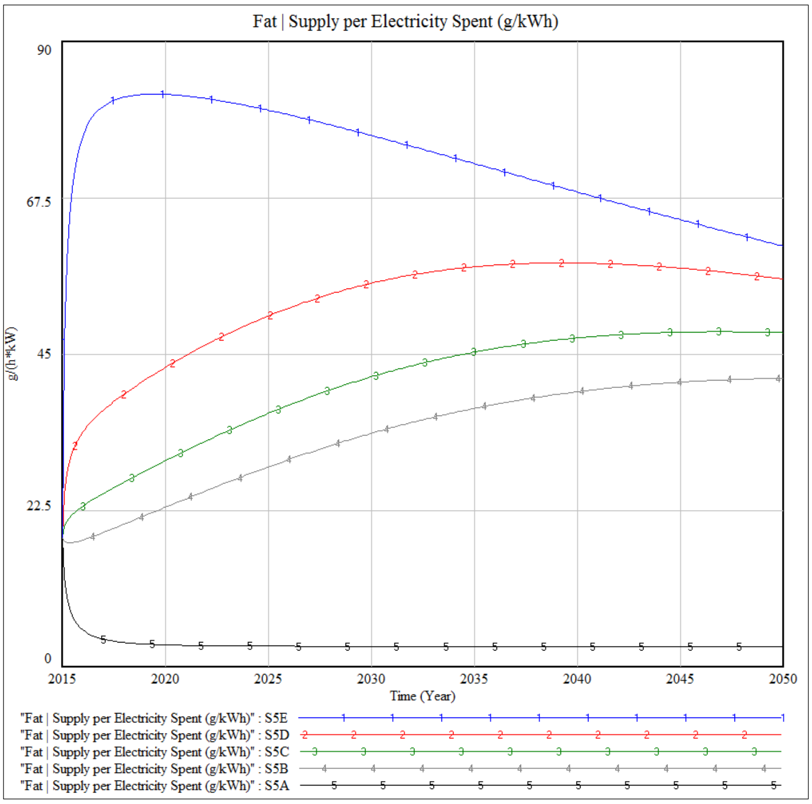

Figure 95: S5 - Fat | Supply per Electricity Spent

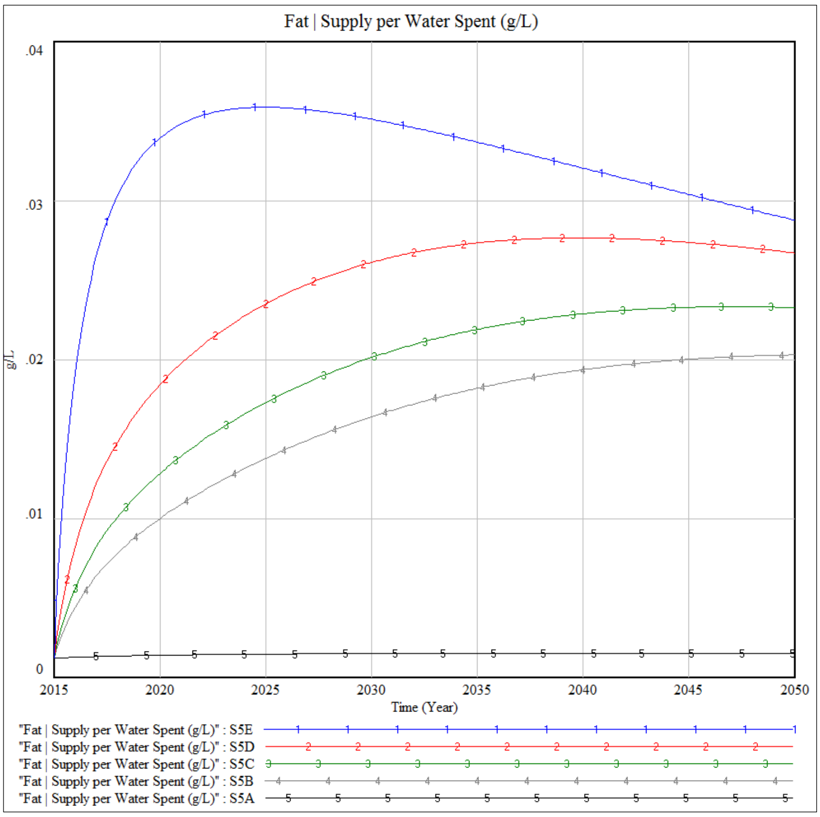

Figure 96: S5 - Fat | Supply per Water Spent

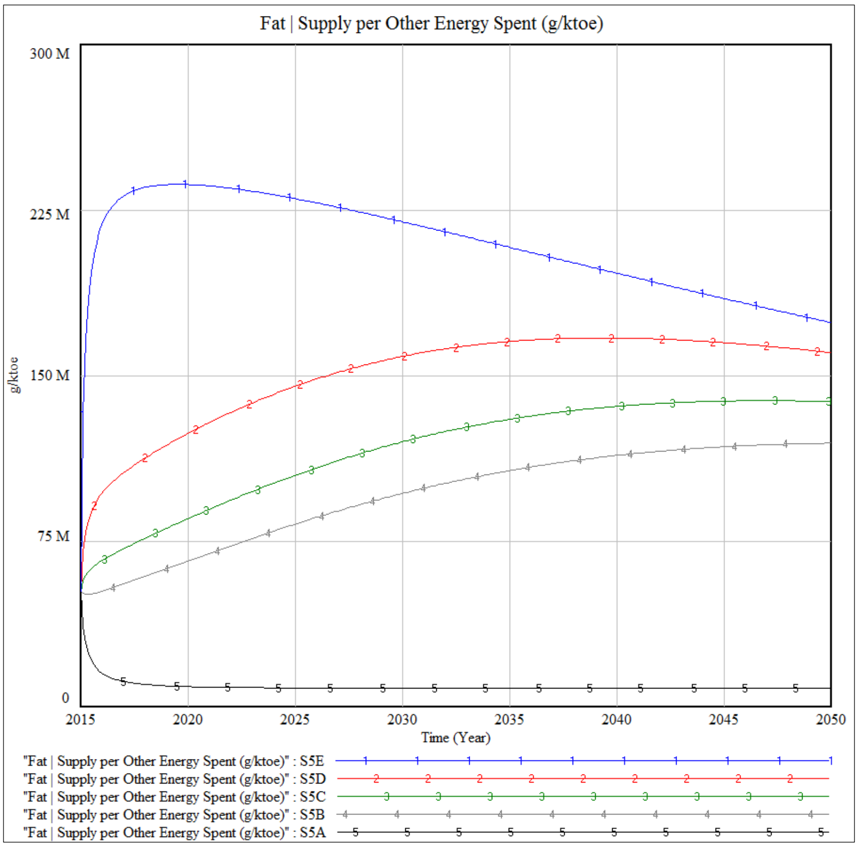

Figure 97: S5 - Fat | Supply per Other Energy Spent

6.2.6 Variations in Non-Food Crops

Major non-food crops in Malaysia are the palm oil (PO) and rubber, which are grown primarily for the cash. Malaysia's total land for palm oil is 5.1 million hectares [244]. These products provide revenue for the country when exported. Hence, a dynamic exists between benefiting from a weak USD/MYR by exporting cash crops, and benefiting from a strong USD/MYR when importing food crops to satisfy the nation's food security. As industry expert have pointed out (W2), palm oil agriculture is a major water user.

This scenario looks into the impacts of palm oil and rubber industry variables on the key indicators of WEF security nexus in Malaysia namely: land use for marginal crops, total CO_2e emissions, total costs, and total export revenue. The analysis is performed by looking at what happens when we increase and decrease the desired productions of palm oil and rubber above and below the current levels. As such, relevant input indicators in assisting this analysis are such as: desired PO produce per year, desired rubber produced per year, desired non-food land allocation portion, and desired SSL for staple food types. In S5A, the values used are based on the current status of Malaysia as understood from recent statistics [244,245]. S6B and S6C looks into the dynamics change when the desired non-food products produced per year are increased and decreased. S6D looks into the scenario where non-food land portion are gradually reduced based upon total available land in Malaysia. S6E considers the situation where Malaysia expands on more non-food product, by setting a higher target of yearly production rate and increased land use. Table 30 provide the list of relevant constants. Table 31 provides the list of scenario values and Table 32 provides the list of key indicators.

Table 30: Relevant Constants for S6

Relevant Constants	**Value**	**Units**	**Source**
Palm Oil Yield	4000	kg/ha	[244]
Rubber Yield	1000	kg/ha	[236]
PO | Water Withdrawal per kg Production	2941	L/kg	[42]
Rubber | Water Withdrawal per kg Production	13748	L/kg	[246]
PO | Electricity Used per kg Production	0.16	kWh/kg	-
Rubber | Electricity Used per kg Production	0.16	kWh/kg	-
PO | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	-
Rubber | Other Energy Used per kg Production	5.70×10^{-8}	ktoe/kg	-
PO Price	0.70	USD/kg	[247]
Rubber Price	2	USD/kg	[247]
PO | Production Cost per kg	1.6	MYR/kg	[248]
Rubber | Production Cost per kg	1	MYR/kg	[247]

PO | CO_2e Emissions per kg Production	1.70×10^{-6}	kT/kg	-
Rubber | CO_2e Emissions per kg Production	6.40×10^{-6}	kT/kg	[249]

Table 31: Scenario S6

Scenario: Variations in Non-Food Crops (S6)	**A**	**B**	**C**	**D**	**E**	
Variable			**Values**			**Units**
Desired PO Produce per Year (billion)	18.8	28	9.4	18.8	37.6	kg/year
Desired Rubber Produce per Year (billion)	0.72	1.4	0.3	0.72	2.0	kg/year
Available Land for Non-Food Crops (million)	6.6	6.6	6.6	6.6	13.2	ha
Desired Non-Food Land Allocation Portion	0.2	0.2	0.2	0.1	0.5	dmnl
Rice | Desired SSL	0.65	0.65	0.65	0.65	0.65	dmnl
Wheat | Desired SSL	0	0	0	0	0	dmnl
Sugar | Desired SSL	0	0	0	0	0	dmnl
Livestock | Desired SSL	0	0	0	0	0	dmnl

Table 32: Key Indicators for S6

Key Indicators	**Units**
Agriculture Total | CO2e Emissions per Year	kT/year
Non-Food Total | CO2e Emissions per Year	kT/year
Non-Food | Total Export Revenue per Year	MYR/year
Non-Food | Total Production Cost per Year	MYR/year
Staple Food | Import Cost per Year	MYR/year
Staple Food | Total Production Cost per Year	MYR/year
Non-Food | Water Withdrawal per Year	L/year
Non-Food | Electricity Used Per Year	kWh/year
Non-Food | Fuel Used per Year	ktoe/year
Land Prepared for PO	ha
Land Prepared for Rubber	ha
Effective Non-Food Land Allocation Portion	dmnl

Results and Discussion:

Figure 98 to Figure 103 show graphs for the non-food crop sector where similar behaviours are exhibited by the key indicators of CO_2e emissions per year (kT/year), electricity used per year (kWh/year), other energy used per year (ktoe/year), total production cost per year (MYR/year), total export revenue per year (MYR/year), and water withdrawal per year (L/year). In all the indicators, the scenarios follow the decreasing order of S6E, S6B, S6C, S6A, and S6D.

Similar behaviour is shown in all key indicators for mainly two reasons. Firstly, the non-food crops, palm oil and rubber, are not the primary basic needs within the WEF security nexus (water, energy, and staple food) and hence, their demand are not modelled as driven by population growth. Secondly, palm oil and rubber are well-established industries where primary variables for their industry expansions have been modelled as desired production per year in mass (kg/year) and amount of land to allocate for non-food crops (ha).

However, meaningful comparisons with the food sector (section 8.2.4) can still be made on the indicators. On energy used per year, non-food crop sector uses about 1.6-5.1 TWh of electricity per year and about 600-1800 ktoe/year of other energy uses per year. On the other hand, energy use for staple food sector is about 1-9 TWh/year for electricity and 420-3200 ktoe/year for other energy. On water withdrawals per year, it is about 13-39 TL/year for non-food and about 6.6-20.8 TL/year for staple food. Comparatively, without normalising to amount of land or mass of production, non-food crop sector uses about the same amount of electricity and other energy as staple food sector but uses about double as much more water.

Figure 101 and Figure 102 show the cost and export revenue earned from non-food crop respectively. It can be seen that the total cost of production for non-food crop (RM 16-50 billion/year) is about half of the revenue generated (RM 32-98 billion/year). However, with recent appreciation of palm oil prices [250], Malaysia is expecting to draw a larger profit margin from this sector.

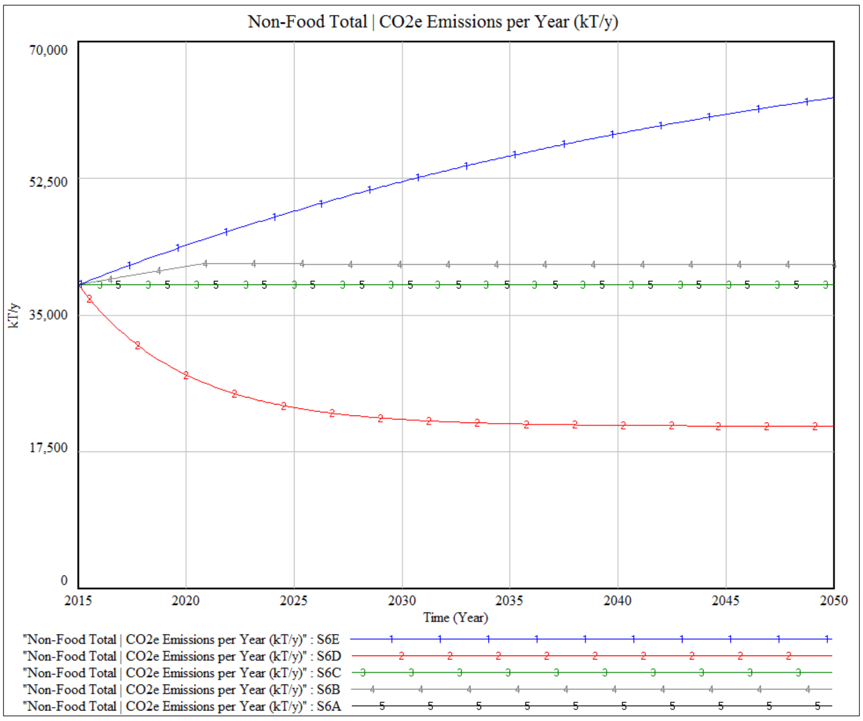

Figure 98: S6 - Non-Food Total | CO2e Emissions per Year

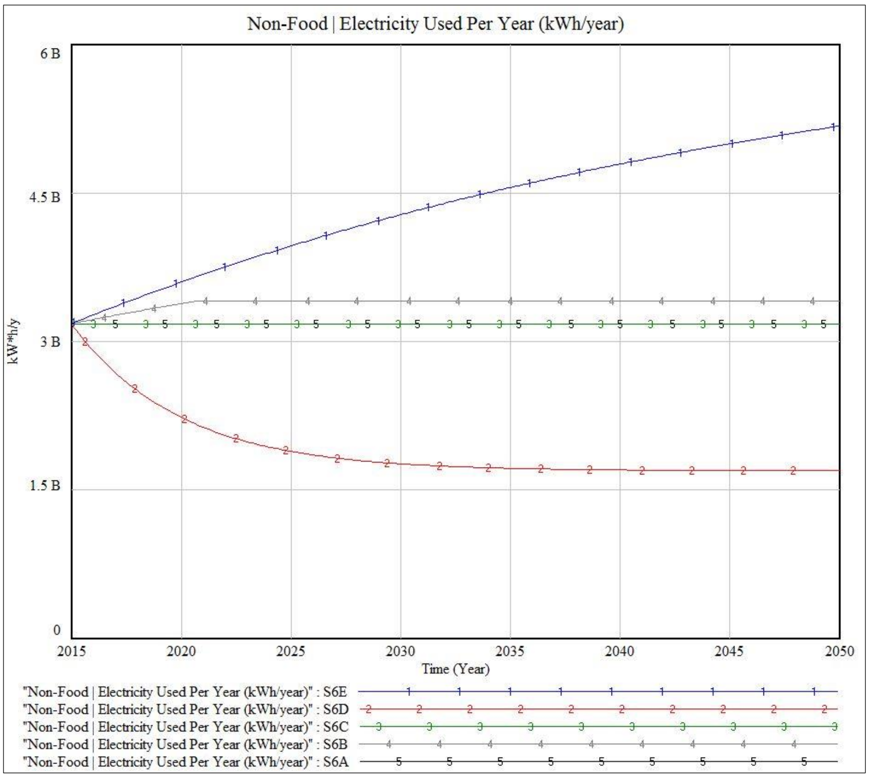

Figure 99: S6 - Non-Food | Electricity Used per Year

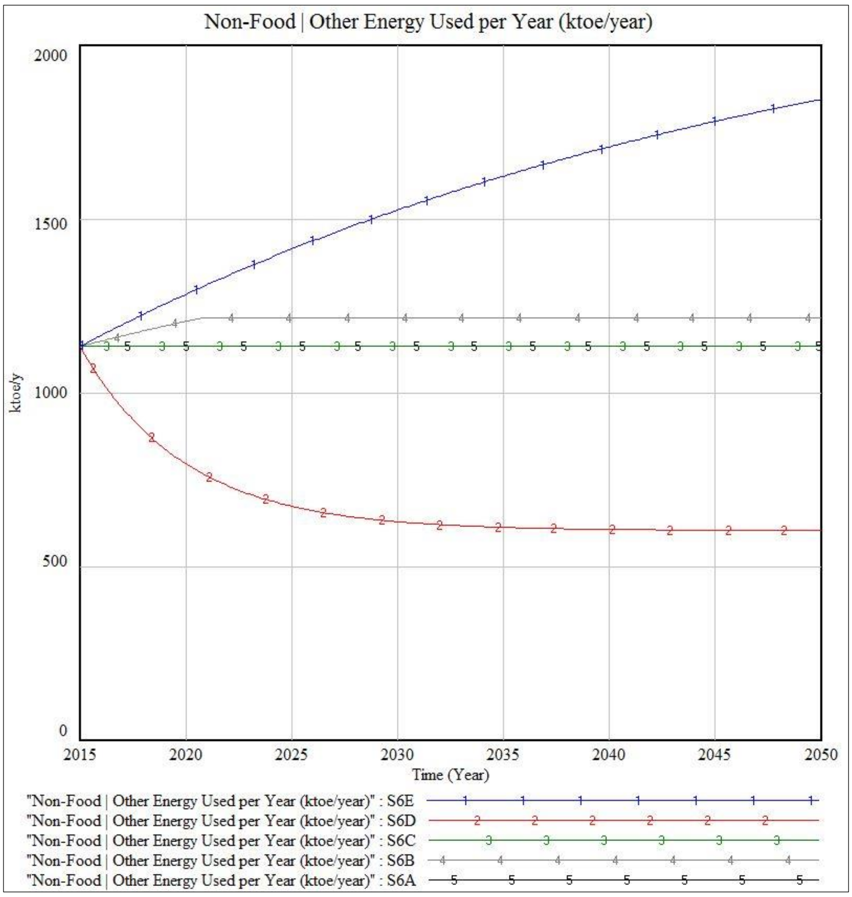

Figure 100: S6 - Non-Food | Other Energy Used per Year

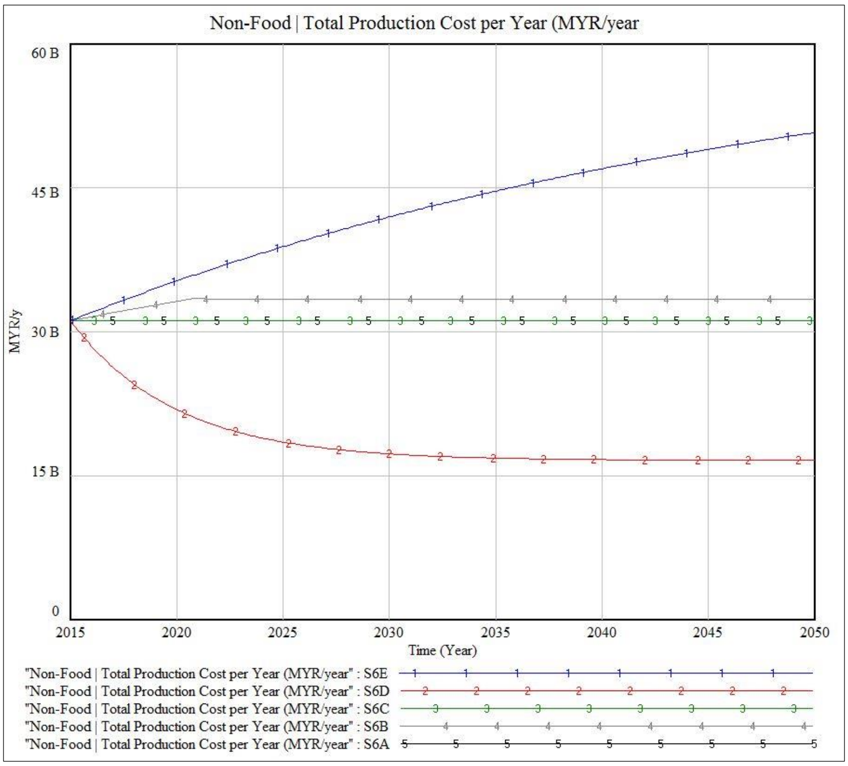

Figure 101: S6 - Non-Food | Total Production Cost per Year

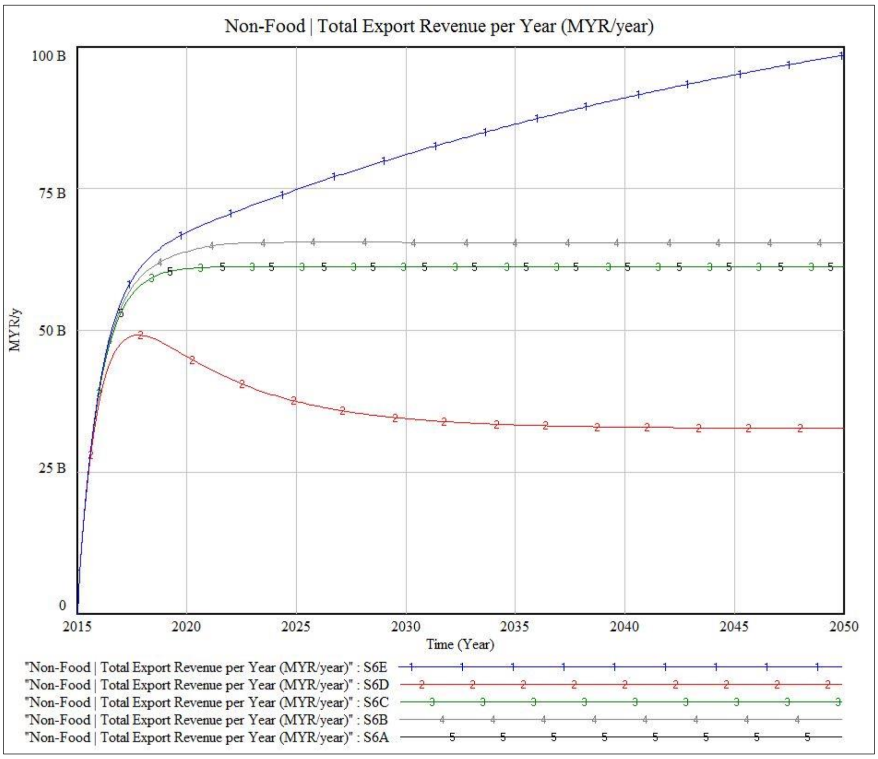

Figure 102: S6 - Non-Food | Total Export Revenue per Year

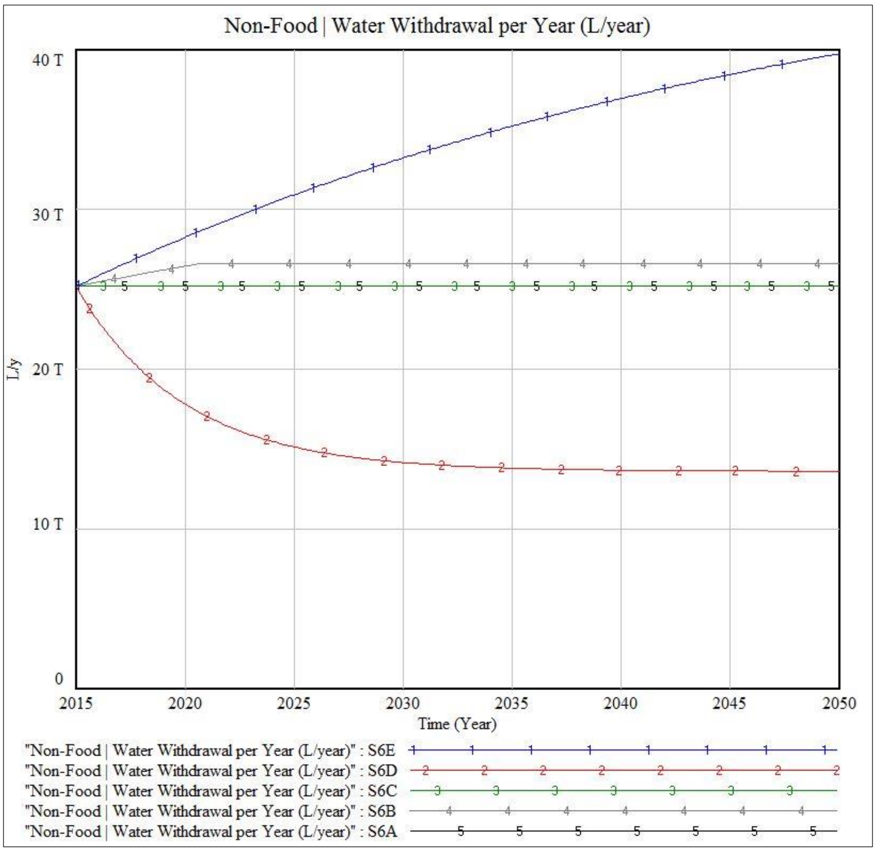

Figure 103: S6 - Non-Food | Water Withdrawal per Year

6.2.7 Combined Scenarios

This scenario is constructed after understanding the results from the previous six scenarios (sub-sections 7.3.1-7.3.6, 8.2.1-8.2.6). S7A considers a situation very close to our base case. For the energy sector, the desired RE penetration is kept at 5 %, focusing on gas and coal energy type without nuclear penetration. For water, effective water tariffs are set at RM 0.0007/L and RM 0.0017/L for domestic and industrial sector respectively whilst no efforts of water use reduction attempted. For food, desired SSL for rice is maintained at 65 % level, no expansion of marginal crops and no expansion of non-food crops. On top of that, food consumption per capita are maintained at base case level. S7B is designed around the most optimistic scenarios based upon the results of previous six scenarios. For energy, a moderate amount of renewable penetration is set at 20 % where water use can be reduced without increasing LCOE too much. Whilst nuclear penetration is introduced at 20 %, hydro and solar share of RE penetration is divided equally. For water sector, water tariff is doubled and water consumption per capita per year is reduced by 20,000 L/(ppl*year). For food sector, desired SSL for rice, wheat, and sugar are increased to 80 %, 20 %, and 20 % respectively. Available marginal land is set at 3,000,000 ha for marginal crop expansion. As a result of marginal crop expansion, staple food requirements per capita have been reduced by 10 %. Whilst desired non-food crop is maintained, desired non-food crop allocation portion has been reduced by half, as understood by key stakeholders (W2, F1) that too much non-food crop land is indeed bad for the environment especially water. Table 33 provides the list of scenario values and Table 34 provides the list of key indicators.

Table 33: Scenario S7

Scenario: Combined Scenarios (S7)	A	B	
Variable	**Values**		**Units**
Desired RE Penetration	0.05	0.2	dmnl
Nuclear | Non-RE Share	0	0.2	dmnl
Gas | Non-RE Share	0.5	0.4	dmnl
Coal | Non-RE Share	0.5	0.4	dmnl
Oil | Non-RE Share	0	0	dmnl
Diesel | Non-RE Share	0	0	dmnl
Hydro | RE Share	0.75	0.5	dmnl
Solar | RE Share	0.25	0.5	dmnl
Bio+others | RE Share	0	0	dmnl
Wind | RE Share	0	0	dmnl
Marine | RE Share	0	0	dmnl
Domestic | Effective Water Supply Tariff	7.00×10^{-4}	1.40×10^{-3}	MYR/L
Industrial | Effective Water Supply Tariff	1.70×10^{-3}	3.40×10^{-3}	MYR/L
Water Consumption per Capita per Year	1.20×10^{5}	1.00×10^{5}	L/(ppl*year)

Rice | Desired SSL	0.65	0.8	dmnl
Wheat | Desired SSL	0	0.2	dmnl
Sugar | Desired SSL	0	0.2	dmnl
Livestock| Desired SSL	0	0	dmnl
Livestock Feed| Desired SSL	0	0	dmnl
Available Marginal Land (million)	0	3	ha
Marginal Land Preparation Time	-	35	year
Rice Consumption per Capita per Year	80	72	kg/(ppl*year)
Wheat Consumption per Capita per Year	60	54	kg/(ppl*year)
Sugar Consumption per Capita per Year	30	27	kg/(ppl*year)
Livestock Consumption per Capita per Year	60	54	kg/(ppl*year)
Desired PO Produce per Year (billion)	18.8	18.8	kg/year
Desired Rubber Produce per Year (billion)	0.72	0.72	kg/year
Available Land for Non-Food Crops (million)	6.6	6.6	ha
Desired Non-Food Land Allocation Portion	0.2	0.1	dmnl
Fractional Change in GNI	0.05	0.05	1/year
USD/MYR Exchange Rate	4	4	dmnl

Table 34: Key Indicators for S7

Key Indicators	**Units**
WEF Total | CO2e Emissions per Year	kT/year
Energy Fraction of CO2e Emissions	dmnl
Water Fraction of CO2e Emissions	dmnl
Food Fraction of CO2e Emissions	dmnl
Total Power Produced Yearly	kWh/year
Total Agriculture Electricity Usage as a Fraction of Total Electricity Produced	dmnl
Total Water Electricity Usage as a Fraction of Total Electricity Produced	dmnl
Water Withdrawn per Electricity Produced	dmnl
Fraction of Electricity Water Withdrawal from Internal Renewable Water	dmnl
Fraction of Electricity Water Consumption from Internal Renewable Water	dmnl
Fraction of Supplied Water from Internal Renewable Water	dmnl
Total Land Use for Agriculture	ha
Total Land Use for Food	ha
Total Land Use for Non-Food	ha
Fraction of Land Use	dmnl
Overall Food Land Efficiency	kg/(ha*year)
Overall Non-Food Land Efficiency	kg/(ha*year)
Food Yield from Total Agricultural Land Use	kg/(ha*year)
Agriculture Product Land Yield	kg/(ha*year)
Average Electricity Used per Unit Land per Year	kWh/(ha*year)
Average Water Used per Unit Land per Year	L/(ha*year)
Average Other Energy Used per Unit Land per Year	ktoe/(ha*year)

Results and Discussion:

Figure 104 shows the total CO_2e emissions from all WEF sectors. It can be seen that under current circumstances (S7A), i.e. current WEF situation of Malaysia, total CO_2e emissions from WEF sectors will be increasing from 110,000 kT/year in 2015 to 181,000 kT/year in 2050. On the contrary, improving decision-making and implementing the correct policies would reduce the number to 158,000 kT/year in 2050, as observed in sub-scenario S7B. Figure 105, Figure 106, and Figure 107 show the fractional contribution of CO_2e from each respective sectors. It can be learned that CO_2e emissions for water supply, services and wastewater treatment (Figure 107) are not as significant energy and food sectors. For S7A from Figure 107, fractional CO_2e emissions from the water sector decreases steadily from 4.7 % in 2015 to 3.3 % around 2028 and stabilises at that value until 2045, before it starts increasing to 3.5 % towards 2050. For energy, fractional CO_2e emissions dips slight from 55.0 % at 2015 to 53.0 % at 2019 before increasing again towards 63.0 % in 2050 (Figure 105). Consequently, Figure 106 shows that emissions from food sector increases from 40.3 % to 42.6 % in 2018 before decreasing again to 33.4 % in 2050. On the other hand, scenario S7B improves the balance of CO_2e emission from WEF sectors, especially for energy and food sectors. From Figure 105, it can be seen that fractional emissions from energy sector increases steadily from 55.0 % in 2015 to 59.7 % in 2050. Before 2027, the fractional energy emissions from scenario S7A is lower than that of S7B but S7A overshoots S7B from then on and remains higher than S7B towards 2050. Similarly for fractional food emissions, S7B starts to decrease steadily from 40.1 % in 2015 to 36.7 % in 2050, with which for S7A, fractional food emissions are higher than S7B before 2029 and lower after. The increased balance in the overall acceleration and retardation of emissions in each respective sectors is beneficial as it provides extra time for reaction to environmental degradation (or improvement). In alignment with efforts and treaty agreed in Kyoto Protocol and Paris Agreement, global consensus is to slow down climate change. One of the primary ways of achieving this aim is to minimise emission and Lai's work [251] has shown that it is indeed possible for Malaysia to adopt carbon capture and storage technologies to address this issue, provided the barriers of implementation are overcome with key-enablers addressed. For the case of WEF security nexus in Malaysia, it is beneficial locally and globally that the WEF sectors would prioritise developments and policies that results in less emission.

Figure 108, Figure 109, and Figure 110 attempt to provide an understanding of the position of electricity sector within the WEF security nexus. From Figure 108, it can be seen that the total power produced for S7A is higher than S7B. This is because of the delays in constructing new power plants, both RE and nuclear, due to the policy of having higher RE penetration in S7B. Agricultural electricity use constitutes about 3.0 % of total electricity production in 2015, and decreases to about 2.5 % for S7A and 2.2 % for S7B. On the other hand, electricity use fraction for water sector starts out at 8.3 % of total power produced, as illustrated by Figure 110. However, this value is higher for S7B as compared to S7A before 2033, after which it slums lower than that of S7A and stays at 6.2 %. For S7A, this fraction stabilises at about 6.3 % up until 2044 before it increases again to 6.6 % in 2050, and is predicted to continue increasing post 2050. This is because water demand management that decreases water demand per capita delays the need for new water facilities until the point where water supply facilities can no longer facilitate the ever-growing demand, because of ever-growing population. Electricity use in water treatment, supply, and wastewater treatment are generally low for a country such as Malaysia, for example when compared to the United States of 4 % [252], could probably be because Malaysia is rich in internal renewable water resources.

As depicted by Figure 111, supply water as a fraction of total internal renewable water resources are in the order of 0.6 % and 0.5 % in 2015, that has a slow increase to 1.0 % to 0.8 % to 2050, for S7A and S7B respectively. As such, it can be deduced that whilst water resources may be abundant in Malaysia, efforts such as increasing water tariff and water demand management play important roles in retarding the depletion of internal renewable water resources.

Figure 112, Figure 113, and Figure 114 illustrate the electricity generation sector as a user of water resources in the form of water used per unit electricity generation as well as water withdrawn and consumed for generation as a fraction of total internal renewable resources. For water withdrawn per electricity produced, S7B improves the efficiency to 125 L/kWh in 2050 from 127 L/kWh in 2015, as opposed to S7A, which observes a deterioration to 138 L/kWh. Despite the improvement in water withdrawal per unit electricity generation, water withdrawal (2.3-3.9 % for S7A and 2.3-3.2 % for S7B) and water consumption (0.3-4.0 % for S7A and 0.3-3.3 % for S7B) as a fraction of total internal renewable resources continues to increase from 2015 to 2050. This is because new power plants are continually being built due to ever-growing demand.

Figure 115, Figure 116, and Figure 117 show the dynamics of land use for food sector. Under current conditions (S7A), total agricultural land will increase from 6.6 Mha in 2015 to 6.9 Mha in 2050 where majority of the land would be non-food land (maintained at 6.1 Mha) as opposed to the slight growth of food land from 516000 ha to 780000 ha. From this, it can be seen that only about 7-11 % of land used are for foods. Figure 118, shows agricultural fraction of food and non-food land use. It can be seen that for S7A in 2015 that food and non-food land is about 7.7 % and 92.3 % in respectively. Towards 2050, these fractions change only slightly to 11.2 % and 88.8 % for food and non-food. A much larger change is seen S7B where the fraction of non-food land decreases from 92.3 % to 52.7 % whilst the fraction of food land increases from 7.7 % to 47.3 %. Consequently, the agricultural product land yields can be understood from Figure 119. For agricultural product land yield and food yield from total agricultural land, the results show that S7B is better than S7A. On the contrary, S7A shows better results for overall food land efficiency than S7B. This is caused by the fact that bombara groundnut, the crop selected for MC1, may have a relatively land yield as compared to other food crops.

On top of that, the resource use (electricity, other energy, and water) per unit land is higher for S7A as can be seen from Figure 120, Figure 121, and Figure 122. In contrast for S7B, if the amount of non-food land is limited, grow more food to increase SSL of staple food, as well as adopting marginal crop, the benefits can be viewed from several angle. Firstly, total agricultural land will decrease as a result of reducing land for non-food crops, as depicted by Figure 115 and Figure 117. At the same time, total land use to grow staple food, such as rice, wheat, and sugarcane as well as to grow marginal crops such as bombara groundnut and moringa oleifa, increases from 516000 ha in 2015 to 2.9 Mha in 2050. However, taking such a step comes with pros and cons. The advantages are the reduction in resources use per unit land use on top of having better food independence (higher SSL) whilst the disadvantage is that the revenue obtained from exporting non-food products would be less, at RM 32 billion a year (S7B) as compared to the potential of RM 61 billion per year (S7A). However, the loss of potential earnings from non-food crop is partly counter-balanced by the lower import bills in S7B (RM 38 billion in 2015 to RM 60 billion in 2050) as compared to S7A.

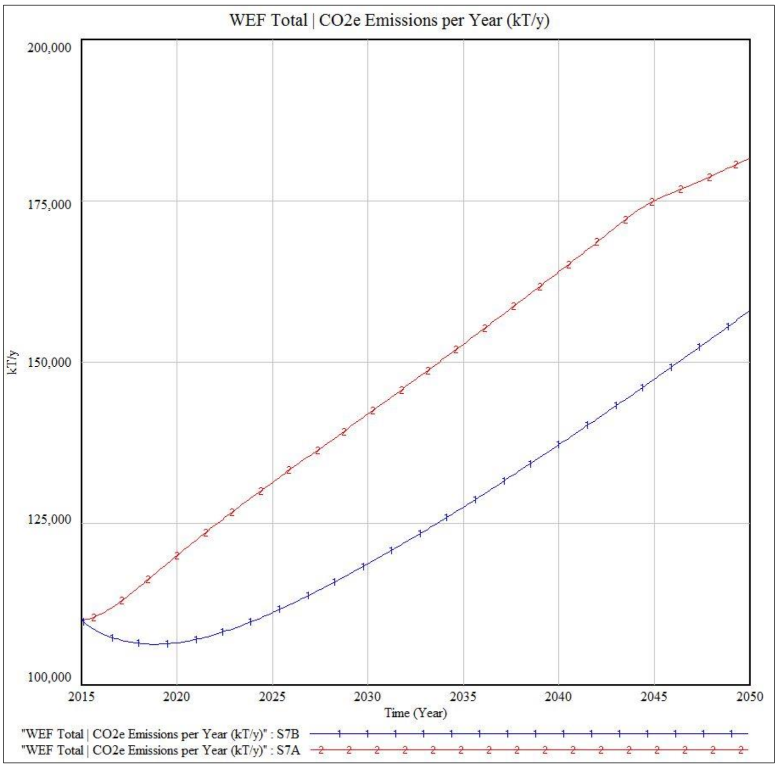

Figure 104: S7 - WEF Total | CO2e Emissions per Year

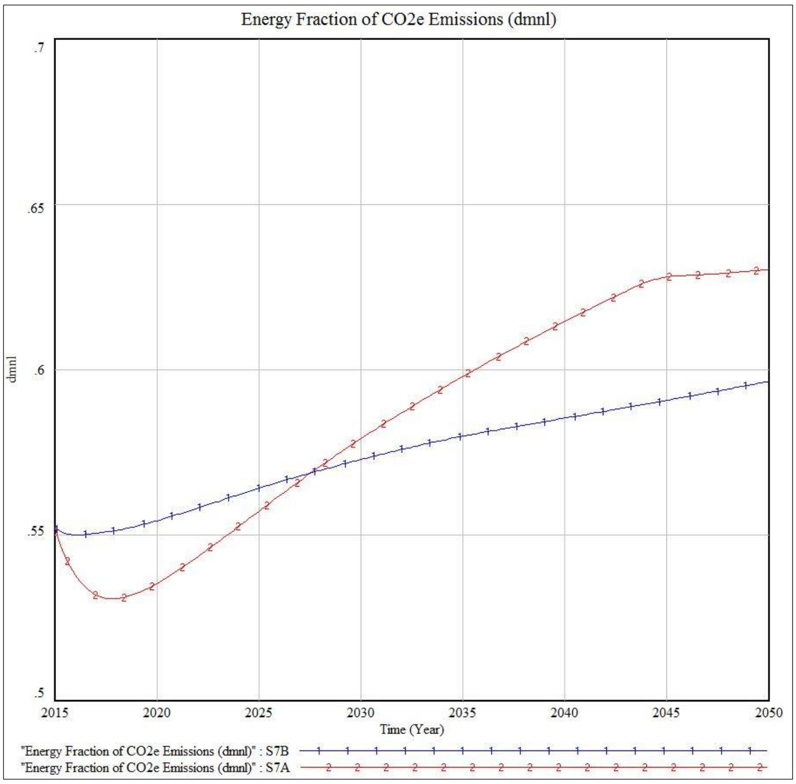

Figure 105: S7 - Energy Fraction of CO2e Emissions

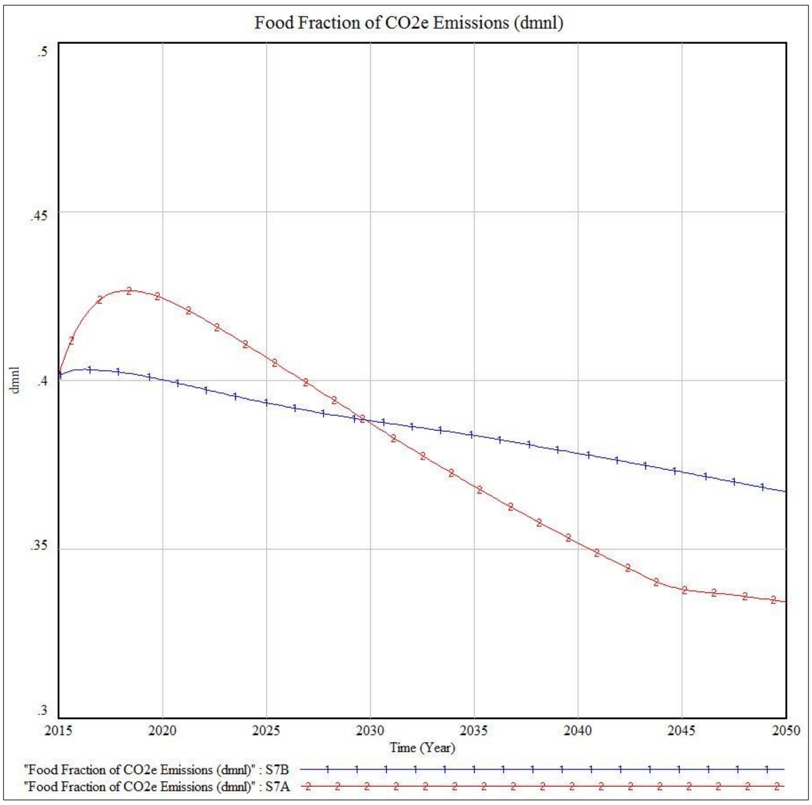

Figure 106: S7 - Food Fraction of CO2e Emissions

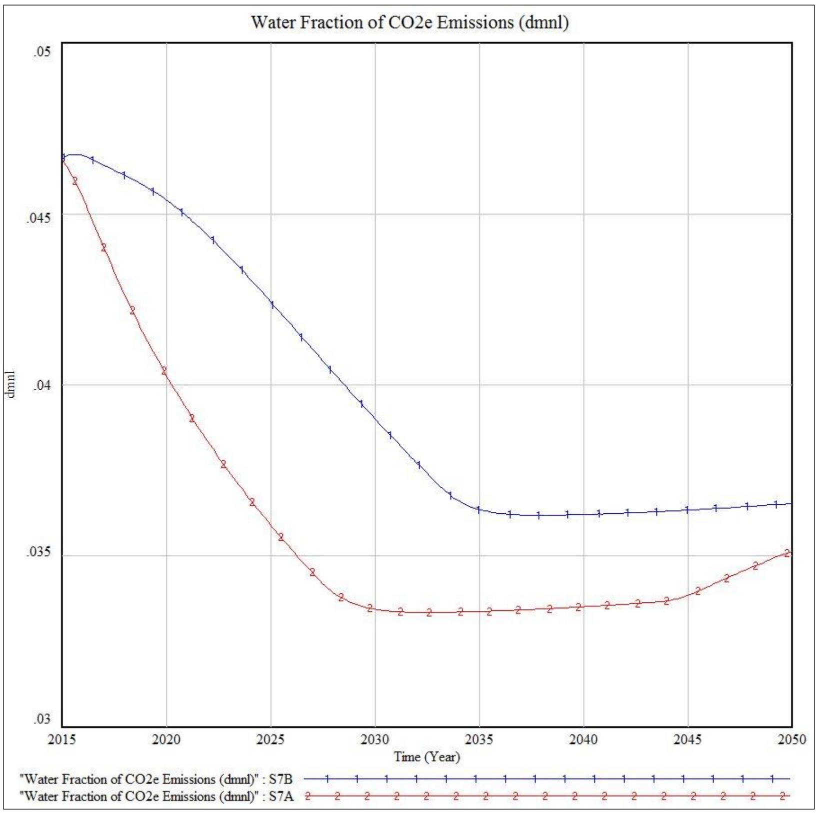

Figure 107: S7 - Water Fraction of CO2e Emissions

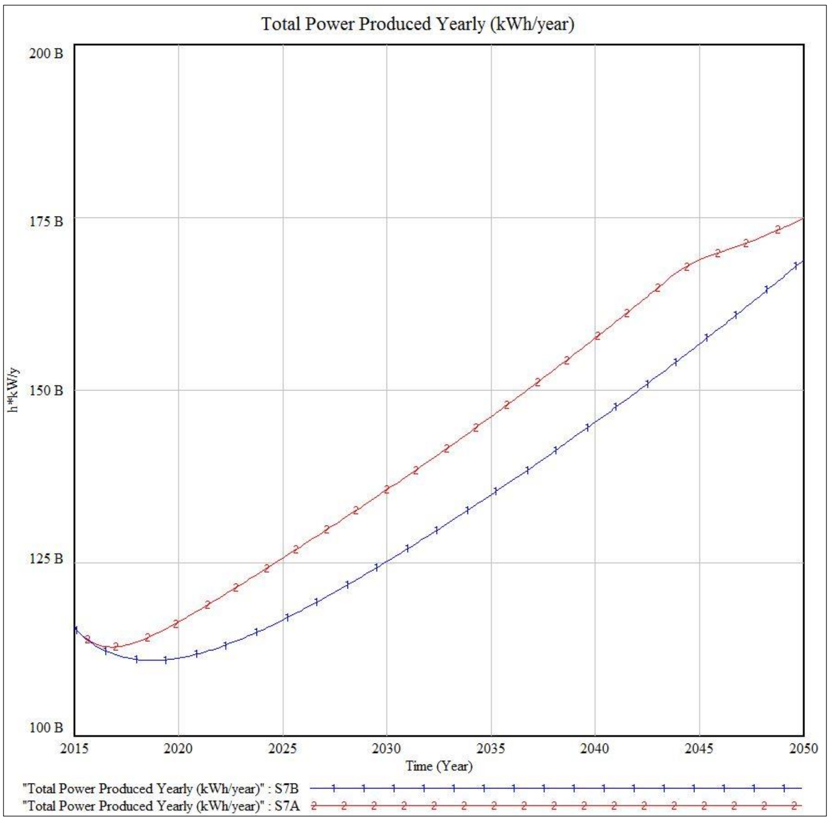

Figure 108: S7 - Total Power Produced Yearly

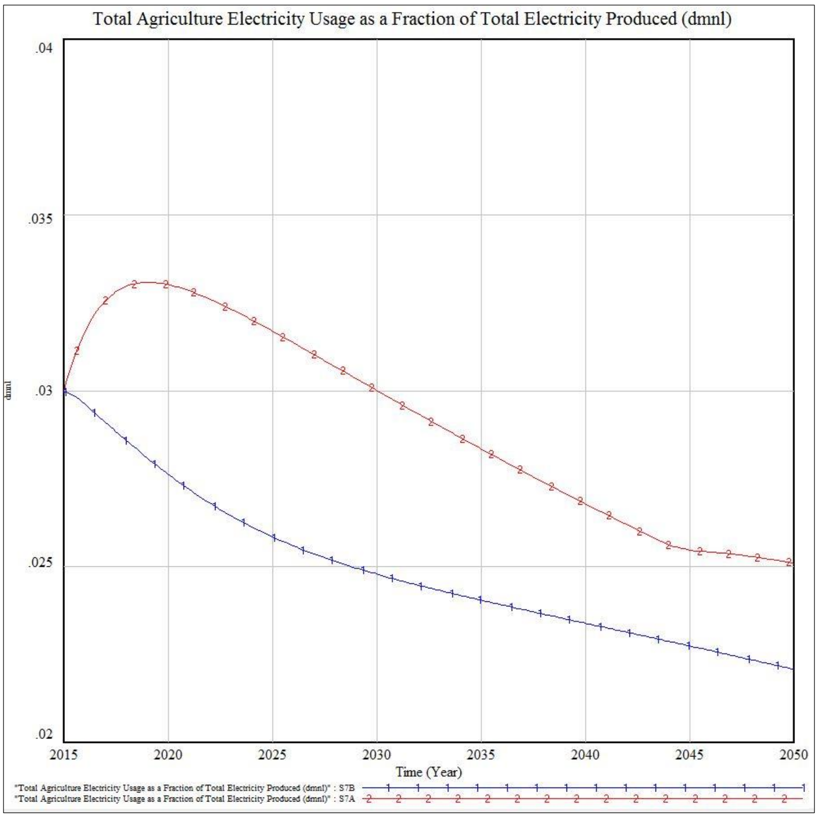

Figure 109: S7 - Total Agriculture Electricity Usage as a Fraction of Total Electricity Produced

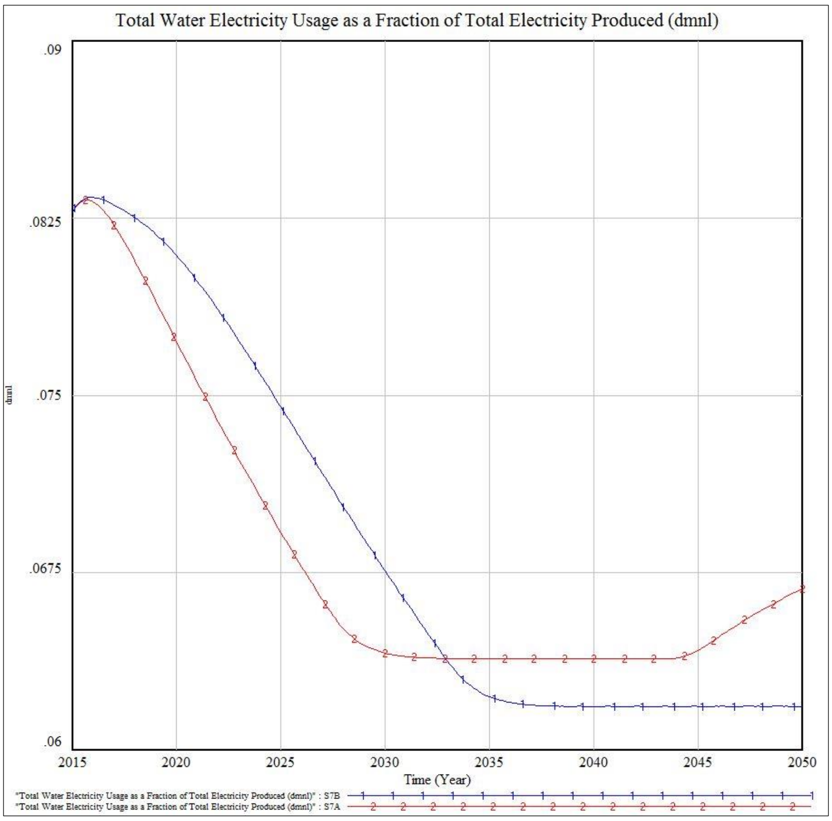

Figure 110: S7 - Total Water Electricity Usage as a Fraction of Total Electricity Produced

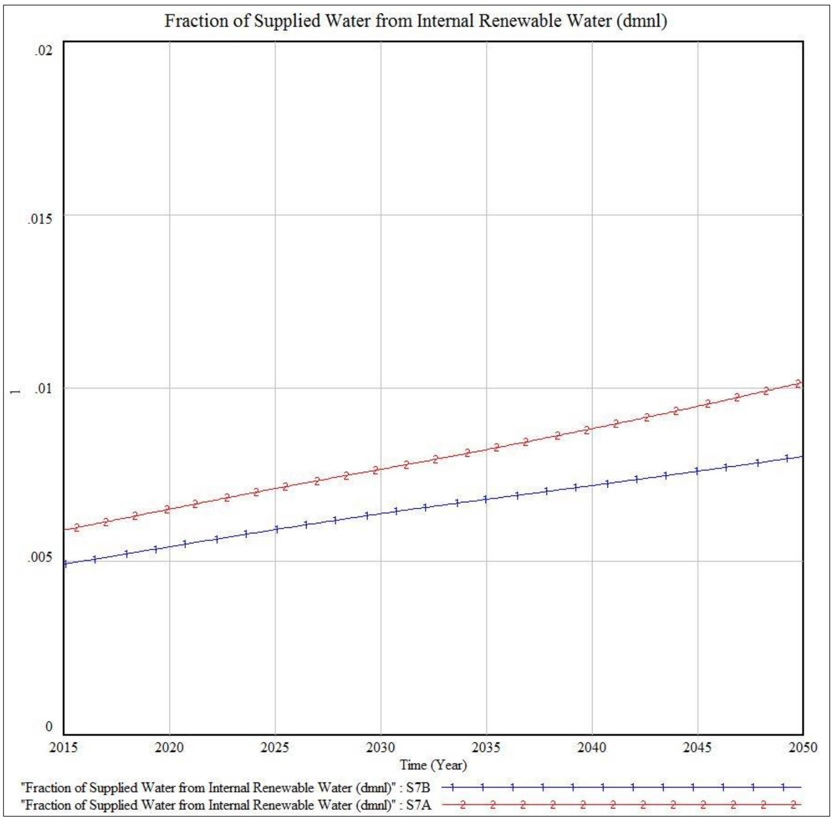

Figure 111: S7 - Fraction of Supplied Water from Internal Renewable Water

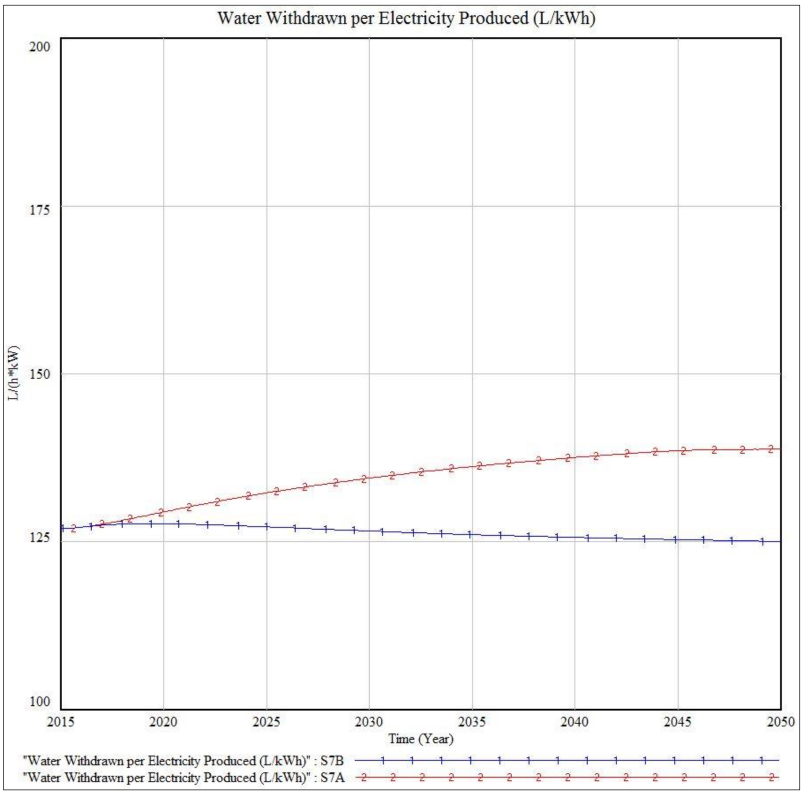

Figure 112: S7 - Water Withdrawn per Electricity Produced

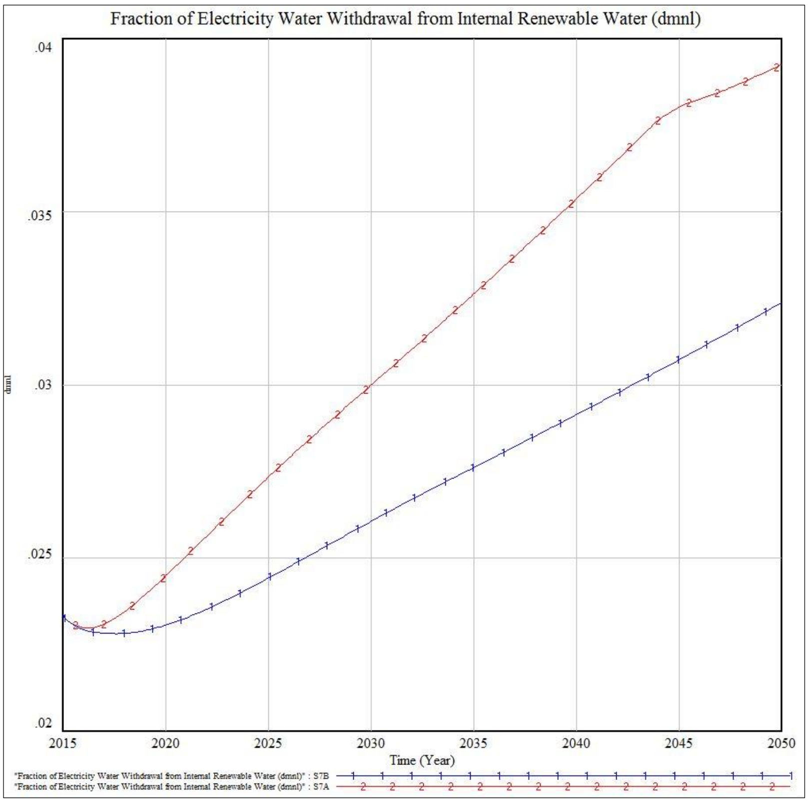

Figure 113: S7 - Fraction of Electricity Water Withdrawal from Internal Renewable Water

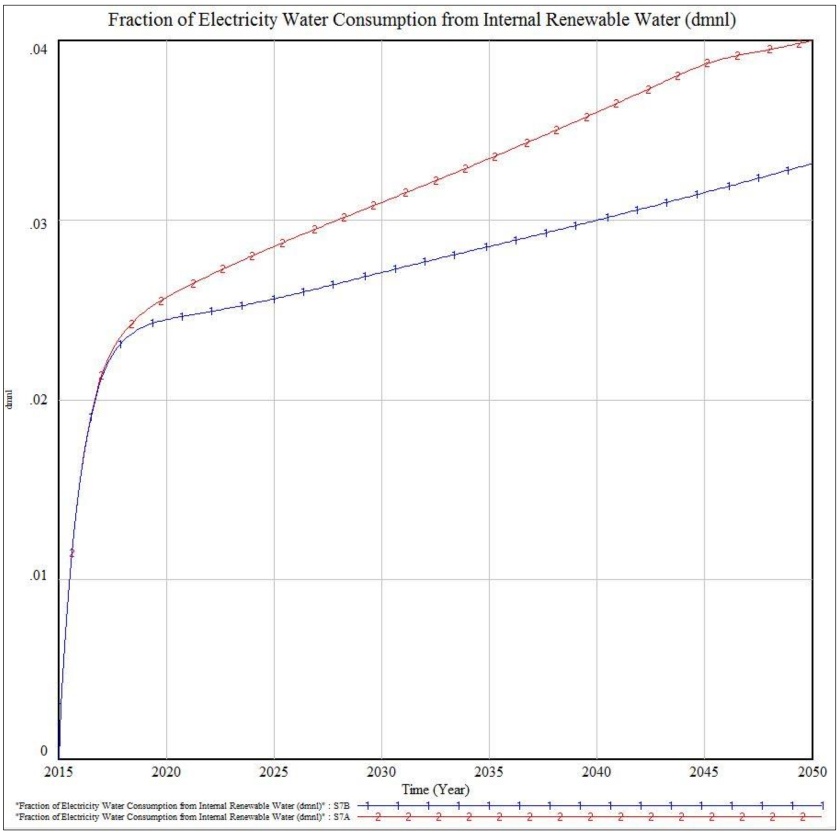

Figure 114: S7 - Fraction of Electricity Water Consumption from Internal Renewable Water

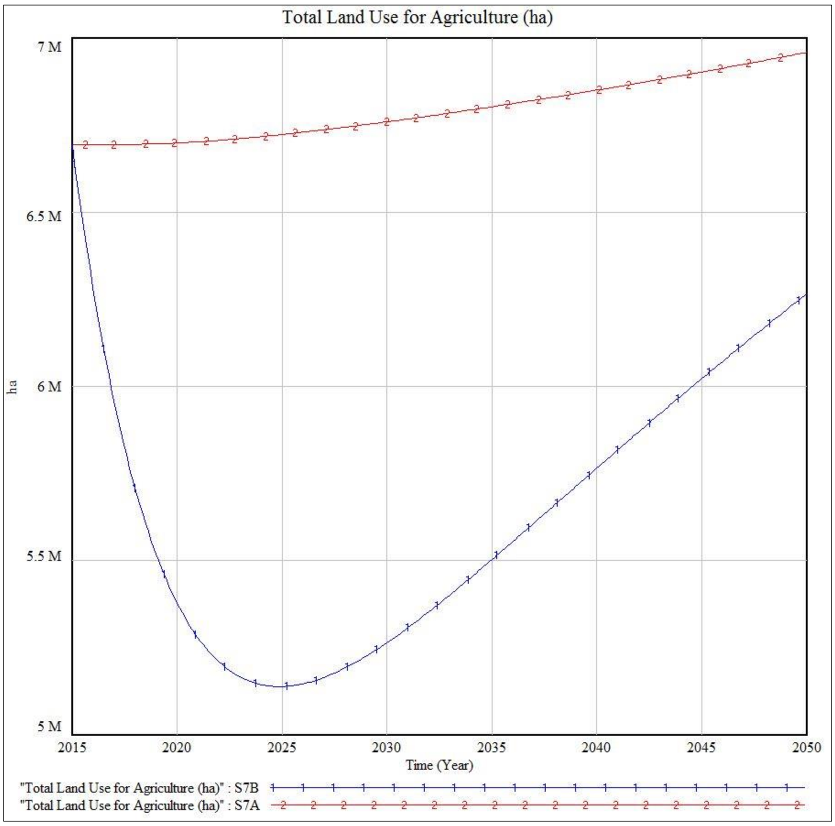

Figure 115: S7 - Total Land Use for Agriculture

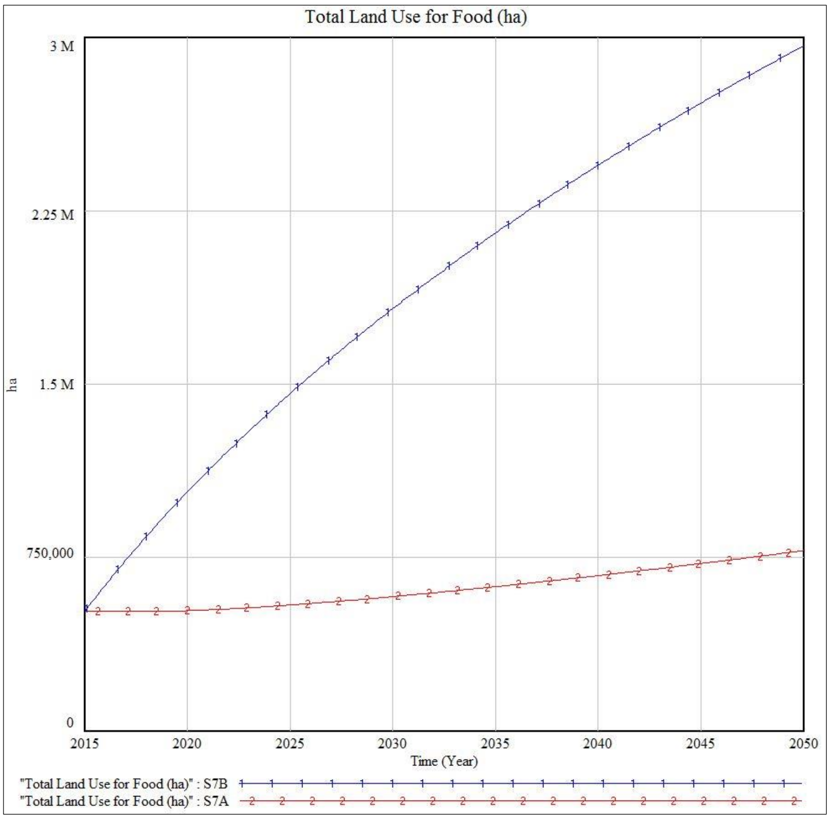

Figure 116: S7 - Total Land Use for Food

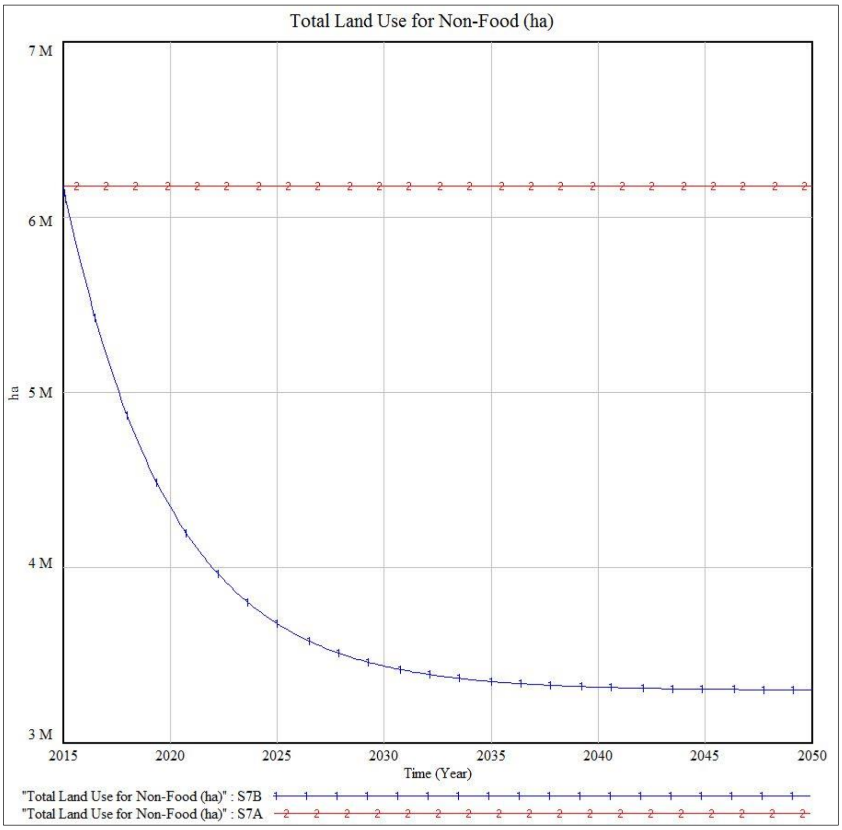

Figure 117: S7 - Total Land Use for Non-Food

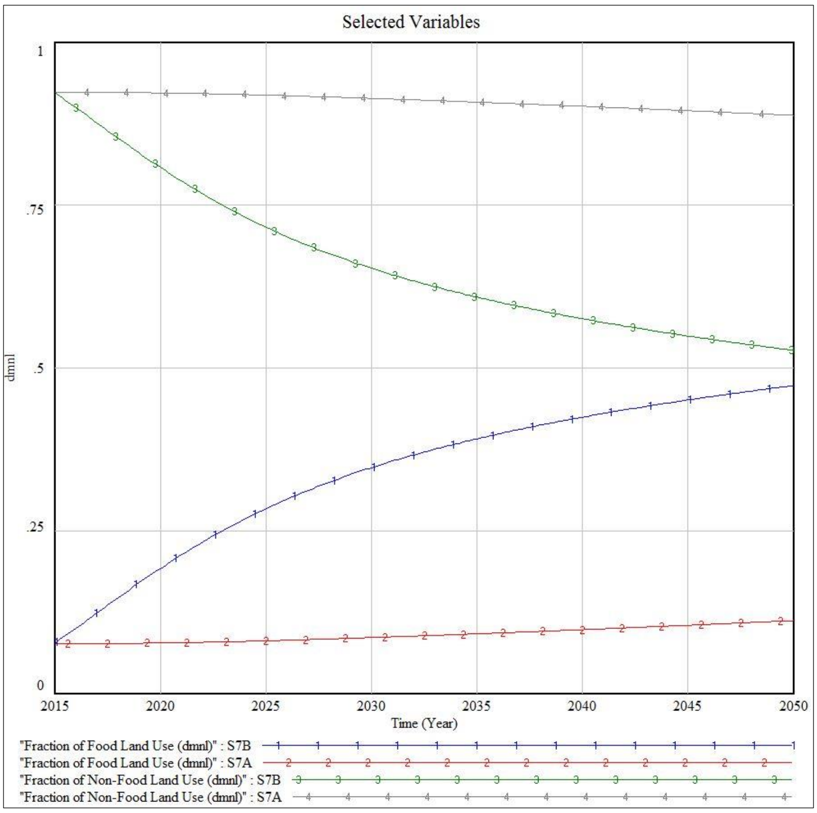

Figure 118: S7 - Fraction of Food and Non-Food Land Use

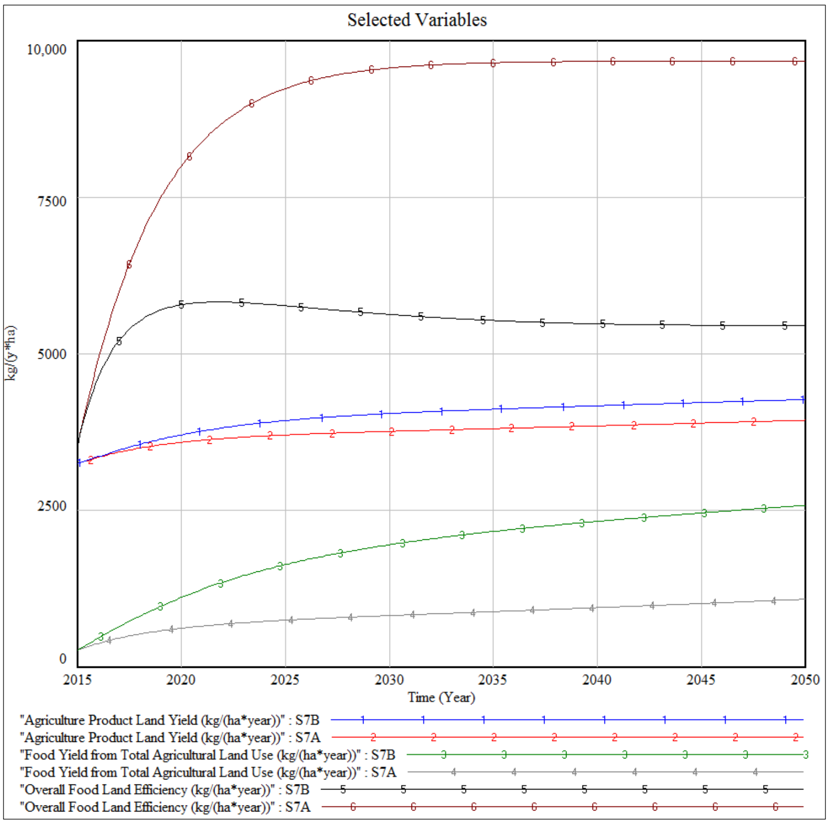

Figure 119: S7 - Yield and Land Efficiency

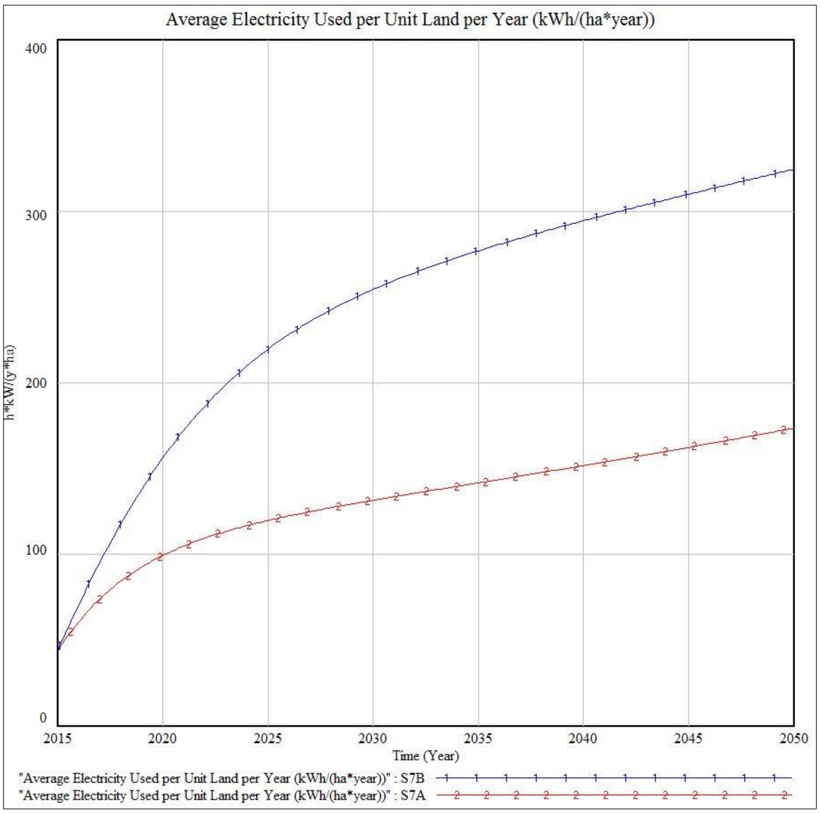

Figure 120: S7 - Average Electricity Used per Unit Land per Year

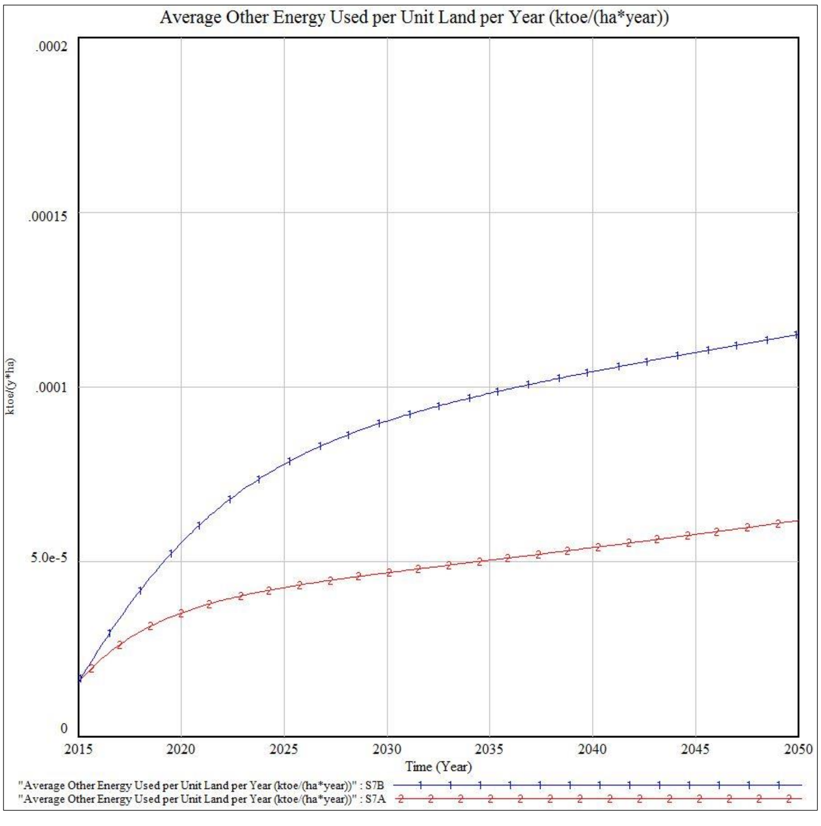

Figure 121: S7 - Average Other Energy Used per Unit Land per Year

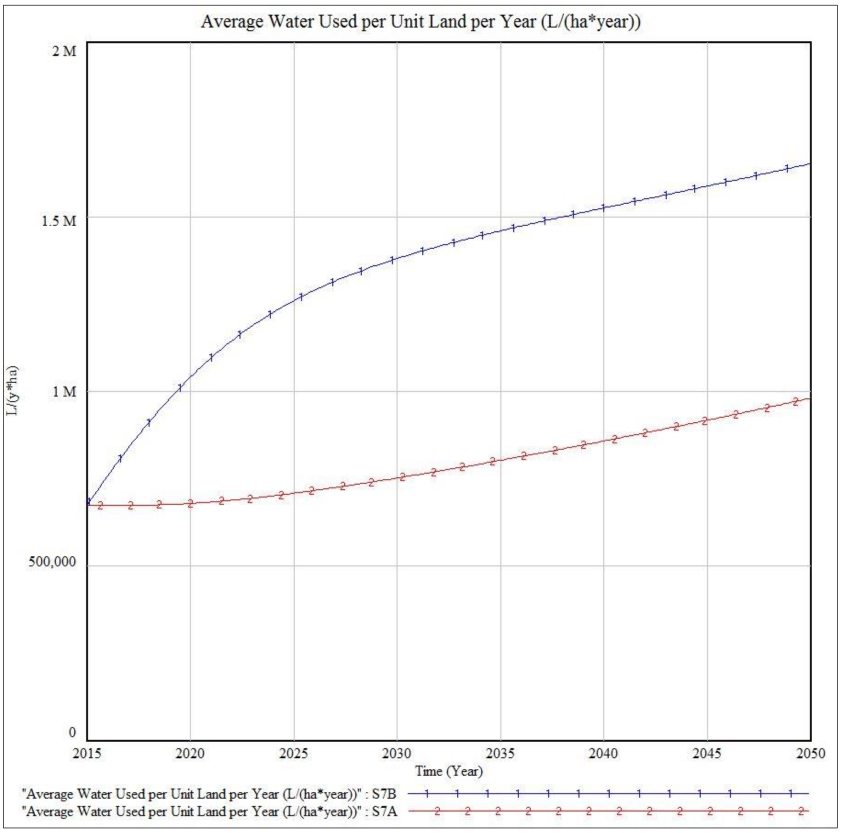

Figure 122: S7 - Average Water Used per Unit Land per Year

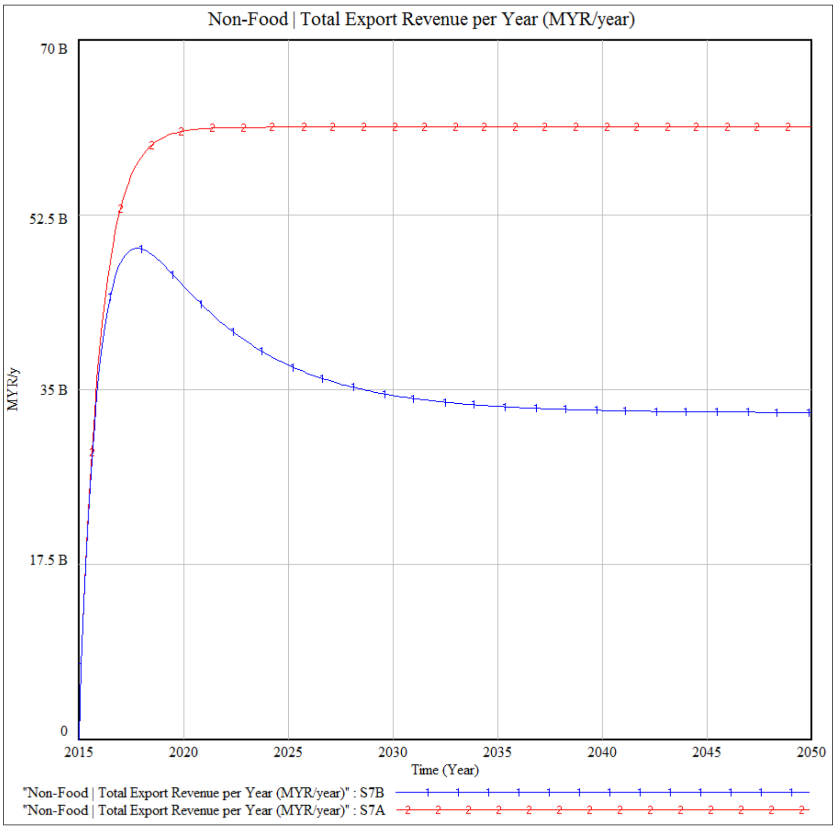

Figure 123: S7 - Non-Food | Total Export Revenue per Year

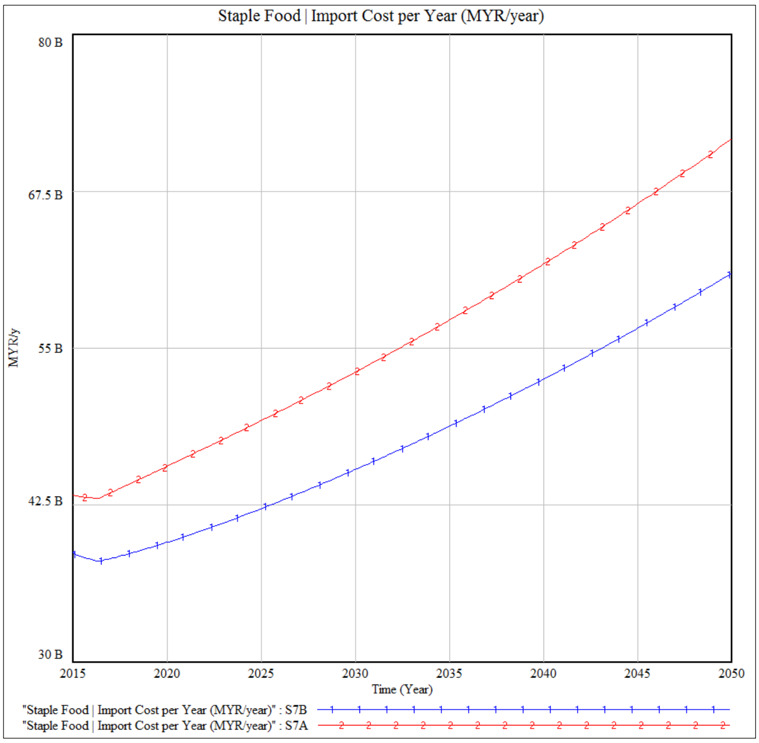

Figure 124: S7 - Staple Food | Import Cost per Year

6.3 Summary

The scenarios were constructed largely around the current problems of Malaysia within the WEF security nexus, such as low RE penetration, nuclear penetration, water demand management, SSL of staple foods, and activities of non-food crop. These problems were obtained and derived from the extensive literature review, qualitative interviews from industrial stakeholders, as well as iterative improvements from the CLD formation. As such, these scenarios are representative of the reality and issues that Malaysia is currently facing. These issues are interwoven on an intricate level and is thus necessary to look at their dynamical relationships, as would be provided in the following chapter. It is very important to investigate the WEF security nexus of Malaysia holistically, i.e. their dynamic interactions, because, as demonstrated and proven in chapter 4, activities in one sector do indeed affect other sectors.

Key findings from the simulation, scattered across seven well-defined scenarios, show that the WEF sectors in Malaysia are indeed interrelated and exhibit interesting dynamical relationships. They include renewables being necessary for the long term energy plan of Malaysia, nuclear power is necessary to keep electricity tariff low, water tariff of supply and services are severely low, increasing self-sufficiency level (SSL) of Malaysia's staple food is important, under-utilised crops are efficient in meeting nutrient requirements, and cash crops stresses water sector more than the energy sector. With that, the dynamics and interactions between key indicators of the WEF security nexus of Malaysia were demonstrated and understood, as well as their changes and differences over time under varying scenarios.

Chapter 7 Conclusion and Further Works

7.1 Introduction

The aim of this work has been to establish a measurement system for the WEF security nexus for a developing nation, namely Malaysia. Water, energy, and food are amongst the most basic necessity of human to achieve proper livelihood. WEF security nexus, being a relatively new concept, describes that these three resources are interlinked on a fundamental level and that actions in any one sector do in fact affect other sectors. By considering the complexities manifested from the combination of a unique geo-economic setting such a Malaysia, the intricacies of WEF sectors, and the STEEP factors (social, technological, economic, environment, and policies), this research employed a systems methodology, namely SD, in an attempt to quantitatively measure the wellbeing, sectoral balance, and sustainable development of the WEF security nexus for Malaysia. Through SD process, steps such as interview with key industrial stakeholders of WEF security nexus, construction of CLD, transformation to SFD, and simulation of well-designed scenarios, the dynamics of interactions within the WEF security nexus could be analysed and understood. Key findings showed that the WEF sectors are indeed interrelated, with which recommendations could be put forward to improve WEF security nexus for Malaysia, as would be discussed in this chapter. This chapter concludes the research by providing a closure in several subsections namely the research conclusions and fulfilment of research objectives, recommendations and implications to policy and practice, contributions of research, limitations of research, and suggestion for further works.

7.2 Research Conclusions and Fulfilment of Research Objectives

The research started out with an understanding of the background, description of the problem, which finally evolved into research objectives. The research objectives have been devised based upon the understanding of the problem description and they provide an overarching guideline for this research. As such, revisiting the research objectives by summarising all efforts, understanding, and findings acquired would provide a conclusive closure to this research.

RO1: To investigate the intrinsic relationship between water, energy and food in a developing nation such as Malaysia and establish the definition for an optimum WEF security nexus.

The research began with background reading of water, energy, and food security, which provided the fundamentals to the understanding of the importance and urgency of each resource respectively. Facts and figures showed that it is paramount to address issues pertaining to the resources' securities, such as low availability and accessibility in large parts of the world as well as poor livelihood conditions as a result of the resources' absence, and to consider their interlinkages and trade-offs on an intrinsic level. Comprehensive and detailed literature review were conducted on past WEF security nexus works, which includes proposed frameworks, WEF in other regions, and techniques to measure WEF. The proposed frameworks had different central focus, which were dependent on the context of study that was usually governed by varying regions, scale, and themes of study. Consequently, the past frameworks were summarised in Figure 1, where relationships between the three sectors are defined by bi-sectoral trade-offs surrounding a central focus - the context of study.

The next phase of literature review looked into international definitions for water, energy, and food security respectively. As there were various different definitions established, a comparative analysis was conducted for each resource definition in order to adopt the best working definition for this research. Although the definitions varies according to resource type (water, energy, and food) and source, they largely encapsulates the important 4A concept, i.e. availability, affordability, accessibility, and acceptability. The differences between the resources types in terms of definitions are manifested in several ways namely energy security emphasises on the long terms and short terms uninterrupted availability of energy, water security prioritises adequacy and protection against water-related negativities, and food security concerns itself with safety, nutrition, and preference. The most comprehensive and widely used definitions have been adopted as the working definition for Malaysia's very own resource securities.

Subsequently, it is paramount to understand how international development agendas fit with Malaysia's own national development plans. Thus, reviews of MDG, SDG, developed vs developing country, Malaysia's national plans, and Malaysia's WEF sectors have been conducted. It was found that goals of MDG and SDF are aligned with the interests of WEF security nexus, such as to eradicate poverty and hunger, ensure environmental sustainability, ensuring sustainable management of water and sanitation for all, and ensuring affordable and reliable energy for all. For Malaysia, it is discovered that whilst national development plans do coincide with those of international agenda, its WEF sectors are unique in their respective issues and goals. Key attributes of WEF sectors in Malaysia are namely economic sustainability for water sector, energy sector that is highly regulated and has low RE penetration, and a fragile food security due to low SSL. As a result of understanding the development agendas (international and Malaysia), the definitions and requirements of WEF security nexus, and the status of Malaysian WEF sectors, a conceptual framework for the WEF security nexus of Malaysia was established (Figure 12). All acquired understanding allowed for the initial formation of CLD to represent the interrelationships of Malaysia's WEF security nexus.

RO2: To construct a causal loop diagram (CLD) for the WEF security nexus in Malaysia.

Upon construction of the initial CLD for Malaysia's WEF security nexus, the research ensues with the interview process with key stakeholders from the WEF sectors. The interview process began by a process of screening and identification, where suitable candidates were then selected and contacted via email. Next, a series of initial questions were designed for the purposes of obtaining detailed information of each sector, understanding their interrelationships, and identifying key indicators for WEF. The questions were designed with the intention to probe for important areas of interest to the WEF whilst allowing maximum opportunity for personal inputs. Following the initial questions, a true/false questionnaire, as shown in Appendix V, was provided for the interviewees to validate the constructed CLDs. The combination of information obtained from the initial interview and the true/false questionnaire prompted the revision, improvement, and finally the completion of the CLDs constructed. This was discussed in Chapter 4.

The WEF security nexus CLD constructed can be divided into eight sections, namely electricity type, water supply and treatment, water demand management, food demand, population, power plant and emission, water-energy relationship, and water and energy for food. Whilst the variables are interconnected within each of their specific loops, each loops are also interconnected to each other to form the larger WEF security nexus loop. The finalised CLD encompasses all the necessary areas of interest for Malaysia's WEF security nexus and establishes a basis for the construction of SFD.

RO3: To construct stock and flow diagram (SFD) for the WEF security nexus in Malaysia.

As soon as construction of CLD is completed, construction of SFD commenced. As opposed to CLD, SFD were divided into more parts as it was necessary to be specific when constructing SFD. The SFDs constructed can largely be characterised into several familiar groups, namely water, energy, food, and non-resource based. The non-resource based SFDs are such as population demands and economic indicators. The primary drivers of demand were the population and their growth over time. Multiplying population by per capita requirement of each resource type gives the total requirement at any specific time. Subsequently, the total requirement of each resource type would be used to calculate the initiation rates of relevant stocks of each sector. For energy sector, the main SFD sections involved were the energy capacities, which influences the eventual calculation of LCOE, energy emissions, water usage, and forecast of future energy requirements. To address the issue of RE penetration, ten types of energy have been considered, namely gas, coal, oil, diesel, nuclear, hydro, solar, bio, marine, and wind. Additionally, desired RE penetration as well as individual RE share variables have been included to facilitate the study of different levels of RE penetration. For water sector, the main backbone was given by the urban water cycle SFD, which starts and ends at the natural water resources. The immediate interface between society and natural water resources were the two stocks of water treatment, namely water supply treatment and water sewage treatment. These water treatment capacities allowed for the calculation of groundwater and surface water treatment rates, unit cost of water production, energy use in water, forecast of water facilities requirement, and water-related emissions. For food sector, the main SFDs are divided into two - staple food and cash crops. For staple food, main SFDs were land use of rice, wheat, sugar cane, and livestock. Palm oil and rubber were considered cash crops whilst marginal crop consisted of bombara groundnut and moringa oleifa. On top of that, desired SSL for each crop type were included to allow for analysing different food-related scenarios. Total food requirement, as calculated from growing population and per capita needs, was used to calculate amount of new cropland expansion, based upon values of desired SSL and land yield of each crop type. Consequently, total cropland determined the amount of crop production each year. When SSL of crops were not at 100 %, there exist import of staple food, which led to the calculation of import cost per year. The amount of cropland and land yield were used to calculate amount of crop production per year. As a result, amount of crop production per year can be used to calculate nutrition, energy (in calories), fats, and protein, available per year. The links from water and energy to food were given in resource use in agriculture, where energy used consist of electricity and other energy, whilst water used consists of water withdrawals. Besides that, food emissions were included, calculated from CO_2e produced per kg of crop production.

Verification of the WEF security nexus SFD occurs throughout the construction phase, and are performed using the five methods outlined in 3.11.2, namely boundary adequacy, dimensional consistency, parameter assessment, extreme conditions, and integration error. Validation of the SFD was performed, wherever possible, with historical data, to the extent where the SFD is deemed ready and fit for purpose. With verification and validation completed, the SFD is ready to be utilised for simulation of scenarios.

RO4: To critically analyse the well-being of WEF security nexus on Malaysia, based upon inputs of interview and simulated results of SFD.

Before simulation of SFD, it was necessary to design scenarios, where relevant indicators and input values are varied, to address the reality and possible situations of Malaysia's WEF security nexus running into the future. As such, seven scenarios were designed based upon the accumulated understanding and knowledge of Malaysia's WEF security nexus and development plans. They are divided into three categories, namely two scenarios for energy, one for water, and three for food. A final seventh scenario is designed based on the results of previous six, which encompasses interactions from all three sectors. Within each scenarios, there are sub-scenarios that facilitates the changing of values of input variables. Energy scenarios looked into penetration levels of RE and nuclear energy. Water scenario considered varying values of water tariff and per capita requirement for water. Food sector investigated the effects of changing SSL of staple foods, utilisation of marginal crops, and varying land for cash crops.

Simulating the scenarios yielded a plethora of interesting results, which allowed for meaningful interpretation and discussion. Key findings for energy sector showed that RE are necessary for the long-term energy plan of Malaysia while nuclear power is necessary to keep electricity tariff low. RE has been demonstrated to keep CO_2 emissions lower, as much as 20 % lower as compared to a purely non-RE energy scenario. However, it is paramount to not overexpand on RE, as otherwise it would cause LCOE to be significantly higher. Results for water sector demonstrated that the water supply and services are unhealthy in terms of finance, as revenues collected from water tariff are well below the cost to sustain the water services. Environmentally, impact of water sector remains minimal throughout all four sub-scenarios. For food sector, simulations showed that SSL is more important than the strength of MYR when it comes to food security, marginal crops like bombara groundnuts and moringa oleifa can assist in nutrient security, and cash crops are significant water users. Finally, the simulation of combined optimistic scenarios provided insights on the dynamics of the entire WEF security nexus. By applying the favourable values as learned from previous scenarios, the balance of the nexus resources were balanced in terms of fractional resource use from one sector to another. Efficiency was also seen to increase in indicators such as water withdrawn per electricity produced, yield and land efficiency, and average electricity and water used per unit land per year. As a result of this simulation and newfound understanding, it is possible to erect a set of recommendations for policy makers in order to improve the WEF security nexus, as discussed in the following section.

7.3 Recommendations and Implications to Policy and Practice

Whilst knowledge are invaluable by itself, taking action is necessary if any practical changes or improvements are to be realised. This subsection proposes recommendations that would improve the WEF security nexus of Malaysia, in terms of wellbeing, sectoral balance, and sustainable development, and discusses the implications that they would have on policymaking and practical actions. The recommendations are based upon the entirety of understanding acquired from all previous sections and chapters, namely the concepts of WEF security nexus, the recognition of Malaysia's WEF security status and problems, the proposed conceptual framework for Malaysia, the inputs from interviews with key industry stakeholders, the CLDs, and the results of SFD simulation.

Achieving a reasonable proportion of RE penetration

Whilst it is undeniable that RE penetration is in general good for the energy sector and overall energy outlook for a country, this fact remain relative and debatable for Malaysia because of the geographical and climatic conditions of Malaysia. A reasonable RE penetration of 20 % shows that not only will LCOE remain at acceptable levels, water usage, withdrawals, and consumption, as well as CO_2e emissions will be reduced. On top of that, overall water efficiency in producing a unit of electricity will also be lower than the current case for Malaysia. However, care must be taken to not overexpand on RE capacities as results show that doing so would increase the LCOE significantly, thereby burdening the people on affordability of electricity. On top of that, renewable energies are highly dependent on the weather and geographical setting. Over-penetration on RE would render the nation dependent on weather conditions, whereby under severe unfavourable weathers could potentially cause major blackouts. Prime examples of high LCOE and geographical woes are given by those experienced by South Australia in 2016, where price surge as a result of over-penetration [253], and state-wide blackout caused by severe weather conditions [254].

Education on Nuclear benefits

Nuclear power plays an important role because of its high power density, low running costs, and low CO_2e emissions. On top of that, the alternative replacement, namely renewable energy, may not be enough to cover the entire energy demand of the country, due to their relatively lower energy efficiencies. This is because the nation cannot afford to overexpand on RE when the costs are still very high, as doing so would reflect on a very high LCOE. As such, nuclear energy is a suitable candidate for the mid-term, where RE prices are still high, before which RE expansion is always in the horizon of long term plan, where future advancements allow for better affordability. However, social factors are the primary barrier to implementation of nuclear power as it suffers from poor public acceptance. This is because of the lack of understanding on current safety measures available associated with radiation, which is feared to cause public health problems. As such, it is necessary to educate the public on the current technological level of nuclear power. However, the strong links between nuclear power and nuclear weapon, as discussed in section 8.2.2, necessitate the establishments of proper control and security of the nuclear industry. This is important because having nuclear equipment and material landing in the wrong hands could potentially lead to war and terrorism activities. Therefore, ensuring the safety and security of nuclear industry management would take top priority before which deploying of nuclear power and reaping its benefits can be considered.

Centralising and streamlining water governance

Whilst the water supply and services tariff is separate from the sewage tariff, the main disconnect of the water sector in Malaysia is between the states and federal governments. As pointed out by key stakeholder (W2), policy implementation becomes difficult, as it requires approval from both federal and states governments. To make the matters worse, states and federal governments may often have misaligned their interests when it comes to managing the water sector. For example, increasing water tariff to better reflect the cost of water production is not possible because state governments did not agree to it (W2). As such, it is thus necessary to revamp the governance structure of water sector in Malaysia, in a way such that compliance and compromise can be obtained for both the state and federal level. This can be achieved by centralising the governance and authority of the water sector.

Socio-economic improvement of water economics

This policy recommendation should be implemented in close relation with the centralising and streamlining of water management, as the latter would allow for easier implementation of the former. Two important actions should be carried out under this recommendation, namely the increase of water tariff such that the water sector is financially self-sufficient and increase efforts to reduce average water consumption per capita. As illustrated from the results of water demand management scenario, water supply and services revenue are well below the water supply treatment costs. This has also caused the poor awareness of public that water is a scarce and precious resource. Given the fact that total internal renewable water resources is a constant amount, while population and per capita usage are not, it is thus necessary to put efforts on the demand side of water management, i.e. increase tariffs and reduce per capita usage.

Increasing the SSL of staple food

Rice, being the main food of Malaysians (among wheat, sugar, livestock), are not grown at 100 % SSL in Malaysia. This point itself demonstrated Malaysia's vulnerability in terms of food security, as the country is at the mercy of its rice supplying nations, primarily Thailand, to provide sufficient food for its people. Coupled with food sovereignty, where the grower of crops possess the rights to keep all of its food products exacerbates the vulnerability further. Furthermore, the ever-increasing import bills, which are estimated to have a potential growth to RM 72 billion by 2050, aggravates the stress on the food economy. As such, it is thus necessary to improve the SSL of food in Malaysia, especially rice, so that Malaysia would achieve better food independence. This can be achieved by expanding land for staple food crop growing.

Embark upon widespread adoption of local under-utilized crops

This recommendation is an extension upon the previous one in increasing the SSL of Malaysia's staple food, as it reduces the stress on growing conventional crops. Marginal crops such as bombara groundnuts and moringa oleifera are nutrient-rich foods, which can be adopted into the diet of Malaysians. In doing so, the nutrient requirement would be met easier, and thus the need to grow conventional crops would be reduced. On top of that, the average resource (electricity, other energy, and water) would be reduced per unit of nutrients produced. However, such foods are not in the everyday diet of Malaysians, and are currently grown on small scales. As such, it would be beneficial to increase its adoption by strategies such as aggressive push marketing, among many others.

Controlling land use of non-food crops

Non-food crops such as palm oil and rubber are water thirsty; this is on top of the fact that they occupy a large part of Malaysia's land. Whilst they may secure lucrative export revenue for the country, care must be taken to not over-extend on non-food crops for two reasons namely change in water dynamics due to non-food crop planting (W2) and their land can be used to grow marginal crops. As such, having a policy that puts a limit on the maximum amount of land allocated for non-food crop would ensure enough land for food crops and marginal crops, on top of reducing the disturbance on natural water cycle.

7.4 Contributions of Research

This research contributed significantly to the qualitative and quantitative understanding of WEF security nexus in Malaysia within the contexts of wellbeing, sectoral balance, and sustainable development.

Through comprehensive literature review of past and existing WEF works, it was discovered that a method to holistically, systematically, and quantitatively model and predict the behaviour of key indicators in the WEF sector is absent, more so for Malaysia. As such, this research set out to fill this knowledge gap by employing a mixed method approach of qualitative information extraction via key stakeholder interviews and quantitative systemic modelling and measurement through SD. The creation of the SD model to simulate and measure the WEF security nexus of Malaysia is thus the novel and primary outcome of this research.

From the interviews and CLDs constructed, a qualitative understanding on the status of Malaysia's WEF security nexus have been understood. State of affairs and pressing problems for each of the WEF sectors have been discovered, to name a few - RE penetration for energy, economic sustainability for water, and SSL for food. Key indicators at important inter-sectoral WEF junctures have been identified which consequently prompts the understanding of Malaysia's WEF interlinkages. On top of that, the interviews conducted also provided insights into possible actions that could improve the wellbeing of each sector, in terms of technology, economy, social, environment, and policies. As a result, these insights have been translated into carefully designed quantifiable scenarios, before which simulation could take place.

Subsequently, an SFD has been constructed to simulate and measure the identified WEF security key indicators of Malaysia. The completed SFD, which is a calculating tool constructed to predict the behaviours of key indicators under user-desired scenario values, is capable of providing numerical outputs in the forms of graphs and table. As such, this research has provided a ready-made calculator for the WEF security nexus of Malaysia. Simulating the designed scenarios yielded results, which consequently provided predictions and behaviours of WEF key indicators in Malaysia.

Finally, by understanding the simulated results, this research provided a thorough and detailed understanding into the WEF security nexus of Malaysia, within the context of wellbeing, sectoral balance, and sustainable development.

The outcome of this research forms a vital and novel contribution to knowledge, when it is a pioneering work to address the WEF security nexus for Malaysia; especially in considering their securities for the country as a system rather than unaffected individual entities. Prior to this research, there were no quantitative systemic model, which holistically considers three resource sectors and encompass the STEEP factors at the same time. This work will contribute towards spearheading the awareness and, hopefully, trigger further and more in-depth work in transdisciplinary resource and technology management. As a pioneering effort, this research has nonetheless provided the foundation and the fundamental understanding to an integrative and inclusive cross-sectoral national resource backbone - The WEF security nexus measurement system of Malaysia. For academics, the understanding of WEF security nexus, its intrinsic interrelationships and sectoral issues, as well as the method to measure them are valuable newfound knowledge. For industrial stakeholders and governmental decision makers, the research findings provides basis and evidence for further action while the SD model provides a potential tool to be adopted.

7.5 Limitations of Research

A number of limitations are present for this research:

- Accuracy of data - Due to the sheer number of variables, it is not possible to obtain all data accurately as many are based upon literature review. In addition, some data are estimated from another country or region where it may not be the same for Malaysia. As such, it is necessary to improve the accuracy of data by prioritising the source of data. This can be accomplished by maximising the portion of data that are provided by official parties, such as the Department of Statistics Malaysia, international organisations, and peer-reviewed journals. Also, sufficient steps of increasing model and simulation confidence by including substantial steps as explained in section 3.6 as well as demonstrated by section 5.15. On top of that, numerical accuracy importance is secondary to model confidence in SD, as have been explained numerous times in the past by Sterman [164], Barlas,[181], and Forrester and Senge [183].

- Technical depth - As this research is broad by nature, the depth of technical details must be carefully compromised within acceptable limits. However, necessary depth has been provided wherever necessary. For example, an average LCOE is calculated from established energy LCOEs, instead of calculating LCOE for each energy type before determining the average LCOE. This difficulty stems from the fact that accurate data such as CAPEX and OPEX of power plants are difficult to obtain, and they differ for different power plants. To overcome this limitation, an average LCOE is calculated by considering individual published LCOEs from established energy organisations, such as the World Energy Council. The confidence of this estimated LCOE is increased when simulation yield values within acceptable range of actual published values of LCOE. This method is deem acceptable as the objective of the model is achieved, that is to calculate and capture the dynamics of LCOE changes under different energy mix scenarios. Also, this is consistent with the explanations of Sterman [164], Barlas,[181], and Forrester and Senge [183], where the model is deemed good enough when it is fit for purpose.

7.6 Suggestions for Further Works

Whilst this research may have completed, there exist a range of opportunities for further works where this research can be expanded upon. As WEF security nexus is a broad topic in its own respect, plenty of areas exists where understanding and knowledge into this area can be improved.

- **Expansion of model to include sectors related to population wellbeing and national development**

  The CLD and SFD developed can be further expanded into areas to provide additional understanding from neighbouring fields, particularly important are population wellbeing and national development. For example, healthcare, communication, automotive, and industry can be added to the model. From a systems thinking point of view, decisions made in any of these sectors would likely affect the WEF security nexus, as well as each other, at least on a national level. Consequently, the decision making process would be more inclusive and comprehensive.

- **Improve accuracy of data and explore use of live data**

The models developed in this research utilises data from literature review and interviews, which may be slightly inaccurate or out of date. This may result in inaccurate results or increased rate of error. Improving the accuracy of data, through works of experiments and actual measurements would definitely improve the accuracy of results. On top of that, the use of real time or live data into the model to monitor and predict the states of WEF security nexus can be explored.

- **Integration with other methods**

As this is a highly diversified topic, a single methodology may not be enough to fully analyse the full extent of its intricacies. Different parts of the model may require different tools and technique to better analyse. This would provide technical sophistication and accuracy of results obtained. This is because while SD and Vensim software may be powerful methodology and tools, there are parts where they fall short. For example, agent-based modelling can be combined with SD modelling, where specific, detailed, and complex phenomena can be recreated [255] within the larger SD model. Consequently, a more detailed picture of the WEF security nexus of Malaysia can be acquired.

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Appendix I

This section provides the large tables and figures which are discussed in the main body of this report.

Table 35: Water Index and Indicators

Name of Index or Indicator (water)	***Type***	
	Composite Index	**Indicator**
National Water Security Index	✓	
Household water security index	✓	
Productive Economy Indicators	✓	
Urban Water Security	✓	
River Basin Health Indicators	✓	
Resilience to Water-Related Disasters	✓	
access to piped water supply		✓
access to improved sanitation		✓
hygiene		✓
Agricultural water security subindex	✓	
Productivity of irrigated agriculture		✓
Independence from imported water and goods		✓
Resilience		✓
Industrial water security subindex	✓	
Productivity (financial value of industrial goods relative to industrial water withdrawal)		✓
Consumption rate (net virtual water consumed relative to water withdrawn for industry)		✓
Energy water security subindex	✓	
Utilization of total hydropower capacity		✓
Ratio of hydropower to total energy supply		✓
drainage (measured as the extent of economic damage caused by floods and storms).		✓
Watershed disturbance		✓
Cropland		✓
Imperviousness		✓
Livestock density		✓
Wetland disconnection		✓
Pollution		✓
soil salinization		✓
Nitrogen		✓
Phosphorous		✓
Mercury		✓
Pesticides		✓
total suspended solids		✓
organic loads		✓
Potential acidification		✓
thermal impacts from power plant cooling		✓
Water resource development		✓
Dam density		✓
river network fragmentation		✓
relative water consumption compared to supply		✓
residency time change downstream from dams		✓
gini coefficient		✓
domestic water use		✓
gross domestic product		✓
under-5 mortality rate		✓

exposure (e.g., population density, growth rate);	✓	
basic population vulnerability (e.g., poverty rate, land use);	✓	
hard coping capacities (e.g., telecommunications development); and	✓	
soft coping capacities (e.g., literacy rate).	✓	
change in water used / bioenergy produced		✓
change in water used for energy crops / cultivated land		✓
change in amount of water pumped / energy used		✓
change in amount of water pumped / fossil energy used		✓
change in water pumped / irrigated land		✓
change in yield / water consumed		✓
change in water used for additional livestock needed to compensate protein loss / total energy generated		✓
change in yield / water applied		✓
change in pollutants in water resources / yield		✓
change in water used / agricultural land		✓
change in amount of desalinated water appllied to the field / land where crops are grown		✓
change in amount of desalinated water appllied to the field / yield		✓
Basic household needs	✓	
Food production	✓	
Environmental flows	✓	
Annual growth rate of water use by sector		✓
water resource (surface and ground)		✓
water supply (surface and ground)		✓
water resource use rate (surface and ground)		✓
national total water use		✓
water use quantity per CNY 10000 industrial added value		✓
effective irrigation use ratio		✓
Percentage of water function zones achieving water quality standard		✓
demographic projections		✓
urban and rural populations by development group		✓
total actual renewable water resources per capita: trends and projections		✓
annual average monthly blue water scarcity in the world's major river basins		✓
water withdrawal by sector		✓
total dam capacity per capita by region		✓
hydropower: technical potential and installed capacity by region		✓
energy requirement to deliver 1 m^3 water safely for human consumption from various water sources		✓
indicative energy use of municipal water and wastewater services		✓
energy requirements and cost implications of desalination by technology		✓
water footprint of energy generation by fuel		✓
water use for electricity generation by cooling technology		✓
Internal water resources		✓
External water resources		✓
population with access to safe water		✓
population with access to sanitation		✓
irrigated land		✓

Table 36: Energy Index and Indicators

Name of Index or Indicator	***Type***	
	Composite Index	**Indicator**
Coal reserve-to-production(R/P) ratio		✓
Oil import dependence ratio		✓
Natural gas reserve-to-consumption ratio		✓
Availability factor of conventional thermal electricity		✓

Availability factor of non-thermal electricity		✓
Energy intensity-total primary energy consumption per dollar of GDP		✓
Gross generation efficiency of fossil fuel-fired power plants		✓
Crude oil distillation capacity		✓
Patents owned by LME (state-owned)		✓
Energy industry technical updating and transformation investment/investment in fixed assets of state-owned units in energy industry		✓
Share of China's CO2 emissions out of global CO2 emissions		✓
China's SO2 emissions		✓
China's volume of soot emissions		✓
Share of renewable energy out of total electricity generation		✓
Share of nuclear energy out of total electricity generation		✓
Growth rate of ex-factory price index for coal		✓
Growth rate of ex-factory price index for petroleum		✓
Growth rate of ex-factory price index for electricity		✓
Volatility of coal prices		✓
primary energy supply per capita		✓
electrification level; access to modern cooking fuels level		✓
net import-to-consumption ratios		✓
proved reserves-to-production ratios		✓
risk-weighted domestic and world production diversity indices		✓
fuel mix diversity indices		✓
refinery output-to-capacity ratio		✓
total stocks-to-annual consumption ratio		✓
electricity retail price-to-gdp ratio		✓
liquid fuel retail price-to-gdp ratio		✓
energy subsidies-to-government budget ratio		✓
energy import cost-to-total export revenue ratio		✓
residential sector energy consumption per household or per capita		✓
transport sector energy consumption per capita-kilometre		✓
sectoral energy intensity		✓
energy sector CO2 emissions per unit energy		✓
energy sector CO2 emissions per capita		✓
Imported resource dependence		✓
Diversification of resources		✓
System stress		✓
Net electricity generation efficiency		✓
Global Warming Potential		✓
Terrestrial Acidification Potential		✓
Particulate Matter Formation		✓
Radioactive waste generation		✓
Shannon's Diversity Index	✓	
net energy import dependency		✓
energy intensity of GDP		✓
CO2 per unit of electricity produced		✓
global energy trade (absolute)		✓
global energy trade (intensity)		✓
geographic diversity of exports		✓
cost of energy imports in relation to GDP		✓
cost of energy exports in relation to GDP		✓
carriers dependence on imported fuels		✓
end-use sectors dependence on imported fuels		✓
energy intensity		✓
diversity of energy sources in primary energy supply		✓
diversity of primary energy sources in carriers		✓
diversity of primary energy sources in end-use sectors		✓
end-use sector diversity of carriers		✓
reserves or resource to production ratios		✓

average age of infrastructure		✓
spare capacities for electricity generation		✓
rate of energy sector growth		✓
rate of energy export revenue decline		✓
supply risks	✓	
ratio of oil imports to world total oil imports		✓
geopolitical oil supply market concentration		✓
economic risks	✓	
US dollar index volatility		✓
oil price volatility		✓
ratio of value of oil imports to GDP		✓
Transportation risks	✓	
Dependence risks	✓	
Oil import dependence		✓
diversification of oil import source		✓

Table 37: Food Index and Indicators

Name of Index or Indicator	***Type***	
	Composite Index	**Indicator**
stability of food price and supply		✓
household food production		✓
food crop diversity		✓
sufficiency of household food		✓
percentage household expenditure on food		✓
number of meals taken in a day		✓
household dietary diversity		✓
degree of access to utilities and services		✓
average dietary energy supply adequacy		✓
Average value of food production		✓
Share of dietary energy supply derived from cereals, roots and tubers		✓
Average protein supply		✓
Average supply of protein of animal origin		✓
Percent of paved roads over total roads		✓
Road density		✓
Rail lines density		✓
Gross domestic product per capita (in purchasing power equivalent)		✓
Domestic food price index		✓
Prevalence of undernourishment		✓
Share of food expenditure of the poor		✓
Depth of the food deficit		✓
Prevalence of food inadequacy		✓
Cereal import dependency ratio		✓
Percent of arable land equipped for irrigation		✓
Value of food imports over total merchandise exports		✓
Political stability and absence of violence/terrorism		✓
Domestic food price volatility		✓
Per capita food production variability		✓
Per capita food supply variability		✓
Access to improved water sources		✓
Access to improved sanitation facilities		✓
Percentage of children under 5 years of age affected by wasting		✓
Percentage of children under 5 years of age who are stunted		✓
Percentage of children under 5 years of age who are underweight		✓
Percentage of adults who are underweight		✓
Prevalence of anaemia among pregnant women		✓

Prevalence of anaemia among children under 5 years of age		✓
Prevalence of vitamin A deficiency in the population		✓
Prevalence of school-age children (6-12 years) with insufficient iodine intake		✓
Total population		✓
Number of people undernourished		✓
Minimum Dietary Energy Requirement (MDER)		✓
Average Dietary Energy Requirement (ADER)		✓
Minimum Dietary Energy Requirement (MDER) - PAL=1.75		✓
Coefficient of variation of habitual caloric consumption distribution		✓
Skewness of habitual caloric consumption distribution		✓
Incidence of caloric losses at retail distribution level		✓
Dietary Energy Supply (DES)		✓
Average fat supply		✓
Prevalence of food over-acquisition		✓
Maximum Dietary Energy Requirement (XDER)		✓
change in value of agricultural produce		✓
change in yield / water applied		✓
change in land occupied by the plant / water treated		✓
change in total hours saved from extracting and carrying water / land under cultivation		✓
change in income from agriculture / agricultural land		✓
change in energy used / agricultural land		✓
change in amount of food harvested per worker / cost of agricultural inputs		✓
change in capital and cost expenditure for equipment / cost of workforce		✓
change in cost / water used for irrigation		✓
change in cost / irrigated land		✓
change in income due to food export		✓
food consumption as a share of household ependiture		✓
proportion of populaiton under global poverty line		✓
agricultural import tariffs		✓
presence of food safety net programmes		✓
access to financing for farmers		✓
public expenditure on agricultural R&D		✓
agricultural infrastructure		✓
existence of adequate crop storage facilities		✓
road infrastructure		✓
port infrastructure		✓
volatility of agricultural production		✓
diet diversification	✓	
nutritional standards	✓	
micronutrient availability	✓	
protein quality		✓

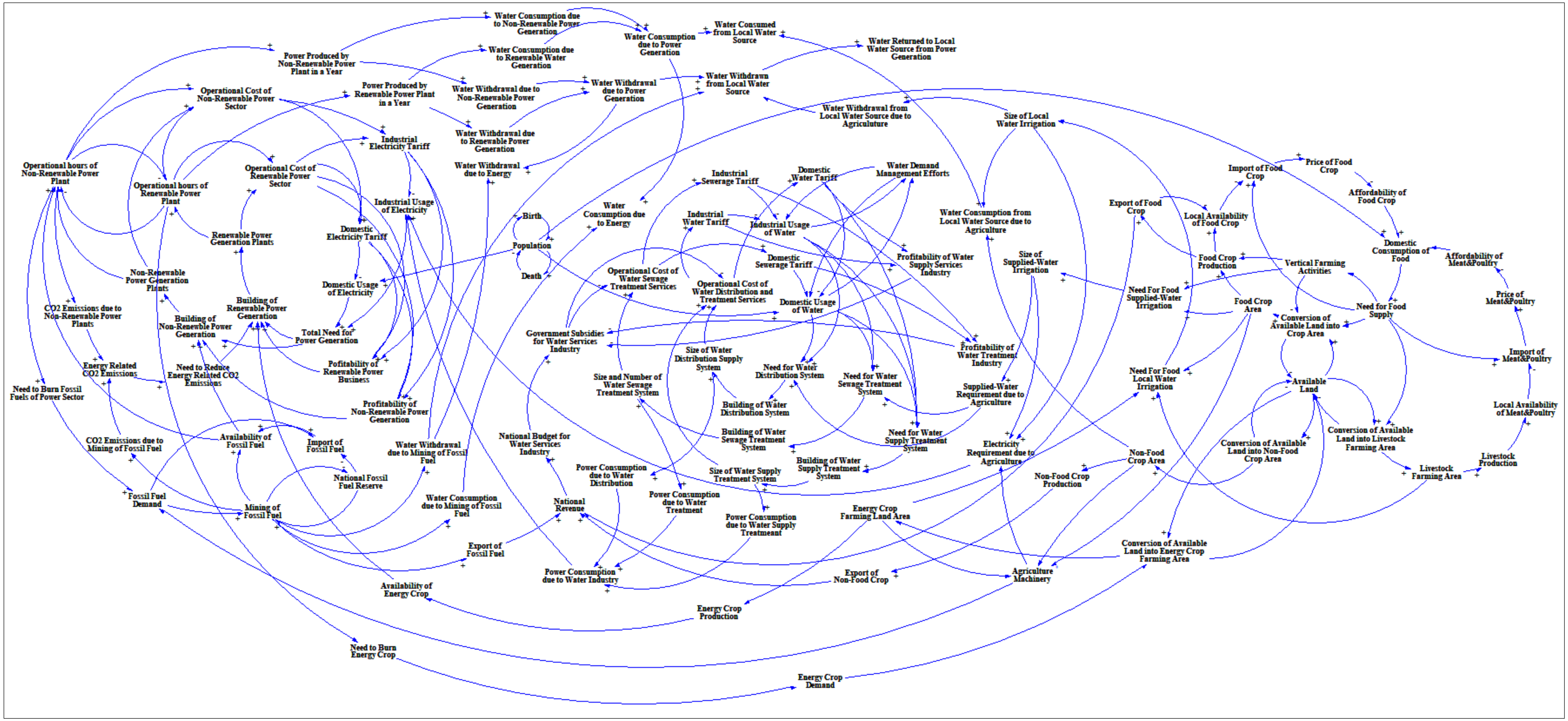


Figure 125: WEF Security Nexus Model ver 1

Appendix II

This section provides earlier iterations of causal loop diagrams (CLD).

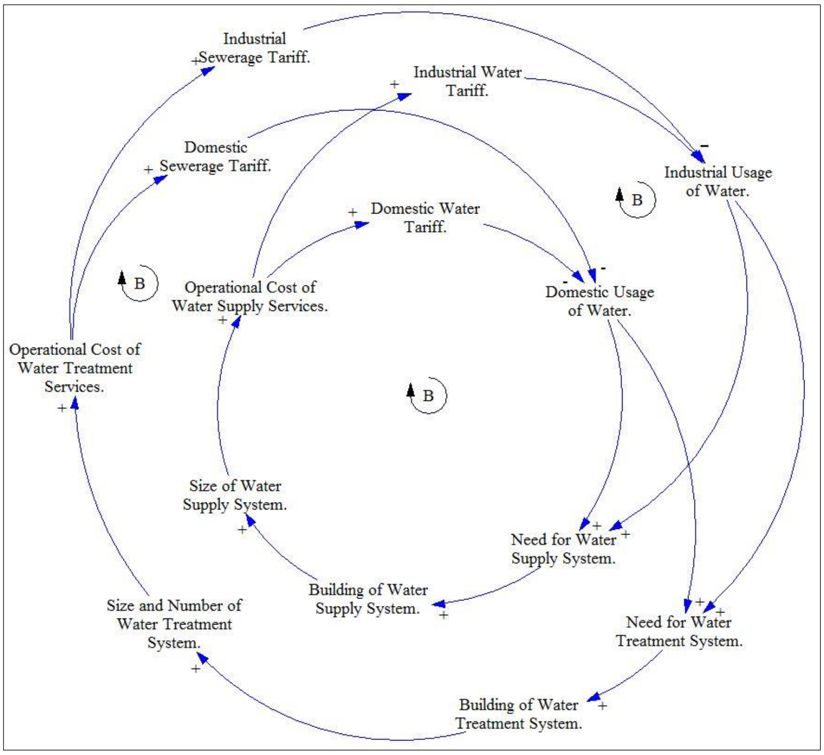


Figure 126: CLD of water loop ver 1

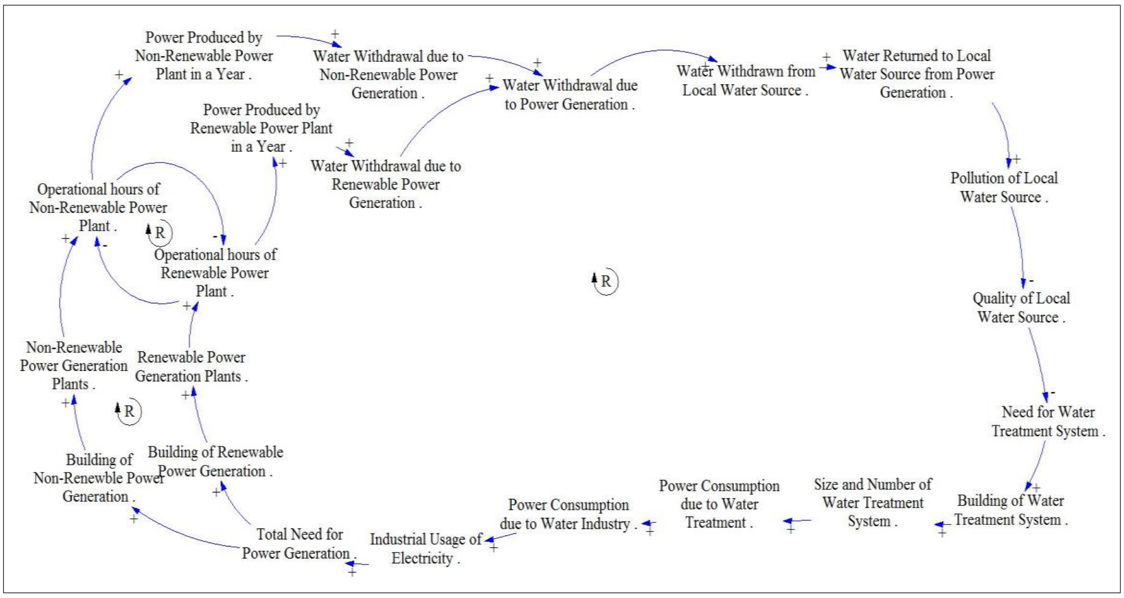


Figure 127: CLD of water-energy loop ver 1

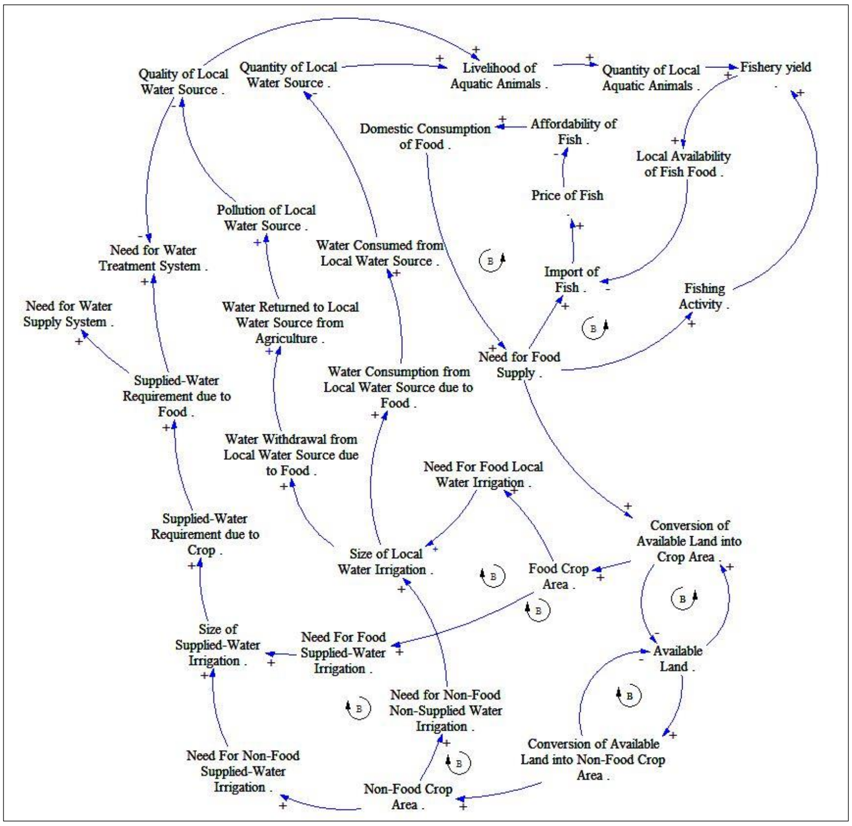


Figure 128: CLD of water-food loop ver 1

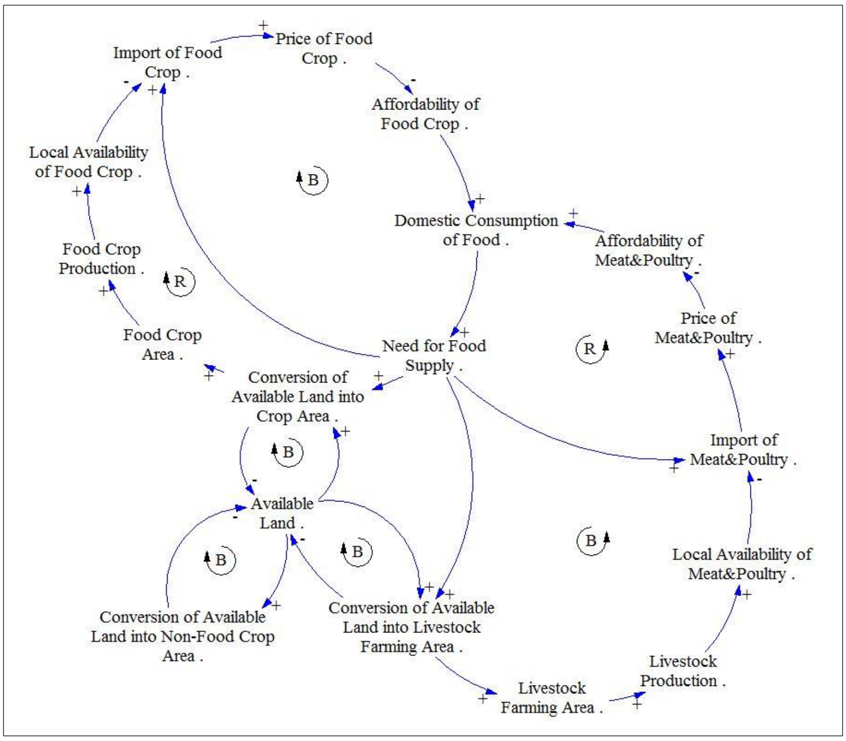


Figure 129: Food Demand, Affordability, Availability, and Land Use Loops ver 1

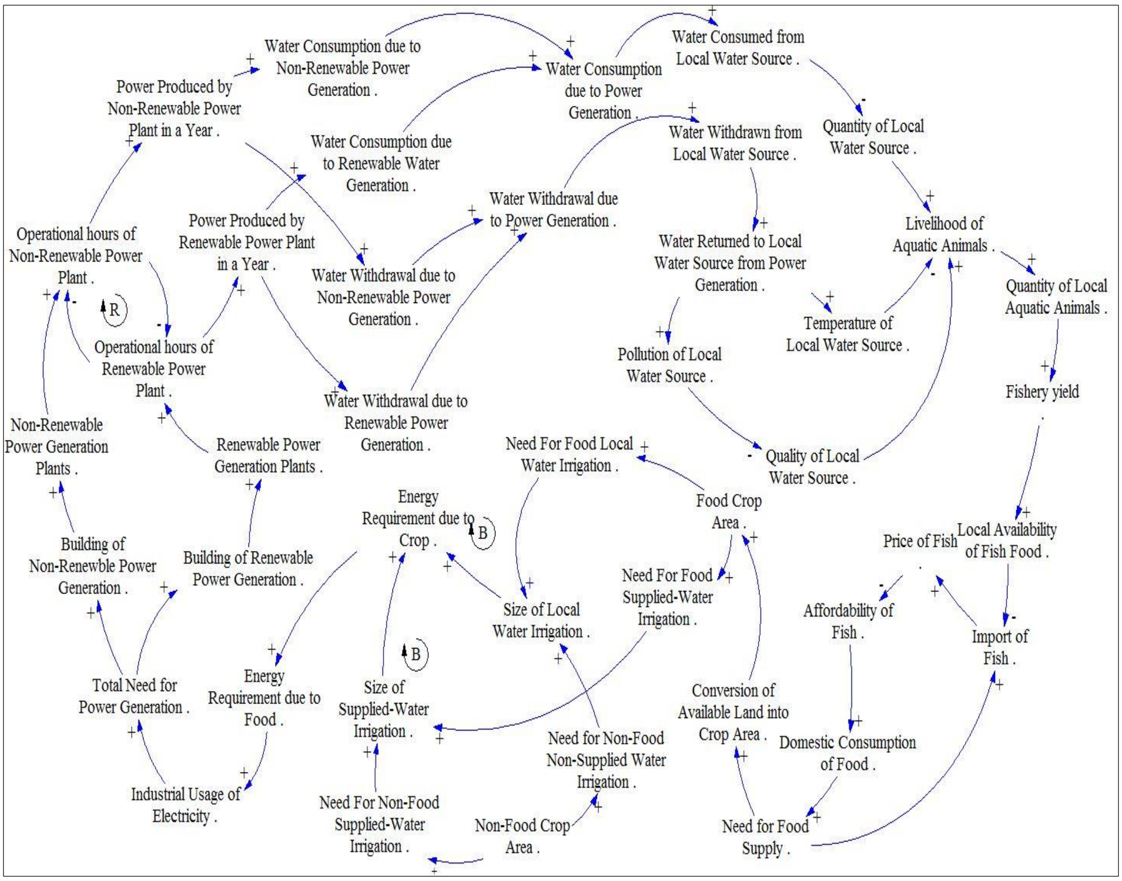


Figure 130: Energy-food loop ver 1

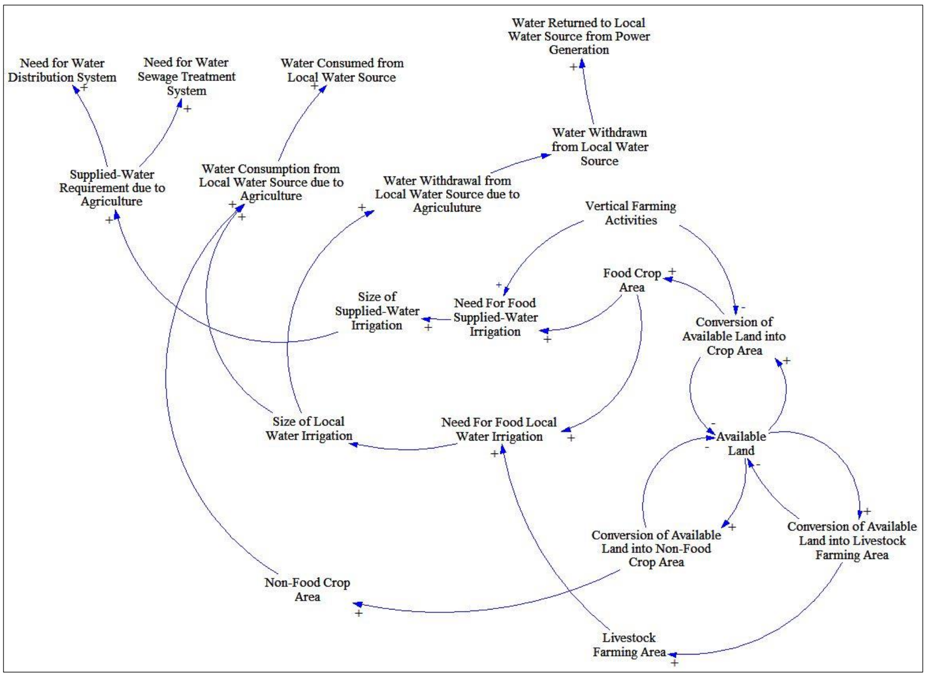


Figure 131: Water-food loop ver 2

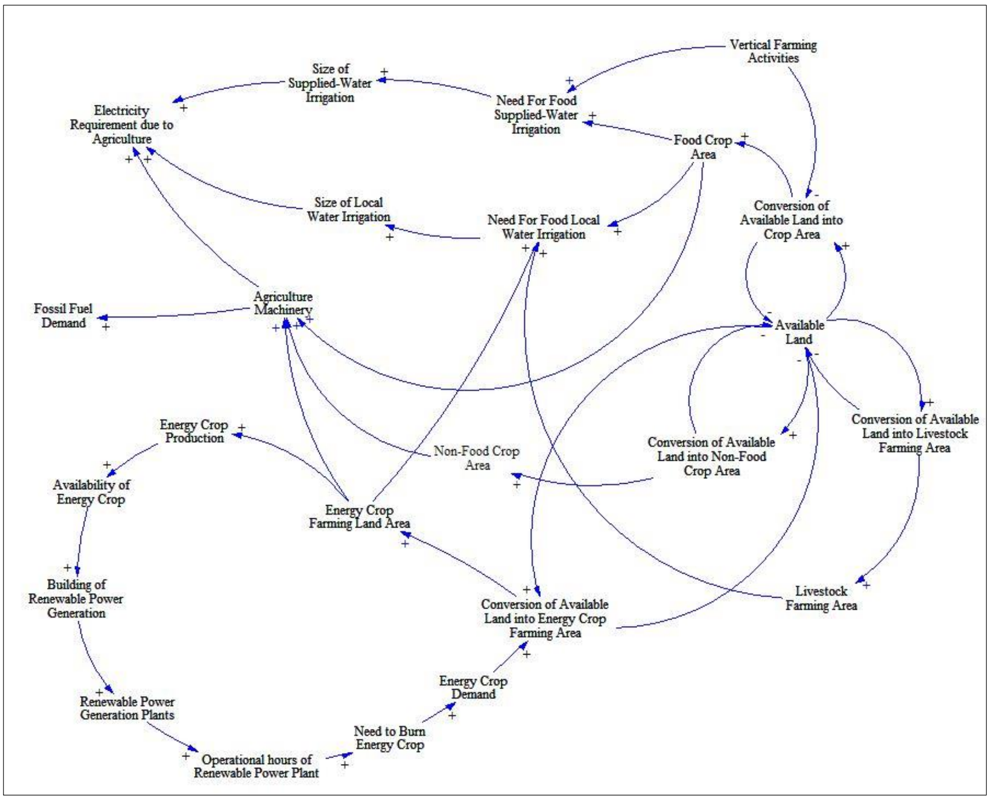


Figure 132: Water and Energy for Food CLD ver 1

Appendix III

This section provides validation graphs for section 7.2.

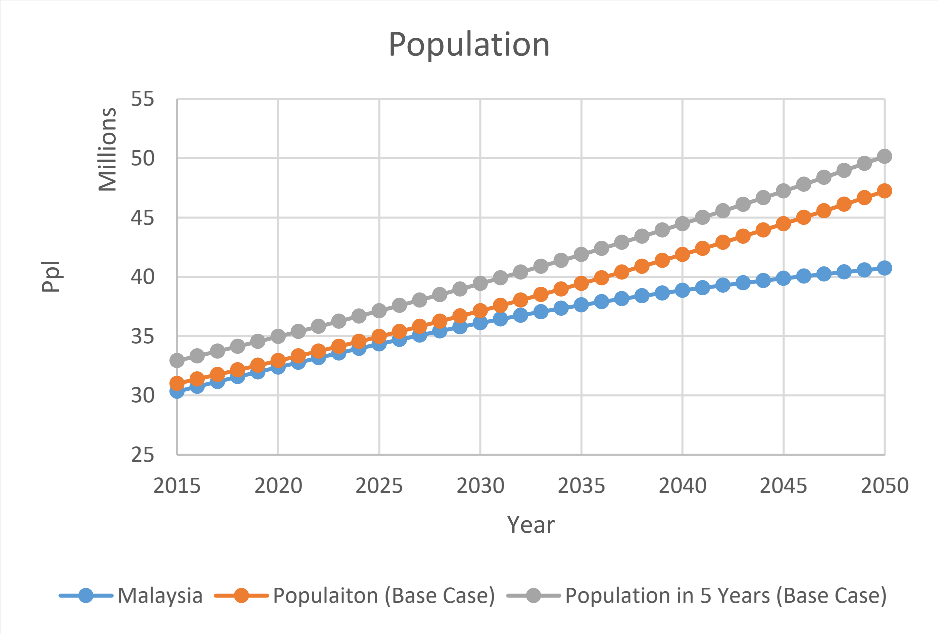


Figure 133: Population validation graph

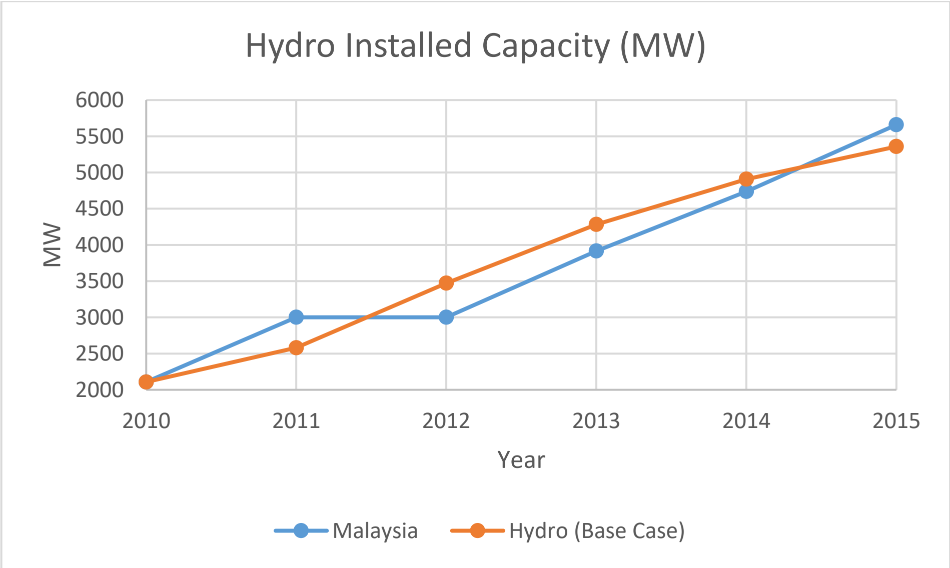


Figure 134: Hydro installed capacity validation graph

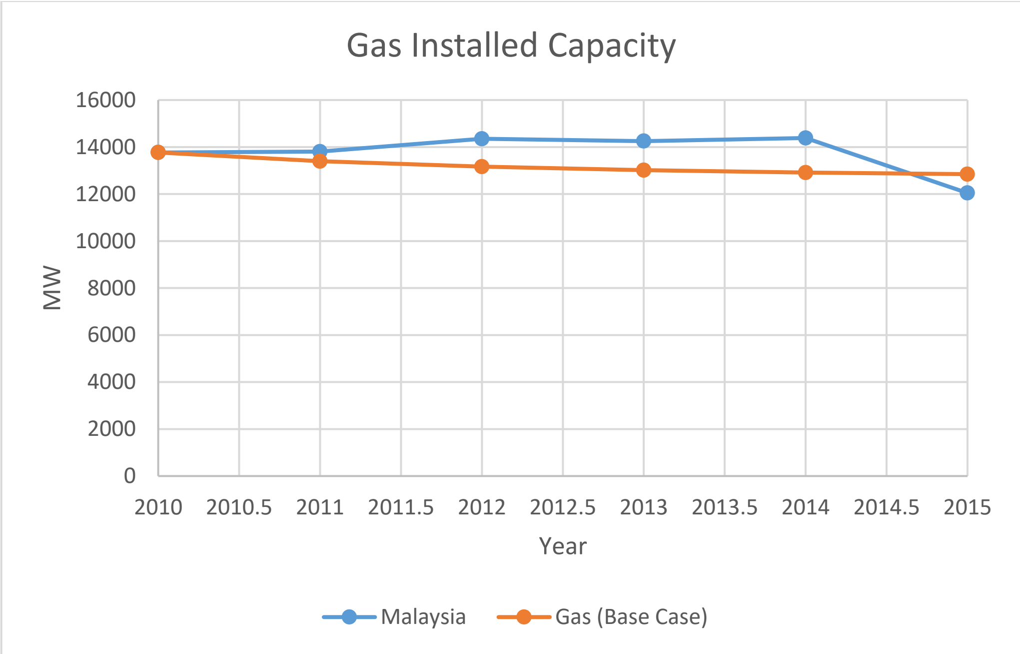


Figure 135: Gas Installed Capacity Validation Graph

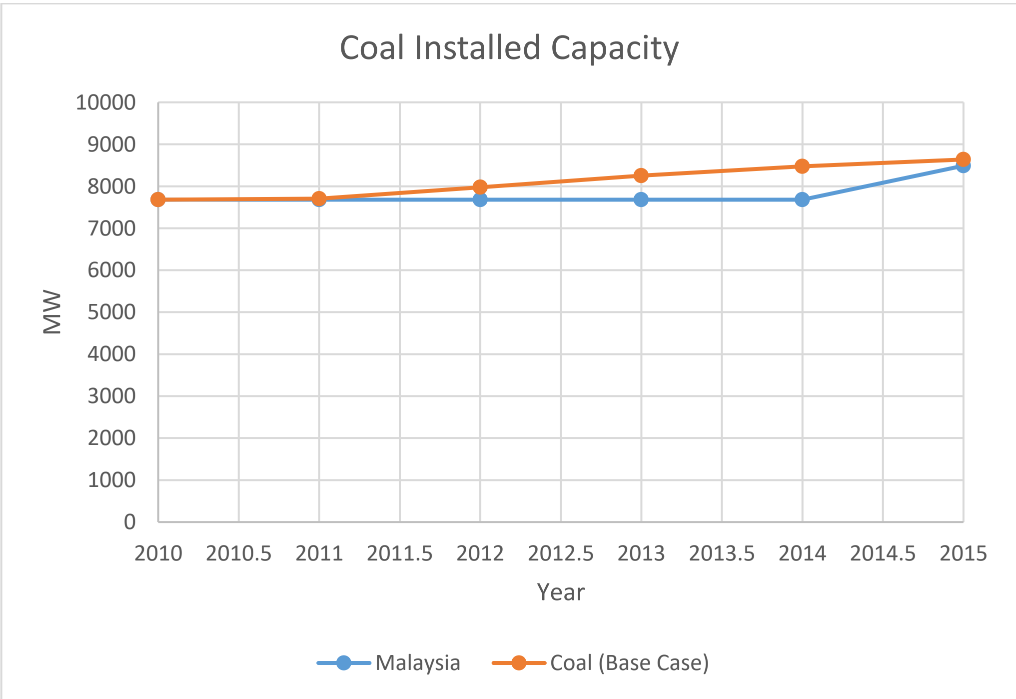


Figure 136: Coal Installed Capacity Validation Graph

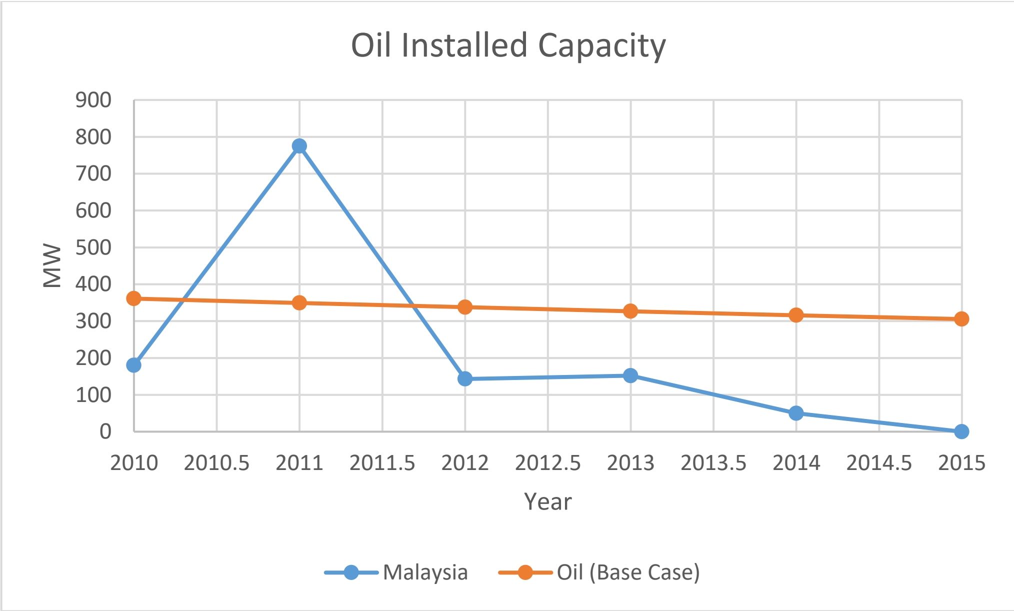


Figure 137: Oil Installed Capacity Validation Graph

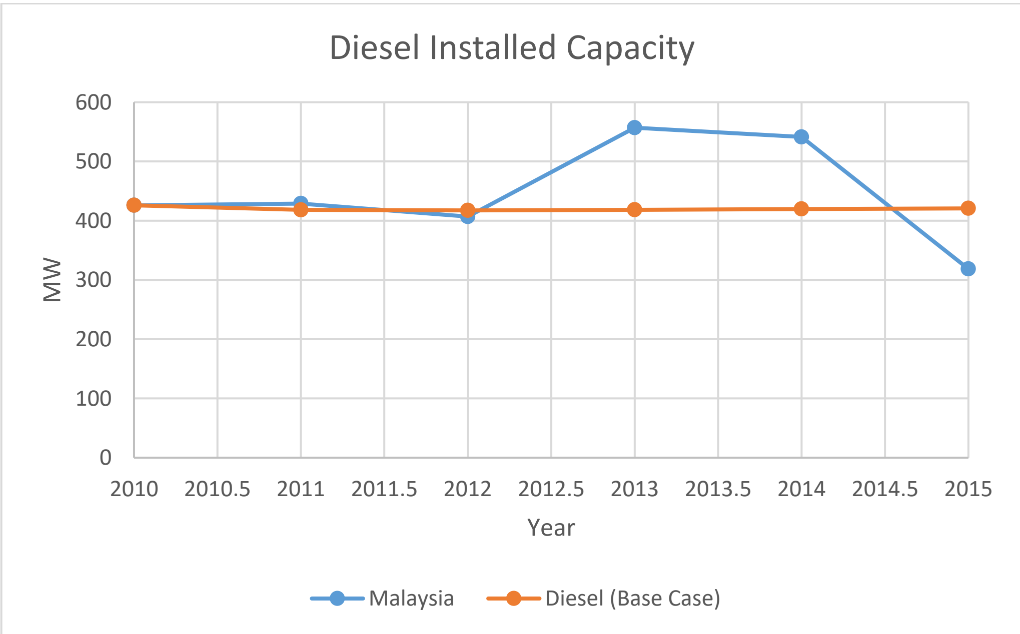


Figure 138: Diesel Installed Capacity Validation Graph

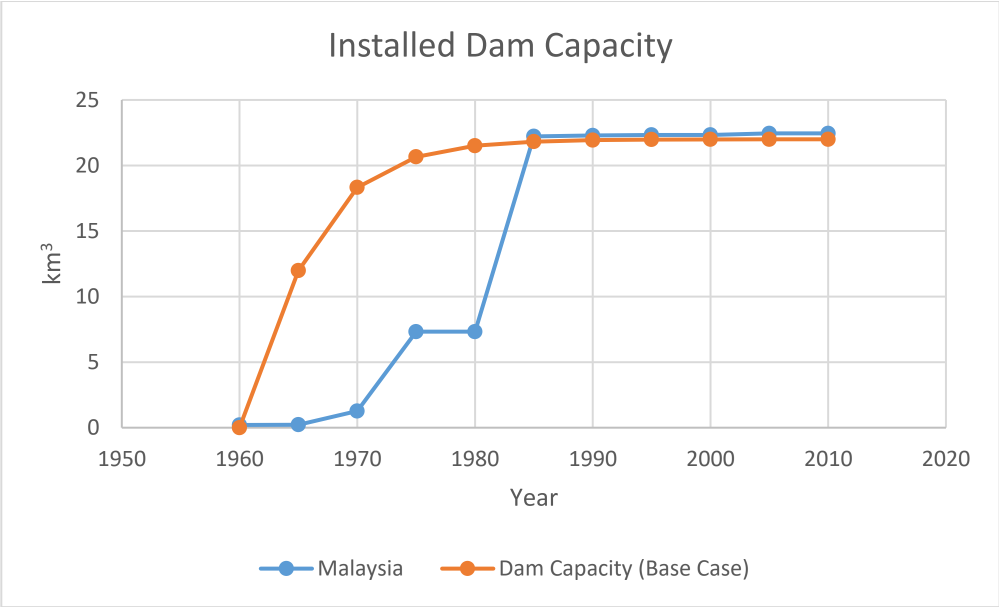


Figure 139: Installed Dam Capacity Validation Graph

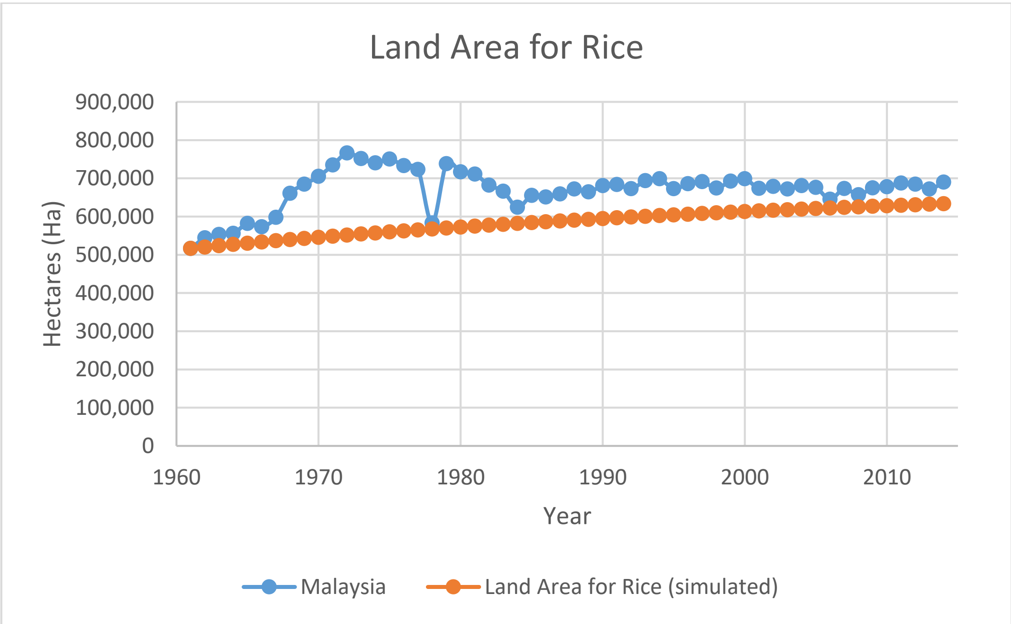


Figure 140: Land Area for Rice Validation Graph

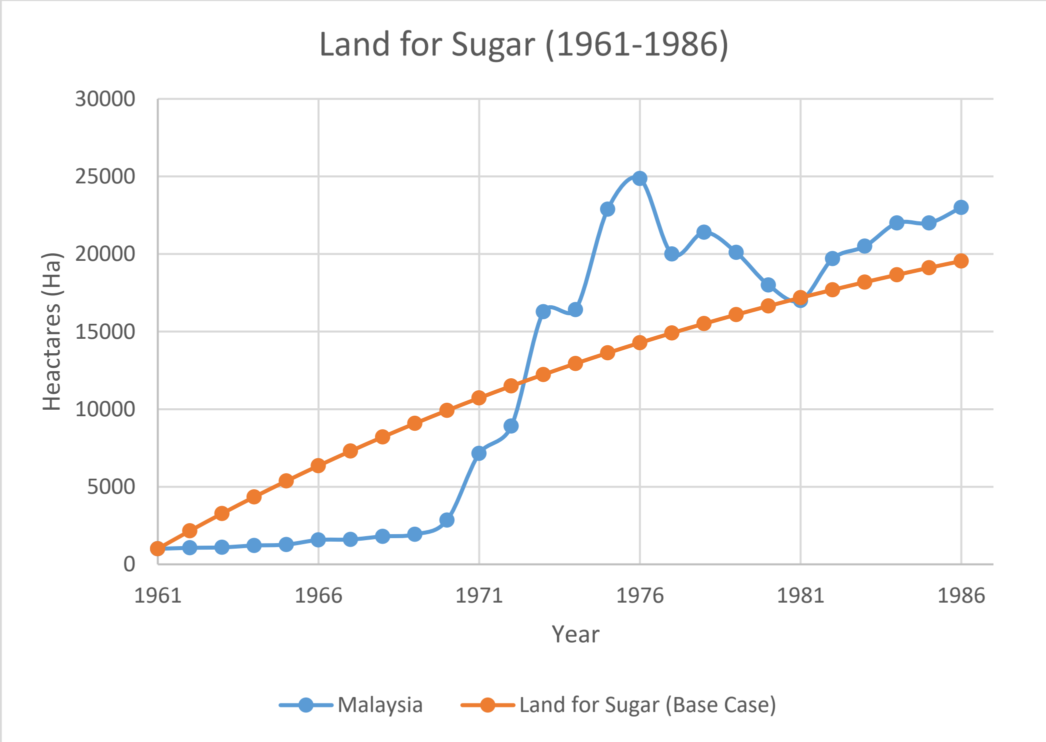


Figure 141: Land for Sugar Validation Graph

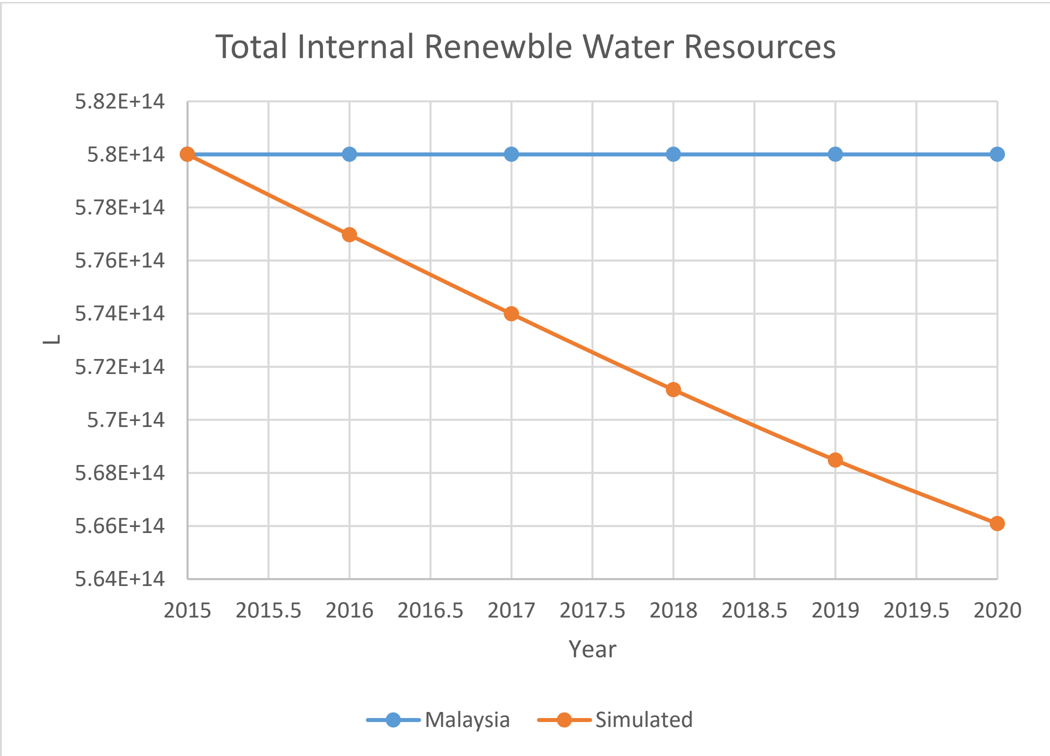


Figure 142: Total Internal Renewable Water Resources Validation Graph

Appendix IV

This section provides the broad interview questions used to ask key industrial stakeholders and the CLD validation tables.

(Energy)

Name:

Date:

Company:

Position:

1. **How would you define energy security?**
2. **How can we measure energy security?**
3. **What do you think of the energy security in Malaysia?**
4. **What are the strengths and weaknesses of energy security in Malaysia?**

5. **What are the energy-water relationships that you know of?**
6. **What are the important elements in the energy-water nexus?**
7. **Do the Causal Loop Diagrams constructed represent the relationships between energy and water security in Malaysia accurately?**
8. **Are there additional elements which you think should be added to the CLD to show the relationships between energy and water security in Malaysia?**

9. **What are the energy-food relationships that you know of?**
10. **What are the important elements in the energy-food nexus?**
11. **Do the Causal Loop Diagrams constructed represent the relationships between energy and food security in Malaysia accurately?**
12. **Are there additional elements which you think should be added to the CLD to show the relationships between energy and food security in Malaysia?**

13. **Have you heard of or have any understanding of the Water-Energy-Food Security Nexus before this interview?**
14. **Do you think that having a holistic understanding on the performance of the WEF Security Nexus in Malaysia is important? Why and Why not?**
15. **If yes, what do you think are important areas to look at when looking into the performance of WEF Security Nexus in Malaysia?**

(Food)

Name:

Date:

Company:

Position:

1. **How would you define food security?**
2. **How can we measure food security?**
3. **What do you think of the food security in Malaysia?**
4. **What are the strengths and weaknesses of food security in Malaysia?**

5. **What are the food-water relationships that you know of?**
6. **What are the important elements in the food-water nexus?**
7. **Do the Causal Loop Diagrams constructed represent the relationships between food and water security in Malaysia accurately?**
8. **Are there additional elements which you think should be added to the CLD to show the relationships between food and water security in Malaysia?**

9. **What are the food-energy relationships that you know of?**
10. **What are the important elements in the food-energy nexus?**
11. **Do the Causal Loop Diagrams constructed represent the relationships between food and energy security in Malaysia accurately?**
12. **Are there additional elements which you think should be added to the CLD to show the relationships between food and energy security in Malaysia?**

13. **Have you heard of or have any understanding of the Water-Energy-Food Security Nexus before this interview?**
14. **Do you think that having a holistic understanding on the performance of the WEF Security Nexus in Malaysia is important? Why and Why not?**
15. **If yes, what do you think are important areas to look at when looking into the performance of WEF Security Nexus in Malaysia?**

(Water)

Name:

Date:

Company:

Position:

1. **How would you define water security?**
2. **How can we measure water security?**
3. **What do you think of the water security in Malaysia?**
4. **What are the strengths and weaknesses of water security in Malaysia?**

5. **What are the water-energy relationships that you know of?**
6. **What are the important elements in the water-energy nexus?**
7. **Do the Causal Loop Diagrams constructed represent the relationships between water and energy security in Malaysia accurately?**
8. **Are there additional elements which you think should be added to the CLD to show the relationships between water and energy security in Malaysia?**

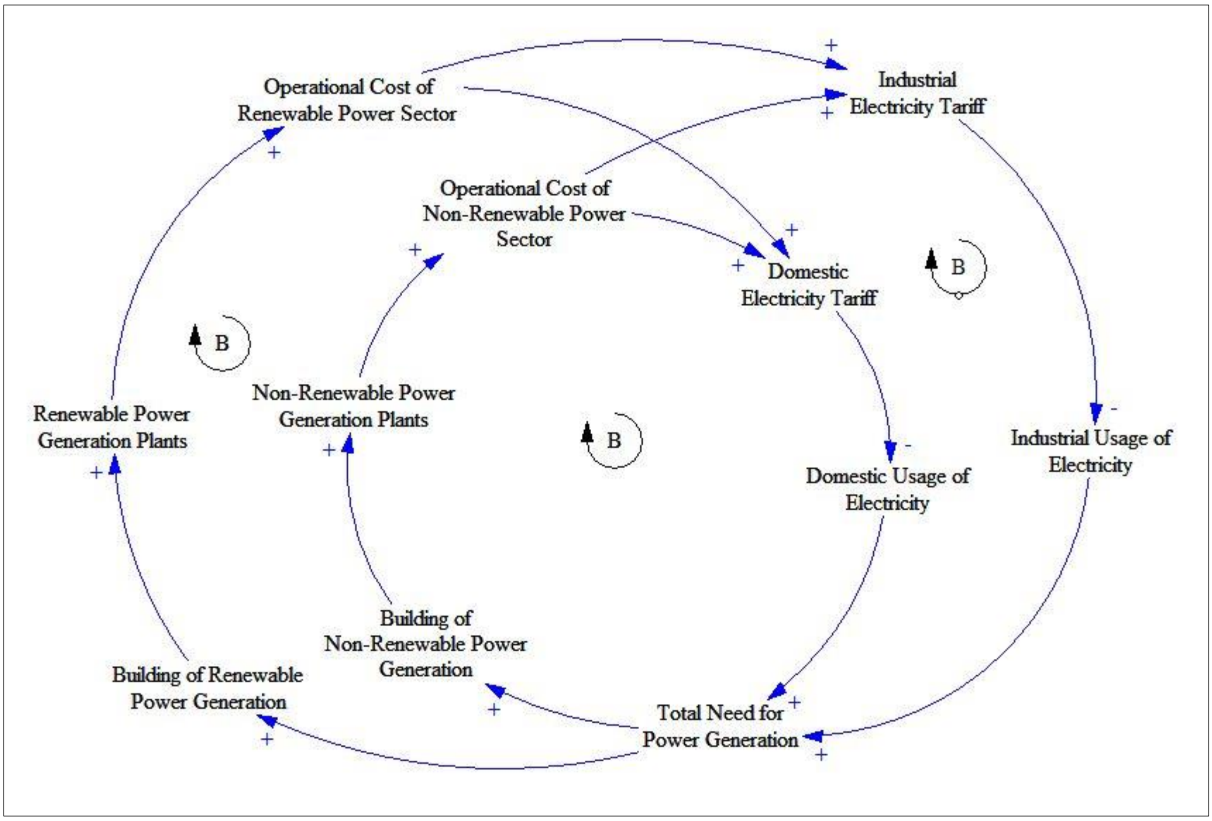
9. **What are the water-food relationships that you know of?**
10. **What are the important elements in the water-food nexus?**
11. **Do the Causal Loop Diagrams constructed represent the relationships between water and food security in Malaysia accurately?**
12. **Are there additional elements which you think should be added to the CLD to show the relationships between water and food security in Malaysia?**

13. **Have you heard of or have any understanding of the Water-Energy-Food Security Nexus before this interview?**
14. **Do you think that having a holistic understanding on the performance of the WEF Security Nexus in Malaysia is important? Why and Why not?**
15. **If yes, what do you think are important areas to look at when looking into the performance of WEF Security Nexus in Malaysia?**

Name: Company:

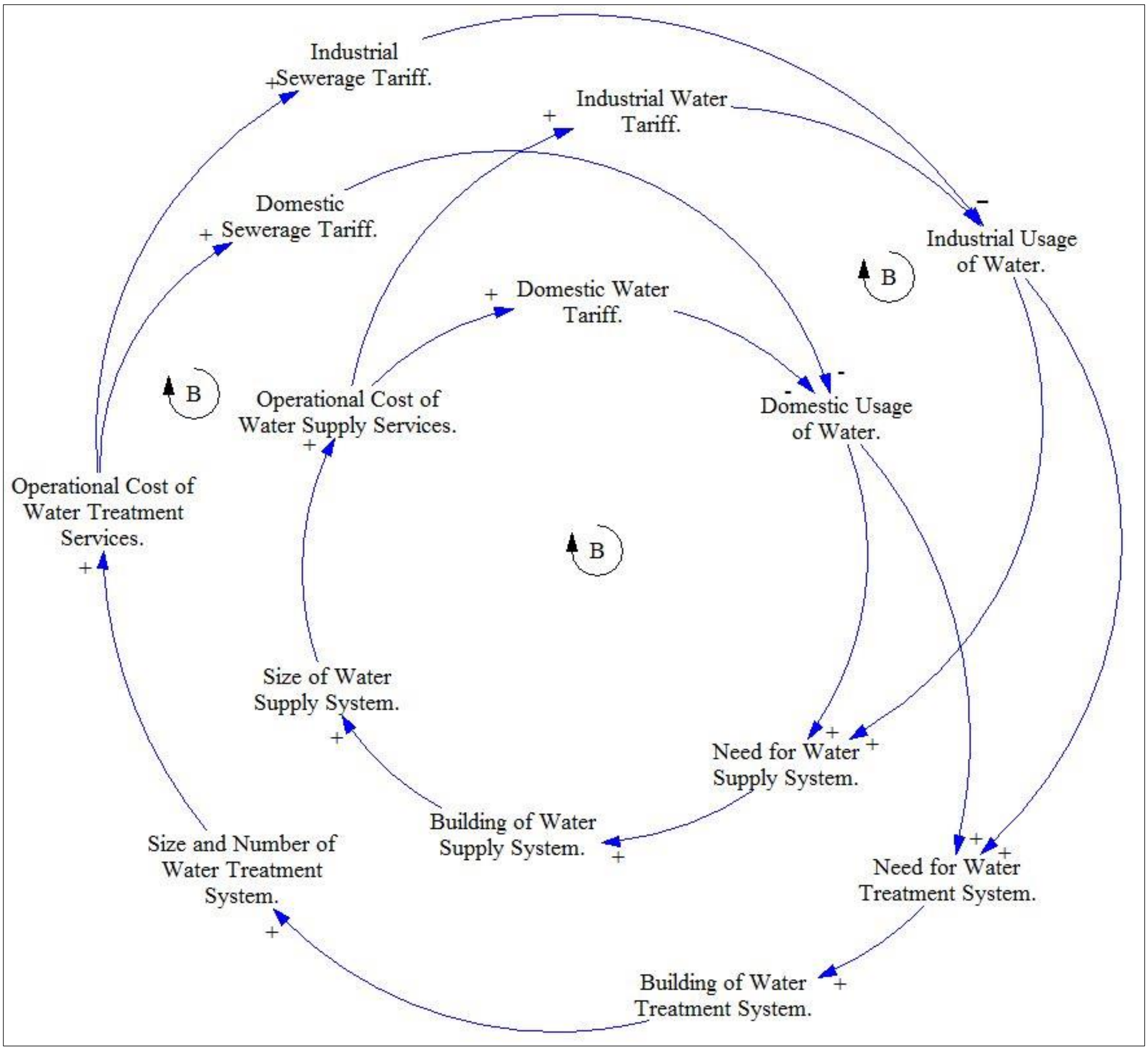
Date: Position and Title:

Electric Type, Demand, and Tariff Loops



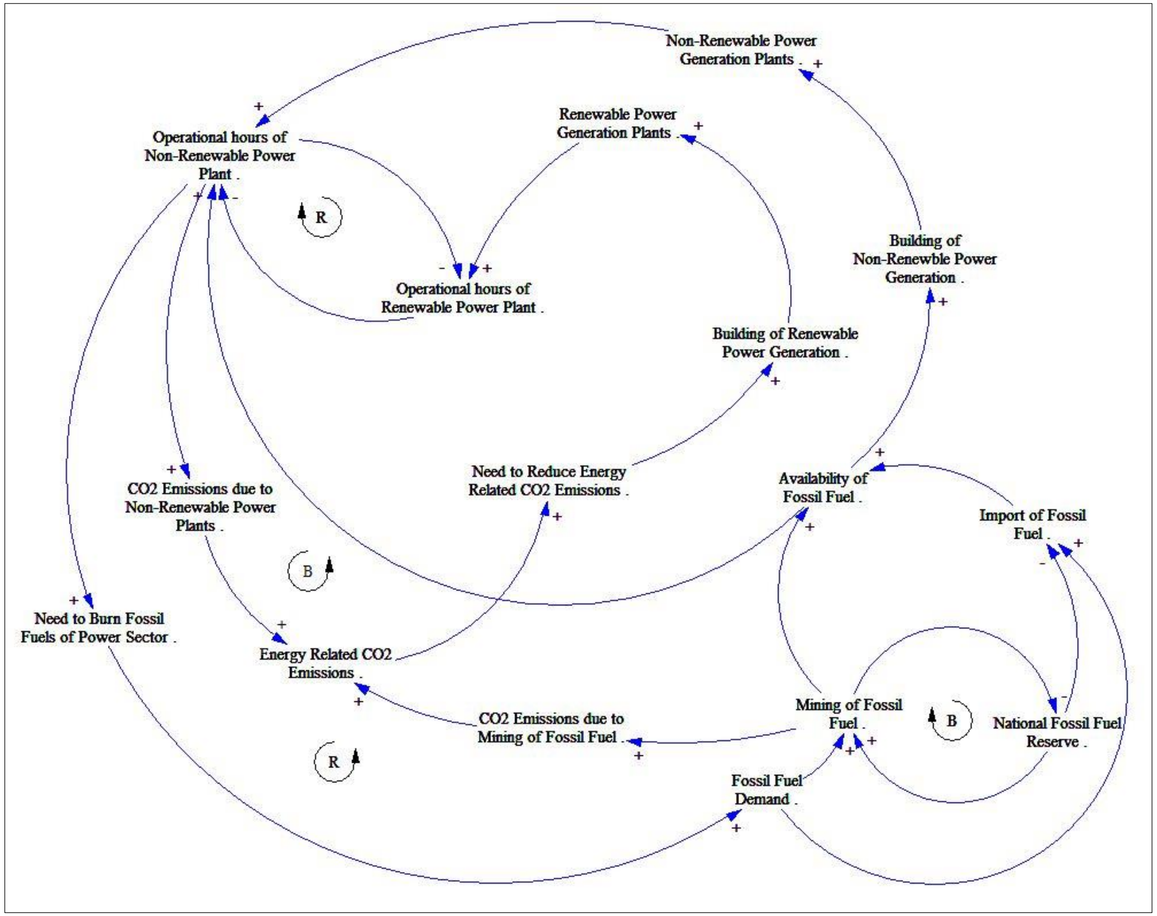
Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase Building of Non-Renewable Power Generation	increase in Non-Renewable Power Generations Plants				
increase Non-Renewable Power Generations Plants	increase in Operational Cost of Non-Renewable Power Sector				
increase Operational Cost of Non-Renewable Power Sector	increase in Domestic Electricity Tariff				
increase Domestic Electricity Tariff	decrease in Domestic Usage of Electricity				
increase Domestic Usage of Electricity	increase in Total Need for Power Generation				
increase Total Need for Power Generation	increase in Building of Non-Renewable Power Generation				
increase Building of Renewable Power Generation	increase in Renewable Power Generations Plants				
increase Renewable Power Generations Plants	increase in Operational Cost of Renewable Power Sector				
increase Operational Cost of Renewable Power Sector	increase in Domestic Electricity Tariff				
increase Total Need for Power Generation	increase in Building of Renewable Power Generation				
increase Operational Cost of Non-Renewable Power Sector	increase in Industrial Electricity Tariff				
increase Operational Cost of Renewable Power Sector	increase in Industrial Electricity Tariff				
increase Industrial Electricity Tariff	decrease in Industrial Usage of Electricity				
increase in Industrial Usage of Electricity	increase in Total Need for Power Generation				

Water Supply, Treatment, Demand, and Tariff Loops



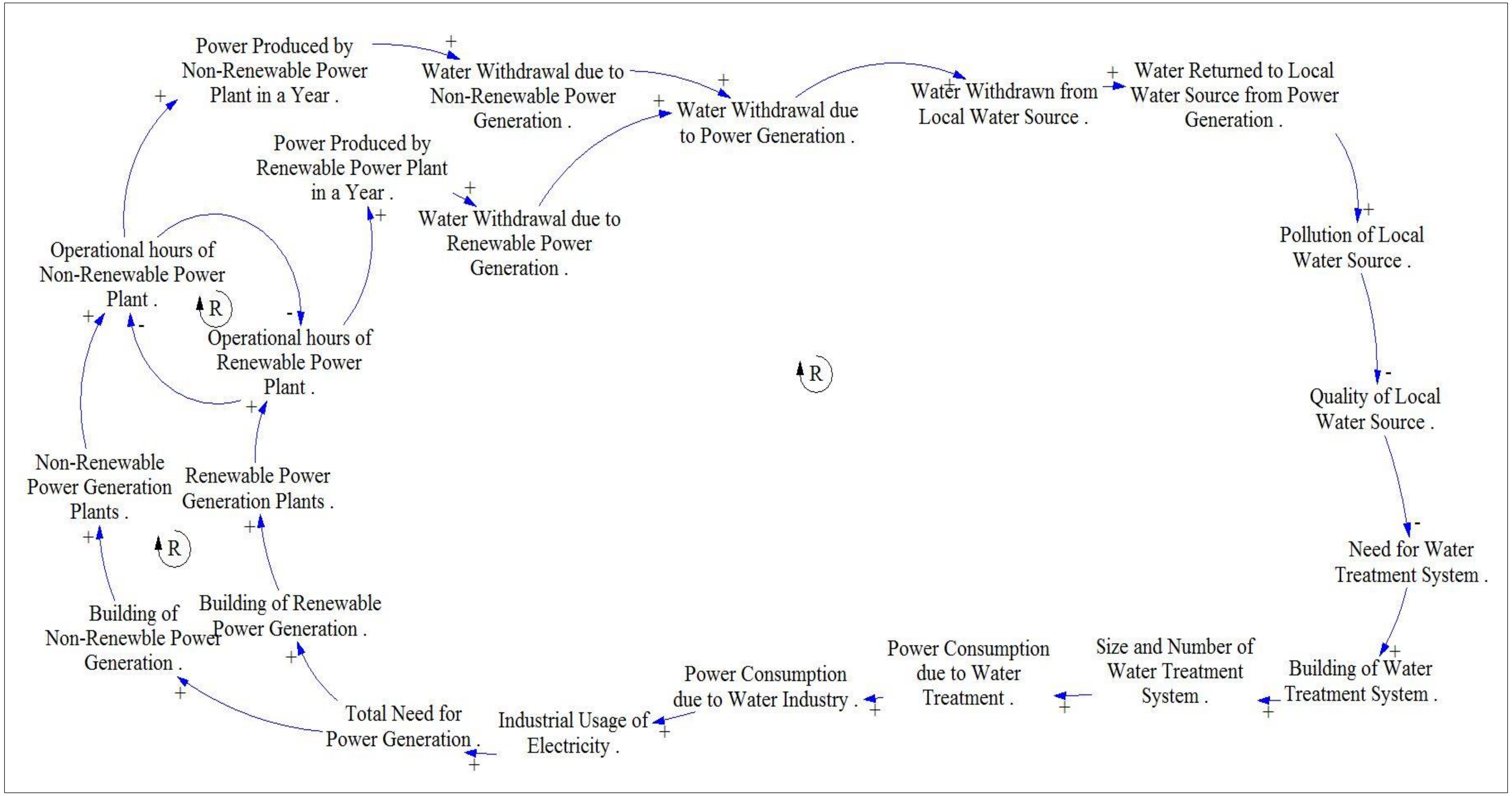
Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Domestic Usage of Water	increase in Need for Water Supply System				
increase in Need for Water Supply System	increase in Building of Water Supply System				
increase in Building of Water Supply System	increase in Size of Water Supply System				
increase in Size of Water Supply System	increase in Operational Cost of Water Supply Services				
increase in Operational Cost of Water Supply Services	increase in Domestic Water Tariff				
increase in Domestic Water Tariff	decrease in Domestic Usage of Water				
increase in Operational Cost of Water Supply Services	increase in Industrial Water Tariff				
increase in Industrial Water Tariff	decrease in Industrial Usage of Water				
increase in Industrial Usage of Water	increase in Need for Water Supply System				
increase in Domestic Usage of Water	increase in Need for Water Treatment System				
increase in Industrial Usage of Water	increase in Need for Water Treatment System				
increase in Need for Water Treatment System	increase in Building of Water Treatment System				
increase in Building of Water Treatment System	increase in Size and Number of Water Treatment System				
increase in Size and Number of Water Treatment System	increase in Operational Cost of Water Treatment Services				
increase in Operational Cost of Water Treatment Services	increase in Industrial Sewerage Tariff				
increase in Operational Cost of Water Treatment Services	increase in Domestic Sewerage Tariff				
increase in Industrial Sewerage Tariff	decrease in Industrial Usage of Water				
increase in Domestic Sewerage Tariff	decrease in Domestic Usage of Water				

Power Plant Operational Hours, Fossil Fuel Mining, and Emissions Loop



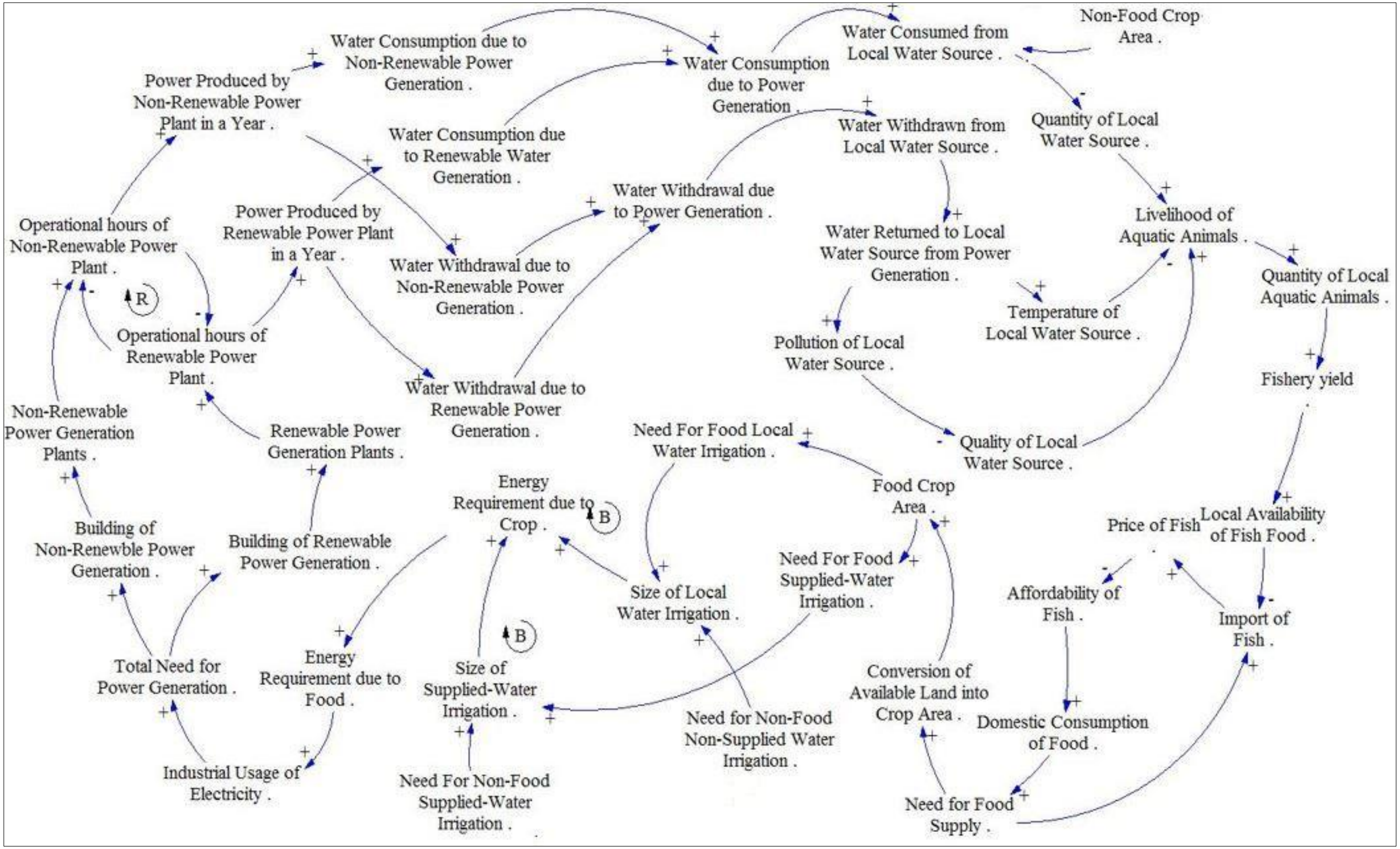
Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Operational hours of Non-Renewable Power Plant	decrease in Operational Hours of Renewable Power Plant				
increase in Operational Hours of Renewable Power Plant	decrease in Operational hours of Non-Renewable Power Plant				
increase in Operational hours of Non-Renewable Power Plant	increase in CO_2 Emissions due to Non-Renewable Power Plants				
increase in CO_2 Emissions due to Non-Renewable Power Plants	increase in Energy Related CO_2 Emissions				
increase in Energy Related CO_2 Emissions	increase in Need to Reduce Energy Related CO_2 Emissions				
increase in Need to Reduce Energy Related CO_2 Emissions	increase in Building of Renewable Power Generation Plants				
Increase in Renewable Power Generation Plants	increase in Operational hours of Renewable Power Plants				
increase in Mining of Fossil Fuel	decrease in National Fossil Fuel Reserve				
increase in National Fossil Fuel Reserve	increase in Mining of Fossil Fuel				
increase in Operational hours of Non-Renewable Power Plant	increase in Need to Burn Fossil Fuel of Power Sector				
increase in Need to Burn Fossil Fuel of Power Sector	increase in Fossil Fuel Demand				
increase in Fossil Fuel Demand	increase in Mining of Fossil Fuel				
increase in Fossil Fuel Demand	increase in Import of Fossil Fuel				
increase in Mining of Fossil Fuel	increase in Availability of Fossi Fuel				
increase in Import of Fossil Fuel	increase in Availability of Fossi Fuel				
increase in Availability of Fossi Fuel	increase in Operational hours of Non-Renewable Power Plant				
increase in Availability of Fossi Fuel	increase in Building of Non-Renewable Power Generation				
increase in Mining of Fossil Fuel	increase in CO_2 Emissions due to Mining of Fossil Fuel				

Water-Energy Relationships



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Operational hours of Non-Renewable Power Plant	increase in Power Produced by Non-Renewable Power Plant in a Year				
increase in Operational hours of Renewable Power Plant	increase in Power Produced by Renewable Power Plant in a Year				
increase in Power Produced by Non-Renewable Power Plant in a Year	increase in Water Withdrawal due to Non-Renewable Power Generation				
increase in Power Produced by Renewable Power Plant in a Year	increase in Water Withdrawal due to Renewable Power Generation				
increase in Water Withdrawal due to Non-Renewable Power Generation	increase in Water Withdrawal due to Power Generation				
increase in Water Withdrawal due to Renewable Power Generation	increase in Water Withdrawal due to Power Generation				
increase in Water Withdrawal due to Power Generation	increase in Water Withdrawn from Local Water Source				
increase in Water Withdrawn from Local Water Source	increase in Water Returned to Local Water Source from Power Generation				
increase in Water Returned to Local Water Source from Power Generation	increase in Pollution of Local Water Source				
increase in Pollution of Local Water Source	decrease in Quality of Local Water Source				
increase in Quality of Local Water Source	decrease in Need for Water Treatment System				
increase in Need for Water Treatment System	increase in Building of Water Treatment System				
increase in Building of Water Treatment System	increase in Size and Number of Water Treatment System				
increase in Size and Number of Water Treatment System	increase in Power Consumption due to Water Treatment				
increase in Power Consumption due to Water Treatment	increase in Power Consumption due to Water Industry				
increase in Power Consumption due to Water Industry	increase in Industrial Usage of Electricity				

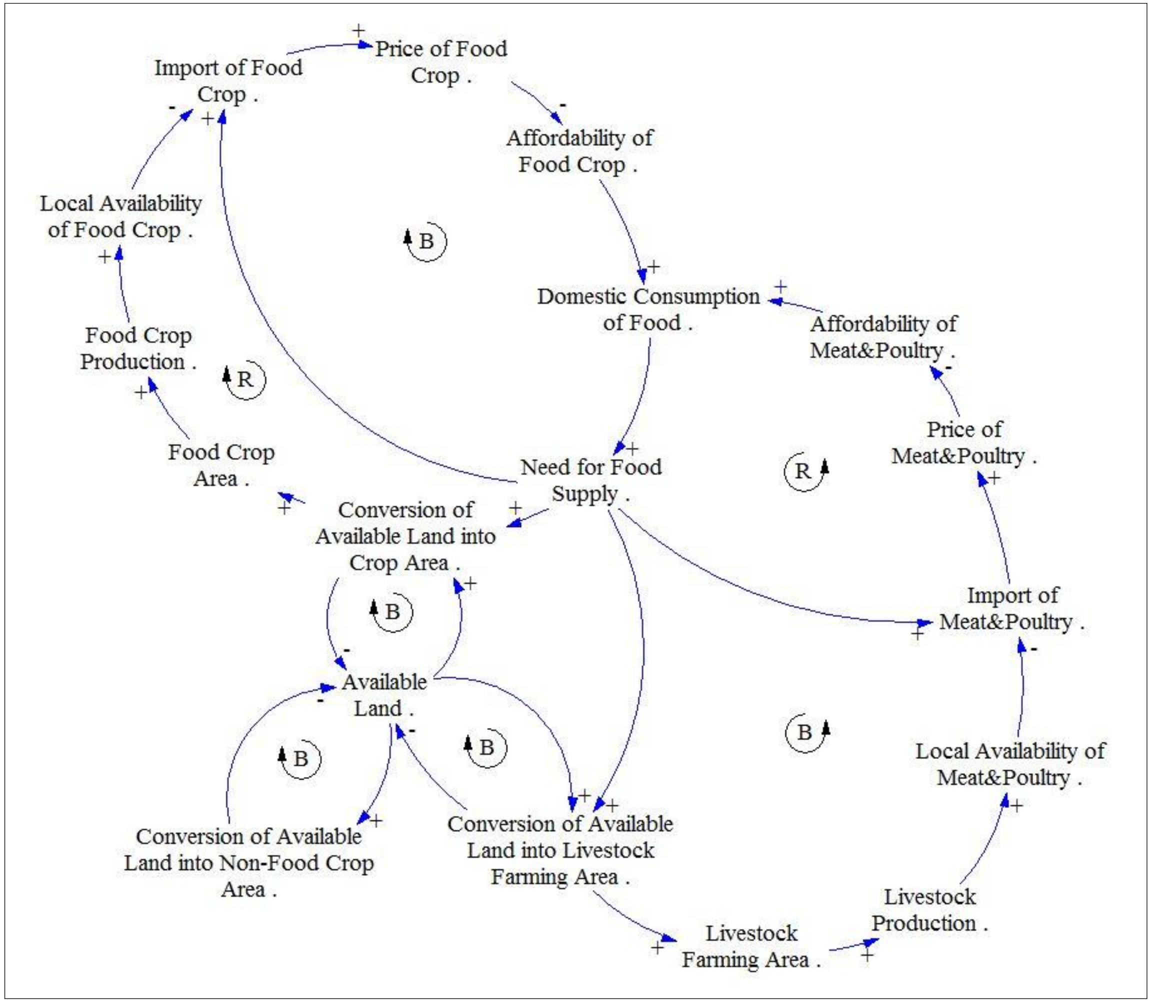
Energy-Food Relationships



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Power Produced by Non-Renewable Power Plant in a Year	increase in Water Consumption due to Non-Renewable Power Generation				
increase in Power Produced by Renewable Power Plant in a Year	increase in Water Consumption due to Renewable Power Generation				
increase in Water Consumption due to Non-Renewable Power Generation	increase in Water Consumption due to Power Generation				
increase in Water Consumption due to Renewable Power Generation	increase in Water Consumption due to Power Generation				
increase in Water Consumption due to Power Generation	increase in Water Consumed from Local Water Source				
increase in Non-Food Crop Area	increase in Water Consumed from Local Water Source				
increase in Water Consumed from Local Water Source	decrease in Quantity of Local Water Source				
increase in Quantity of Local Water Source	increase in Livelihood of Aquatic Animals				
increase in Livelihood of Aquatic Animals	increase in Quantity of Local Aquatic Animals				
increase in Quantity of Local Aquatic Animals	increase in Fishery Yield				
increase in Fishery Yield	increase in Local Availability of Fish				
increase in Local Availability of Fish Food	decrease in Import of Fish				
increase in Import of Fish	increase in Price of Fish				
increase in Price of Fish	decrease in Affordability of Fish				
increase in Affordability of Fish	increase in Domestic Consumption of Food				
increase in Domestic Consumption of Food	increase in Need for Food Supply				
increase in Need for Food Supply	increase in Import of Fish				
increase in Need for Food Supply	increase in Conversion of Available Land into Crop Area				
increase in Conversion of Available Land into Crop Area	increase in Food Crop Area				

increase in Food Crop Area	increase in Need for Food Local Irrigation				
increase in Food Crop Area	increase in Need for Food Supplied-Water Irrigation				
increase in Need for Food Local Irrigation	increase in Size of Local Water Irrigation				
increase in Need for Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation				
increase in Size of Local Water Irrigation	increase in Energy Requirement due to Crop				
increase in Size of Supplied-Water Irrigation	increase in Energy Requirement due to Crop				
increase in Energy Requirement due to Crop	increase in Energy Requirement due to Food				
increase in Energy Requirement due to Food	increase in Industrial Usage of Electricity				
increase in Need For Non-Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation				
increase in Need For Non-Food Non-Supplied Water Irrigation	increase in Size of Local Water Irrigation				
increase in Water Returned to Local Water Source from Power Generation	increase in Temperature of Local Water Source				
increase in Water Returned to Local Water Source from Power Generation	increase in Pollution of Local Water Slource				
increase in Temperature of Local Water Source	increase in Livelihood of Aquatic Animals				
increase in Pollution of Local Water Slource	decrease in Quality of Local Water Source				
increase in Quality of Local Water Source	increase in Livelihood of Aquatic Animals				

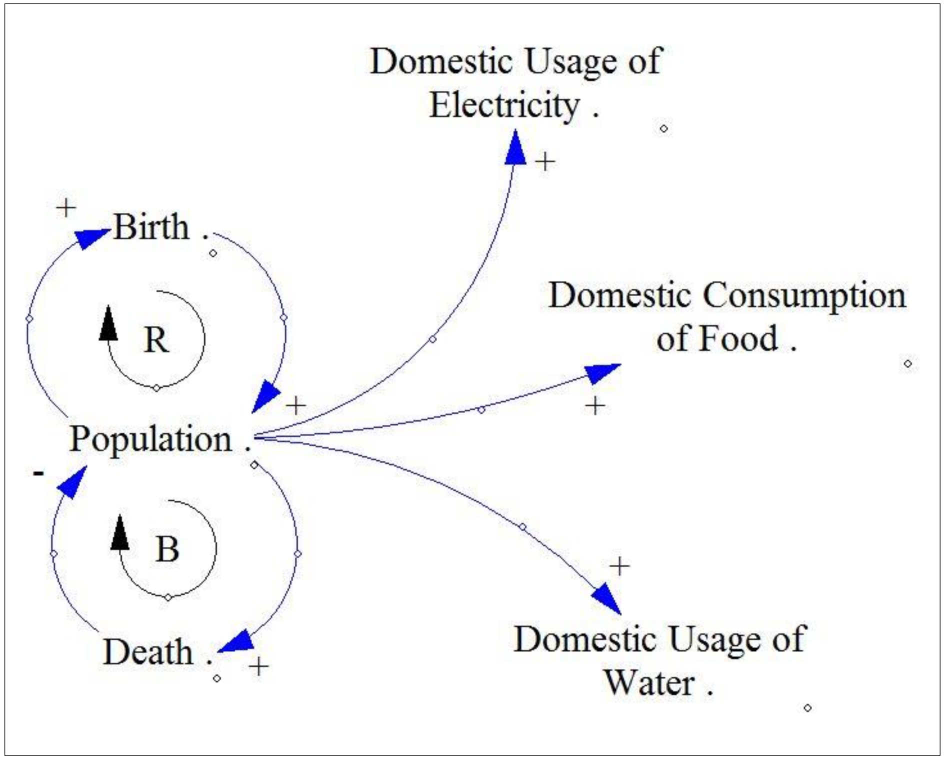
Food Demand, Affordability, Availability, and Land Use Loops



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Import of Food Crop	increase in Price of Food Crop				
increase in Price of Food Crop	decrease in Affordability of Food Crop				
increase in Affordability of Food Crop	increase in Domestic Consumption of Food				
increase in Domestic Consumption of Food	increase in Need for Food Supply				
increase in Need for Food Supply	increase in Conversion of Available Land into Crop Area				
increase in Conversion of Available Land into Crop Area	increase in Food Crop Area				
increase in Food Crop Area	increase in Food Crop Production				
increase in Food Crop Production	increase in Local Availability of Food Crop				
increase in Local Availability of Food Crop	decrease in Import of Food Crop				
increase in Need for Food Supply	increase in Import of Food Crop				
increase in Need for Food Supply	increase in Import of Meat & Poultry				
increase in Import of Meat & Poultry	increase in Price of Meat & Poultry				
increase in Price of Meat & Poultry	decrease in Affordability of Meat & Poultry				
increase in Affordability of Meat & Poultry	increase in Domestic Consumption of Food				
increase in Need for Food Supply	increase in Conversion of Available Land into Lifestock Farming Area				
increase in Conversion of Available Land into Lifestock Farming Area	increase in Lifestock Farming Area				
increase in Lifestock Farming Area	increase in Lifestock Production				
increase in Lifestock Production	increase in Local Availability of Meat & Poultry				
increase in Local Availability of Meat & Poultry	decrease in Import of Meat & Poultry				
increase in Conversion of Available Land into Crop Area	decrease in Available Land				
increase in Conversion of Available Land into Lifestock Farming Area	decrease in Available Land				

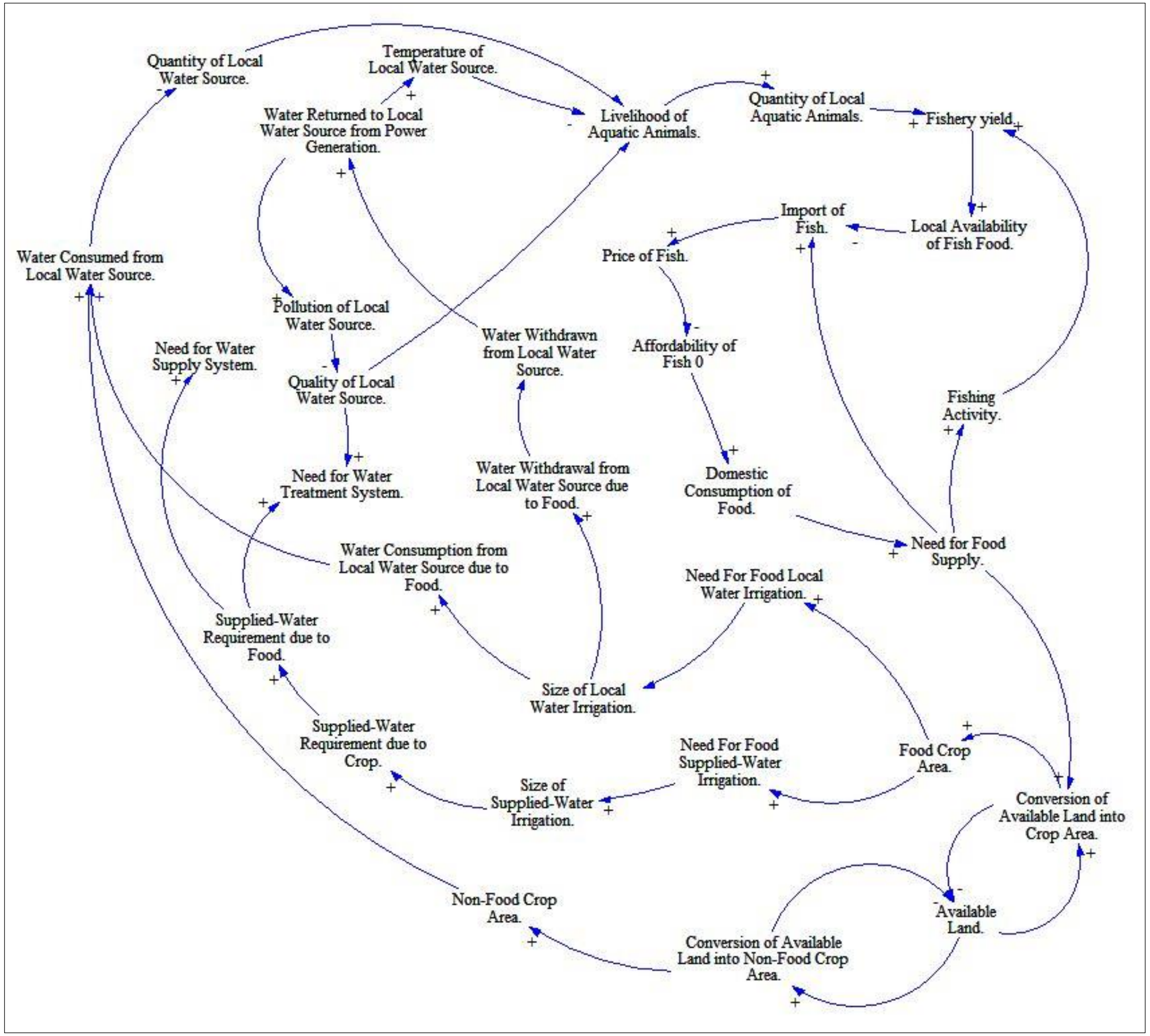
increase in Conversion of Available Land into Non-Food Crop Area	decrease in Available Land				
increase in Available Land	increase in Conversion of Available Land into Crop Area				
increase in Available Land	increase in Conversion of Available Land into Lifestock Farming Area				
increase in Available Land	increase in Conversion of Available Land into Non-Food Crop Area				

Population as Drivers of Demand Loop



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Population	inrease in Birth				
increase in Population	increase in Death				
increase in Birth	increase in Population				
increase in Death	decrease in Population				
increase in Population	increase in Domestic Usage of Electricity				
increase in Population	increase in Domestic Consumption of Food				
increase in Population	increase in Domestic Usage of Water				

Food-Water Relationships



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Need For Non-Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation				
increase in Need For Non-Food Non-Supplied Water Irrigation	increase in Size of Local Water Irrigation				
increase in Need for Food Local Irrigation	increase in Size of Local Water Irrigation				
increase in Need for Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation				
increase in Size of Supplied-Water Irrigation	increase in Supplied-Water Requirement due to Crop				
increase in Supplied-Water Requirement due to Crop	increase in Supplied-Water Requirement due to Food				
increase in Supplied-Water Requirement due to Food	increase in Need for Water Treatment System				
increase in Supplied-Water Requirement due to Food	increase in Need for Water Supply System				
increase in Size of Local Water Irrigation	increase in Water Withdrawal from Local Water Source due to Food				
increase in Water Withdrawal from Local Water Source due to Food	increase in Water Returned to Local Water Source from Agriculture				
increase in Water Returned to Local Water Source from Agriculture	increase in Pollution of Local Water Source				
increase in Pollution of Local Water Source	decrease in Quality of Local Water Source				
increase in Quality of Local Water Source	increase in Livelihood of Aquatic Animals				
increase in Need for Food Supply	increase in Fishing Activity				
increase in Fishing Activity	increase in Fishery Yield				
increase in Size of Local Water Irrigation	increase in Water Consumption from Local Water Source due to Food				
increase in Water Consumption from Local Water Source due to Food	increase in Water Consumed from Local Water Source				
increase in Water Consumed from Local Water Source	increase in Quantity of Local Water Source				
increase in Conversion of Available Land into Non-Food Crop Area	increase in Non-Food Crop Area				

increase in Non-Food Crop Area	increase in Water Consumed from Local Water Source				

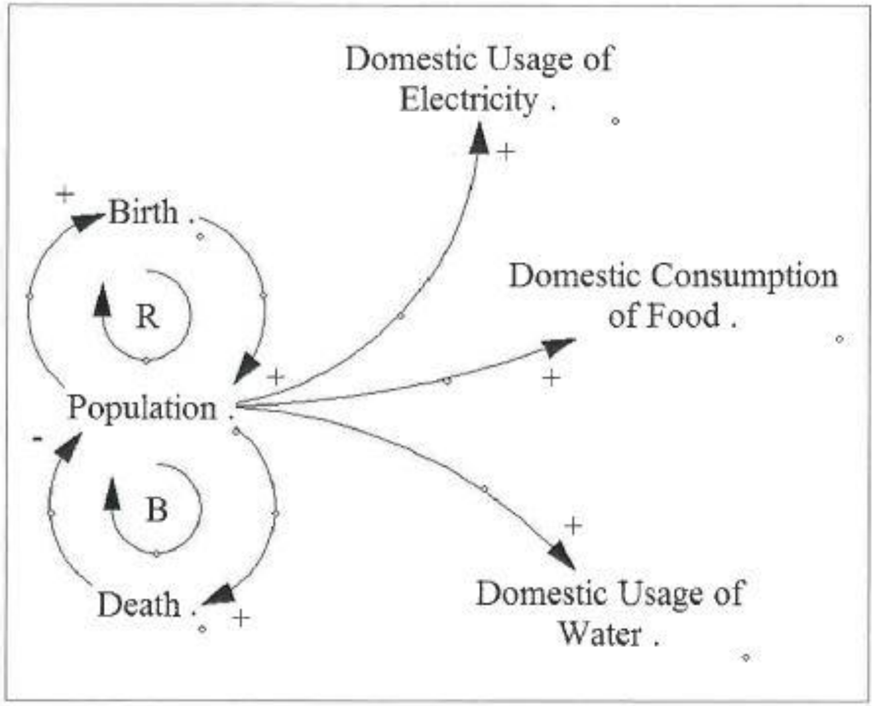
Appendix V

This section presents the answered CLD validation tables.

increase in Energy Requirement due to Crop	increase in Energy Requirement due to Food	✓			production = post harvest
increase in Energy Requirement due to Food	increase in Industrial Usage of Electricity			✓	Recycle waste to energy
increase in Non-Food Crop Area	increase in Need For Non-Food Supplied-Water Irrigation			✓	
increase in Non-Food Crop Area	increase in Need For Non-Food Non-Supplied Water Irrigation		✓		
increase in Need For Non-Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation		✓		Non food not a priority
increase in Need For Non-Food Non-Supplied Water Irrigation	increase in Size of Local Water Irrigation		✓		
increase in Water Returned to Local Water Source from Power Generation	increase in Temperature of Local Water Source		✓		
increase in Water Returned to Local Water Source from Power Generation	increase in Pollution of Local Water Slource		✓		
increase in Temperature of Local Water Ssurce	increase in Livelihood of Aquatic Animals		✓		
increase in Pollution of Local Water Slouce	decrease in Quality of Local Water Source	✓			
increase in Quality of Local Water Source	increase in Livelihood of Aquatic Animals	✓			

Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Need For Non-Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation	✓			Grow energy crops or industrial crop
increase in Need For Non-Food Non-Supplied Water Irrigation	increase in Size of Local Water Irrigation	✓			
increase in Need for Food Local Irrigation	increase in Size of Local Water Irrigation	✓			Agric takes 30% of global H2O
increase in Need for Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation	✓			
increase in Size of Supplied-Water Irrigation	increase in Supplied-Water Requirement due to Crop			✓	Not in Rainfed fields.
increase in Supplied-Water Requirement due to Crop	increase in Supplied-Water Requirement due to Food		✓		Not relations between fields/food
increase in Supplied-Water Requirement due to Food	increase in Need for Water Treatment System		✓		
increase in Supplied-Water Requirement due to Food	increase in Need for Water Supply System		✓		Not directly related
increase in Size of Local Water Irrigation	increase in Water Withdrawal from Local Water Source due to Food	✓			
increase in Water Withdrawal from Local Water Source due to Food	increase in Water Returned to Local Water Source from Agriculture		✓		Not all can be recovered
increase in Water Returned to Local Water Source from Agriculture	increase in Pollution of Local Water Source			✓	Depend on recycling policy
increase in Pollution of Local Water Source	decrease in Quality of Local Water Source	✓			
increase in Quality of Local Water Source	increase in Livelihood of Aquatic Animals	✓			
increase in Need for Food Supply	increase in Fishing Activity	✓			
increase in Fishing Activity	increase in Fishery Yield		✓		
increase in Size of Local Water Irrigation	increase in Water Consumption from Local Water Source due to Food	✓			
increase in Water Consumption from Local Water Source due to Food	increase in Water Consumed from Local Water Source			✓	Depending on distribution policy
increase in Water Consumed from Local Water Source	increase in Quantity of Local Water Source	✓			
increase in Conversion of Available Land into Non-Food Crop Area	increase in Non-Food Crop Area	✓			

G. Population as Drivers of Demand Loop



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Population	inrease in Birth	✓			But not with Govt policy of 1child/household like in China
increase in Population	increase in Death		✓		Human lives longer with modern medicines
increase in Birth	increase in Population	✓			
increase in Death	decrease in Population	✓			
increase in Population	increase in Domestic Usage of Electricity	✓			
increase in Population	increase in Domestic Consumption of Food	✓			
increase in Population	increase in Domestic Usage of Water	✓			

Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Import of Food Crop	increase in Price of Food Crop	✓			Depending on Exchange rate/tariff.
increase in Price of Food Crop	decrease in Affordability of Food Crop	✓			
increase in Affordability of Food Crop	increase in Domestic Consumption of Food	✓			Not relevant to premium crops.
increase in Domestic Consumption of Food	increase in Need for Food Supply	✓			
increase in Need for Food Supply	increase in Conversion of Available Land into Crop Area		✓		Vertical/hydrophonic are soilless.
increase in Conversion of Available Land into Crop Area	increase in Food Crop Area		✓		Depending on soil quality and H_2O
increase in Food Crop Area	increase in Food Crop Production	✓			but not necessarily correlated. supply
increase in Food Crop Production	increase in Local Availability of Food Crop		✓		Depending on distribution system of
increase in Local Availability of Food Crop	decrease in Import of Food Crop				grown for commercial.
increase in Need for Food Supply	increase in Import of Food Crop	✓			Depending on Food Balance Sheet too.
increase in Need for Food Supply	increase in Import of Meat & Poultry		✓		more income related
increase in Import of Meat & Poultry	increase in Price of Meat & Poultry	✓			relatively true.
increase in Price of Meat & Poultry	decrease in Affordability of Meat & Poultry	✓			
increase in Affordability of Meat & Poultry	increase in Domestic Consumption of Food	✓			
increase in Need for Food Supply	increase in Conversion of Available Land into Lifestock Farming Area	✓			
increase in Conversion of Available Land into Lifestock Farming Area	increase in Lifestock Farming Area	✓			land based. However feedlotting requires
increase in Lifestock Farming Area	increase in Lifestock Production	✓			less land area.
increase in Lifestock Production	increase in Local Availability of Meat & Poultry	✓			
increase in Local Availability of Meat & Poultry	decrease in Import of Meat & Poultry		✓		increase in poultry relative but ma meat not in Jordan.
increase in Conversion of Available Land into Crop Area	decrease in Available Land		✓		
increase in Conversion of Available Land into Lifestock Farming Area	decrease in Available Land	✓			livestock is not land intensive
increase in Conversion of Available Land into Non-Food Crop Area	decrease in Available Land	✓			food crop is a priority.
increase in Available Land	increase in Conversion of Available Land into Crop Area			✓	Provided they are arable
increase in Available Land	increase in Conversion of Available Land into Lifestock Farming Area	✓			
increase in Available Land	increase in Conversion of Available Land into Non-Food Crop Area			✓	Depending on priorities of food & non food crops.

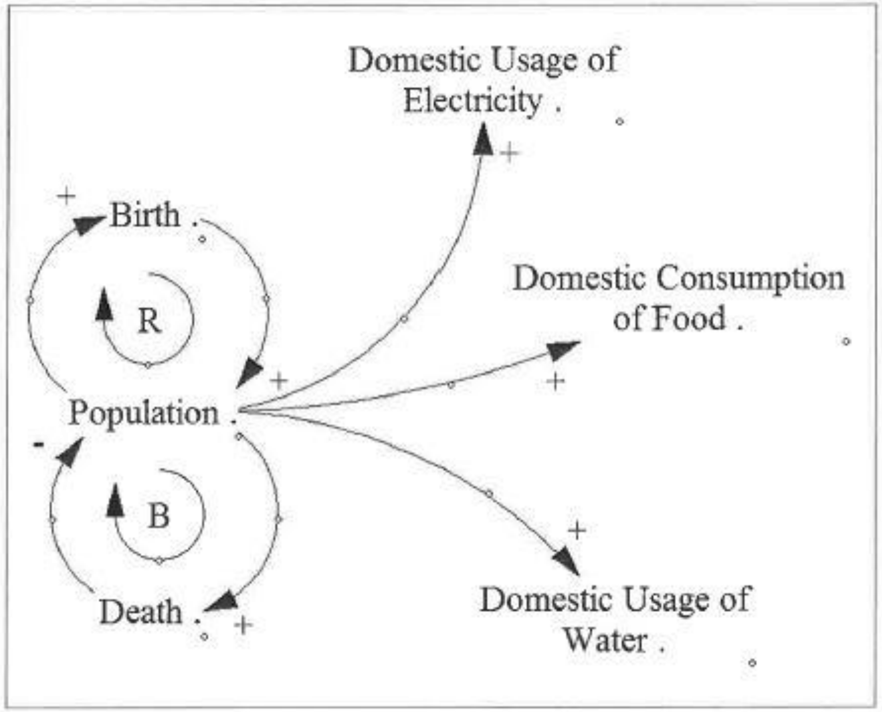
Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Power Produced by Non-Renewable Power Plant in a Year	increase in Water Consumption due to Non-Renewable Power Generation		✓		not directly related, tho can be recycled.
increase in Power Produced by Renewable Power Plant in a Year	increase in Water Consumption due to Renewable Power Generation		✓		Renewal inputs require drying.
increase in Water Consumption due to Non-Renewable Power Generation	increase in Water Consumption due to Power Generation		✓		
increase in Water Consumption due to Renewable Power Generation	increase in Water Consumption due to Power Generation		✓		
increase in Water Consumption due to Power Generation	increase in Water Consumed from Local Water Source			✓	Not in the case of hydro electric
increase in Water Consumed from Local Water Source	decrease in Quantity of Local Water Source	✓			
increase in Quantity of Local Water Source	increase in Livelihood of Aquatic Animals	✓			
increase in Livelihood of Aquatic Animals	increase in Quantity of Local Aquatic Animals	✓			
increase in Quantity of Local Aquatic Animals	increase in Fishery Yield	✓			
increase in Fishery Yield	increase in Local Availability of Fish	✓			
increase in Local Availability of Fish Food	decrease in Import of Fish			✓	depending on growth of aqua industry
increase in Import of Fish	increase in Price of Fish	✓			
increase in Price of Fish	decrease in Affordability of Fish	✓			
increase in Affordability of Fish	increase in Domestic Consumption of Food	✓			
increase in Domestic Consumption of Food	increase in Need for Food Supply	✓			
increase in Need for Food Supply	increase in Import of Fish		✓		there are other alternatives
increase in Need for Food Supply	increase in Conversion of Available Land into Crop Area	✓			
increase in Conversion of Available Land into Crop Area	increase in Food Crop Area	✓			
increase in Food Crop Area	increase in Need for Food Local Irrigation			✓	depending crop types
increase in Food Crop Area	increase in Need for Food Supplied-Water Irrigation			✓	Rainfed farming might not be affected
increase in Need for Food Local Irrigation	increase in Size of Local Water Irrigation	✓			
increase in Need for Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation	✓			particularly in semi-arid areas
increase in Size of Local Water Irrigation	increase in Energy Requirement due to Crop	✓			
increase in Size of Supplied-Water Irrigation	increase in Energy Requirement due to Crop		✓		Some irrigation are gravity fed

Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Need For Non-Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation		✓		Non-food dost not need irrigation system but used a lot of from the ground which lead to quantity issue.
increase in Need For Non-Food Non-Supplied Water Irrigation	increase in Size of Local Water Irrigation		✓		
increase in Need for Food Local Irrigation	increase in Size of Local Water Irrigation	✓			
increase in Need for Food Supplied-Water Irrigation	increase in Size of Supplied-Water Irrigation	✓			
increase in Size of Supplied-Water Irrigation	increase in Supplied-Water Requirement due to Crop	✓			
increase in Supplied-Water Requirement due to Crop	increase in Supplied-Water Requirement due to Food	✓			
increase in Supplied-Water Requirement due to Food	increase in Need for Water Treatment System		✓		Food need to be increase for population which lead to ~~[illegible]~~ water demand.
increase in Supplied-Water Requirement due to Food	increase in Need for Water Supply System		✓		
increase in Size of Local Water Irrigation	increase in Water Withdrawal from Local Water Source due to Food	✓			
increase in Water Withdrawal from Local Water Source due to Food	increase in Water Returned to Local Water Source from Agriculture	✓			
increase in Water Returned to Local Water Source from Agriculture	increase in Pollution of Local Water Source	✓			
increase in Pollution of Local Water Source	decrease in Quality of Local Water Source	✓			
increase in Quality of Local Water Source	increase in Livelihood of Aquatic Animals	✓			
increase in Need for Food Supply	increase in Fishing Activity		✓		Not only fish but other such as weed
increase in Fishing Activity	increase in Fishery Yield	✓			
increase in Size of Local Water Irrigation	increase in Water Consumption from Local Water Source due to Food	✓			
increase in Water Consumption from Local Water Source due to Food	increase in Water Consumed from Local Water Source	✓			
increase in Water Consumed from Local Water Source	increase in Quantity of Local Water Source		✓		Quality and quantity is two different entity
increase in Conversion of Available Land into Non-Food Crop Area	increase in Non-Food Crop Area	✓			

Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Operational hours of Non-Renewable Power Plant	increase in Power Produced by Non-Renewable Power Plant in a Year	✓			
increase in Operational hours of Renewable Power Plant	increase in Power Produced by Renewable Power Plant in a Year	✓			
increase in Power Produced by Non-Renewable Power Plant in a Year	increase in Water Withdrawal due to Non-Renewable Power Generation	✓	~~✓~~		
increase in Power Produced by Renewable Power Plant in a Year	increase in Water Withdrawal due to Renewable Power Generation		✓		
increase in Water Withdrawal due to Non-Renewable Power Generation	increase in Water Withdrawal due to Power Generation	✓			
increase in Water Withdrawal due to Renewable Power Generation	increase in Water Withdrawal due to Power Generation		✓		
increase in Water Withdrawal due to Power Generation	increase in Water Withdrawn from Local Water Source	✓			
increase in Water Withdrawn from Local Water Source	increase in Water Returned to Local Water Source from Power Generation	✓			
increase in Water Returned to Local Water Source from Power Generation	increase in Pollution of Local Water Source	~~✓~~	✓		Proper treatment needed before water is returned to local source
increase in Pollution of Local Water Source	decrease in Quality of Local Water Source	✓			
increase in Quality of Local Water Source	decrease in Need for Water Treatment System		✓		
increase in Need for Water Treatment System	increase in Building of Water Treatment System	✓			
increase in Building of Water Treatment System	increase in Size and Number of Water Treatment System	✓			
increase in Size and Number of Water Treatment System	increase in Power Consumption due to Water Treatment	✓			
increase in Power Consumption due to Water Treatment	increase in Power Consumption due to Water Industry	✓			
increase in Power Consumption due to Water Industry	increase in Industrial Usage of Electricity	✓			

Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Domestic Usage of Water	increase in Need for Water Supply System	✓			
increase in Need for Water Supply System	increase in Building of Water Supply System	✓			
increase in Building of Water Supply System	increase in Size of Water Supply System	✓			
increase in Size of Water Supply System	increase in Operational Cost of Water Supply Services	✓			
increase in Operational Cost of Water Supply Services	increase in Domestic Water Tariff	✓			
increase in Domestic Water Tariff	decrease in Domestic Usage of Water	✓			
increase in Operational Cost of Water Supply Services	increase in Industrial Water Tariff	✓			
increase in Industrial Water Tariff	decrease in Industrial Usage of Water	✓			
increase in Industrial Usage of Water	increase in Need for Water Supply System	✓			
increase in Domestic Usage of Water	increase in Need for Water Treatment System	✓			Introduce Demand Management
increase in Industrial Usage of Water	increase in Need for Water Treatment System	✓			Introduce Demand Management
increase in Need for Water Treatment System	increase in Building of Water Treatment System	✓			
increase in Building of Water Treatment System	increase in Size and Number of Water Treatment System	✓			
increase in Size and Number of Water Treatment System	increase in Operational Cost of Water Treatment Services	✓			
increase in Operational Cost of Water Treatment Services	increase in Industrial Sewerage Tariff		✓		Not related
increase in Operational Cost of Water Treatment Services	increase in Domestic Sewerage Tariff		✓		
increase in Industrial Sewerage Tariff	decrease in Industrial Usage of Water		✓		
increase in Domestic Sewerage Tariff	decrease in Domestic Usage of Water	✓			

G. Population as Drivers of Demand Loop



Cause	Effect	True	False	Don't Know	Extra Comment / Remark
increase in Population	inrease in Birth	✓			
increase in Population	increase in Death	✓			
increase in Birth	increase in Population	✓			
increase in Death	decrease in Population	✓			
increase in Population	increase in Domestic Usage of Electricity	✓			
increase in Population	increase in Domestic Consumption of Food	✓			
increase in Population	increase in Domestic Usage of Water	✓			