PRIME MINISTER'S DEPARTMENT
ECONOMIC PLANNING UNIT

AKADEMI SAINS MALAYSIA

WST 2040

WATER SECTOR TRANSFORMATION

WATER-FOOD-ENERGY NEXUS (WFE)

(VOLUME V)

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WATER SECTOR TRANSFORMATION 2040

SUB-SECTORAL FINAL REPORT

WATER–FOOD–ENERGY NEXUS (WFE)

(VOLUME V)

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WATER-FOOD-ENERGY NEXUS (WFE) (VOLUME V)

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FOREWORD

The Economic Planning Unit (EPU), on 3rd April 2020, appointed the Academy of Sciences Malaysia (ASM) as its strategic partner to undertake the Study on Water Sector Transformation Agenda 2040 (WST2040), to transform the water sector from an enabler to becoming a dynamic growth engine by 2040, as stated in the 12th Malaysia Plan (12th MP). This standalone Volume 5, "Water-Food-Energy Nexus (WFEN)", forms part of 9 compendia of reports. Volume 1, the Main Report, summarised the output of Volume 2 to Volume 9. The details in Volume 1, can be found in each of the 8 standalone reports.

The emphasis in all these reports is on achieving a secure, sustainable, and vibrant water industry in Malaysia, to forge it into a dynamic, efficient, sustainable, and revenue-generating industry. The study, if the recommendations are implemented, will contribute significantly to the national gross domestic product (GDP), create new job opportunities, and facilitates the development of science, technology, innovation, and economy (STIE), and will enhance the research, development, innovation and commercialisation (RDIC) of indigenous new products for both the national and global platforms. This transformation agenda is planned over two decades and four phases of four five-year Malaysia Plans (MP), starting with 12th MP.

The water-food-energy nexus, or WFEN, is an emerging area of focus internationally and a nascent area of focus for Malaysia. Its core ideas and principles are established – a holistic approach towards resource security that considers the interactions between resources, such as water, food, and energy is better placed to address resource security concerns than a silo, individual approach. The chief reason for this is the richness of interactions across resources. Water use in food production has implications for both water and food security; water use in energy production has implications for both water and energy; and so on. Beyond these two-way nexus interactions, three-way nexus interactions add a further layer of complexity, and create the conditions for policymakers to devise avenues through which to take advantage of any opportunities that may arise through the adoption of integrated practices, or technologies which allow an integrated approach to resource management to flourish.

To achieve this ambition, we have partnered with expert advisors and researchers from multiple organisations led by Institute of Strategic and International Studies, Malaysia (ISIS), and leveraging on their knowledge and expertise. This sectoral study team has arrived at a series of policy recommendations which strive to achieve a mainstreaming of nexus concepts in Malaysia. On behalf of ASM, I would like to take this opportunity to thank the WFE Nexus team headed by Dr. Ahmad Hezri Adnan FASc, currently of MIER (Malaysian Institute of Economic Research) for all their dedication, hard work, and commitment.

Thank you.

Ir. Dr. Salmah Zakaria FASc,
Chairperson, Project Management Committee WST2040,
Water Sector Transformation (WST2040) Study Team, EPU-ASM,
Chairperson, ASM Water Committee, 2015-2021

PREFACE

Issues about resource security are central to the long-term development of any nation. Recent years have seen a significant shift towards emphasising sustainable development and addressing climate change and its resultant impacts. These trends require a serious rethink of how Malaysia handles its natural and strategic resources to promote more significant conservation and use efficiency. Applying nexus approaches to water, food, and energy resources is one step in the relevant direction. It forces stakeholders, from regulatory and government authorities to corporations and individuals, to view resources not singularly but as interrelated components. Nexus approaches, in other words, allow us to develop a complete picture view of the impacts of targets to enhance security in one key resource on others. For instance, aims to improve food security may require greater water use in irrigation, which requires greater energy use to pump water. Nexus approaches allow us to map out and understand the extent to which the quest to enhance food security can challenge the nation's water and energy security.

Because of the nascent focus on the water-food-energy nexus (or WFEN) in Malaysia, this report sets the stage for future endeavours in Malaysia that might assist in the institutionalisation and mainstreaming of WFEN-related matters nationally. Key contributions of this study include its role in laying out the landscape of nexus interactions nationally. It identifies the key nexus arenas across various geographical regions where either two- or three-way nexus interactions are seen playing out regularly. Challenges may arise if targets for resource security in one resource are set in isolation from others.

In terms of two-way nexus interactions, a significant emphasis of this study is on water use in food production, particularly in the context of irrigation for paddy production, which is a crucial consideration given the role of rice as a national food staple as well as the size and political clout of the paddy farming community from a socioeconomic perspective. It also highlights the energy use requirements of paddy production, whereby energy is required to lift and pump water from rivers and other water storage to irrigate crop fields. Water is also used in energy production more generally; water is consumed for steam generation in thermal power plants and is withdrawn for electricity generation in hydropower dams. And this interaction cuts both ways: energy is used to transfer water via pumping and the treatment of raw and sewage water.

Beyond the two-way nexus are the more complex three-way nexus interactions. In the context of Malaysia, three major three-way WFEN interactions have been identified. This study develops in-depth analyses of key three-way nexus 'flashpoints', including large-scale solar (LSS), hydropower, and biogas. In particular, emphasis has been placed on the available opportunities to mitigate the adverse effects that might arise from the intricate and convoluted relationships between the three key strategic resources in these particular arenas. To illustrate this issue, consider large-scale solar. A form of renewable energy, LSS is promoted as a technology that can assist in decarbonising electricity generation in Malaysia. It requires limited water use, although freshwater is often withdrawn from water bodies to clean solar panels. Yet challenges arise because areas of high solar irradiation are often either forested or are productive arable land, which means the emphasis on LSS can lead to deforestation or the conversion of agricultural land, which can have negative knock-on consequences for water and food security, in addition to concerns over the impact on biodiversity and ecosystems.

For this reason, our analysis has highlighted the potential benefits of a shift in Malaysia's emphasis on LSS towards agrivoltaic LSS and floating LSS. These circumvent some of the concerns associated with deforestation and land-use change; if LSS farms were located atop of abandoned mining pools, for instance, concerns over both could be avoided. If LSS farms did not inhibit using the same land for agricultural production, food security concerns can also be limited to a greater extent than would be the case if the issue was not approached from a three-way, WFEN lens. This study uses this same logic to analyse the potential of biogas and hydropower as WFEN 'solutions'.

Using the understanding developed through this study on the key areas of WFE nexus 'flashpoints' or challenges, as well as the institutional arrangements around matters of resource security in Malaysia, this study has proposed a long-term roadmap that seeks to institutionalise and mainstream nexus-related considerations in policymaking and planning nationally, in line with the visions and aspirations of Malaysia's Water Sector Transformation 2040. The elements of this roadmap cover the focus areas of governance, people, infrastructure and technology, information and RDIC, and economics and finance, focusing on five distinct proposals to achieve the desired institutionalisation of WFEN approaches in Malaysia. These are as follows:

1. Establishing River Basin Organisations (RBOs) to govern nexus dynamics at the river basin-level, mainly where cross-sectoral (or cross-border) challenges affect resource availability and use.
2. Establishing a WFEN Centre of Excellence (CoE) to facilitate the adoption and mainstreaming of nexus approaches and concepts, in particular its role as a knowledge and research hub for matters relating to the WFEN, as well as disseminating this knowledge for the benefit of the various stakeholders involved and facilitate the deployment of technologies to address resource security concerns.
3. Establishing river basin-level hydrological databases and related decision-support systems to inform policymaking. This review highlights the importance of facilitating extensive data collection and monitoring and the application of this data to generate insights into the development of nexus solutions at the river basin level.
4. Using economic and other policy instruments to address nexus issues. These include economic incentives and disincentives (e.g., subsidies or punitive measures such as penalties), the use of cross-sectoral targets, revised institutional arrangements, informational tools, and others.
5. Facilitating investment in and deployment of infrastructure and technologies to support mainstreaming of WFEN to allow for nexus approaches to contribute to sustainable economic growth, including approaches to public-private partnerships in generating investment through voluntary agreements or incentives. Innovating financing arrangements are also analysed to create the necessary investment to enhance water sector infrastructure.

By following through on the proposals outlined in this analysis, the study team hopes that Malaysia would by 2040 have a clear vision and strategy for the mainstreaming of nexus considerations in sectoral development planning where the use of resources such as water, food, and energy is concerned, and particularly where their usages intersect and form a 'nexus'. In doing so, Malaysia would be in a stronger position to ensure that an emphasis on resource security in one area, food, would not create significant adverse consequences for concurrent goals to address or manage water and energy security. By following through on these actions over the course of the next two decades, Malaysia would also be in a strong position by 2040 to act as an international leader in nexus approaches and solutions and be able to leverage on this ecosystem from commercial, economic, and geopolitical perspectives in an age where issues, such as climate change, transcend national interests and boundaries with regularity.

Dr. Ahmad Hezri Adnan FASc
Chairperson
Water-Food-Energy (WFE) Nexus Sub-sector
Water Sector Transformation (WST2040) Study Team

LIST OF ACRONYMS

ASM	Academy of Sciences Malaysia
BOD	Biochemical Oxygen Demand
CCGT	Combined-Cycle Gas Turbine
CDM	Clean Development Mechanism
CERs	Certified Emission Reduction Credits
COD	Chemical Oxygen Demand
CoE	Centre of Excellence
CPO	Crude Palm Oil
DO	Dissolved Oxygen
DOSM	Department of Statistics Malaysia
DSS	Decision Support System
EC	Energy Commission
EFBs	Empty Fruit Bunches
EPU	Economic Planning Unit
EQA	Environmental Quality Act 1973
FFBs	Fresh Fruit Bunches
FiT	Feed-in Tariff
GHG	Greenhouse Gas
GITA	Green Investment Tax Allowance
GITE	Green Investment Tax Exemption
GTFS	Green Technology Financing Scheme
IoT	Internet of Things
IRENA	International Renewable Energy Agency
IWRM	Integrated Water Resources Management
JPS	Department of Irrigation and Drainage
LAP	Lembaga Air Perak
LP	Linear Programming
LSS	Large-Scale Solar
MADA	Muda Agricultural Development Authority
MCM	Million Cubic Metres
MLD	Million Litres per Day or Megalitres per Day
MP	Malaysia Plan
NAHRIM	National Water Research Institute of Malaysia
NAP	National Agrofood Policy
NAWABS	National Water Balance Studies
NKEA	National Key Economic Areas
NREPAP	National Renewable Energy Policy and Action Plan
NRW	Non-Revenue Water
NWRS	National Water Resources Study 2011
PES	Payment for Ecosystem Services
POME	Palm Oil Mill Effluent
PPP	Public-Private Partnership
PV	Photovoltaic

RE	Renewable Energy
RBO	River Basin Organisation
SCORE	Sarawak Corridor of Renewable Energy
SDGs	Sustainable Development Goals
SESB	Sabah Electricity Sdn. Bhd.
SS	Suspended Solidso
STP	Sewage Treatment Plant
TNB	Tenaga Nasional Berhad
WEF	World Economic Forum
WFE	Water-Food-Energy
WFEN	Water-Food-Energy Nexus
WEI	Water Exploitation Index
WSI	Water Stress Index
WSIA	Water Services Industry Act 2006
WST2040	Water Sector Transformation 2040
WtE	Waste-to-Energy
WTP	Water Treatment Plant
WWF	World Wildlife Fund
WWTP	Wastewater Treatment Plant

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EXECUTIVE SUMMARY

Overview

Water, food, and energy are basic necessities in the ensuring of human life and are essential components of economic development. Sustained economic and population growth is expected to increase demand for all three resources, in a hungrier, thirstier, and increasingly energy-intensive world. Accordingly, efforts have been made to enhance water, food, and energy security in order to address these external pressures, but nascent research focusing on nexus interlinkages between strategic resources (such as water, food, and energy) highlights the complex and highly interconnected nature of these resources. Such complexities and the challenges they create require integrated solutions.

One of the key takeaways of this study is the highlighting of nexus challenges or 'arenas' in the context of Malaysia. A precursor study, overviewing the Water-Food-Energy (WFE) Nexus in Malaysia (Hezri, 2018) identified potential arenas where nexus approaches are relevant and can have significantly positive results. The objective of this study, therefore, is to provide greater in-depth analysis and understanding of these nexus challenges, as well as to recommend policy responses to address these nexus challenges across Malaysia, as part of the Water Sector Transformation (WST2040). To this end, some of the critical two- and three-way nexus interactions relevant to the context of Malaysia are discussed in the table below:

Table 1. Two-and Three-Way Nexus Arenas in Malaysia

Interaction	Nexus Arenas
Water-Energy	• **Choice of energy generation technology**: Different types of technologies (Thermal, CGGT, PV, etc.) has different water consumption factor and water withdrawal factors. Solar photovoltaic (PV), for example is one of the most efficient in terms of water usage • **Source of water for cooling and condensation**: Water for cooling is mostly from seawater, while freshwater is required for steam generation. Potential nexus arena is where water for cooling is from freshwater resources. • **Impact of water pollution**: High turbidity, such as in the case of Sg. Perak (from Teluk Kepayang has led to critical levels for condensation/steam generation
Energy-Water	• **Efficiency in energy for water supply**: Energy is to lift, treat, and distribute water • **Efficiency in energy for wastewater**: Significant energy is used for wastewater treatment • **Impact of urbanisation**: As urban areas grow vertically, more energy is required to lift and distribute water
Water-Food	• **Competing food security targets**: Meeting self-sufficiency levels of some produce will increase agricultural demand on water • **Water for development**: Low water levels have affected food production, which in turn affect farmers' incomes (i.e., Sg. Kelantan) • **Efficiency in food production**: Agricultural practices utilise less water and produce more crop per drop
Food-Energy	• **Agricultural land**: Food production faces competing uses, including the food-fuel debate in relation to biofuels as well as Large Scale Solar farms • **Waste to wealth**: Opportunities for wastewater to be translated into energy production through biogas production

Food-Energy-Water • **Biogas**: Production of biogas may improve water quality if it reduces effluents such as Palm Oil Mill Effluents (POME)

Water-Energy-Food • **Large-Scale Solar**: While large scale solar is water efficient, it may result in competing use of agricultural land, directly or indirectly

Water-Energy-Food • **Hydropower and dams**: Single purpose hydro dams can affect downstream activities, including for food production. Multipurpose hydropowers and dams provide a nexus opportunity to meet the various demands.

Scope 1: Review and Analysis of Current Policies

Scope 1 of this Report highlights current policies across the relevant sectors, focusing on the utilisation of the nexus approach in Malaysia. However, given that nexus approaches still remain a relatively novel concept – especially in Malaysia – existing policy documents make no explicit mention of the WFEN. Nexus approaches are nonetheless enshrined in the various sectoral policies which entail a focus on resource efficiency and resource optimisation. It is the implementation of cross-sectoral policies – a critical aspect of such nexus approaches – that made challenging due to a few factors. First, there is an absence of cross-sectoral policy targets, such as for targets for water use efficiency in agriculture and energy production, energy use in wastewater treatment, and energy use in pumping or lifting of water. Secondly, the lack of the use of policy instruments, and in particular economic instruments to either provide incentives for the nexus approach, or disincentivise 'siloed' approaches to resource security or inefficient and wasteful practices, are inhibiting the environment for the utilisation of nexus methods. Thirdly, the institutional framework is complex and fragmented both across and within sectors. This complexity is exacerbated further by fragmentation across state and federal lines, where water is constitutionally a state matter, yet water security matters – and indeed even river basins – regularly transcend such boundaries. Fourth, a lack of data hampers the measurement of cross-sectoral impacts and the effects of policy responses. Finally, there is a general lack of foresight and strategic resource planning in order to determine the appropriate strategic interventions required at a national level to address issues of strategic resource security and sustainability in Malaysia.

Major Policies Across the Water, Food, and Energy Sectors

#	Policy Name	Year	Mandate	People	Governance	Information & RDIC	Economic & Finance
1	11th Malaysia Plan	2015–2020	EPU	Yes	Partially	Partially	Partially
2	National Water Resources Policy (NWRP)	2012	KASA	Partially	No	No	No
3	National Agrofood Policy 4	2011–2020	MAFI	Partially	Partially	No	No
4	National Energy Policy	2010	KeTSA	Partially	Partially	Partially	Partially
5	National Energy Efficiency Action Plan	2015–2025	KeTSA	Partially	Partially	Partially	Partially

The policy recommendations are listed below:-

1. Review National Water Resources Policy (NWRP) to include the monitoring of WFE Nexus by adopting the Water Stress Index (WSI) indicator.
2. Include water and energy use efficiency policy targets for water, energy, and food production in associated policies.
3. Establishment of a single National Water Department (NWD) as part of a strategy in NWRP.
4. Establishment of River Basin Organisations (RBOs) to better incorporate WFEN approaches within the water, food, and energy sectors.
5. Establishment of a Centre of Excellence (CoE) on WFEN Nexus as part of the 12th MP.
6. Develop informational instruments, including a WFEN Technical Guide and Manual as part of the NWRP.
7. Include a focus on capacity building on modelling for WFE Nexus as part of the revised NWRP.
8. Establish a Decision Support System (DSS) based on a hydrological or "hydrosocial" database as part of the monitoring and evaluation of NWRP.
9. Increase the use of economic instruments to promote resource efficiency and nexus approach through the NWRP.
10. Include pilot infrastructure and technology to support WFEN approaches/initiatives as a means of implementation in NWRP.

Scope 2: Comparative Strategy Analysis

Our review of international best practices utilising nexus approaches is centred on five elements that are crucial in the determination of whether nexus approaches can be successfully incorporated and mainstreamed into policymaking and used as tools to alleviate concerns related to strategic resource security and efficient resource use. The first of these elements is the establishment of RBOs to act as custodians of river basins determining the optimal utilisation of strategic resources and acting as a key factor in water diplomacy in the presence of competing interests, whether transboundary or cross-sectoral. Second is the establishment of a WFEN Centre of Excellence (CoE), which would act as a local source of expertise on the mainstreaming of nexus approaches. It would play a critical role in developing the domestic capacity to study and model nexus issues and considerations at the river basin level, and use these insights to facilitate the deployment of nexus-related infrastructure and technology to alleviate strategic resource security issues. The third area considered relates to the standard of data collection and analysis required to understand and model nexus issues; to that end, best practices are highlighted with regard to hydrological databases and associated decision support systems and their impact on policymaking. Fourth, we analyse a variety of policy instruments used to address nexus issues, and resource use more broadly. Finally, we look at the role of the public and private sectors in providing investment, or the conditions for investment, in nexus infrastructure and technologies, including an analysis of the potential of large-scale solar, biogas, hydropower, and water treatment plants in alleviating nexus concerns across various regions in the world.

Scope 3: Study Potential of the Nation's Water Sector Industry Taking into Consideration Current Global Markets Towards Marketing the Water Sector as a Dynamic New Economic Sector Capable of Driving the Nation's GDP Growth in the Future

This scope analyses nexus issues and opportunities from the perspective of resource security, highlighting the various activities occurring at the river basin level which have implications for water, food, and energy. Following this it overviews the National Water Innovation Roadmap 2040, which indicates key water sector issues, including scarcity and pollution, and the framework for facilitating innovative technological developments to address these concerns. It provides a detailed analysis of the nexus-related technologies that can address resource security issues highlighted in our international best practice review. This includes an emphasis on large-scale floating solar technologies, Palm Oil Mill Effluent (POME) biogas, a by-product of oil palm production, and hydropower, offering insights into their potential as nexus-enhancing technologies that can have positive implications for water, food, and energy security.

Scope 4: Transformation Strategy and Initiative Implementation Framework

The nexus approach aims to transition the industry from a silo approach to an integrated and strategic resource management approach by 2040. To achieve this, the overall ecosystem of the water sector will need to be reformed as below:

The recommended strategies and initiatives are outlined below:-

- **Identify nexus hotspots and Reduce 'Water Stress Index' (WSI) in relation to food and energy sectors**: To enhance identification and monitoring of WFE nexus, the WSI is proposed to be adopted as an indicator to identify nexus hotspots. The aim is to reduce river basins from 'Severe Stress' to 'Stress', 'Low Stress' or 'Not Stressed' in major granary areas.
- **Establish a multi-tiered institutional arrangement:** Three initiatives are proposed under this strategy to transform towards in-situ development and integrated governance and transitioning towards Integrated Water Resources Management (IWRM).
    - o Establish a National Water Department (NWD) to manage interactions between water and food, energy, and other sectors, encouraging a holistic view of water/water industries;
    - o Establish a River Basin Organisation (RBO) at every state to better incorporate WFEN approaches within the water, food, and energy sectors, including investment facilitation; and
    - o Develop informational policy instruments, including a WFEN Technical Guide and Manual
- **Capacity building, communication, education, and public awareness:** To address the lack of capacity, two initiatives are proposed: -
    - o Establish a WFEN CoE consisting of technical and policy expertise; and
    - o Initiate and strengthen R&D in WFE Nexus/Nexus Modelling in Malaysia
- **Piloting infrastructure and technology to support WFEN approaches/initiatives:** As a novel concept, pilot projects are required to test the nexus solutions in the context of Malaysia. This process should be bottom up and led by innovation from the private sector and facilitated by the government. For example, an establishment of a pilot project fund that accepts proposals from the private sector to address specific issues related to nexus challenges could be established.
- **Establish a database with usable information as a policy decision tool at the basin level:** Establish a Decision Support System (DSS) for WFEN, including the development of a hydrological database

with improved monitoring of water catchment areas, alongside the development of modelling systems covering critical/stressed river basins

- **Increase the use of economic instruments to promote resource efficiency and nexus approach:** This includes undertaking assessments on the economic value of water at river basin levels. From these assessments, the appropriate mechanisms that can enhance the economic value and potential of river basins will be identified.

1.0 BACKGROUND TO THE STUDY

1.1 What is the Water-Food-Energy Nexus?

Water, energy, and food are tightly interconnected strategic resources and emphasis has emerged in recent decades on the water-energy-food nexus (Vogt et al., 2010; Endo et al., 2020). Roughly, 8% of global water withdrawals are used to generate energy. Energy, in turn, is needed to transport and fertilise crops: food production, and its associated supply chains, are responsible for approximately 30% of total global energy demand. Indeed, crops themselves can be used to produce biofuels (Hoff, 2011). Considering the increasing and varied demand of water resources from all sectors and the destruction of the utility value of water through pollution, it is now crucial and urgent that the whole spectrum of water-energy-food nexus be given attention and analysed.

There exist clear and significant interactions between water, energy, and food that may result in competition, synergies, and a multitude of trade-offs between different sectors or interest groups. However, current planning, foresight, and implementation of policies that affect these strategic resources are performed separately (Ghodsvali et al., 2019). Given the aims of building a sustainable and inclusive future, current 'business-as-usual' policy and regulatory frameworks can no longer be considered viable models of economic development. Malaysia, and indeed many other nations, cannot rely on the same finite water, energy, and food resources far into the future without significant changes in existing policy and regulatory frameworks in ways that address the issues and opportunities that exist because of the deep synergies between these three resources.

The nexus approach provides a more integrated way to balance the various policy choices (see Figure 1). It must be noted that there is no single bullet and these policy choices are often contextual. The study design will analyse specific contexts of two-way nexus, and, if any, how they manifest themselves into three-way nexus. Additionally, these two-way and three-way nexuses interact with megatrends and pressures such as population growth, climate change, increase in pollution, increase in consumption, urbanisation as well as challenges related to governance and the wider political economy. Indeed, many nexus analyses in the academic and policy literature include variables such as land-use and climate as an additional nexus element; for instance, focusing on three-way interactions of water-energy-climate or even the four-way water-energy-food-climate nexus. In the context of this study, many of the three-way nexus interactions analysed can be extended to include climate as a fourth nexus element; this is because the interactions analysed involve renewable energies such as solar, biogas, and hydropower, meaning the adoption of WFEN technologies would have implications for climate change mitigation – and in some cases, adaptation – as well. Nonetheless, by understanding this complex landscape, decision-making and policy choices can shift towards single resource to multiple resources. The outcome of the study will provide some of the policy choices to meet and balance the trade-off and synergies of current policy targets. On the one hand, it can ensure greater security across all three resources. On the other, it provides opportunities to take advantage over the economic potential of these strategic resources.

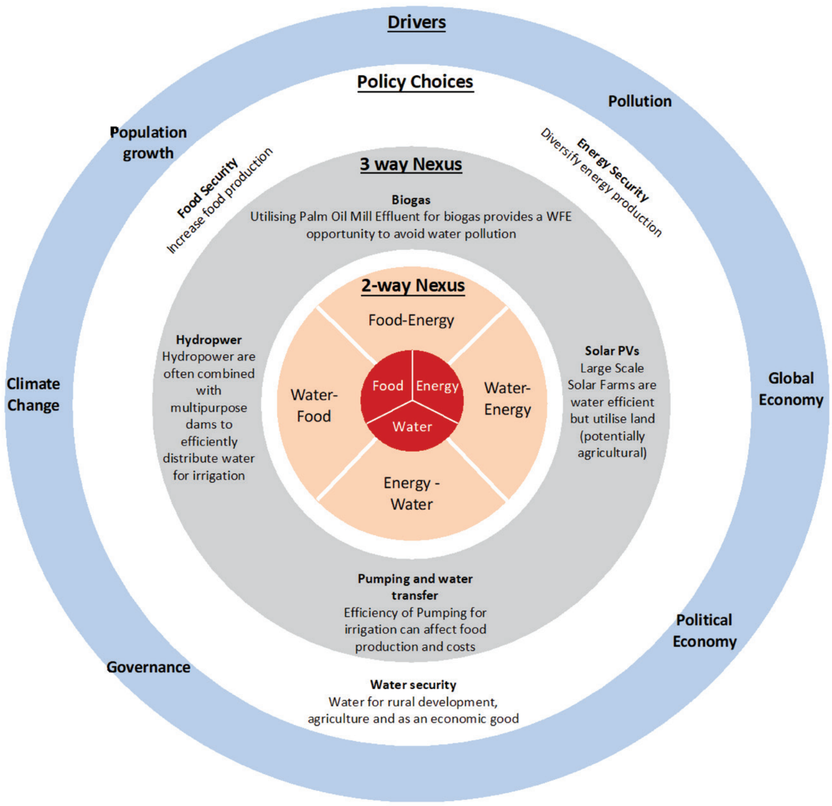

Figure 1. The Nexus 'Wheel'

1.2 Premise and Strategy of the WFE Nexus

1.2.1 Achieving WFEN Security to Support Livelihoods

The WFE nexus had a strong focus on resource security in its early years (Simpson & Jewitt, 2019). With projections of increase in the global demand of water, energy, and food, the nexus poses a challenge for both resource and human security (Simpson & Jewitt, 2019; UNESCAP, 2013; World Economic Forum, 2011). The securitisation of these three resources is underpinned by the idea of 'limits' which was first brought about in the 1970s and 1980s. More recently, work on the planetary boundaries demonstrate the biophysical limits of a "safe operating space for humanity", highlighting the link between natural resource security and human security (Rockström et al., 2009).

To ensure WFE security, the starting point is to build upon the three independent security frameworks. Bizkova et al. (2013) identified the elements of each independent security as can be seen in the figure below.

Table 2. Water, Food, and Energy Security Parameters (Bizikova et al., 2014)

Food Security	• Food availability: influenced by production, distribution, and exchange of food;
	• Access to food: including affordability, allocation, and preference;
	• Utilisation: nutritional value, social value, and food safety
	• Food stability over time
Water Security	• Water access;
	• Water safety;

- Water affordability so that every person can lead a clean, healthy, and productive life while ensuring that the natural environment is protected and enhanced

Energy Security
- Continuity of energy supplies relative to demand;
- Physical availability of supplies;
- Supply sufficient to satisfy demand at a given price

From the preceding study on WFE Nexus in Malaysia by Hezri (2018), it was found that water is the most critical in terms of security. In particular, the water sector performed poorly in relation to efficiency due to high rates in non-revenue water. Non-revenue water was 36.4 percent in 2020, which is above the World Bank's recommendation of being less than 25 percent of produced water. Sustainability is also compromised due to challenges related to pollution. In 2019, the Compendium of Environmental Statistics (2020) reported that 10 river basins (7%) were classified as polluted and 49 rivers (34%) slightly polluted out of 144 river basins monitored. Furthermore, in the past 30 years, in comparison with other countries, revenue of water utilities has only shown a slight increase despite cost escalations and rising operation costs. While the overall reserve margin at 16.3 percent is above the minimum threshold of 15 percent at the national level, some water utilities reserve margin is below 5 percent. These challenges demonstrate the vulnerability and challenges to address water security in Malaysia.

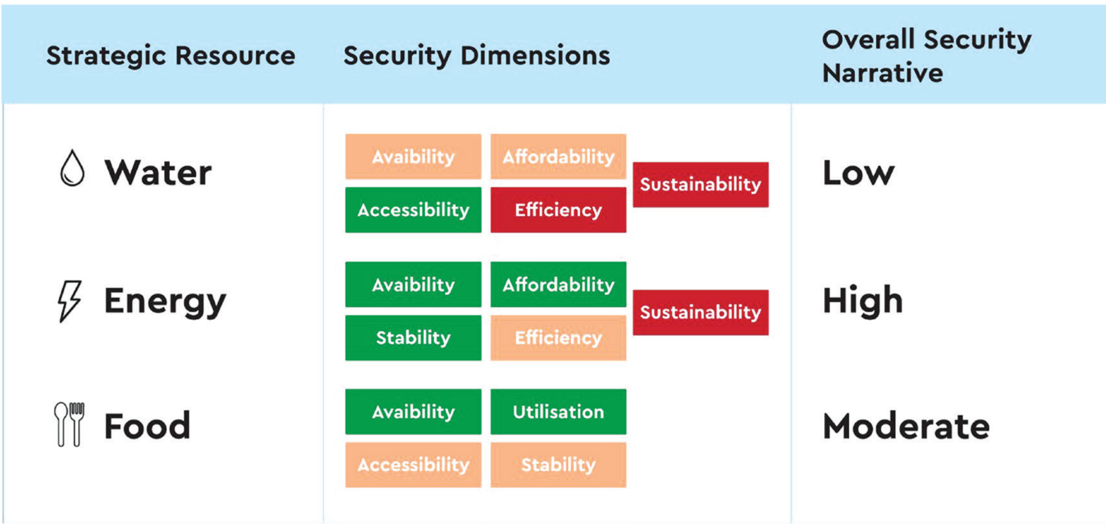

Figure 2. Comparative Policy Responses for Water, Food, and Energy Security (Hezri, 2018)

Globally, the Water-Energy-Food (WEF) Nexus Index is a tool that measures WEFN security in a composite manner. The index aggregates 21 globally available indicators. The WEF Nexus Index Value[1] for Malaysia is 67.8, placing the nation in the 18th position amongst countries assessed. Malaysia has an index score of 79.4 for the water pillar, 64.1 for energy, and 59.9 for food. Under the water pillar, Malaysia is ranked 4th in the world based on accessibility and availability. In terms of energy, Malaysia ranked 29th, while for the food pillar, Malaysia ranked 53rd in the world. This demonstrates the difference in assessment on security if it was based on availability and accessibility alone and does not take into consideration other factors such as efficiency, sustainability, and stability. Nonetheless, it highlights the abundance in natural resources generally, and in particular, for water in the context of Malaysia.

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[1] Water Energy Food, WEF Nexus Index website – https//wefnexusindex.org/

Figure 3. Malaysia's WFE Nexus Index

1.2.2 WFEN as an Economic Imperative

One of the major challenges of the nexus approach is to balance resource prospecting with creating new abundance. While security concerns have dominated nexus literature and approaches previously, on the other hand, countries with abundance of resources can utilise the nexus approach as an economic opportunity.

Globally, an emerging trend is the reframing of "wicked problems", or those which are complex, dynamic, and seemingly intractable as opportunities rather than challenges. These opportunities are then taken through solution ecosystems, largely driven by businesses alongside networks of civil society, experts, and government. Through the fourth industrial revolution and greater volume, velocity and veracity of information, increased comprehension of the challenges and solutions are possible to address such wicked problems. It is driven partly by the need to internalise sustainability in businesses as well as creation of new forms of value. For example, Nestlé has undertaken efforts such as harvesting rainwater from their warehouse roofs, reducing sanitise flushes in cleaning circuits to address issues of water. Furthermore, efforts to address water-energy nexus has also been implemented such as reducing the blowdown rate of cooling towers in their manufacturing facilities in the Murray-Darling river basin in Australia to reduce energy losses and increase efficiency. Nonetheless, moving towards such a system requires developing an integrated ecosystem with various actors and integrators to bridge the disparate organisations together in a partnership arrangement. These includes business leaders, data holders, and data analysts to inform decisions, civil society to promote action and monitoring, and experts to provide strategic direction.

From a policy and government perspective, development of the ecosystem also requires an enabling environment driven by progressive policies. The nexus approach looks at the possible policy tools that can address nexus issues. This includes fiscal tools, such as market-based instruments and environmental taxes that can potentially create interdependencies and synergies between the WFE systems as well as financial tools and technological innovation.. The potential policy tools adapted from Brears (2018) are listed in Table 3 below:

Table 3. Policy Tools for Nexus Economics (Brears, 2018)

Policy Tools	Objective	Mechanisms	Examples
Market-based instruments and pricing	Integration of natural asset base to market decisions	Tariffs, levies, charges, tradeable permits, soft loans, etc.	Water tariff based on level of scarcity, payment for ecosystem services
Environmental taxes	To raise the cost of production or consumption as demand side management	Taxes on high consumption of energy, carbon and/or water	Carbon tax, fuel tax
Financial and investments	Encourage synergies across WFE nexus	PPPs, Finance products, subsidies, and grants	Incentives for multiple resource innovations
Technological innovation	Improve performance resulting in higher efficiency	Innovation	Precision farming, pumping, etc.

In the context of Malaysia, the economic imperative is arguably lacking. As highlighted above, Malaysia's potential to become a hub for water is evident in its high ranking in terms of availability. Nonetheless, efforts will need to be undertaken to transform the ecosystem to be more in line with sectors such as energy and telecommunications. As an example, the revenue for the water industry in Malaysia is RM6bil, in comparison with RM60bil in the energy sector. Moving forward, the overall ecosystem needs to shift towards seeing water generally, and the nexus approach more specifically, as economic imperatives.

1.2.3 Achieving Sustainability and Circularity

The WFE nexus approach is strongly linked to sustainability and sustainable development. The integrated and systems approach of nexus builds upon the need for addressing the balance between the social, economy, and environment. In many ways, the nexus approach is a quintessential sustainable development approach – whereby it promotes problem solving that is not piecemeal but rather taking into consideration the interactions and interdependencies in a holistic manner. In this sense, the nexus approach itself is a sub-set of sustainable development.

The green economy approach is also closely related to sustainability and sustainable development. Brears (2018) argues that the WFE nexus approach can reduce pressures towards achieving green growth. Some of the relevant areas highlighted include the following:

- Increase resource productivity – through increasing efficiency and decoupling resource use with environmental degradation
- Using waste as a resource – through a circular economy
- Economic incentives – improvements in resource productivity will require investment and incentives such as through pricing of resources (and ecosystem services)
- Ecosystem services – ecosystem conservation can lead to multiple benefits to other sectors

At the international arena, the Sustainable Development Goals (SDGs) was adopted by all United Nations member states as the global development agenda. Although it consists of 17 individual goals, it is meant to be addressed in an integrated manner (United Nations, 2015). In the context of nexus, all three resources have their own individual goals. To achieve the SDGs in an integrated manner, the sustainability perspective will ensure that the achievement of one goal does not compromise the achievement of another (trade-offs) as well as promoting mutually beneficial solutions (synergies).

1.2.4 Towards a Transformation Strategy for the Water Sector by 2040

The key outcome of this study is to chart a transformation strategy for the water sector until 2040. The evolution of the water industry can be seen through its development across various paradigms linked to the above premise. The first paradigm is water as a plentiful resource, followed by water for development, water as an economic good, water scarcity as security issue, and water sustainability (see Figure 4).

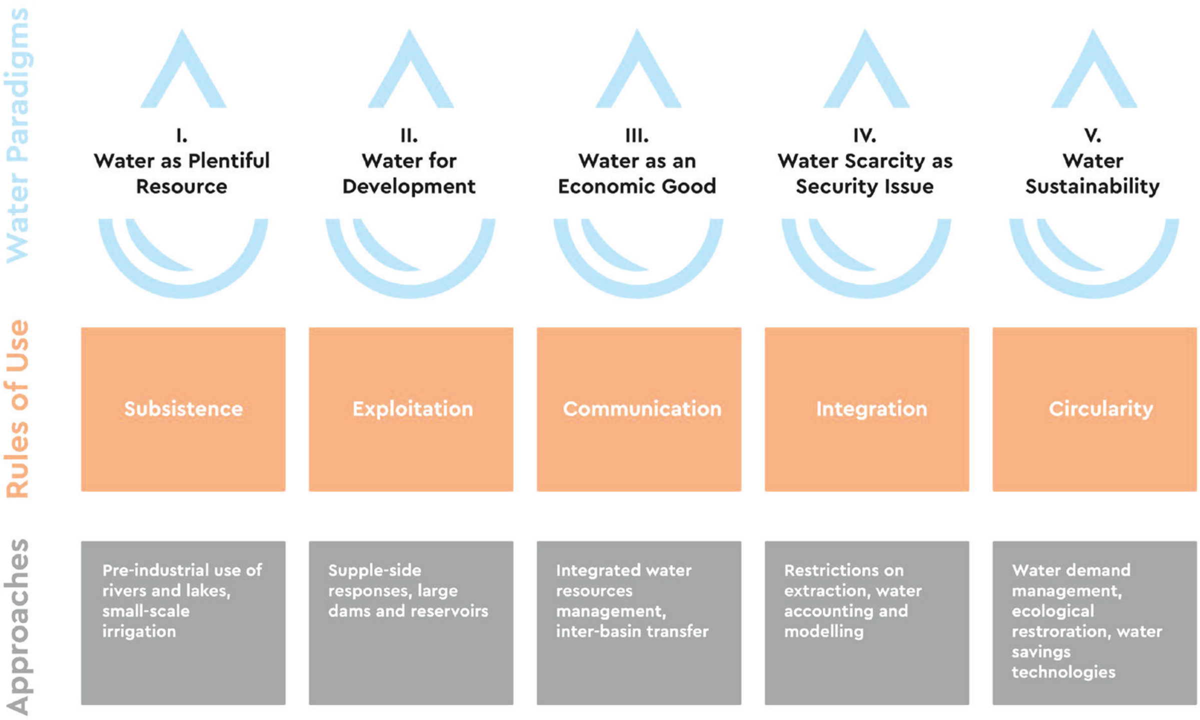

Figure 4. The Evolution of Water Paradigms (Hezri, 2018)

Malaysia first recognised the need to embark on a water reform journey way back in the 1990s when its economy was booming and the population fast increasing. By the 2000s it was evident that the water services industry must be financially viable and cannot continue as a social service. The shift in paradigm whereby water was considered an economic good underpinned the endorsement of the *Water Services Industry Act 2006* or the WSIA management reform programme. Arguably, Malaysia is still in the Type II reform with little emphasis on equity and sustainability. The nexus focus belongs to the Type IV and Type V reform. Interestingly, this study, is part of the water sector transformation plan aims for Malaysia to transition the sector towards seeing water as an economic resource. Nonetheless, the Economic Planning Unit's overall objectives, aims for also addressing water security and sustainability within the transformation. For the purpose of this study, and towards achieving the overall objectives of the WST2040, the policy recommendations will be geared towards the transformations required to move in order to evolve water governance to address water from an economic resource point view (Type III); water from a security point of view; and sustainability of the water sector.

2.0 OBJECTIVES OF THE SUB-SECTORAL STUDY

This study has the following objectives:

i. Mapping of the key nexus stakeholders from both the public and private sectors as well as those from academic CoEs;
ii. Identifying key 'nexus arenas', where the quest for security in one area has compromised others across Malaysia. These will cover both the two- and three-way nexus interactions that commonly play out across the country;
iii. This study develops in-depth analyses of key nexus flashpoints, such as water pumping, large-scale solar, hydropower, and biogas, amongst others, as the basis for developing seven concrete policy recommendations or strategies that will allow a mainstreaming of the nexus approach, situate it within the broader framework of the circular economy and sustainable development, and in doing so allow the WFEN approach to contribute significantly to the achievement of strategic resource security in Malaysia.
iv. Ultimately, the Study Team endeavours to prepare a WFEN roadmap that contributes towards the complete Roadmap for the National Agenda on Water Sector Transformation 2040.

3.0 SCOPE OF THE SUB-SECTORAL STUDY

The study combines internal and external relationship analyses. Internal relationship analyses present inner features of coupled systems by capturing the interactions between different sectors. The external relationship analyses, meanwhile, cover both physical and social dimensions of economic development.

3.1 Internal Relationship Analyses

To make a clear outline of the internal relationship analysis, the interactions between different sectors are distinguished as one-way impact analyses and interactive impact analyses. These one-way impact analyses indicate how changes in one specific sector may affect associated sectors. It provides valuable preliminary insights for decision-making even in the absence of a comprehensive description of the entire nexus system, as it accounts for potential trade-offs between different sectors. Many studies employ one-way impact analyses to investigate nexus impacts due to its analytical simplicity and lower research resource requirements (such as data, financing, and time, amongst others). Examples of such one-way impact analyses include:

- Land use changes caused by the production of biofuels, which may have adverse consequences on water quality and quantity. This points to the need to consider physical and environmental consequences in bioenergy policymaking.
- Rapid development of hydropower dams may result in a greater sediment starvation, leading to profound and negative effects on the downstream productivity of river basins.
- The development of solar technologies provides new ways to address the scarcity of energy resources, with significant impacts on existing interlinkages between nexus sectors.

Interactive impact analyses, meanwhile, describe the characteristics of the nexus more comprehensively. These reveal the interrelationships between different sectors through their bilateral relationships and feedback loops. These interactions help to determine the roles of multiple sectors in the collective system and identify the driving factors and processes in the development of any coupled systems. Changes in the strength of feedback loops, and any rearrangements of couplings may alter the dynamics of the system. Examples of such interactive impact analysis include:

- Evaluation of bilateral relations between two neighbouring state governments in the management of water, energy, and food resources. For example, it has been noted that energy and food production has greater impacts on water resources in Perak, while the impact of water supply changes on food production was more pronounced in Selangor.
- Wastewater reuse for agricultural production, as is performed in Barat Laut Selangor, may inspire new solutions to advancing the WFE nexus in water-scarce basins by reducing energy requirements for the pumping and improving of water quality through nutrient retention in agricultural irrigation.

This study employs quantitative methods in the form of mathematical statistics and modelling to identify the nature and extent of the internal relationships through both the one-way impact analyses and interactive impact analyses.

3.2 External Relationship Analyses

The WFE nexus system is usually set in a certain circumstance, i.e., external factors are assumed to be controlled or representative of the prevailing status quo. Any external environmental changes can complicate the performance of nexus systems by altering the production and use of water, energy, and food through interconnected processes. With water systems a central node, external threats to water resources and systems in Malaysia have deep implications for WFE nexus systems. These external threats refer to physical and social occurrences, with an emphasis on how long these threats persist (i.e., whether they involve abrupt or gradual changes. Climate change and resource depletion, for example, are chronic issues that have persistent repercussions for nexus issues, while incidents of extreme weather or severe pollution are acute, short-term occurrences). Figure 5 provides an overview of the external factors or occurrences that may have effects on the WFE nexus.

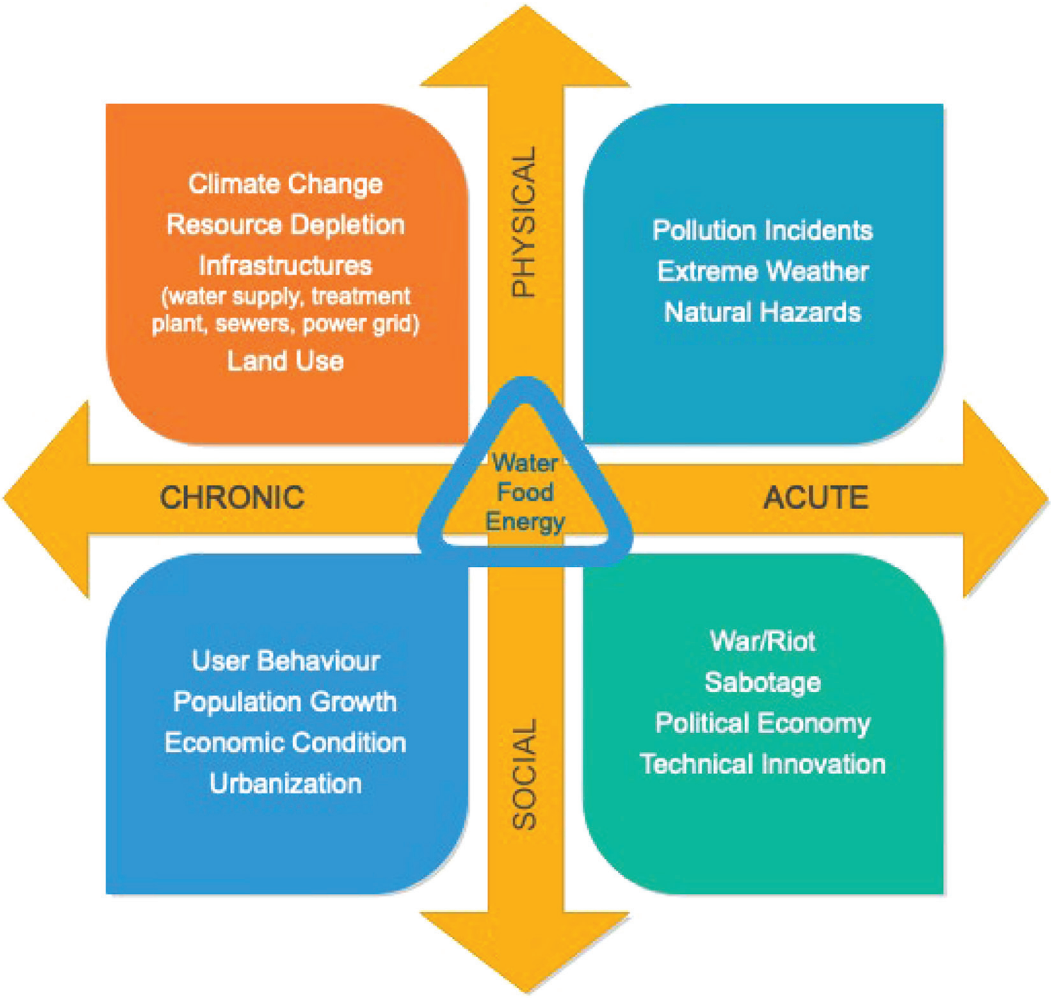

Figure 5. External Threats to WFE Systems (Zhang et al., 2018)

The study will employ a combination of quantitative (e.g., system dynamics, life-cycle, and econometric analyses) and qualitative (interviews and focus group discussions) methods to identify the nature and extent of the external relationships at play.

3.3 Study Design

3.3.1 Overview of Nexus Arenas

Nexus study is highly contextual and geographically dependent and requires both "zooming in and zooming out" geographically. In this study, a review is undertaken to assess international policies and nexus approaches. This gives a preliminary understanding of nexus approaches applied internationally as a guidance both conceptually as well as practically. Following on from that, the framework is applied to national, state, and river basin levels to contextualise the nexus arenas.

Following an international review, the study builds upon previous approaches to nexus assessment. Flammini et al. (2014) provided a few elements of nexus assessments of which are adapted below:

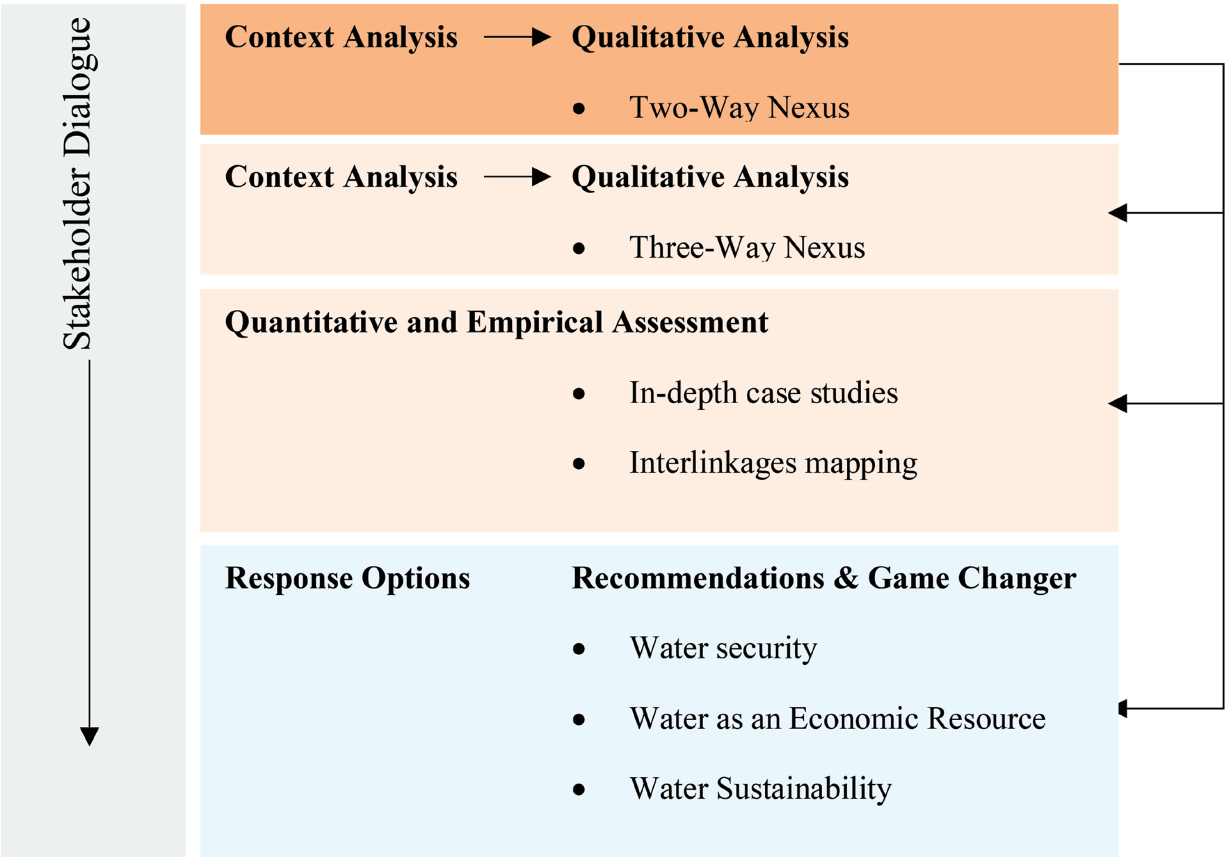

Figure 6. Assessment for WFE Nexus (adapted from Flammini et al., 2014)

The current phase focuses on context analysis through desktop qualitative analysis. The context analysis reviews international case studies, national level context. It begins from two-way nexus in selected nexus arenas within Malaysian states. The case studies are undertaken at the state level to identify potential nexus arenas. This is being done by investigating whether there are nexus issues across to resources, namely water-energy (energy production), energy-water (potable water production), water-food (food production), and food-energy (i.e., waste to energy).

Through the assessment of two-way interactions, the findings will demonstrate whether any of the interactions manifest themselves in three-way interactions. For example, reviews internationally demonstrate that two-way interactions between water-energy highlight that solar PV are much more water efficient. However, reviews also highlighted that adopting LSS could result in land use competition with agricultural land. Such interactions would result in a three-way nexus that deserves further attention. These state- or river basin case studies may include, but are not limited to the following:

- Three-way (water-food-energy) nexus issues within the Sungai Muda catchment area, which has knock-on effects involving Kedah, Penang, and Perlis, economic powerhouses, as well as Sabah and Sarawak;
- Two-way (energy-food) nexus, and pollution-related issues as a result of farming (i.e., in Lojing and others);
- Two-way (water-food) nexus issues such as in aquaculture and/or biomass;
- Three-way (water-food-energy) nexus issues arising as a result of bioenergy development;
- Three-way (water-food-energy) nexus issues in the Northern region as a result of the recent establishment of solar farms

These have been selected due to the abundance of data covering these locations, such as from the list of catchment areas involved in the NAWAB (National Water Balance) studies. The outputs of these case studies will be analysed and deliberated upon through the undertaking of consultative sessions and discussions with stakeholders and experts.

It is also important to note that stakeholder dialogues feature prominently across all stages of the study. This is due to the fact that nexus arenas are highly contextual, requiring local and tacit knowledge of practitioners and local stakeholders. Furthermore, there is a lack of publicly available data on resource use related to the production of each sector.

The three phases are depicted in Figure 7 below:

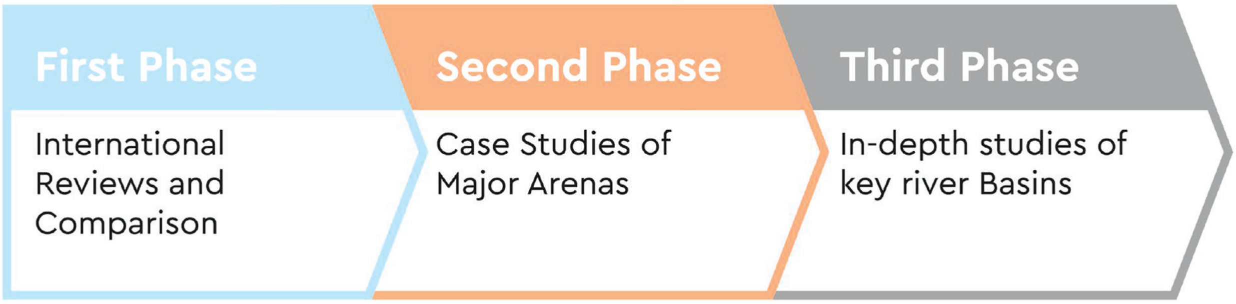

Figure 7. Phases of the WFE Nexus Study

3.3.2 In-Depth Nexus Arenas

Following the initial mapping of the state-level nexus, the Study Team will prioritise four to five in-depth case studies which combine internal and external relationship analyses along the lines described in Sections 4.1 and 4.2. Candidates for such in-depth evaluations on strategic basins will be chosen based on assessment of nexus issues, impact, and opportunities from the comprehensive case studies done in the second phase, from Figure 10. This in-depth case study is to understand the key nexus arena itself and map out potential threats and solutions.

The in-depth case studies will map out the interlinkages across the different sectors. This will demonstrate and visualise how the sectors interact in reality. The mapping will be drawn based on stakeholder dialogues and in-depth understanding of the interlinkages of the different sectors at the river basin level.

Quantitatively, the nexus approach has also applied modelling as part of the nexus assessment. This study is not expected to establish comprehensive modelling, as it is both highly complex as well as due to the lack of reliable data. Input/output models will be undertaken if the data is available. Economic data will also be used to calculate the outcome of inefficiencies as well as potential revenue related to nexus opportunities. These will be addressed in the next phase of the study.

3.4 Other Considerations

Besides that, WFE Nexus will incorporate the five key areas for roadmap development, such as People, Governance, Information and Research Development, Finance and Information Technology. These considerations include:

Table 4. Key Considerations for WST2040 Roadmap Development in relation to the WFE Nexus

Area	Details
People	Address human capital requirements to enhance nexus security and capabilities
Governance	Identify and assess institutional frameworks governing the WFE nexus areas and propose framework improvements.
Information and R&D	Assess info structural practices in water, food, and energy sectors and recommend best practices.
Finance	Analyse economics and finances of water, food, and energy sectors and their potential opportunities and threats
Information Technology	Identify potential game changers for WFE Nexus

4.0 SUB-SECTORAL STUDY PROCESS

The study process for the WFEN subsector of the WST2040 study has been split into seven sections that are reflected in the reports that have been submitted to date, including the Inception, Draft Interim, Interim, Draft Final, and Final reports.

The key objective of this final report in relation to the previous reports already submitted is the finalisation of the policy recommendations and strategies derived from the analyses that have been conducted in the preparation of these previous reports. These policy recommendations and strategies are designed to further stimulate the adoption of WFEN approaches and thinking across the key resource sectors in Malaysia, namely water, food, and energy. These recommendations include policies to improve the institutional ecosystem surrounding resource use and the establishment of nexus principles in Malaysia; people-focused capacity- and knowledge-building measures to enhance human capital in the context of the WFEN; the use of informational and economic policy instruments to promote the adoption of nexus concepts, practices, and technologies; and policies that result in the research, development, deployment, and commercialisation of indigenous nexus-related technologies.

5.0 FINDINGS BASED ON EACH SCOPE OF THE SUB-SECTORAL STUDY

5.1 TOR Scope 1: Review and Analysis of Current Policies

5.1.1 Policy and Enabling Environment Review

This section assesses the current policy and enabling environment landscape towards addressing WFE Nexus in the context of Malaysia. The assessment is undertaken across the policy cycle, namely planning, policy design and formulation, policy implementation and monitoring and evaluation levels. Each stage of the cycle is aligned to the focus areas utilised as part of the overall WST2040 of which are governance, people, information and RDCI, finance, and infrastructure and technology.

5.1.1.1 GOVERNANCE: Indicator and Identification for WFE Nexus

The WFE Nexus is a relatively new area and one that is complex and contextual. Complex due to the fact that it cuts across three sectors: water, energy, and food and contextual as WFE nexus issues are not the same in every location and are dependent on a variety of internal and external factors, including availability of resources, consumption patterns, climate, pollution and infrastructure. As a result, it is critical that a tool to identify nexus hotspots is available to inform policy. This will ensure that an evidence-based approach is utilised in the policy landscape. The review highlighted the importance of *information systems* towards identifying nexus hotspots. This can be in the form of indicators, such as the Water Stress Index (WSI) or comprehensive hydrological databases that can be used as a cross-sector communication tool on the status of nexus. To further translate these communicative instruments into implementation, sectorial *policy targets* can be institutionalised. A review of the status of nexus-related information system, indicators and policy targets are further investigated below.

In terms of *information systems*, a review of the national landscape highlights little evidence of a WFE Nexus monitoring or identification tool being used in the policy landscape. The National Water Balance Study (NAWABs) does include a chapter to assess the WFE Nexus at the river basin level. However, much of the analysis focuses on the security of supply for the three sectors individually. This information is not sufficient to identify the criticality of the WFE Nexus at the river basin level. Most of the information is based on global literature review rather than specific to the river basin. As a result, it does not assist in identifying or projecting whether the WFE Nexus is a priority policy issue, as there is no index or indicator that indicates, for example, the threshold in terms of WFE Nexus security.

Beyond NAWABs, there is no comprehensive hydrological or hydrosocial database2. In the context of nexus, it is crucial for a comprehensive cross-sector water demand accounting to be in place that includes both hydrological data, which captures physical water scarcity as hydrosocial data, which captures the interactions between water resources and social phenomena (Bozorg-Haddad, Baghban, & Loáiciga, 2021). These include data related to water uses such as for irrigation, dams, mining as well as its relationship with external factors such as climate change, population density and growth and technological impacts. These factors demonstrate high correlation with water availability such as per capita renewable water (Bozorg-Haddad et al., 2021). In Malaysia, there is no such integrated database. To regulate water demand, a previous study by ASM found that there is no threshold or capping of water abstraction for human use (Academy of Sciences Malaysia, 2016). The study also highlighted that the current approach to data and information is still sectoral and information such as rainfall, flow, water levels, and water quality is not available for all sectors to forecast and plan future demands, warning systems, and as decision support systems specifically. This was corroborated during site visits undertaken as part of this report where hydrological data at granaries were not available to project the impact of future water availability with water demand for irrigation, taking into consideration the competing uses of future water demand.

In the food and agriculture sector, indicators such as irrigation efficiencies are not widely available. Literature review demonstrated that irrigation efficiency in Malaysia in granary areas is between 40–50% (with MADA around 70%). Irrigation intensity, measured at metres per hectare is a policy target for granary areas (to increase from 20 to 50 metres per hectare), though no available data is provided. Similarly, there is no publicly available data for water use in energy production.

At the international level, the Sustainable Development Goals (SDGs) Goal 6 Clean Water and Sanitation Target 6.4 is to "increase water use efficiency and ensure freshwater supplies". The indicators include "change in water-use efficiency over time" and the "level of water stress: freshwater withdrawal as a proportion of available freshwater resources". From a water point of view, as nexus focuses mainly on water resource use (in particular, in food and energy sectors), these indicators can provide guidance for the WFE Nexus identification as well. However, the Department of Statistics identified that these indicators are partially available and need further development.

As a result of the unavailable indicators, identifying WFE Nexus hotspots in the first place is a major challenge. There is no system that identifies the nature of the problem as well as link the availability of resources with the current and projected demand.

5.1.1.2 GOVERNANCE: Strategic Resource and Development Planning

Historically, Malaysia's natural resources endowment has been the basis of the country's economy (Hezri, 2016). The management of strategic resources, including energy, water, and minerals has enabled Malaysia's economic growth over the years since its formation. While the reliance on raw materials as exports has declined significantly, there is still a high dependence on natural resources, in particular, the oil and gas industry in Malaysia's economy generally which contributes to the federal government's revenues. Additionally, the extraction industry is set to grow to meet the global demands. This is evidenced by the recent launch of the National Mineral Industry Transformation Plan framework 2021–2030, which aims to increase the contribution of the mineral industry to the country's economy from RM9.9 billion in 2019 to RM29 billion to 2030. While the minerals industry is not one of the sectors under the nexus approach, it is tightly linked in terms of relation to pollution, watershed management (i.e., deforestation), and river morphology (i.e., sand mining).

Strategic planning in the agrofood sector is largely driven by the Ministry of Agriculture and Food Industries. The **NAP4** included the establishment of the Strategic Agrofood Industry Development Council (Majlis Pembangunan Industri Agromakanan Strategik) which includes members from the private sector. It also highlighted the role of the Prime Minister's Office that previously provided strategic direction via the Economic Transformation Programme (ETP). National Key Economic Areas (NKEA) were identified in the agriculture sector, including on paddy, swiftlet nest, aquaculture, herbs, fruits, organic vegetables, seaweed, feedlot cattle, and dairy sectors. A total of 16 Entry Point Projects were included under the supervision of Performance and Delivery Unit (PEMANDU). NAP4 also highlighted the dynamic clusters, led in particular by the economic growth corridors. However, it is unclear how these institutions interact with wider strategic and long term issues beyond specific sectors and commodities. In terms of implementation, however, the agriculture has had a mechanism for an integrated approach since the 1970s in granary areas through the Integrated Agriculture Development Areas. The establishment of MADA, KADA, and IADAs consolidated relevant implementing agencies under one institution, including for irrigation.

The challenge of addressing silos is also apparent in the strategic planning of the oil and gas industry, whereby vertically, the **Petroleum Development Act 1974**, which effectively led to the states to surrender their rights to petroleum resources in lieu of cash payments and annual royalties. In the context of WFE nexus, however, the strategic direction provided by the various energy policies, do not focus on cross-sectoral impacts (horizontally) generally. Nonetheless, since the **National Energy Policy in 1979**, followed by **Five-Fuel Diversification Policy (2000)**, the **National Biofuel Policy (2006)**, **National Renewable Energy Policy and Action Plan (2010)**, and the **New Energy Policy (2010)**, there has been a focus on environmental sustainability. However, the main focus is on renewable energy and towards reducing dependency on fossil fuel rather than on impacts to the water sector specifically and adaptation more generally.

Institutionally, the oil and gas sector consists of the **Malaysian Petroleum Resource Corporation (MPRC)** under the purview of EPU. It was established towards building a thriving regional hub for the oil and gas sector. This includes providing trade and investment facilitation, support technology innovation, human capital development, market access, and access to finance. Recently, it launched the National

OGSE Blueprint 2021–2030 with the aim of catalysing an energy transition. No similar institution was found for the water sector or for planning and managing strategic resources as a whole in Malaysia.

In terms of overall development planning, Malaysia's resource mobilisation at the federal level is based on the five yearly Malaysia Development Plans. In the context of the WFE nexus, the 11th MP emphasises the need to move beyond the sector-based approach to advance water, energy, and food security:

> "In the Eleventh Plan, Malaysia is breaking free from the conventional wisdom of development at all costs to green growth, which is a more sustainable path of growth. This will see Malaysia enter the ranks of advanced economies in 2020 with an economy resilient to the adverse impact of climate change and with a secure and sufficient supply of natural resources such as water, food, and energy. Partnership and shared responsibility across all levels of society, including individuals, will be key to safeguarding the environment and biodiversity. Successful green growth will not only expand economic opportunities, but also enhance inclusivity and reduce disaster risks." (Malaysia, 2015: pp. 6–30)

This marks that at the development planning level, there is a focus on addressing interactions, synergies, and trade-offs across sectors, including the water, food, and energy sectors. However, there is little clarity on how this will be implemented in an integrated manner. Generally, in terms of overall strategic resource planning, while this review highlighted elements which are evident within sectors, there is little evidence of a cross-sectoral strategic organisational arrangement to plan from a multi-sectoral point of view. Furthermore, there is little evidence of long term capabilities to undertake cross-sectoral assessment such as through strategic foresight.

5.1.1.3 GOVERNANCE: An Institutional Arrangement to Govern Nexus Planning

The need to further strengthen integrated and cross-sector governance was strongly highlighted in the 12th MP where a specific focus on "Institutionalising the Water-Energy-Food Nexus Approach" was included as a strategy (Chapter 9, Strategy B2) which states:-

> The water, energy, and food sectors will be managed integrally to address challenges related to urbanisation, land-use, and climate change. The water-energy-food nexus is a vital element in ensuring comprehensive water resource management and water security across the sectors. This nexus will provide a framework that determines the appropriate distribution of water resources to all sectors. Going forward, the water-energy-food nexus approach will be institutionalised, while technical expertise of relevant ministries and agencies will be enhanced to ensure effective implementation. (EPU, 2021: pp. 9–19)

As highlighted in the National Water Resources Management Plan, water governance is fragmented across water resources management and water supply management as well as differs across states. The silo approach is exacerbated in the WFE Nexus where fragmentation occurs both across and within sectors. International review highlighted the need to have organisational instruments that coordinate across multiple sectors. This is usually undertaken through a process of consolidation. The institutional coordination is required to be consolidated at various stages of the policy cycle, including planning and implementation.

The water sector is complex and multi-layered with no single agency responsible for strategic planning and management of water resources. The National Water Resources Council (Majlis Sumber Air Negara) was established as the apex body for coordinating water resource body. However, challenges remain both horizontally and vertically. Horizontally, water resource management and water supply and more generally water use is governed by various sectors. Vertically, the state still maintains power and authority over water resources management. The Water Industry Act 2006 and the National Water Services Commission Act 2006 provided a mechanism for the federal government to acquire water-related assets and leased back to water industry operators. However, the laws do not provide link to the planning and management of other sectors. In terms of strategic planning, much has been written on the challenges to govern water resources as a whole, let alone, planning across other sectors that are prominent for resources use, including agriculture and energy (i.e., hydropower and other uses).

For the water-food nexus and agriculture water more specifically, the Division of Irrigation and Agricultural Drainage (BPSP) is placed under MAFI which is mandated to oversee agriculture water development and management. Institutionally, the agriculture sector has had a mechanism for an integrated approach since the 1970s in granary areas through the Integrated Agriculture Development Areas. The establishment of MADA, KADA, and IADAs consolidated relevant implementing agencies under one institution, including for irrigation. In terms of regulations, there is no special act to accompany the agricultural water management. For paddy specifically, the Irrigation Areas Act 1953 regulates matters on irrigation, while the Drainage Works Act 1954 covers drainage matters for the Peninsular Malaysia. These acts are only applicable to areas gazetted as granary areas and do not cover water resources aspects. From a legal perspective, one of the challenges is that there no specific regulations to avoid water use wastages for agriculture end users (i.e., farmers).

The energy sector is governed by the federal government and therefore does not face issues towards the vertical integration of the sector (except for the case of Sabah and Sarawak, where the Economic Planning Unit plays a significant role in energy-related matters). Nonetheless, similar to the water sector, demand side management falls under the purview of various ministries including the Ministry of Housing and Local Government for building energy efficiency as well as waste, Ministry of Transport for transportation, in particular for fuel, Ministry of Trade and Industry for industrial processes, and the Ministry of Domestic Trade and Consumer Affairs for household consumption. The Ministry of Environment and Water also addresses energy efficiency through, for example, the Green Technology Master Plan. In the context of WFE Nexus, the focus is mostly water usage at the energy production stage and therefore the focus will largely be at the federal sector with the Ministry of Energy and Natural Resources

In terms of the energy-water nexus, and in particular, energy to move water, pumping is a major part of the cost to bring drinking water to the consumers as well as for irrigation. Furthermore, inter-basin transfers also require significant energy to move water. Currently, transporting of water is largely governed internally by water treatment companies. While the costs are not insignificant, market forces will most likely incentivise energy efficient practices. In the context of nexus, inter-basin transfers as well as granary areas (i.e., IADAs) also play a very important role in ensuring energy efficiency. Institutionally, river basin organisations can play a role to improve energy efficiency. A major gap is that there is an absence of National Water Services policy encompassing both water supply and sewerage sectors. For planning purposes, there is a need to integrate water supply and demand including for food and energy sectors which addresses issues such as energy efficiency in producing potable water.

From an institutional point of view across the three sectors, the review notes no institutional arrangement exists for governing WFE Nexus. The implementation consists of only specific nexus trade-offs (and synergies) or weak policy integration and coherence between different sectors and mainly focuses on resource optimisation. Where water transfers inter-state, such as in the case of Penang and Kedah (Sg. Muda), the agreements do not take into consideration nexus factors or drivers such as ecosystem services preservation beyond the raw water transfer. Furthermore, in the water sector, as highlighted previously, there is no single institutional framework to streamline the governance of water use across water resource management and water supply management. The National Water Resources Council (Majlis Sumber Air Negara) is the apex body for the water sector but does not address nexus issues specifically. In the context of water-food nexus, while BPSP is under the Ministry of Agriculture and Food Industries. At the national and federal level, as fragmentation occurs within each sector, it is not plausible to consolidate institutions across all three sectors. Nonetheless, consolidation should occur within each sector, and with water identified as the choke point for nexus challenges, consolidation across the water sector, and in particular, across significant resource users is recommended.

At the river basin level, three states have also established the State Water Resources Council (Majlis Sumber Air Negeri (MSANg)), namely Selangor (LUAS), Sabah, and Kedah. Challenges remain at the river basin level where there are no river basin authorities that act to integrate and coordinate activities in a river basin, including implementing IWRM. LUAS has arguably progressed towards ensuring integrated management at the water basin level. However, a river basin authority will also need to engage multi-stakeholders to take into account various competing uses of water, including its impacts downstream. This will require taking into account a nexus approach in any multi-tiered institutional arrangement.

The nexus approach will need to take into consideration the complexities and fragmentation within each sector. Nonetheless, implementing the nexus approach requires a multi-tiered structure that coordinates across the levels of government, including at the river basin (vertically); and across the different sectors and stakeholders (horizontally). While each individual sector (water, energy, and food) is already complex and fragmented, the review demonstrates that two potential successful models, in situ initiatives (such as the integrated agriculture development areas) that are able to take into consideration the contexts at the appropriate scale; and an integrated approach that facilitates partnership, including with the private sector (i.e., palm oil industry). In the context of nexus and the water sector, two frameworks are required to be established, an institutional framework at the federal level that integrates the water sector including the DID and a governance structure at the river basin that incorporates nexus thinking.

Currently, LUAS provides an example where it adopts various instruments for IWRM. This includes (as highlighted before), issuing licenses for water resource abstraction, diversion of water for generating electricity (amongst others) as well as adoption of Payment for Ecosystem Services (PES). These provide a good starting point for governing nexus at the river basin level. The experience in LUAS demonstrates the importance of state and river basin level governance for addressing issues that range from water resource management to water demand management, of which is required in the context of governing the nexus.

5.1.1.4 GOVERNANCE: Policy Design, Targets, and Instruments

The review highlighted that there is room for the policy design to incorporate nexus thinking across the cycle. This includes cross-sector policy targets as well as policy instruments to catalyse implementation.

Existing policy targets are mainly related to efficiencies and resource optimisation that may have indirect consequences to the nexus. The energy sector focuses mainly on policy targets on energy production (i.e., installed capacity) as well as on increasing energy efficiency and reducing intensities. The food sector does demonstrate cross-sector policy targets on resource optimisation, specifically related to land. At the national level, the water sector also includes policy targets on non-revenue water (NRW). These policy targets will indirectly impact the nexus through increasing resource efficiency as a whole. However, there are few direct cross-sector policy targets. The National Agrofood Policy (2011–2020) does focus on land use optimisation, including reduction in land use for agriculture from 922,000 hectare (2010) to 841,000 hectare (2020). However, there are little to no policy targets found across the nexus between water and food and energy production.

Internationally, while policy targets vary and are more at the river basin level (as opposed to national), there are various policy targets that can be designed for the water-food nexus, including (OECD, 2010):-

- Financial target to improve water use efficiency in agriculture (i.e., water charges)
- Sustainable limits on the use of water
- Policy targets related to water use efficiency in irrigated agriculture
- Measuring and setting water use efficiency targets, for example, the relationship between accumulated yield (kg DM ha-1) and water use (mm)
- Irrigation efficiency, crop productivity, etc.
- Water availability, including water level, reserve margin, etc.

The review also highlighted the lack of cross-sector policy instruments, whether in the form of regulations, economic instruments or informational guidelines (i.e., action plans). Within sectors, the energy sector in particular has a range of policy instruments to implement its policy aspirations. For demand side management specifically, one of the strategies identified in the 11th MP, various action plans and instruments have been included such as the National Energy Efficiency Action Plan (NEEAP), Minimum Energy Performance Standards (MEPS) and the Green Investment Tax Allowances (GITA) and Green Income Tax Exemption (GITE) to provide economic incentives.

The water sector employs various informational and management instruments. This includes IWRM Management Best Practices and the NWRP Action Plans (2013–2020). However, the use of regulatory and economic instruments across sectors is lacking. In relation to the nexus approach, a technical manual would support the implementation of nexus implementation.

In more detail, the **NWRP**, drafted between 2010 and 2011, made no explicit mention of the nexus. At least in part, this may be due to the timeline before major breakthroughs in the nexus approach such as the Bonn Conference in 2011. Nonetheless, the NWRP does address and capture the linkages across various strategies and actions indirectly. For example, the focus on water for food and rural development captures the linkages between water sources and food security.

NAP4 aims to optimise land use by increasing yield but reducing overall land use for agriculture. In relation to water use efficiency, while it aims to increase efficiency, its policy targets aim to increase the irrigation intensity from 20 to 50 metres per hectare. This demonstrates the focus is on increasing productivity rather than efficiency of water use. Although food and nutrition security is slowly gaining focus in nexus literature, these nexus synergies are not portrayed in the National Plan of Action for Nutrition of Malaysia III (2016-2025). The objective of **NPANM III**, 2016–2025 goes beyond improving household food security whereby the element of nutrition security is given greater emphasis in line with global directions and agenda, such as ICN2 Declaration and Framework for Action as well as Nutrition and the post-2015 Sustainable Development Goals (SDGs) in the next decade.

As stated before, the energy sector has a focus on energy transition and energy efficiency. The focus on efficiency is part of demand management strategies employed by the energy sector. Arguably, demand management strategies are utilised less from the food and water sectors with no notable policies and initiatives. In the food sector, recent focus on food waste and food loss has been introduced in the policy landscape. In the water sector, efficiency is often related to non-revenue water, but not less in terms of consumer demand management.

A review of the **Green Technology Master Plan 2017–2030** and the **Climate Change Policy 2009** demonstrated that while various related areas are identified, such as on energy and water security, there is no explicit mention of WFE nexus or establishment of the interconnections across the sectors.

Although there is no clear indicator of nexus implementation, the nexus approach is conceptualised in urban planning as seen in **Malaysia Smart City Framework (2018)** and the **National Urbanisation Policy 2 (NUP2)**. The urban population in Malaysia is expected to increase to 79.6% in 2025 and projected at 85% by 2040. Smart city initiatives adopt new technologies to optimise resource use, adopt sustainable energy management, promote investment in green infrastructure, reduce urban traffic and road congestion, and improve quality of life.

The demand for a green supply chain will become prominent as the environmental aspects gain importance in the transportation sector. The **National Transport Policy (2019–2030)** supports the shift towards environmentally sustainable transport for cities. The policy supports sustainable mobility through integrating measures that induce behavioural change to optimise mobility patterns, coupled with effective planning and technology design that are targeted to provide not only integrated transport but also an interactive one. Several initiatives to develop policy instruments were recommended such as the study of current regulation in Act 333 to support the growth and the use of EEVs/electric vehicles (EVs), provide incentives for EEV manufacturers and users, and consider different models of EEV, mandatory requirement for purchase of low carbon emission vehicles in Government Green Procurement, or Execute implementation of Low Carbon Mobility Blueprint Action Plan. The shift to; for example, electric vehicles and low carbon emissions may impact the water-energy nexus depending on the technologies deployed.

On a broader level, Malaysia is embarking on various policies and initiatives towards a circular economy. Malaysia is expected to produce a sustainable consumption and production blueprint in 2021. While the blueprint is not expected to address the nexus explicitly, the focus is on resource efficiency generally. It includes a focus on food waste and loss as well as a focus on eco-industrial parks that aims to utilise the waste and by-products of industries as inputs as well as more efficient resource use through; for example, centralising utilities such as wastewater treatment plants.

Many of the policy aspirations highlighted above do not consist of clear policy targets in relation to nexus. A brief mapping of the national level policies is conducted in Table 5 below. The three sectors demonstrate that there may be trade-offs in achieving the various policy targets within the sector (nexus pressure). Existing policy targets are mainly related to efficiencies and resource optimisation that may have indirect consequences to the nexus. The energy sector focuses mainly on policy targets on energy production (i.e., installed capacity) as well as on increasing energy efficiency and reducing intensities. The food sector does demonstrate cross-sector policy targets on resource optimisation, specifically related to land. At the national level, the water sector also includes policy targets on non-revenue water (NRW). These policy targets will indirectly impact the nexus through increasing resource efficiency as a whole. However, there are few direct cross-sector policy targets. The National Agrofood Policy (2011–2020) does focus on land use optimisation, including reduction in land use for agriculture from 922,000 hectare (2010) to 841,000 hectare (2020). However, there are no policy targets found across the nexus between water and food and energy production.

In terms of policy instruments, the energy sector has clear instruments to guide its implementation towards efficiency. This includes promoting efficient use of electricity in the **Electricity Supply Act 1990** to more recent policies and initiatives such as the **Efficient Management of Electrical Energy Regulations (EMEER) 2008**, **Minimum Energy Performance (MEPS)** for five categories of domestic electrical products, **Energy Performance Contracting (EPC)** implemented in the government sector, and various incentives for energy efficiency. An **Energy Efficiency and Conservation Act** is also currently being drafted.

The agrofood sector promotes sustainable agricultural practices through **MyGAP**, a comprehensive certification scheme for the crop, aquaculture, and livestock sectors. This includes seven elements, namely improving crop storage records, selection of type of crop according to standards, sustainable use of insecticides, employee health, harvesting training, irrigation practices, and soil fertilisation practices.

The water sector, as previously highlighted has enacted the **Water Industry Act 2006 and the National Water Services Commission Act 2006** though it does not provide a connection to addressing wider issues such as nexus nor act directly as an instrument towards increasing efficiency. There is also currently no regulatory or informational (i.e., technical guide) within the water sector to address the nexus approach.

Table 5. Policy Targets Across Water, Food, and Energy Sectors

Policy	Policy Target	Nexus Pressures	Nexus Opportunities
Water Security Policy Targets			
All shall have access to safe, adequate, and affordable water supply, hygiene, and sanitation (NWRP 2012).	• No policy targets	Insufficient allocation due to pollution from food production Availability for energy production	Set integrated and cross-sector standards relating to food and energy security
Water for food and rural development (NWRP 2012)	• No policy targets	Competing priorities	Opportunity to link to food and development issues
Water for Economic development (NWRP 2012)	• No policy targets	Competing priorities	Opportunity for provision of water to link to food and energy production
Food Security Policy Targets			
Increase in SSL from 2010 – 2020 (National Agrofood Policy 2011–2020)[2]	• Paddy from 71.4% – 69.8% (reduction) • Fruits from 65.8% to 76.3% • Vegetables from 41.2% to 67.6% • Fish from 101.7% to 110.4%	Increase in water for irrigation Increase in land for fruits and vegetables Increase in pollution due to aquaculture	More optimum usage of resources including water for paddy Hybrid systems for food and energy production
Optimum land use (National Agrofood Policy 2011–2020)	Reduction in land use for agriculture from 922,000 hectare (2010) to 841,000 hectare (2020).	Risk of reduction in production and not meeting SSL	More optimum usage of water and energy
Increase land size for commodity plantations (National Commodities Policy 2011–2020)[3]	Increase in land use from 5.9 hectares (2010) to 6.9 hectares (2020) Cap oil palm to 6.5 hectares by 2023 (now 5.8 hectares)	Competing land for food and energy production (including biofuels and biogas production) Ability to increase energy production through biofuels	Integrated and circular economy approaches such as through utilising by-products and waste (biomass) for biogas production
Increase in irrigation intensity (National Agrofood Policy 2011–2020)	Increase in irrigation intensity from 20 to 50 metres per hectare Energy Security Policy Targets	Competing priorities. Increased water consumption for food production	Policy target on irrigation efficiency in granary areas
Energy Security Policy Targets			
Increase renewable energy mix	Achieve 20% Renewable Energy Mix by 2025	Competing priorities including land for LSS versus land for agrofood production	Floating solar and other technological solutions
	Produce 2.5 GW through Large Scale Solar (LSS), (10% of electricity demand)	Impacts of hydro to downstream activities including food production	Nexus approach for multi-purpose dams
	4% of energy from hydro by 2022		

[2] Please note that the National Agrofood Policy 2021–2030 is currently being drafted
[3] Please note that the National Commodities Policy 2021–2030 is currently being drafted

5.1.1.5 PEOPLE: Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus[4]

Nexus concepts are relatively new and as a consequence, explicit mentions of nexus approaches, concepts, or ecosystems are not present in any existing policy documents. Accordingly, there are no ongoing CEPA activities specifically designed to address and promulgate the nexus approach, but apparent is the clear recognition of the need to raise awareness on the cross-sectoral impacts of water, energy, and food as well as its interconnections with environment and natural resources generally.

The **11th MP** has a strategy (Focus area A: Strengthening the enabling environment for green growth: Strategy A2: enhancing awareness to create shared responsibility) for an integrated CEPA programme to engage all levels of society on the environment, climate change adaptation and mitigation, conserving natural resources, and the role of green growth in raising productivity. Initiatives include comprehensive communication and awareness programmes as well as a platform for knowledge sharing and collaboration.

The **National Agrofood Policy 2011–2020 (NAP4)** highlighted the need for food safety and sustainability, including sustainable management of water resources. This includes a focus on Good Agricultural Practices (MyGAP) which requires increasing awareness and capacity building.

Energy-related policies have focused on demand side management; for example, through the **National Energy Efficiency Action Plan** and through initiatives such as the **Minimum Energy Performance Standards (MEPS)**. While increased efficiencies will indirectly impact water and food sectors, no explicit mention of the interlinkages are highlighted.

Nonetheless, the focus on demand side management, with specific initiatives is less evident in the water sector. The **National Water Resources Policy** does have a focus on awareness (Core Area 4: Capacity Building and Awareness; Target 18: Improve Understanding and Awareness of The Importance of Water Resources Security and Sustainability). While this provides an entry point into the nexus approach, no explicit mention on cross-sectoral linkages or programmes under this target is mentioned.

The focus of CEPA activities above and in the **Green Technology Master Plan 2017–2030** (Strategic Thrust 1: Promotion and Awareness) is arguably more targeted to the general public. The focus of GTMP is on changing the mindset of the *rakyat* to embark on a green lifestyle. There is currently a gap for capacity building that focuses on technical expertise to understand integrated and complex approaches such as the nexus. This includes enhancing modelling capabilities and capacities.

As a new area, there is a need for capacity building, in particular, towards developing the ability to identify of the WFE nexus challenges and opportunities. This requires modelling expertise capabilities to develop nexus models in the context of Malaysia and in the context of river basins. Currently, no policies or initiatives are known to develop WFE nexus modelling capabilities.

5.1.1.6 INFRASTRUCTURE AND TECHNOLOGY: Technological and Infrastructure Facilitation and Investment

In terms of infrastructure, there is currently no policy or tool to facilitate specifically the nexus concept. Nonetheless, infrastructure and technological facilitation is based on specific technologies and aims.

Hydroelectric plants were facilitated through various policies since 1981. The **Four Fuel Diversification Policy (1981)** catalysed the need to reduce over dependence on oil and diversify, including through promoting hydroelectric. The **Renewable Energy Act (2011)** promoted small hydro by introducing

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[4] This review is limited to the nexus sub-sector. The Advocacy, Awareness, and Capacity Building (AACB) sub-sector focuses generally on the CEPA activities in the water sector.

the quota-based Feed-in Tariff (FiT) mechanism. However, no policy or instrument was found towards encouraging multiple use of hydro and dams. Nonetheless, multipurpose dams such as Kenyir have been developed, though it is unclear whether it is an outcome of a specific policy or tool as the main objective was for generating and storing energy. Various policies including the upcoming **National Energy Policy** will focus on hydropower (both small and large) as a source for transitioning to renewable energy. This provides an opportunity to address the nexus in its design and infrastructure towards ensuring multiple purpose dams.

Other emerging technologies to affect the energy transition will also impact the water sector. A review from international literature estimates that water consumption for LSS operations are almost negligible, with water consumption occurring only during the cleaning of PV panels (Macknick et al., 2012; Meldrum et al., 2013; Gao et al., 2018). Nonetheless, it requires large tracts of land. If agricultural land is degazetted for the purpose of large scale solar, it will result in a direct competition between food and fuel. Similarly, the transition towards biofuels could, and arguably, has resulted in this competition. In this sense, technologies such as agrivoltaics that integrates farming in LSS farms and floatovoltaics (floating solar) provides potential nexus opportunities.

Interbasin transfers may also be a solution to address various nexus-related challenges and opportunities. Examples of existing interbasin transfers including in Penang, which relies on energy intensive inter-basin water transfer from Sg. Muda, and the Pahang-Selangor Raw Water Transfer (Langat). There have also been smaller scale and intra state water transfers such as the water transfer from Triang, Jelebu to the water treatment plant in Ngoi-Ngoi, Pantai through a 12.5km gravity pipe, which reduces dependence for raw water from Sg. Terip by 50% (previously 100%). These interbasin transfers are often the result of complex negotiations involving both federal and state governments.

While various other technological solutions are available as a nexus opportunity, the concept is still relatively new, requiring experimental infrastructure. At the moment, the review found that no policy tool is currently available to facilitate innovation, investments and/or funding for pilot projects related to nexus.

5.1.1.7 INFORMATION AND RDIC: Monitoring and Evaluation Systems

There is no available information sharing or monitoring and evaluations system across resources. It is expected that firm and facility level information is available. Some of the data required for monitoring the WFE nexus will be collected in the course of this study.

In the water sector, National Water Balance Management System (NAWABS) has been developed as a comprehensive river basin management instrument to assess the current water availability and demands on a basin scale and determine water management strategies going forward to ensure the adequacy of future supply. However, as indicated before, although nexus is assessed in the chapter, it does not provide information that is sufficient to monitor progress and identify potential WFE nexus hotspots.

Indicators on water use for energy production at the facility level are not available. There is also no periodical measure of water intensity of major crops to provide comparison of water use efficiency and its relationship with accumulated yield. This challenge is also linked to the lack of policy targets as well as a monitoring and evaluation framework generally.

The lack of information also inhibits investments and private sector participation. Advancements in technology through IR4.0 and big data analytics provide the basis for investment decisions and innovation by identifying the problem in the first place. The nexus flashpoints are highly contextual and there is a need for accessible and usable data to be available to further identify the phenomenon and problems in the first place, and subsequently identifying the responses through an evidence-based approach.

5.1.1.8 ECONOMICS AND FINANCE: Economic Instruments

Economic instruments can provide both incentives and disincentives to compel actors to implement policy objectives. In relation to the nexus approach, there is no evidence found of cross-sectoral use of economic instruments. This includes the absence in use of instruments such as water pricing for agriculture and irrigation (such as through mixed tariff based on consumption) for the water-food nexus. Similarly, for potable water production (energy-water nexus), from our preliminary analysis, the potable water production and wastewater treatment's electricity tariffs may fall under TNB's Tariff band D (low voltage industrial tariff) of 29.0 sen/kWh. Electricity tariff for agricultural activities may fall under "Special Agricultural Consumer" - under TNB's Tariff band H1 (Medium Voltage General, Special Agriculture Tariff) of 22.6 sen/kWh. There is currently also a lack of clear incentives for applying technologies that encourage nexus thinking.

Within the sectors, as highlighted before, the energy sector in particular has a range of policy instruments to implement its policy aspirations to facilitate energy efficiency. Specifically, for demand side management, various action plans and instruments have been included such as the **National Energy Efficiency Action Plan (NEEAP)**, **Minimum Energy Performance Standards (MEPS)** and the **Green Investment Tax Allowances (GITA)** and **Green Income Tax Exemption (GITE)** to provide economic incentives. Within the agro-food sector, and in particular the rice sector, the economic instruments utilised is more towards achieving rice self-sufficiency. In 2017, it was found that 45 percent of the total budget of the Ministry of Agriculture and Agro-based industries went to supporting rice production through subsidies as well as trade policy (World Bank, 2019). Meanwhile, the water sector has seen little use of economic instruments with Malaysia's water tariffs for irrigation being one of the lowest in the world. If one adds to these costs what consumers pay through trade policy (which raises domestic prices) and what taxpayers pay through subsidies and compares the total with the total production value of rice, the cost is also high. This measure of the transfers from consumers and taxpayers is known as the producer single commodity transfer.

5.1.2 Proposals for the Improvement of Policies

5.1.2.1 Summary of Policy Review

The review in the previous subsection highlighted the various gaps in the policy cycle in relation to the nexus approach. The gaps, in many ways, are to be expected as the nexus is a relatively new concept. However, the review across the policy cycle also highlighted more general gaps across the policy cycle. In particular, there were gaps even within sectors in progressing across the policy cycle including on policy targets, policy instruments, monitoring and evaluation and the use of economic instruments. As the nexus cuts across three sectors of various policies, the major policies of each sector and their inclusion of nexus thinking is summarised in Table 6 below:

Table 6. Major Policies in the Water, Food, and Energy Sectors

N	Policy Name	Year	Mandate	People	Governance	Information & RDIC	Economic & Finance
1	Eleventh Malaysia Plan	2015–2020	EPU	Yes	Partially	Partially	Partially
2	National Water Resources Policy (NWRP)	2012	KASA	Partially	No	No	No
3	National Agrofood Policy 4	2011–2020	MAFI	Partially	Partially	No	No
4	National Energy Policy	2010	KeTSA	Partially	Partially	Partially	Partially
5	National Energy Efficiency Action Plan	2015–2025	KeTSA	Partially	Partially	Partially	Partially

It is worth noting that many of the major policies reviewed in parallel to this report are currently under renewal. This includes the National Water Resources Policy, the National Agrofood Policy (2021–2030), and an updated National Energy Policy. The recommendations provided in this study do not take into account changes that are proposed in the current redrafting of these policies, but provide inputs that might potentially be embraced by these policies. The recommendations, or strategies, are listed below. The following sections highlight recommendations related specifically to proposals for policy improvements. Other sections in this report detail out the transformation roadmap based on the strategies below.

1. Monitor and reduce 'Water Stress Index' (WSI) and 'Water Exploitation Index' (WEI) in relation to food and energy sectors
2. Establish a multi-tiered institutional arrangement to govern WFEN across the policy cycle
3. Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus
4. Establish a database with usable information as a policy decision tool at the basin level
5. Use economic instruments to promote resource efficiency and a nexus approach
6. Piloting infrastructure and technology to support WFEN approaches/initiatives

5.1.2.2 Policy Recommendations

The policy recommendations reflect the strategies listed above and the roadmap proposed as part of the WST2040. The recommendations are as below:-

1. **Review NWRP to include the monitoring of WFE Nexus by adopting the Water Stress Index (WSI) indicator**. This includes the establishment of a monitoring and evaluation system on WSI. The NWRP should include a policy target on the feasible and targeted level for WSI in Malaysia. For example, the policy target should target to have all river basins defined as 'low-stress' or 'not stressed' in accordance with the WSI methodology adopted internationally. The focus on measuring water stress is also an indicator under the SDGs (Target16.4).

2. **Include water and energy use efficiency policy targets for water, energy, and food production in associated policies**. This includes policy targets on irrigation efficiency in granary areas in NWRP and NAP (2021–2030) for food production (i.e., 75%), energy efficiency targets for water treatment and wastewater treatment in NWRP, and water use efficiency targets in the National Energy Policy and any other relevant action plans. This is in line with SDG16.4 towards enhancing water use efficiency.
3. **Establishment of a single National Water Department (NWD) as part of a strategy in NWRP**. The agency will be responsible, amongst others, to manage interactions between water and food, energy, and other sectors, and encouraging a holistic view of water/water industries. Specifically, the Department of Irrigation and Drainage (BPSP), currently under MAFI, should be included under the NWD alongside JPS, JBA, and JPP. This is also in line with Strategy B4 of the 12MP, which calls for a strengthening of water resource governance and the proposed NWD can play a key role in harmonising water-related legislation as well as the implementation of IWRM. The NWD can also play a crucial role in monitoring, reporting, and addressing water pollution, another key objective of the 12MP. In particular, the NWD may play a key role in the administration of the proposed smart monitoring system to enable real-time monitoring of water pollution, early warning systems, and to enable greater enforcement of anti-pollution measures.
4. **Establishment of River Basin Organisations (RBOs) to better incorporate WFEN approaches within the water, food, and energy sectors**. The NWRP policy should explicitly aim to support states establishment of RBOs at the state level, including providing federal support in its establishment. This is in line with the 12th MP focus on Water Sector Transformation with Strategy B2 explicitly review the respective water-related legislation in line with the Water Resources Bill 2016, including the establishment of water resources management authority in all states.
5. **Establishment of a Centre of Excellence (CoE) on WFEN Nexus as part of the 12th MP**. Under Strategy B2, a specific focus on Institutionalising the Water-Energy-Food Nexus Approach was defined, as follows; "the water-energy-food nexus approach will be institutionalised, while technical expertise of relevant ministries and agencies will be enhanced to ensure effective implementation". Under this strategy, it is proposed that a CoE on WFEN Nexus is established to support the technical expertise component, with NAHRIM and ISIS recommended as co-hosts. This should also be included as part of the revised NWRP. The establishment of these three institutions – the NWD, RBO, and CoE – would form a critical component of the institutionalisation of WFEN approaches in Malaysia, another objective described in the 12th MP, allowing for the collection of technical expertise from across the relevant Ministries to achieve in a coordinated manner the effective implementation of nexus concepts.
6. **Develop informational instruments, including a WFEN Technical Guide and Manual as part of the NWRP**. The revised NWRP should be drafted strategically to link with policy instruments that will ensure the implementation of the policy. For WFE nexus, a technical guide and manual is required to guide relevant agencies on WFE nexus implementation.
7. **Include a focus on capacity building on modelling for WFE Nexus as part of the revised NWRP**. As a relatively new area, the information on identification of WFE nexus is still nascent in Malaysia and as part of developing the enabling environment for institutionalising WFE nexus (as part of the 12th MP) and transforming the water sector into a regional water hub, capacity building should be included in the updated NWRP specifically on modelling. This is in line with the 12th MP objective of implementing comprehensive awareness, advocacy, and capacity-building programmes, allowing stakeholders to access the information and knowledge required to mainstream nexus approaches and concepts into their operations.

8. **Establish a Decision Support System (DSS) based on a hydrological or "hydrosocial" database as part of the monitoring and evaluation of NWRP**. The decision support system will leverage on the modelling capacities housed in the proposed CoE. The purpose of the decision support system is to both identify WFE nexus challenges through an improved monitoring of water catchment areas, alongside the development of modelling systems covering critical/stressed river basins. The DSS can be part of a broader M&E system for the NWRP. This is in line with the 12th MP objective of strengthening the water data ecosystem. In particular, it is in line with the goals to establish a local, data-driven DSS based on comprehensively collected data, and the use of this data and tool to undertake water-related analyses and provide strategic directions to the relevant stakeholders. The inclusion of indicators relevant to climate change, such as climate variabilities, sea-level rise, storm surges, high tides, and pollution would further the depth of this database and associated DSS, allowing climate impacts to also be taken into consideration in the implementation of evidence-based and risk-informed actions, as called for in the 12th MP.
9. **Increase the use of economic instruments to promote resource efficiency and nexus approach through the NWRP**. The review highlighted little evidence of the link between policy instruments with the NWRP. It is proposed that the next iteration reviews effective economic instruments such as water abstraction charges, financial target to improve water use efficiency in agriculture (i.e., water charges), sustainable limits on the use of water and others. These should be based on comprehensive studies conducted by WFEN CoE on the value of river water in major/stressed river basins. These instruments will also have implications for objectives described in the 12th MP, including those related to mitigating water pollution (e.g., through punitive economic instruments), and more broadly the objective of mainstreaming nexus considerations into water resource management to achieve greater resource security (in particular, water) across key sectors.
10. **Include pilot infrastructure and technology to support WFEN approaches/initiatives as a means of implementation in NWRP**. This should include a mechanism for promoting innovative financing, in line with the 12th MP (Water Sector Transformation Strategy B4), where both public and private sectors funding is channelled to promote WFE nexus innovation. This can be in the form of matching funds, government guarantee, and/or other forms of financing. Further, through the RBO and WFEN CoE, the private sector will be encouraged to invest in nexus-related projects, another goal of the 12th MP.

5.2 TOR Scope 2: Comparative Strategy Analysis

The WFEN approach perceives integration as a fundamental step for ensuring resource security in a global context of increasing and competing demands. In many ways, these approaches are adopted by international initiatives (such as Sustainable Energy for All and the World Economic Forum), international financial institutions (such as the World Bank, Asian Development Bank, and International Renewable Energy Agency), governments (e.g., German Development Cooperation and Japan International Cooperation Agency), the private sector (e.g., WBCSD), and support from the research/academic sector (e.g., IFPRI, ERIA, SEI, CSIRO, IIASA).

This section looks into the international best practices on WFEN theory and applications across the rural-urban divide from multi-scale perspectives, including local, state, river basin, national, and transboundary perspectives. These best practices are segmented into five areas based on their relevance to the WFEN in the context of Malaysia.

5.2.1 Addressing the WFEN through the Establishment of River Basin Organisations

The WFEN remains relatively new, under-researched, and under-addressed area, with features that are complex, contextual, and dynamic. It cuts across three strategic resources and three distinct but deeply-interrelated sectors. Nexus issues are contextual; they are not the same in every location and are dependent on a variety of internal and external factors, including the availability of resources, consumption patterns across sectors and the varying uses of resources, climate, pollution, infrastructure, and governance. They vary in size, typically on the scale of river basins. From the perspective of the WFEN, river basins are the appropriate level at which to govern nexus issues because they involve competition between various sources of demand for resources, and these dynamics typically play out at the scale of a river basin. For this reason, the establishment of river basin organisations can play a significant role ameliorating the various challenges that make WFEN analyses and solutions complicated to administer. Indeed, Kittikoun and Schmeier (2020), in an analysis of over 13 significant river basins across developing and developed countries, find that RBOs play an important role as vessels of water diplomacy in the presence of competing interests, provided they are given the appropriate legal and institutional powers, and their ability to influence strategic resources.

Much of the literature focuses on RBOs to mitigate transboundary issues that arise between countries, such as in the Nile river basin, but these same dynamics are seen to play out from the nexus perspective. Nexus challenges and opportunities typically occur at the river basin-level, due to the fact that these resources, in particular water, are finite – and essential – goods. In response, many countries, including groups of transboundary countries, have established River Basin Organisations (RBOs) to address such complex challenges. From the perspective of water security, cross-sectoral entities which consider ecosystems as a whole (in this context WFEN ecosystems) are better placed to address the cross-sectoral and/or wide-ranging challenges that arise across sectors (and even state or national borders, as is often the case in the literature) including water scarcity and pollution, unsustainable or inefficient land-use patterns or agricultural processes, inefficient resource use, and ecosystem degradation – among many others.

Keskinen et al. (2016) summarise some of the benefits associated with a river basin approach to addressing nexus concerns and mainstreaming nexus approaches. Although their analysis focuses on transboundary river basins, i.e., those which cross state or national borders, it is still relevant in the context of the cross-sectoral boundaries that exist between the three resources in question within river basins at a whole. Indeed, management of nexus issues at a river basin-level is more effective and efficient than, for instance, at the state or national level because of the dynamic and contextual nature of nexus issues. Keskinen at al. (2016) cite that the introduction of nexus considerations in a cross-sectoral context has the potential to "provide new resources and approaches, alter existing actor dynamics, and portray a richer picture of relationships". At the same time, the authors recognise the need for a multi-sectoral, multi-stakeholder approach to administering the nexus at a river-basin level, suggesting that a sole authority should not be tasked with complete ownership of nexus matters, unless it generates interest and participation across stakeholders. It gives the example of WFEN nexus approaches being largely water-sector driven, but highlights the importance of buy-in from food and energy sectors too.

Further, The Global Water Partnership's Integrated Water Resources Management Toolbox highlights specific characteristics of sustainable river basin management; among these are for river basin-wide planning and coordination which enables a balancing of the needs of various water users from a demand-side perspective, and to facilitate and monitor agreements between the many stakeholders within the ecosystem. RBOs can also facilitate public and stakeholder participation in decision-making within river basins, adding a layer of democracy to these processes by empowering stakeholders to become decision-makers; indeed the GWP cites successful RBOs as having broad stakeholder involvement and the determination of solutions that are at the very least acceptable to all parties involved.

5.2.2 Establishing a WFEN CoE to Facilitate Nexus Approaches

Beyond just the creation of a RBO to address cross-sectoral issues within a particular river basin, additional 'authorities' are required to facilitate research into WFEN issues and considerations, as mentioned by Keskinen (2016), in order to bring about a coordinated, multi-sectoral and multi-stakeholder approach to nexus matters, and to serve as entities to facilitate the deployment of infrastructural and technological solutions to nexus issues. One such option proposed is the creation of a national WFEN CoE, a body which can serve as a hub of knowledge and research related to the nexus, disseminates this knowledge for the benefit of the various stakeholders involved, and facilitates technological deployment. For example, the Mekong River Commission (MRC) is a transboundary river basin institution formed and jointly managed by Cambodia, Laos, Thailand, and Vietnam. The aims are to coordinate sustainable management and development of water and related resources for the countries' mutual benefit and the people's well-being in the Mekong River, labelling itself a key actor in water diplomacy in the region.

Another example can be found in the Netherlands through the Environmental Assessment Agency (PBL), which is a Dutch research institute that forms policy recommendations on environmental and regional planning to the Dutch government. Its research areas include sustainable development, energy and climate change, biodiversity, transport, land use, and air quality. PBL published the Integral Circular Economic Report (ICER) for the Netherlands, summarising the Dutch use of raw materials and the associated environmental pressure and socio-economic effects. The ICER report is published every two years with the directive to achieve circular economy penetration and efficiency.

A CoE dedicated to the WFEN would be well-positioned to carry out applied research projects in collaboration with institutional and industrial partners, including the sectoral players which govern and perform activities within the water, food, and energy sectors. Such a knowledge-based platform would be able to cover various themes, or at least various interactions that occur within river basins in order to study these interrelationships deeply and offer concrete solutions to common issues found across river basins. For instance, one theme might be related ensuring efficient energy use in water pumping to support irrigation for paddy, the results of which might have implications for numerous river basins in Malaysia to varying degrees, and a WFEN CoE would be well-placed to address this.

Drawing on best practices internationally, the proposed WFEN CoE would incorporate and house domestic expertise focused on a range of technical areas, such as those covered by international institutions such as the International Institute for Applied Systems Analysis (IIASA), Commonwealth Scientific and Industrial Research Organisation (CSIRO), and the German Development Institute (GDI). For example, IIASA conducts policy research into complex issues such as energy and climate change, resource security, and sustainable development. IIASA has specifically conducted research into WFEN-related issues in conjunction with the Asian Development Bank's (ADB) Water Financing Programme, utilising their expertise in applied systems analysis to analyse competition for resource use between various sectors, such as agriculture, biodiversity and forestry, and energy, in relation to water. The ability to generate such insights on a national level would allow policymakers to have a more holistic approach to understanding and responding to issues related to resource competition and security within any given river basin in Malaysia, ultimately. As Malaysia's WFEN CoE builds its domestic expertise, it is pertinent that steps are made to form working relationships with institutions such as IIASA (and CSIRO) when it comes to the analysis of nexus issues and challenges and the mainstreaming of nexus solutions.

CSIRO, for its part, is tasked with carrying out scientific research to assist industry growth in Australia, as well as facilitating the application of such research to achieve national or international objectives across a wide range of areas – including water, food, and energy, and a range of other related and non-related areas. In a similar way, the WFEN CoE proposed in this study should be tasked with similar objectives – the conduct and application of research by in-house experts in collaboration with international partners, pertinent to the water, food, and energy sectors, as well as nexus issues more holistically, and put itself in the position to ultimately facilitate the deployment of nexus-related infrastructure and technology to address strategic resource security.

5.2.3 Establishing a Hydrological Database and DSS to Inform Policymaking

The rapid rate of urbanisation worldwide suggests that cities are crucial in adopting the WEF nexus approach. Artioli et al. (2017) state that the urbanisation of the nexus approach is part of a movement towards integrated management and that the "smart city" is the most dynamic component of that general trend. When it is necessary to respond to water crises caused by rapid economic development and climate change, South Korea is responding by integrating ICT into water management. Smart water management creates a new dimension in the water-energy-food nexus by improving water security and welfare.

Apart from strong ICT-based technologies, smart water management has progressed rapidly in South Korea because of the current government's interest in the Fourth Industrial Revolution. South Korea is superior in the IoT ecosystem due to the massive digital workforce and culture, strong talent development, and support from governance and institutional setups that have eased digital adoption. For example, the Seoul Metropolitan Government exercises central power to coordinate and accelerate digital adoption. Smart city development projects in Seoul have enjoyed the support by the government, seen from the number of ICT policies and frameworks developed and backed by financial stability and reforms.

Paju's Smart Water City project implementation in 2014 has increased customer satisfaction by 88.2% and removed disbelief of drinking tap water by 24.5%. Smart metering in Goryeong has reduced NRW from 34% to 1%, with savings of up to 0.2 million USD annually. The digitisation provides real-time information to manage better water consumption and meter reading for billing purposes. It allows the operator to collect and analyse data on its consumers' water consumption behaviour.

Cloud platform under IoT for data management ensures data cohesion across the nexus. Thailand, with the help of the Finland government, is digitising its water system management. Powered by cloud assets, the dynamic data streams from multiple sources can be managed to create a real-time Unified Situation Picture of the national water. Data input includes 30 000 sensors across agencies, remote sensing products from JAXA, NOAA, the Thai Navy, and human data from social media sources.

Compared to Korea, Malaysia's slow adoption of smart water lies with Malaysia's poor digital ecosystem and infrastructure. According to an IDC survey, Malaysia is ranked 9th place in the IoT maturity Index behind other ASEAN countries. Apart from that, the fragmentation and non-cohesion across water-energy-food subsectors' coordination build bureaucracy barriers.

Air Selangor is a pioneer in water sector digitisation in Malaysia. At a state level, Air Selangor in 2019 piloted a smart meter programme in Sepang. A total of 7,923 AMI meters were installed in the first phase of the pilot programme and connected via the cellular Narrowband – Internet of Things (NB-IoT). Later in 2020, Air Selangor set up a data analytics centre to build capabilities for big data analytics to cope with the high volume of data and consumption of newer treatment plants with its emerging technologies and a growing consumer base.

Apart from building necessary ICT foundations, nexus assessments also require the utilisation of good knowledge management practices. For example, data verification and exchange, as well as standardisation in basin monitoring can produce credible and valuable nexus analysis. Knowledge platforms can support the multi-sectoral exchanges on nexus best practices in planning and policymaking. For example, the WEF Nexus Resource Platform funded by Germany/EU enables the sharing of nexus experience, information, and funding opportunities.

All this indicates that a key step in Malaysia's journey to successfully incorporate nexus approaches into mainstream river basin management (and ultimately WFEN management) is its ability to facilitate big data collection and monitoring, and the application of this data to generate insights into and develop solutions to nexus issues at the river basin level. In that regard, a critical step is the development of a detailed and usable hydrological database, along with a decision support system (DSS).

The Asian Development Bank, in a review of river basin management planning in Indonesia, highlights numerous requirements for a hydrological database to be suitable for use in river basin management, including an analysis of the data requirements (such as space, time, and relation-oriented data); and the processing tools required for processing (including data entry, data validation, calibration tools, and the use of models to address potentially missing data), analysing (such as for rainfall, rainfall-runoff relationships, evapotranspiration, and other key indicators), applying the data gathered (such as through statistical computations, the development of distribution functions, data interpretation, forecasting, and so on); and processing tools to manage the database itself. The ADB suggests that these databases be supported by a decision support system (DSS) which links the hydrological database to the various nexus-related concerns within a particular river basin; for example, in assessing water demand for irrigation and competing uses.

5.2.4 Using Economic and Policy Instruments to Address Nexus Issues

Governing nexus requires reforms and legislation instruments. In California, two water conservation bills became subject to permanent legislation in May 2018 after the seven-year drought (2011–2017) in which a state of emergency was declared, and infrastructure, legislation, and social reforms took place in California's water management system. Although no clear nexus linkages are addressed, the state's response to securing water security under extreme drought is reviewed as a resource management best practice to reduce nexus pressure. The new laws require cities and water districts to set strict annual water budgets by 2022 and set mandatory usage targets on standardised water allowance. Failure to meet these targets will be met with punitive action; fines for non-compliance of $1,000/d in normal conditions and $10,000/d in drought conditions.

Cross-sectoral policy targets also strengthen the development of nexus management. In China, the National Development and Reform Commission (NDRC) expressed the need to develop a good way of undertaking capital accounting of the country's natural resources by 2020. It focuses on studying the implementation of wastewater tariffs to reflect the actual cost of wastewater treatment and develop strategies for water reuse financing.

The Korean government has viewed water insecurity as a big challenge in achieving the water energy food land (WELF) nexus on a national and basin scale. In 2018, Korea revised its national water management system that had fragmented responsibilities among ministries into an integrated structure with the Ministry of Environment as the single authority. The reform optimised the administrative efficiency in water management to ensure cost-effective, equitable, and sustainable use of the country's limited water resources. Under the presidential water commission, they have established water commissions in four river basins. According to the new Framework Act on Water Management, Korea will build a National Water Management Plan every ten years. The first was formulated in 2020, defining policy goals and specific measures on comprehensive water issues, including water quality, water resources, water disasters, conflicts, and water industry.

The California State Water Resources Control Board (SWRCB) recently updated California's Recycled Water Policy. Under this new directive, the California WateReuse Action Plan (2019) sets ambitious water recycling goals to increase water resource resilience in the next 30 years.

Incentives promote the adoption of resource-efficient technologies and shaping behavioural change, which in turn influence the development of sustainable technical solutions. Additionally, energy and water tariffs must be set accordingly to reflect the true cost of wastewater treatment.

For example, the city of Zaragoza in Spain saw a 27% reduction in overall water consumption between 1996 and 2008 after the city implemented a water-conserving tariff supported by economic incentives. Consumption-based tariffs could guarantee the business case for nexus investment while simultaneously ensuring socially equitable tariffs, especially for low-income groups.

During and after California's century drought, the Metropolitan Water District of Southern California (MWD) initiated a mass scale infrastructure investment to ensure water reliability to California's densely populated south and expand the region's water recycling capacity, set to be the largest in the US. MWD is a state-owned cooperative of 26 cities and water agencies serving nearly 19 million people. One of the initiatives was revising 'The Local Resources Programme' in 2014 to provide economic incentives for water recycling, groundwater recovery, and clean-up projects, including seawater desalination efforts. As an outcome, the Regional Recycled Water Programme recharged local groundwater sources with 567,759 m^3/d of treated effluent. From July 2016–June 2017, the programme collected a daily average of 608,000 m^3 of recycled water, putting more than 597,000 m^3/d into groundwater recharge.

Aligned with water efficiency measures, 'SoCal Water$mart' is implemented to reduce Californian water demands by improving community outreach and behavioural change. The programme offers rebates for high-efficiency appliance installation, irrigation controllers, rain butts, and turf removal. The utility provided rebates of $1 for every square foot of turfgrass converted to California native flora (up to a maximum $1,500 rebate). The public has responded positively to MWD programmes.

5.2.5 Facilitating Investment and Deployment of WFEN Infrastructure and Technology

Financing WEFN and nexus investment, if well regulated by the state, can contribute to sustainable economic growth. The inclusion by the private sector in WFEN, either by voluntary agreements (e.g., Concrete Agreement Netherlands and the Plastics Pact NL) or incentives, is imperative throughout the WEFN process, from planning phases and R&D to implementation, monitoring, and evaluation. By incentivising the private sector, we can bridge nexus investment and capacity gaps. The private sector provides indispensable knowledge in sustainable market solutions, innovative financing, technological innovations, better operational arrangements, and opening up a job market for nexus solutions.

The private enterprise in the agrifood sector understands the significance of the WEFN synergy and trade-offs. SABMiller, one of the world's largest brewers operating across six continents, is invested in "inclusive growth." This idea builds long-term returns over value chains that balance economic and social development and resource use efficiency. Their "Ten Priorities: One Future" framework for sustainable development provides clear policy targets and is mainstreamed to its local subsidiaries. A SABMiller subsidiary in Bogota, called Bavaria, has identified the nexus between declining water quality, poor basin/ water catchment management, and increasing energy demand in water treatment plants leading to rising costs internalised by water users. Bavaria began mapping the basin with a 20-year projection on water supply and demand based on production needs, coupled with user demand units like population growth and irrigation. This collaborative effort is established through a multi-stakeholder platform consisting of The Nature Conservancy, the National Parks System, the Sewage Company of Bogotá, and the local farmers to map investment risks and mitigation opportunities.

Innovative financing by Air Selangor is another example of the private sector's participation in sustainable resource management. Air Selangor raised RM1.15bil from its inaugural Sukuk issuance to finance its capital expenditure to enhance and upgrade water infrastructures, as well as supporting Air Selangor's sustainable and responsible investment projects.

5.2.5.1 Technological Applications to Address WFEN Issues

a. Large Scale Solar (LSS) Projects

The rise of solar projects intensifies nexus pressures by increasing competition for land with agricultural land or forested land. Two forms of nexus solutions – floating solar and agrivoltaics – offer avenues to circumvent such competition.

Floating Solar

Floating solar technologies use unoccupied water bodies, such as lakes or artificial basins to locate and produce solar power where there is limited land availability. The idea is to deploy floating PVs on abandoned water bodies with low utilisation value to scale up RE significantly. This nexus solution could also drive economic development and employment. China has the largest operational "floatovoltaic" plant. Located in Anhui, the Three Gorges New Energy's 150MW floating solar farm was built on a former coal mine pit lake and started feeding power into the national grid by December 2017. South Korea is developing the world's biggest floating solar farm with a 2.1 GW capacity near Saemangeum, an estuarine tidal flat on the coast of the Yellow Sea.

Malaysia has good potential for Floatovoltaics. There are several water reservoirs and former tin mining lakes that could scale up RE. A pilot Floatovoltaic farm of 13 MW built with 38,790 solar panels and 67,128 floaters using up 53 acres of the surface area of a pit lake was constructed in Dengkil, Sepang by the Malaysian solar project developer Solarvest Holdings Berhad.

a. Agrivoltaics

Agrivoltaic is a solar PV management to optimise land occupancy with agricultural activity. A communication group, the Baofeng group, established an Agrivoltaic pilot farm in the Ningxia Province, China. The 1 GW solar park accommodates a goji berry plantation using smart agriculture such as drip irrigation, drones, and Huawei Smart Management System for the plant inspection. The first 640 MW section of the project, which relies on 13,000 Huawei bright string inverters, was grid-connected under China's feed-in programme for solar energy in 2016. The panels were installed at the height of 2.9 m, which offers enough room for the cultivation of goji berries and ensures optimal operation and maintenance activities. The Agrivoltaic pilot has reduced land moisture evaporation up to 40% and improved vegetation coverage and biodiversity.

b. Hydropower and Dams

Nexus analysis is useful for infrastructure development planning. By using an optimisation framework, the synergies of WEF infrastructure are identified and taken into account for infrastructure planning. In Burkina Faso, the scenario modelling and resource optimisation called MAXUS identifies the strategic locations for irrigation capacity and water storage for dam construction.

Apart from identifying strategic locations, transforming existing water reservoirs into multipurpose dams could improve flood control, ensure water reliability, water pollution relief, and reduce GHG emissions.

South Korea attempts to transform the hydropower reservoirs on the Han River basin into multipurpose dams to strengthen the water-energy link. K-water, a state-owned corporation mandated by ME, is the water resource authority to operate all multipurpose dams in an integrated manner. Early projections show that the conversion of the hydropower dam into a multipurpose dam and operated in real-time could secure a flood control capacity of about 240 million cubic metres and an additional water supply capacity of 540 to 880 million cubic metres.

The transformation requires technological nexus solutions. The Jebel Aulia dam, located near the White Nile, is retrofitted with a modular system with turbine generators reaching 0.5 MW capacity each for 40 of its discharge openings. The dam was built in the 1930s for irrigation and flood control and now converted into a multipurpose dam with a hydroelectric capacity of 30.4 MW.

c. Water Treatment Plants

In urban nexus, Water treatment plants (WTP) are defined from the frameworks of resource efficiency and optimising resources. For example, to increase water reliability and reduce energy demand in the water sector, WTPs can be retrofitted with membrane technologies and installed with energy-efficient pumping systems. WEFN implementation supported by good governance and decentralising water services are exemplified below in Amsterdam.

Amsterdam is on an excellent trajectory to sustainable urban development. It offers a good model of how the urban nexus is integrated within its water-energy-food-waste management for decades. Amsterdam's WEFN is largely defined by efficiency discourses, technological innovation and market-based solutions, and cooperation between the existing utility companies, such as Waternet and AEB. The cooperation between Waternet as a water cycle company and the private utility Waste to Energy Company (AEB) is explained further below.

Box: Water-Energy-Water Nexus in Amsterdam

Waternet is a public water company responsible for Amsterdam's water cycle and shaping the water-energy nexus. Waternet has a climate-neutral target by 2020 to reduce energy consumption in the water system and increase renewable energy use in the utility's operations (e.g., wind and solar power, energy recovery from water). Under the water for energy link, energy recovery is achievable from wastewater (chemical and thermal). AEB is the "waste-to-energy" company that produces energy from waste and biomass incineration.

Through cooperation with AEB, wastewater from Waternet gets new value and becomes a resource for another cycle (energy) or "waste to wealth." The flow of biogas and sewage sludge from the WTPs regulated by Waternet is intercepted by the AEB plant and then burned to produce energy. This energy is partially returned to the WTPs for operation or feeds in electricity for the city heating network. Waternet and the AEB plants are located in proximity to one another. This co-location of water and energy infrastructure allows the waste stream to be utilised by the others, allowing for reduced by-products, minimisation of transportation costs, and lowering energy and water requirement (in Amsterdam Westport).

The trade-off and synergy within the water-energy link between the two companies result from compatibility in technological aspects and voluntary cooperation under the directive of Amsterdam municipality.

d. Lifting Water: Irrigation and the Urban Nexus

Irrigated agriculture formed a large portion of water usage and was elaborated in earlier sections on how private enterprises and state-owned corporations lead the way to achieve sustainable growth in their value chains, i.e., drip irrigation, smart water management, and Agrivoltaic. However, not much is known on the implementation of urban nexus in residential buildings. As cities grow, vertical residential buildings will need to ensure water reliability, and at the same time, increase energy saving costs. Apart from that, several smart city frameworks conceptualised rooftop food gardens for urban food resilience. These initiatives must take into account irrigation. Water-saving mechanisms such as rainwater harvesting can be considered, supported by and a network of tanks driven by gravity to limit external energy sources. Some studies also recommend managing smart pump boosters or pressure boosters in high-rise building design to increase water reliability and reduce energy consumption. KPKT could manage regulations and incentives for smart building.

5.3 TOR Scope 3: Study Potential of the Nation's Water Sector Industry Taking into Consideration Current Global Markets Towards Marketing the Water Sector as a Dynamic New Economic Sector Capable of Driving the Nation's GDP Growth in the Future

5.3.1 Water as an Economic Opportunity: Emphasising the WFEN

Water is an enabling resource. In a potable form, it is essential to the sustenance of human (and plant and animal) life. Directly or indirectly, it is an essential ingredient for the agriculture (including the commodity, food, and fishery industries), construction, industrial, utility, and waste sectors. It enables growth and development, but is also becoming an increasingly precious commodity. The perennial issues of water access, quality, and scarcity are only exacerbated by climate change, population and economic growth, urbanisation, and an ageing infrastructure, amongst various other extraneous variables. How policymakers react to these challenges will determine the long-term sustainability and revenue-generating capabilities of the nation's water sector.

Our response to the various challenges facing the water industry will determine not just long-term water sustainability and security, but given deep nexus interlinkages such as those described in this paper, it will affect our food and energy security too. In contextualising water-related issues from the perspective of three important metrics: access to water, water quality, and water scarcity this section overviews some of the key threats to water in Malaysia, and proposes that Malaysia's water sector embrace new technological advancements that are presented by increasing digitalisation and connectivity to alleviate WFE nexus pressure points. This will allow the country to turn the challenge of water insecurity into an achievement of water security and support the growth not only of the sector itself but others with which it is deeply linked.

The first fundamental challenge to water relates to water access, referring to the population coverage of access to clean, treated water. Globally, some 1.6 billion people lack access to this basic resource, and this is in large part due to an absence of infrastructure. In Malaysia, some 92% of the population have access to 'properly managed water supplies' (UNICEF & WHO, 2019), but a significant proportion of those who do not belong to vulnerable or marginalised groups or live in secluded, rural areas. An even more pressing concern is reflected by the one in five Malaysians who lack access to safe and hygienic sanitation services. Again, these largely reflect poor and marginalised groups, some of whom reside in rural areas. The threats of climate change to these groups are also likely to outweigh those faced by the more enfranchised urban populations. It is crucial that action is taken to improve water infrastructure, including minimising water losses, and preventing and reacting to leaks, contaminations, and other issues efficiently, as well as broadening off-grid access to water.

The second significant issue is that of water quality. This primarily relates to the pollution of water resources, which in extreme cases can threaten water security by acting as a constraint on its supply – particularly for agricultural, industrial, and domestic uses where the safety of water is imperative. Water quality faces threats from numerous sources, including pollution across a range of sectors from manufacturing and construction to heavy industry, and agriculture to energy in the form of salinisation, sedimentation, and microbial and toxic pollution. Rapid economic development and urbanisation add a further dimension to issues related to freshwater pollution. In the context of Malaysia, major water pollutants include biochemical oxygen demand (BOD), ammoniacal nitrogen, and suspended solids. Recent years have also seen toxic pollutants affect water bodies across the country, most prominently from the manufacturing and heavy industry sectors. Ensuring Malaysia's water quality by improving the monitoring of pollution incidents and enforcement of anti-pollution regulation, for instance, is a vital element of maintaining water security and is another issue that can benefit from the digitalisation of Malaysia's water sector.

The final substantial challenge facing water is the issue of scarcity. Water scarcity, referring to situations where the demand for clean, treated water exceeds its supply, is a key global issue likely to worsen as a result of factors such as economic and population growth and the resultant increase in demand for water across almost all sectors, as well as climate change. Threats to water quality also double up as threats to water supply and consequently exacerbate the issue of water scarcity. In Malaysia, many districts, especially in states along the nation's west coast, are cited by NAHRIM (2020) to face high levels of water stress, even today. The effects of climate change, including extreme weather and changing weather patterns, as well as droughts, floods, and sea-level rise are likely to worsen these issues of water stress and water scarcity and if unchecked could have significantly negative consequences for Malaysia's long-run water security.

Throughout this analysis of the WFE nexus, certain nexus 'flashpoints', or pressure points have been identified. These typically encompass areas where, for example, significant quantities of one nexus resource (e.g., water) is used in the production of another (e.g., energy), and it is through the use of policy tools (whether economic, financial, or regulatory) as well as the adoption of technology that can address these. The main objective of this section of the report, therefore, is to highlight some of the areas in which solutions can be adopted which are able to address issues related to domestic water security and ensuring that the water sector can act as a driver of future GDP growth. While a holistic addressing of water issues requires technological adoption to be matched by innovative financing mechanisms as well as improved regulatory or governance models, this section will focus most on the technological aspect, and specifically where the adoption or embrace of new technologies and/or practices can address some of the nexus 'flashpoints' – particularly where water features prominently. Many of these technological solutions fall under the broad umbrella of the Fourth Industrial Revolution (or IR4.0), referring in large part to digitalisation and the adoption of connected and 'smart' devices which can play a critical role in maximising efficiencies and mitigating waste in the context of water, but also includes technologies such as renewable energy and its uses in alleviating fossil fuel energy demands within the water sector.

The Digitalisation of Water: Water in IR4.0

IR4.0 is an umbrella term encompassing technologies that marry the digital, physical, and biological worlds. Examples of these technologies include advanced sensors, AI, autonomous vehicles/devices such as drones, automation, blockchain, the internet of things (IoT), robotics, and so on, sometimes retrofitted into existing infrastructure and/or processes. The connectivity of these technologies allows them to harness big data collection and analysis in order to 'learn' and make real-time decisions with implications for resource use efficiency. Advances in AI, the IoT, and predictive analytics have the potential to dramatically revolutionise the water sector, in ways as far reaching as resource monitoring in terms of both quality and quantity, asset and infrastructure management, improved predictive capabilities, and so on. In this technological context, certain key aspirational policy outcomes, which in part address the issues of water access, quality, and scarcity as outlined above, are discussed from the perspective of the WFE nexus. This includes, for instance, the use of technology to enhance the energy efficiency (or even utilise clean energy) of water or wastewater treatment processes. These aspirational policy outcomes along with the activities relevant to their achievement are listed in Table 7 below.

Table 7. WFEN Activities and Aspirational Policy Outcomes

Policy Outcomes	Activities
Increasing energy efficiency Reducing energy consumption Reducing GHG emissions	Water lifting/pumping/distribution, water/wastewater treatment
Increasing water use efficiency Reducing water consumption Minimising water losses	Agriculture/irrigation, energy generation, cooling/condensation, water distribution
Enhancing resilience to climate change	Scenario planning, extreme weather/weather event forecasting, infrastructural risk management
Minimising water pollution	Monitoring of water quality in water bodies
Enhancing circularity	Waste-to-energy (e.g., biogas), water reclamation

Many existing IR4.0 technologies have the potential to address water and WFE nexus security issues, sometimes in combination with, for instance, renewable energy technologies, across the activities listed in Table 7. For instance, advanced sensor systems allow for real-time monitoring of water quality – and consequently the health of water bodies – and can assess the suitability of water for use across industries. This gives planners greater foresight of the quality and quantity of available water, as well as the detection of sources of pollution from agricultural, industrial, or waste sectors, for example, allowing for swift addressing of such issues and the minimisation of disruptions to water supplies. Such systems can also improve efficiency and minimise losses during water distribution processes, by improving the accuracy and response time of centralised utility systems in detecting and fixing leaks or removing contaminants. A list of WFE nexus activities, organised by nexus interactions, as well as opportunities is provided in Table 8. Some of these, particularly those pertaining to the three-way nexus interactions between water, food, and energy, are described in further detail later in Section 5.3.

5.3.2 Overview of the National Water Innovation Roadmap (NWIR) 2040

The National Water Innovation Roadmap (NWIR) 2040 proposed by NAHRIM strives to promote national water assurance (or security) innovation. Floods, droughts, pollution, and other causes of water supply disruptions faced by Malaysia typically affect raw or treated water supply sources that depend on rivers, reservoirs, groundwater, or dams. The directives involved in these plans which are described in this

Table 8. Nexus Interactions, Activities, and Opportunities

Nexus Interaction	Activities	Nexus Opportunities
W-E	Water consumption, efficiency, and quality, energy generation	Opportunities from shifting to less water-intensive energy generation technologies, e.g., solar, biogas using POME.
	Water source, cooling, and condensation	Conflicts and opportunities arise where water used for cooling is drawn from freshwater resources.
	Water use, cooling, and condensation	Opportunities from shifting to less water-intensive cooling technologies, e.g., recirculating tower cooling, dry cooling.
E-W	Energy efficiency, water supply	
	Water losses, water supply	Opportunities through adoption of IR4.0 technologies, e.g., advanced sensor systems, remote monitoring of connected devices, big data analytics.
	Energy efficiency, water, and wastewater treatment	Opportunities from shifting to more energy efficient/ less energy-intensive technologies, e.g., co-digestion, fuel cell systems.
W-F	Water intensity, agricultural production	Opportunities through modernisation of farming, i.e., precision agriculture, entailing digitalisation of farming processes to maximise efficiencies and minimise losses.
	Water efficiency, irrigation	
	Food losses, post-harvest	Opportunities through adoption of digital/connected technology, investment in on-farm/commercial storage and infrastructure (e.g., for transport), to minimise losses; improve financial and market access to benefit smallholders in particular.
W-F-E	Large Scale Solar – agrovoltaics, floating solar	Opportunities to produce food and energy simultaneously with lower water intensity than other forms of energy generation.
	Waste-to-Energy – Biogas	Opportunities for waste/wastewater to be converted into energy through biogas production, prominently in the oil palm industry.

section, are aligned with the National Water Sector Transformation 2040, and are also streamlined under KASA's Environmental Sustainability in Malaysia Roadmap 2020–2030.

The basis of consideration for NWIR 2040 are spelt out as below:

Non-Uniform Raw Water Sources (occurrence of insufficiency and excess water)

Climatic conditions in Malaysia cause excessive rainfall in certain months and prolonged drought episodes in other periods. This situation will disrupt the sustainability of water resources and flood protection. For example, the floods in the East Coast States in December 2014 and the drought episode in Melaka on 29 January 2020 involved scheduled water supply rations involving 250,000 user accounts.

Water Resources Pollution

Raw water quality is severely affected due to pollution of rivers that often occur in several states in Selangor, Johor, Melaka, and Pahang. The causes of pollution from industry, plantations, livestock are among the reasons for ammonia concentrations, turbidity, high odours to cause many episodes of treated supply disruptions that affect millions of account holders.

Low Reserve Margins

Low storage causes prolonged maintenance-related water supply disruptions and outages. It also causes delays in the implementation of new development projects. This is exemplified by the Gebeng Industrial Park, where the Semambu Water Treatment Plant operates with a 4% reserve margin and faces challenges **meeting growing demand for water.**

Water Financing

The terms of water asset migration agreed by the State Government and Pengurusan Aset Air Berhad (PAAB) are limited. Their implementation is based on the lease and requires the transfer of land as an element of financing. A more flexible approach and inclusive of more industry players besides water operators and broader areas of financing such as climate change, flood protection, and forestry (water catchment areas) are needed to enhance the resilience and sustainability of development.

NWIR 2040 aims to develop practical solutions to promote a sustainable water sector. It proposes to do so through five programmes, with each of these programmes comprised of selected activities and with clearly outlined targets and timelines. These are listed below.

Programme 1 – Clean River (CR)

Activities: Odour Threshold and Sensor for Pollution Control; Applications and Portal for National River Trail (Denai Sungai Kebangsaan, DSK); River Eyes, Water Quality Enhancement; and Established Method/ Threshold for Water-Borne Disease (WBD), including pandemic - Emerging Pollutants

Programme 2 – Reserve Margin (RM)

Activities: TAPS (raw water); Coastal Reservoir (raw water); Underground Dam, UGD (raw water); Rainwater Harvesting System (RWHS); Reclaimed water; and National Water Grid

Programme 3 – Smart Water (SW)

Activities: Local SME Entrepreneurship; and Renewable Energy;

Programme 4 – Disaster Risk Reduction (DRR)

***Activities*: IR 4.0; River and Coastal Integrated System; and Flood Control**

Programme 5 – Water Financing (WF)

Activities: PAAB Diversification

The estimated cost of NAHRIM's proposed R&D initiatives for these programmes is approximately RM39mil between 2021 and 2040. NAHRIM has been appointed as the lead agency under several programmes. This includes Programme 1 on clean rivers, under the theme of Water Quality Enhancement, which allocated a total of RM4mil and on emerging pollutants, also within the theme of Water Quality Enhancement, which allocated RM5mil. Programme 3 on smart water, under the theme of Renewable Energy has been allocated a further RM5mil, with another RM25mil parked under funding for Programme 4, to be split between IR 4.0 initiatives (RM10mil), River and Coastal Integrated System (RM10mil), and Flood Control (RM5mil).

This set of projects will create direct and indirect benefits to the country, with estimates indicating it will raise government revenue by RM100mil, lead to RM11.2bil in savings due to disaster reduction and efficiency increases, among others, and create economic value of approximately RM6.4bil in sectors such as water and wastewater treatment, eco-health tourism, and others. It is also estimated that these projects will create an excess of 630,000 jobs.

5.3.3 Three-Way Nexus Interactions

This section of the report overviews three technologies that represent three-way nexus interactions between water, food, and energy. These three technologies – large-scale floating solar or agrivoltaics; biogas; and hydropower dams – are all renewable energy technologies, and this lends to a potentially fourth element to the nexus being analysed, in climate. Nonetheless, these RE technologies are analysed from the lens of being technological solutions to existing nexus issues or pressures relating to water, food, and energy, and their potential for being drivers of sustainable economic growth are detailed within the individual subsections.

5.3.3.1 Three-Way Nexus Interactions: Large-Scale Solar (LSS)

Renewable energy (RE) is a growing focus area for Malaysia particularly with the Fifth Fuel Policy (2001) that recognises RE as part of national power generation mix. The National Renewable Energy Policy and Action Plan (REPAP) is endorsed in 2010 to enhance indigenous RE contribution towards supply security and sustainable socioeconomic development.

The NREPAP also aims to enhance RE awareness while ensuring that environmental conservation remains a mainstream objective. Malaysia then enacted the Renewable Energy Act in 2011 to enable concerted RE development with financial support through a feed-in-tariff mechanism in developing RE-based power (electricity) generation for Malaysia. The RE act has accelerated RE development, especially solar PV that sees its capital cost per kilowatt peak drop significantly over the years. More recently, solar PV development is enhanced especially through developing LSS plants.

a. Background

For Malaysia, solar power generation is the fastest growing source of renewable energy, driven by drastic cost reductions, significant increase in efficiency, and encouraging government policies. LSS generation began its first operation in Peninsular Malaysia in 2018, producing about 32,000 MWh of electricity. In 2019, LSS electricity generation increased to about 646,000 MWh. This is in line with the government policy to achieve 20 percent RE capacity by 2025 (Energy Commission (ST) Malaysia, 2019b).

The Energy Commission's LSS programme (2017 to 2020) aims to accelerate Malaysia's RE production capacity as approved by the Planning and Implementation Committee of Electricity Supply and Tariff (JPPPET). The total capacity allocated for this programme is 1000 MW by 2020 with an annual capacity capped at 250 MW throughout the four-year period (Energy Commission (ST) Malaysia, 2019a).

The first LSS procurement cycle (dubbed "LSS Fast Track") is done via a direct negotiation award mechanism. A total of 250 MW capacity was awarded in this programme. Subsequent LSS tenders are done via a competitive bidding mechanism. There are now five LSS procurement rounds (or awards) with their capacities and planned commercial operational year summarised in Table 9 (Energy Commission (ST) Malaysia, 2017).

In 2018, nine LSS plants are operationalised with 260.5 MW of capacity. The planned LSS capacity is increased in 2020 with the new LSS4 or also called MeNTARI, which is the fourth LSS procurement cycle that offers a capacity of 1000 MW. The request for proposal is announced in May 2020 as part of a move by the government to revive and stimulate the economy following the COVID-19 outbreak (Zahratulhayat Mat Arif, 2020).

Table 9. Procurement Awards for LSS Plants in Malaysia

Procurement Cycle	Capacity (MW)	Start of Commercial Operation
Direct award (fast track)	250	2017
LSS1	401	2017–2018
LSS2	557	2019–2020
LSS3	500	2021
LSS4 (or MeNTARI)	1000	2022–2023

In general, all solar power technologies use a modest amount of water (approximately 20 gal/MWh (gallon per megawatt hour)) for cleaning solar collection and reflection surfaces like PV panels or mirrors and heliostats for concentrated solar power (CSP) technology (Macknick, Newmark, Heath, & Hallett, 2012; Meldrum, Nettles-Anderson, Heath, & Macknick, 2013). An example of the latter (CSP) is the Nevada Solar One parabolic trough plant that consumes 850 gal/MWh on a 360-acre site near Las Vegas (about 300,000 gal/acre annually). In comparison, agriculture in Nevada requires almost 1.2 million gal/acre of water per year, i.e., nearly four times of the solar power plant consumption (ACCIONA, 2021).

b. Nexus Arenas for LSS in Malaysia

Water Use

With growing renewable energy generation in Malaysia, the impact to water and food or land use ought to be taken into consideration. LSS in Malaysia mainly involves solar photovoltaic (PV) farms, with very low water demand. Solar PV arrays are connected to the grid inverter and into 132 kV substation to the grid network. Therefore, water for the farms is not used in direct electricity generation but mainly for cleaning and cooling, e.g., of PV panels.

Land Use

Land use is one of the biggest challenges impact of LSS projects. From our preliminary findings, LSS in Malaysia requires 2.5 to 3.37 acre of land per MWp. Meanwhile, coal-fired power plants require about 0.15 acre/MW and gas-fired power plants require about 0.04 acre/MW. To put in context, LSS requires 22.5 times more land to generate an equal electricity amount than that of a coal-fired power plant and 84.5 times more land than that of a gas-fired power plant (specifically compared with Tanjung Bin (coal) and Segari (gas) plants, respectively). This poses a land use challenge for LSS PV plants.

Innovative solutions are needed to reduce land use and potential environmental impacts of solar energy. One solution to increase land use efficiency is agrivoltaic (also called agrophotovoltaic) farms that use the same land for agriculture and solar PV. The concept involves mounting narrow rows of PV panels at wide spacing on high frames and undersown with food crops. The coexistence of PV panels and crops entails sharing the amount of sunshine and light received. This technology does not work for all types of products but is possible for shade-tolerant crops from fruit trees to peanuts, along with alfalfa, yams, taro, cassava, potatoes, sweet potatoes, and lettuce (Othman, Mat Su, & Ya'acob, 2018).

Japan pioneered the development of agrivoltaic technology: between 2004 and 2017, more than a thousand of these plants have been installed in open fields that are used simultaneously to cultivate the land occupied (Movellan, 2013). The concept was originally developed by Akira Nagashima in 2004, who is a retired agricultural machinery engineer who later studied biology and discovered the "light saturation point" effect: photosynthesis rate increases as the irradiance level is increased but beyond an appropriate point, any further increase in the amount of light that strikes the plant does not cause any significant increase to the rate of photosynthesis. Shading may be a benefit or a disadvantage, considering effects such as the impact of shade on evaporation rates.

Another solution to reduce land use of solar power is floating solar farms. In October 2020, a 13 MW floating solar farm is installed in Selangor, owned by WD Solar Sdn. Bhd. (which is part of Malaysian mining company called WD Group). The solar PV cell arrays cover an area of 53 acre (21.4 hectare or 0.214 km^2) on a pit lake in Dengkil, Sepang (Bellini, 2020). In 2018, only two floating LSS projects were awarded and negated the need for ground-based installations. Cypark Resources Sdn. Bhd. is the developer for these floating solar panel projects at Empangan Terip (30 MW) and Empangan Kelinchi (50 MW), both in Negeri Sembilan.

Besides that, solar energy can be integrated with buildings through building integrated PV (BIPV). This generates smaller amounts of solar power capacities (usually less than 1 MW) and thus typically falls under distributed energy resources category. The solar PV panels can be retrofitted on top of agricultural farms, industries, and residential houses (Mak, 2018). The panels are installed close to the load demand centres, thus generating electric power at the point of consumption. It minimises a need to build new substations or reinforce distribution lines to get the clean solar power into the grid and to the consumers. Besides reducing the cost of building new facilities to transmit the energy, distributed solar generation will also decrease line losses and relieve grid congestion in certain area.

Energy Security and Other Issues

Solar power is dependent on climate conditions and solar irradiations. The solar PV panels are also subjected to effects of wind, dust, sand, and flood and may need higher maintenance for cleaning to ensure efficiency remains robust. Besides that, increase in surrounding temperatures reduces the power production of PV panels. The power output would see a decrease at every 0.4ºC increase in temperature.

A major challenge in solar power is its intermittency, which gives rise to the so-called "duck curve" phenomenon as illustrated in Figure 8. The 'duck curve' depicts the gap or deviation between total electricity demand of utility grid (the black curve) and net power load (the blue curve) due to a high penetration of solar electricity generation (the red curve) during the middle of a day. The peak sun hours in Malaysia are typically between three to five hours in a day (subject to changes in weather conditions), while the peak electricity demand is around middle of a day (noon) (which explains a somewhat shifted shape of the duck curve for the Malaysian case as compared to a western European or North American city or country). Solar power can assist to meet (or "shave off") peak demand load, but we still need to manage solar intermittency, e.g., via backup systems (e.g., peaking plants or batteries). Larger solar power capacity share connected to the grid makes it more challenging to ensure robust energy security for the nation.

The impact of high RE onto the energy system security is a critical component of study as Malaysia embarks on its low carbon generation plan. The integration of renewable generation technologies such as solar in the generation mix has introduced new challenges for managing operational security. First, the intermittency inherent in renewable resources can impact on key power system parameters such as frequency and voltage stability. Second, renewables interface with the grid through power electronics rather than mechanical elements, which means that the physical characteristics of turbine generation that have historically supported the stability of the grid start to become less dominant as the power system transitions away from fossil-fuel- based thermal generation (Billimoria, Mancarella, & Poudineh, 2020).

Other issues to be studied include the microclimate effects of LSS. This will be very dependent on their location, i.e., whether near agriculture or forest areas versus near urban developments. This may also contribute to ecological implications caused by LSS. This study needs to further assess other environmental costs and benefits – the three-way nexus – to minimise any negative impacts and maximise ecosystem benefits.

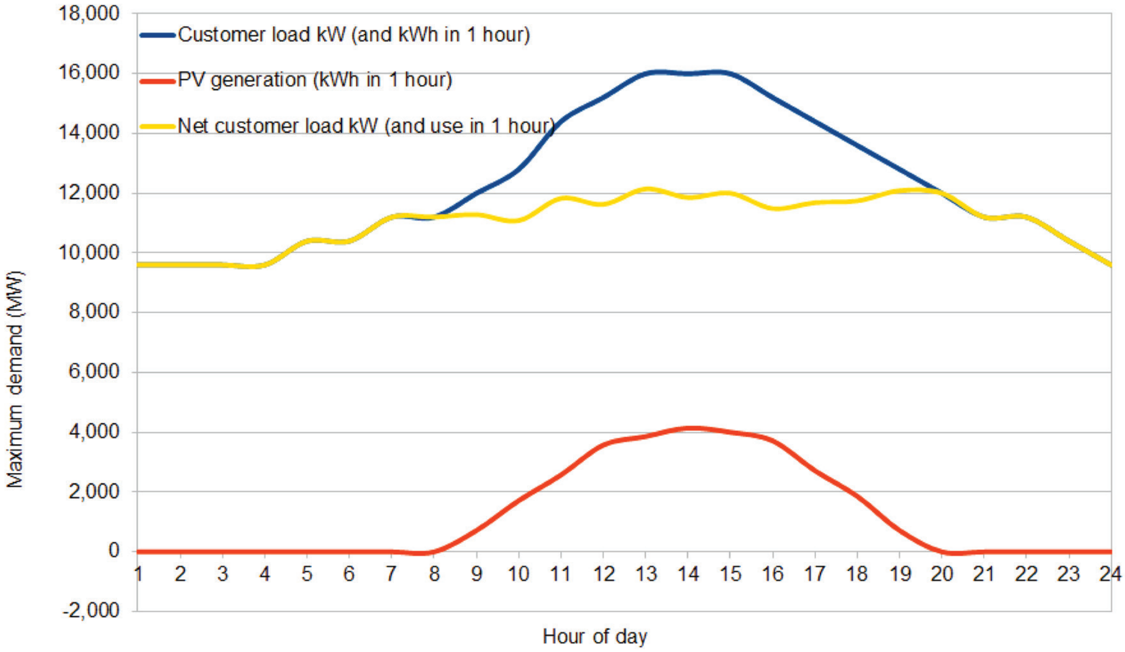


Figure 8. The 'Duck Curve' Phenomenon

c. Case Study: Floating LSS Plant in Dengkil, Selangor

Wawasan Dengkil Sdn. Bhd. successfully bid for a LSS PV operating license through a special purpose vehicle called WD Solar as its operator. The site in Kuala Langat, Selangor is an ex-mining pond that prevents using the acidic water in its operation (pH level is about 3). Therefore, the LSS plant relies on piped water (i.e., utility supplied by Air Selangor, the state government's appointed service provider), which entails pumping energy requirement. An alternative is to withdraw water directly from Sungai Langat on a need basis to meet the plant operational needs.

Water is mainly used to wash the solar PV panels on monthly or quarterly (at minimum) basis that incurs regular operating costs in addition to daily checking of the panels (by an appointed contractor. According to the operator (WD Solar) solar PV capital cost has increased by about 30 to 40 percent in the past year (2020) although operating cost has reduced. In addition, the LSS farm faces risk of flood—its mitigation plan involves pumping out water from the pond. Other operational problem includes algae growth on the pond particularly if the water condition (presently acidic) becomes more neutral.

A future expansion plan is to integrate the farm with operating a water treatment plant by using the available remaining area of this ex-mining pond (as indicated in Figure 9) as a private service provider, which would require obtaining permit from the state authority (Lembaga Urus Air Selangor, LUAS). WD Solar is also considering the option of aquaculture as supplementary activity to fully utilise the farm area.

5.3.3.2 Three-Way Nexus Interactions: Biogas

This chapter aims to build a system dynamics model mirroring an oil palm (food)-POME (water)-biogas (energy) (FEW) nexus, and examines the base and possible spatial-temporal impacts arising from POME-to-biogas technologies in Malaysia. It presents a quantitative nexus assessment of renewable energy policy and innovation that considers the interactions of water, energy, food, and climate structures within a system. Based on system understanding, the FEW model enables simulations to help explore potential outcomes arising from technological upgrading and Malaysia's decreasing feed-in tariff (FiT) rates.

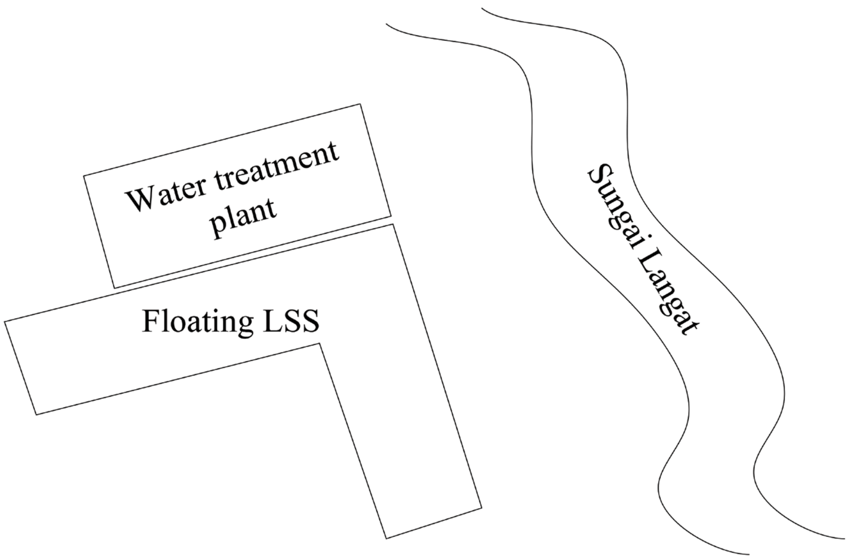


Figure 9. Schematic of WD Solar's Floating LSS Plant

Box: Facts on WD Solar's LSS Farm Plant in Dengkil

- Start of operation: August 2020
- Acreage: 110 m2
- Uses floating PV panels made from HDPE (high density polyethylene)-based double glasses technology
- Capacity: 9.98 MW (AC, alternate current) and 13 MW (DC, direct current)
- Energy generation: 45–50 MWh/day annual (based on 21-year power purchase agreement (PPA) with TNB)
- Capital expenditure: RM30 million (for construction and installation) including connection to the national grid (PMU) via 0.5 km transmission line (at cost of RM1 million/km); return on investment (ROI): 20 years

a. Background

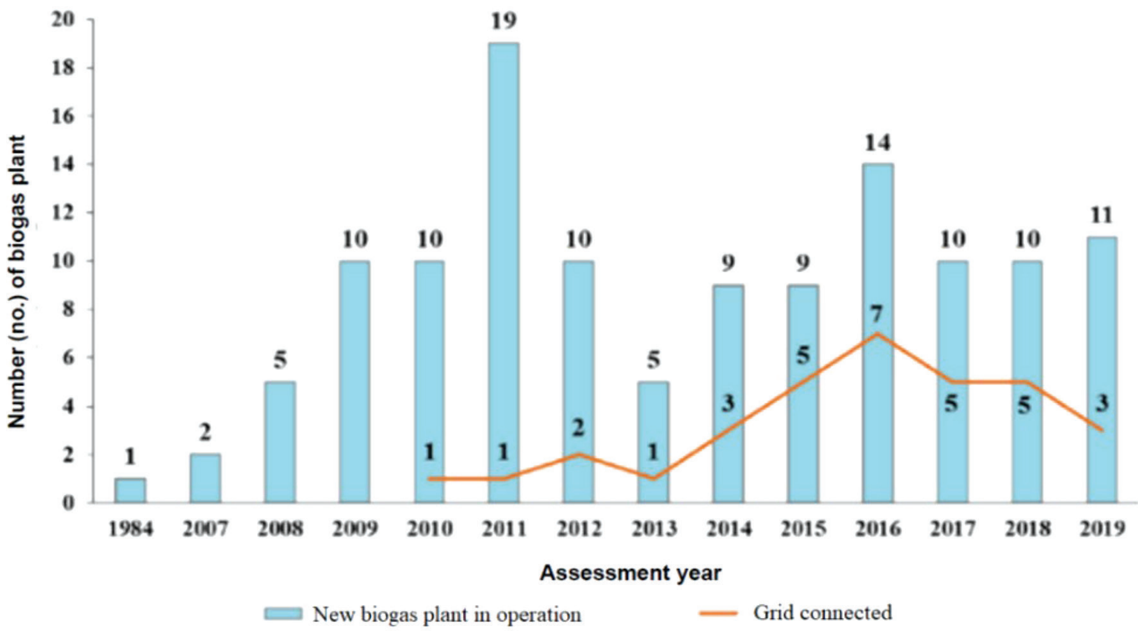
Malaysia produced approximately 19 million tons of crude palm oil (CPO, a milled product of fresh fruit bunches) from 5.9 million ha of registered planted area in 2020. Plantation firms accounted for 72.2% of the planted, followed by 16.3% of independent smallholders and 11.5% by organised smallholders. They are the supply base to a total of 452 mills, which are in vicinity for extracting oil contents of fresh fruit bunches at an optimal rate within 24 hours. The milling process generates biomass products, including POME, empty fruit bunches, mesocarp fibre, and palm kernel shell. In turn, physical biomass is burnt in modified boilers to generate steam for internal use. In this circular power system, empty fruit bunches and palm mesocarp fibre, which are of higher commercial values, are increasingly substituted by the biogas capture of POME (Vijaya et al., 2010). Policy attention is now expanded to promote biogas investments among palm oil mills in Malaysia.

Further to the Environmental Quality Act 1973, the POME discharge standard was enacted in 1978. As summarised in Kamyab et al. (2018), the standard is increasingly stringent. The Malaysian Palm Oil Board (2011) issued a guideline for the National Biogas Implementation under the Entry Project Point 5 of the National Key Economic Areas. Its objective is to encourage the uptake of biogas technology among palm oil mills. Since 1 January 2014, new mills and existing palm oil mills requiring expansion are mandated to install methane capture and methane avoidance facilities (MPOB, 2013). All mill licenses will only be extended if proof of a biogas plant or plan is submitted. It is a national target to have all palm oil mills equipped with biogas technologies.

Institutional efforts to promote biogas have gained momentum. At the international level, a clean renewable energy is recognised by the clean development mechanism for emission-reduction projects to earn certified emission reduction credits. The credits can be traded, sold, and used by countries to meet part of their emission reduction targets under the Kyoto Protocol. In Malaysia, incentives were already offered to companies generating renewable energy under the Promotion of Investments Act 1986. In 2012, the government began to implement the FiT system. Distribution Licensees are obliged to buy the electricity produced from renewable resources from Feed-in-Approval Holders.

Notwithstanding the mandate, biogas technology remains an economic option to palm oil mills. Tan and Lim (2019) found that an integrated POME technology can improve oil extraction rate by up to 0.3%. Yoshizaki et al.'s (2012) 10-year projection suggest a clean development mechanism can generate 25% internal rate of return, with 3.5 years of payback period. Chin et al. (2013) find that the biogas from POME can replace kernel shell and mesocarp fibre as boiler fuel, and be upgraded as gas engine for power generation. Such a combination can help a standard palm oil mill to generate an additional net profit up to RM3.8 million/year. To what extent this may come true depends on the FiT rate locked for 21 years.

Plenty investment in a biogas plant by palm oil mills remains to be made. According to Loh et al. (2019), as at the end of 2019, a total of 125 biogas plants (see Figure 10 for their annual commencements) are in operation nationwide. This represents an 28% national biogas implementation. Thirty of these are connected to national grid and another three to local grid for external users. While the authors attributed the adoption gap to the unattractive economics of the biogas technology, Loh et al. (2017) clarify that the biogas initiative in meeting the nation's emission reduction target continues to be a long-term plan. Towards the same direction, Ghani et al. (2019) suggest that a system understanding helps optimise the potential of biomass.



(*Source*: Loh et al. (2019))

Figure 10. Number of Palm Oil Biogas Plants Established Annually in Malaysia

b. Methodology

In this study, the system dynamics approach was used for modelling FEW nexus. Howarth and Monasterolo (2017) and Markantonis et al. (2019) characterise a nexus as exhibiting non-linear understanding and dynamic feedbacks across sectors. The system dynamics approach meets these salient features. Supported by 35 years of empirical application, Forrester (1993) concluded that the system dynamics approach renders a plausible methodology to understand and influence how systems change through time using feedback loops and non-linear differential equations. He re-iterated that "...system dynamics process starts from a problem to be solved – a situation that needs to be understood, or an undesirable behaviour that is to be corrected or avoided."

Empirical Model

The empirical model developed for modelling FEW nexus that centres on POME issue in Malaysia is presented in Figure 11. Accordingly, the system dynamics model of the FEW nexus contains oil palm (food), POME (water), and biogas (energy) sub-systems as well as their feedback loops.

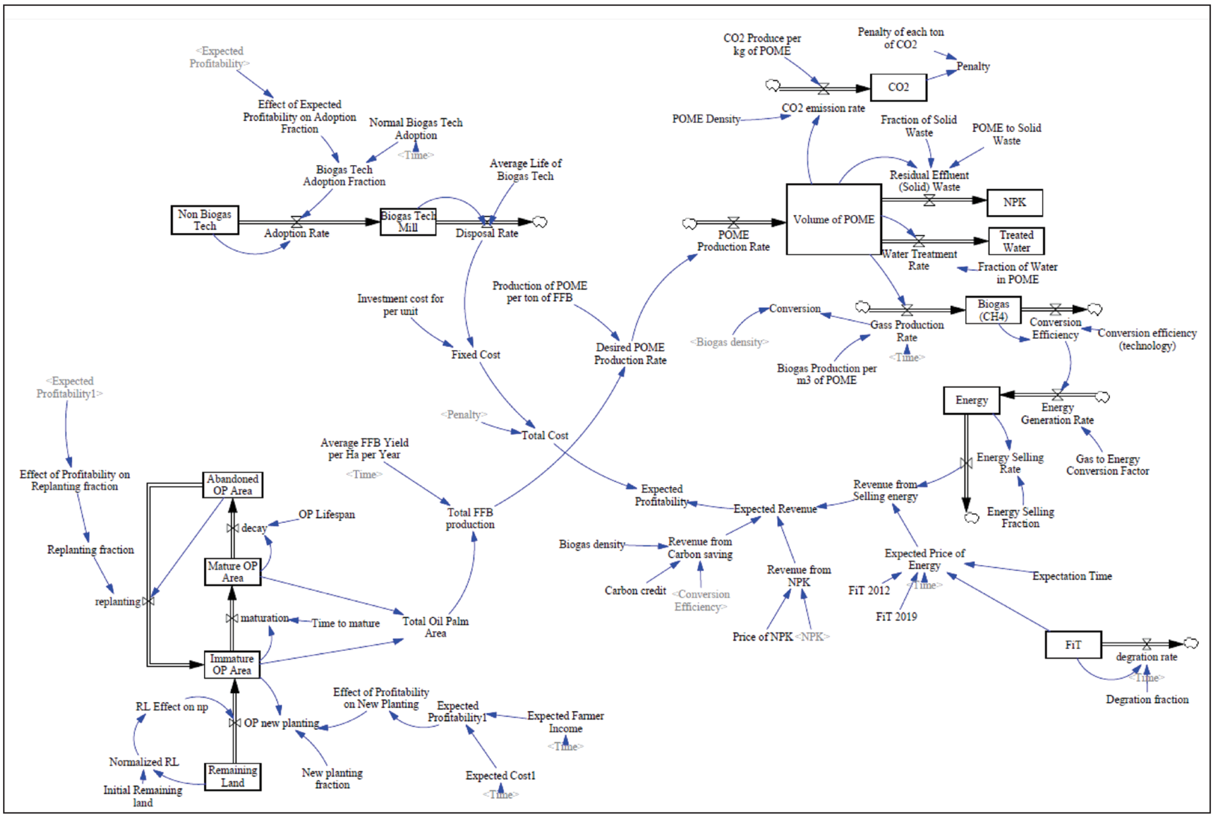


Figure 11. System Dynamics Model of Oil Palm-POME-Biogas

The Oil Palm (Food) Subsystem

The oil palm sub-system is built on Ibragimov et al.'s (2019) work. According to Arshad et al. (2020), the production of oil palm is influenced by its planted area, yield, and relative profitability. When higher relative profit is presented, growers are motivated to intensify the production loop, which, in the case of Malaysia, is characterised primarily by their decisions to expand and replant cultivated areas. This is because the national yield of fresh fruit bunches (FFBs) has been hovering around 20 ton/ha for decades. In 2019, oil palm trees were planted on 5.87 million ha (or more than 70%) of the arable lands in Malaysia. At the time of writing, there is a national cap limiting total oil palm planted area to 6.5 million ha.

In the terminology of system dynamics, Malaysia's oil palm planted area presents a change from an exponential growth to a gradual slow growth towards meeting its equilibrium. Sterman (2000) describes this trend as a S-shaped growth, reasoning that "as the capacity of the environment is approached, the adequacy of the required resources diminishes, and the fractional net increase rate must decline." Such a behaviour is relevant as the opportunity cost of land use prevails between food and non-food crops vis-à-vis agriculture and non-agriculture.

The POME (Water) Subsystem

POME is a liquid wastewater generated from palm oil milling activities. These span from (1) washing and sterilising FFBs, (2) clarification, separation, and cleaning, (3) pressing of empty fruit bunches and crude palm oil, and to (4) factory wash out. On aggregation, it is estimated that 1.5 m^3 of water is used for processing one ton of FFB. Approximately 50% of the water consumption is released as POME (Chan and Chong, 2018). The rest is lost as steam, boiler bow down, wash waters, and leakage.

After the palm oil milling activities, POME is discharged into a waste pond. One ton of POME contains 95%–96% water, 4%–5% of total solids, and 0.6%–0.7% of oil (Ahmed et al., 2015). Discharging the treated POME to a nearby river or stream is the cheapest disposal method (Hosseini and Wahid, 2015). However, because of its significant amount of organic matter, it still poses adverse effects on the environment (Ibrahim et al., 2017). In addition, each ton of POME can produce 28.13m^3 biogas, which otherwise is emitted as methane, carbon dioxide, a small amount of hydrogen sulphide, hydrogen, nitrogen, and trace amounts of carbon monoxide, and oxygen (Aziz et al., 2020). For conserving the environment, an integrated biogas technology presents an efficient management system in the treatment of these by-products.

Accordingly, in the empirical model, the POME sub-system is extended into three parts: treated water, production of organic fertilisers, carbon emission. In the terminology of system dynamics, these variables are stocks in representation of accumulation or storage takes place in the system. In this study, it is assumed that treated water, organic fertilisers, and carbon emission can be saved through the adoption of an integrated biogas technology. They accumulate in their respective stock balances.

The Biogas (Energy) Subsystem

Renewable energy is produced from anaerobic digestion process that turned POME into biogas, and biogas into electricity. Due to the abundance of by-products used in powering mill operations and/or estates, palm oil mills are self-sufficient in meeting their in-house energy consumption (Vijaya et al., 2008). Consequently, the capacity of biogas production points to a surplus production of energy.

The implementation process of a renewable energy begins with capacity acquisition in Malaysia (Ahmad et al., 2015). Capital outlay for a biogas plant is estimated to reach up to USD6 million (Lok et al., 2020) and to be utilised for up to 25 years (Mphtar et al., 2018). As energy sale is regulated, an application is necessary to secure a long-term contract with a utility company. The contract allows a biogas plant to sell the renewable energy at a fixed FiT rate for 21 years. As such, the revenue arising from the sale of the renewable energy is known throughout the contract period. Carbon credit and organic fertilisers provide additional incomes. They lead to the total expected revenue. After considering the cost of production (including both fixed (acquisition) and variable costs), the expected profitability of a biogas project is attained. A learning process will result in higher expectation towards profitability. In turn, this will reinforce the installed capacity of biogas.

In the terminology of system dynamics, Sterman (2000) indicates that the larger the capital outlay, the stronger the capacity acquisition loop will be. As investments in capacity are expensive and irreversible, palm oil mills would be reluctant to invest until a desired investment return is attained. Capacity is thus assumed to adjust to the desired level (rather than what it should be). This presents a delay, and the pressure to expand capacity has a non-linear effect on desired capacity.

Simulation Scenarios

Using secondary data, the study period began with 2000 and progressed annually into 2050. As the study period began prior to the implementation of FiT, the model renders an understanding of changes before and after the policy intervention as well as into the future. Two scenarios were hypothesised and simulated to understand their impacts on the FEW nexus in the long run.

Scenario 1: Changes in POME-to-biogas conversion efficiency

The first scenario explores improvement in POME anaerobic digestion for biogas production. The anaerobic digestion process is a complex mechanism involving hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Focused on interactions among microorganisms, the efficiency of biogas production depends on the temperature and pH. At a thermophilic (c.f. mesophilic) temperature, the entire process complete needs 7–14 (c.f. 30–40) days (Wang, 2016). Optimal pH range is 6.5–7.2 (Sitorus et al., 2013). Shortening the process and meeting these desired conditions will elevate the biogas production process. Considerable research and development attention is thus devoted to improving the biogas production through POME anaerobic digestion.

For shortening the process, pretreatment has been widely explored to prepare the raw material be readily consumable by microbial groups (Aziz et al., 2020). This includes acidified POME, addition of ash, co-digestion, coagulation-flocculation, de-oiling, dissolved air floatation, microwave irradiation, immobilisation media, ozonation, ultrasonication. They increase the rate of reaction in anaerobic digestion.

Bioreactors treating POME have been developed and continuously received improvisation (Aziz et al., 2020). Configurations of reactors include anaerobic fluidised bed reactors, anaerobic sequencing batch reactors, continuous stirred tank reactors, expanded granular sludge beds, up-flow anaerobic filtration, up-flow anaerobic sludge blankets, and up-flow anaerobic sludge fixed-film reactors. Benefited from advances in bioprocess engineering, advanced anaerobic expanded granular sludge beds, anaerobic membrane reactors and up-flow anaerobic sludge blanket-hollow centred packed beds can improve biogas yields and efficiencies.

Other strategies to improve biogas production include inorganic and biological additive supplementations (Choong et al., 2018).

Scenario 2: Changes in the feed-in tariff rate

The second simulation scenario involves changes in FiT rates since, as discussed earlier, FiT is a key consideration determining the net benefit of a biogas investment project. In anticipation of progressive technological efficiency, the Malaysian Energy Centre (2009) proposed that an annual degression of 0.2% be imposed on the FiT of biogas. Degression of FiT rates is thus hypothesised to make a biogas investment project less viable in the long run. Chua et al. (2011) suggest that the degression is needed to promote cost efficiency for attaining grid parity. Accordingly, the feet-in tariff rates have begun to show a declining trend intermittently (see Table 10).

The present FiT rates range from RM0.2210 to RM0.2814 per kWh. Unlike the previous threshold system that catered up to an installed capacity of 30MW, the present system only allows a mill installed with a capacity up to 5MW to bid a FiT rate. The change in the FiT rates and systems was posited to release more quota for encouraging uptake while ensuring fund adequacy for FiT payments to biogas generators. However, the quota system will limit the growth of biogas plant (Chin et al., 2013). More critically, the range of FiT rates is approximate to the total replacement cost of a biogas technology (Loh et al., 2019). Consequently, higher FiT rates were explored to examine whether higher prices are necessary supports to the growth of biogas production.

Table 10. Feed-in Tariff Rates (RM/kWh), Biogas

	01/01/12-31/12/12	01/01/13-27/01/19	28/01/19-to date
Basic FiT rates having installed capacity of			
<5MW			0.2210-0.2814
<4MW	0.3200	0.3184	
>4MW–10MW	0.3000	0.2985	
>10MW–30MW	0.2800	0.2786	
Bonus FiT rates having the following criteria (one or more)			
Gas engine technology with electricity efficiency > 40%	+0.0200	+0.0199	+0.0199
Locally manufactured or assembled gas engine technology	+0.0100	+0.0500	+0.0500
Landfill/sewage gas/agricultural waste fuel source	+0.0800	+0.0786	+0.0786

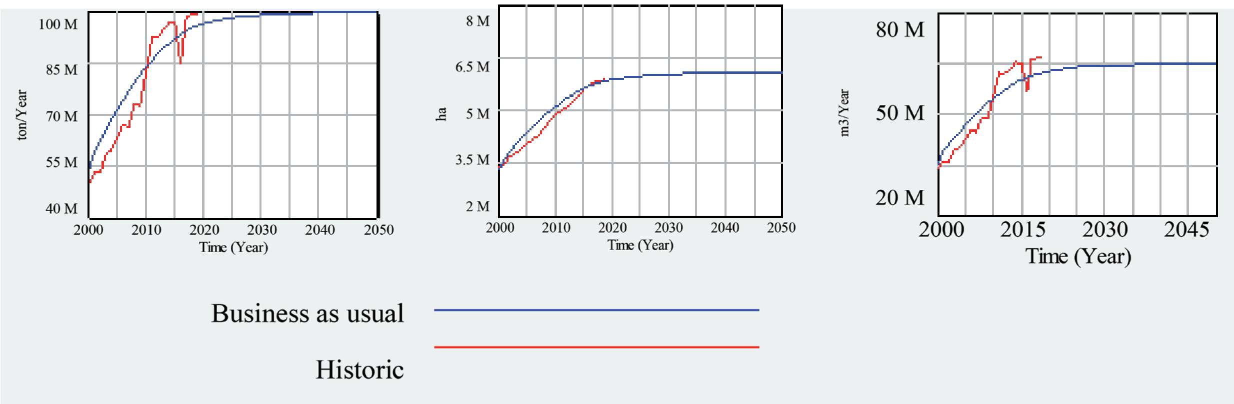
(*Source*: SEDA (2020))

c. Findings

After modelling, the work involved model validation to ensure that the model is fit for understanding the behaviours of oil palm-POME-biogas nexus, and scenario simulations for forecasting the future behaviours of the system.

Model Validation

The process of model validation generated a reasonable goodness-of-fit for the nexus model. Structural validation was initially conducted through inter-modeller reliability. Two independent modellers (co-authors Ibragimov and Ardiansyah) discussed and agreed on the structure of the nexus model with equation specifications. Interaction between variables was validated through actual observation and theoretical expectation. For example, it was verified that an improved POME-biogas conversion rate led to higher total revenues and expected profitability and reinforced the capacity acquisition loop of biogas technology. System behavior was validated when it was found to reproduce data series close to the historic data (see Figure 12). Importantly, synthesis of simulations was conducted and cross-validated model structure, interaction between variables, their behaviour. This validation method allowed us to observe changes in behaviour patterns through value adjustments in variables and variable interactions.



(a) FFB production (b) Total oil palm area (c) POME production

Figure 12. Model Validation through the Reproduction of Historic Data

Further confidence in the nexus model was obtained through multivariate sensitivity analysis. In this exercise, parameters that specified to vary included total FFB production, POME production, biogas production, and expected profitability – all of which are the underlying variables that control the system behaviour. As recommended by Sterman (2000), the variance used here was defined by +25% (best) and -25% (worst) from their respective base value. The best (worst) case scenario assumes strong (weak) conversion from POME to biogas, and high (low) profitability. Monte Carlo iterations built on the combination of these assumptions provide plausible range of uncertainties for the behaviour the palm oil industry is likely to face in Malaysia.

The outputs of the multivariate sensitivity analysis are presented in Figure 13. It shows the 50%, 75%, and 95% confidence bounds for biogas production in a sample of 1,000 iterations. There was a 95% chance that biogas production was between 75 million m^3 and 100 million m^3 in year 2012. It is noteworthy that confidence interval widens with the growth in biogas production throughout the first decade. This suggests an increasing range of uncertainly during the growth phase because the FiT rates, which faced intermittent review, dominate the expected profitability and the adoption of biogas technology.

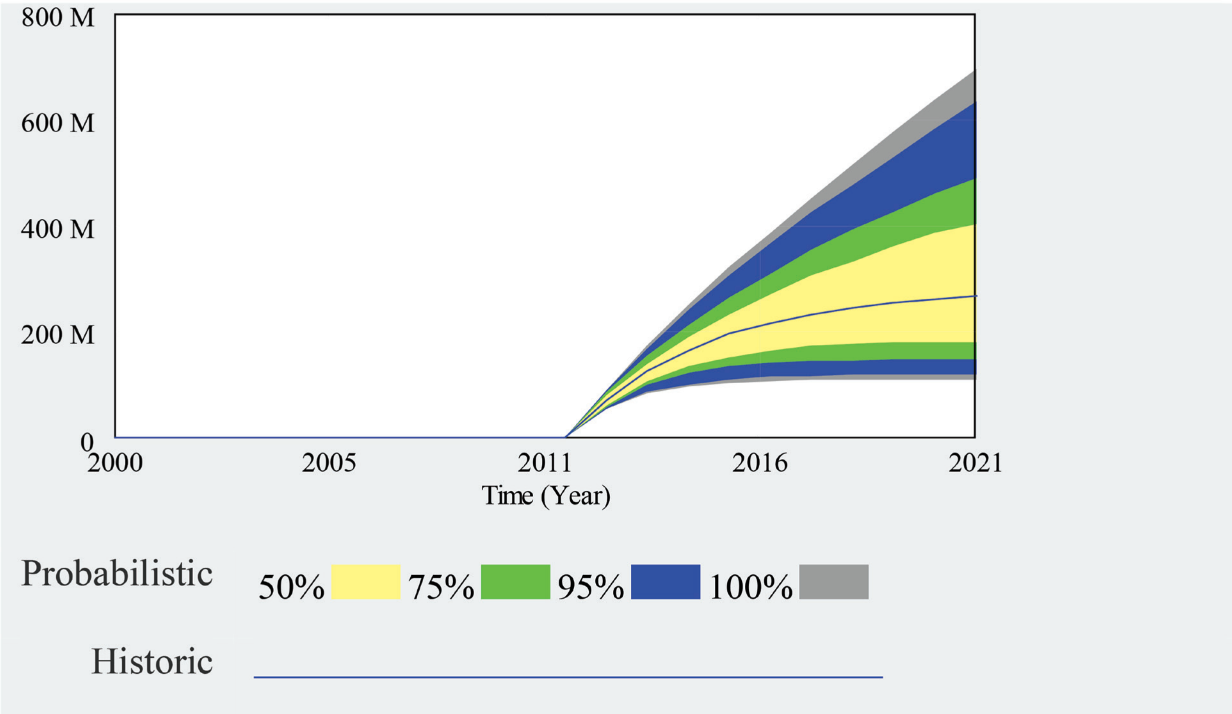


Figure 13. Monte Carlo Output of Biogas Production (m3) from Multivariate Sensitivity Analysis

Scenario Simulations

The simulation results are presented in Tables 11 and 12. As mentioned earlier, according to the sensitivity analysis, facilitation of the processing of POME into biogas is key to reinforcing the FEW nexus model. How much organic fertiliser (to reinforce oil palm production), biogas (to reinforce revenues arising from its sale) and treated water (to reinforce recycling) can be generated from POME is defined by the extent of biogas adoption, which is affected by the expected profitability. Therefore, the simulation results of annual expected profitability, annual rate of new of biogas, and annual biogas production (as a proxy to the production of organic fertiliser and treated water) were extracted.

Scenario 1: Changes in POME-to-biogas conversion efficiency

In Scenario 1, research and development initiatives were assumed to focus on technological upgrading. Simulations were made assuming 10%, 25%, and 50% improvement in the POME-to-biogas conversion efficiency from the present level (28m^3 of biogas produced from 1 ton of POME). In these simulations, suppose technological upgrading did not occur every year, but happened to be a one-time event. Other variables were assumed to remain unchanged.

Table 11. Simulated Results of Improvement in POME-to-Biogas Conversion Efficiency

	Expected profitability (dimensionless)				Adoption rate of biogas (percentage per year)				Biogas production (million m^3 per year)			
Improved efficiency	Base	+10%	+25%	+50%	Base	+10%	+25%	+50%	Base	+10%	+25%	+50%
2025	0.7061	0.7127	0.7210	0.7270	1.16%	1.20%	1.21%	1.22%	52.18	62.07	79.35	97.14
2030	0.6775	0.6768	0.6767	0.6771	1.17%	1.17%	1.17%	1.17%	52.42	62.34	77.90	93.54
2035	0.6618	0.6605	0.6604	0.6603	1.16%	1.16%	1.16%	1.16%	52.72	62.67	78.31	93.95
2040	0.6559	0.6548	0.6547	0.6547	1.15%	1.15%	1.15%	1.15%	52.69	62.83	78.52	94.21
2045	0.6569	0.6561	0.6561	0.6561	1.15%	1.15%	1.15%	1.15%	53.81	62.90	78.63	94.34
2050	0.6628	0.6624	0.6623	0.6623	1.16%	1.16%	1.16%	1.16%	52.59	62.95	78.68	94.41

Table 11 compares the defined changes in POME-to-biogas conversion efficiency to the base case. In the base case, all the selected variables are stable over time. The 50% (10%) improvement case sets the expected profitability to 0.7270 (0.7127) and the annual new adoption rate to 1.22% (1.20%) in 2025. While the impacts seem marginal, the annual production of biogas grows to 97.14 million m^3 (62.07 million m^3) in the same year. This suggests that the growth of biogas production is elastic to efficiency improvement.

With one-off improvement, the growth in the selected variables experience a rapid rise in the short run only to normalisen in the long run. The normalised states of the expected profitability and the annual new adoption of biogas technology are the same as the base case. Research and development are implied to be a long-term commitment, continuously seeking technological upgrading for improving the POME-to-biogas conversion efficiency.

Scenario 2: Changes in the feed-in tariff rate

In Scenario 2, FiT rates were assumed to face annual review. Simulations were made assuming 1% growth as well as 1% and 5% degression from the present FiT rate (by taking the midpoint of RM0.2210–0.2814/kWh). To be conservative, other bonus FiT rates were excluded in the model. Other variables were assumed to remain unchanged.

Table 12 shows the simulation results arising from the defined changes in FiT rate. In the base case, all the selected variables show a declining trend over time. This is attributed to the 0.02% degression in FiT rate annually. The 1% (-1%) improvement case leads the expected profitability to 0.7236–0.9773 (0.7002–0.5482) and the annual new adoption rate to 1.21%–1.44% (1.20%–1.06%) in the 2025–2050 period.

As the positive price growth compounds, its impact on the annual biogas production becomes increasingly diverged from those of the degression cases. By 2050, annual 1% increment (degression) in FiT rate leads to a total of 117.40 (45.20) million m^3 biogas production. The divergence becomes greater under the case of 5% annual degression. These are suggestive that any degression of FiT rate will lead to a significant reduction in production of biogas. Note is made that this is not a result of production adjustment, but rather a result of asset (capacity) retirement (at the end of the 21-year contract with the utility company) in anticipation of future degression.

Table 12. Simulation Results of Changes in Feed-in Tariff Rate

	Expected profitability (dimensionless)				Adoption rate of biogas percentage per year)				Biogas production (million m3 per year)			
Yearly FiT rate	Base	-5%	-1%	+1%	Base	-5%	-1%	+1%	Base	-5%	-1%	+1%
2025	0.7061	0.7002	0.7049	0.7236	1.16%	1.19%	1.20%	1.21%	52.18	51.30	52.01	96.45
2030	0.6775	0.6067	0.6601	0.8280	1.17%	1.11%	1.16%	1.31%	52.42	50.61	50.95	98.98
2035	0.6618	0.5347	0.6100	0.9091	1.16%	1.05%	1.11%	1.38%	52.72	48.39	49.78	102.57
2040	0.6559	0.5250	0.5671	0.9473	1.15%	1.04%	1.07%	1.41%	52.69	46.22	49.01	103.61
2045	0.6569	0.5345	0.5463	0.9665	1.15%	1.05%	1.06%	1.43%	53.81	43.13	48.35	109.44
2050	0.6628	0.5493	0.5482	0.9773	1.16%	1.06%	1.06%	1.44%	52.59	40.91	45.20	117.40

d. Conclusion

This chapter on POME-to-biogas has revealed that an environmental/social threat is being translated into a nexus opportunity between food, energy, and water. Through integrated technology systems, biogas can be used to demonstrate FEW nexus at palm oil mills. It thus qualifies our exploratory work through a system dynamics approach to capture their non-linear interactions and examine the overall system behaviour through simulations.

With the aim to reinforce the circular economy, we simulated two scenarios – (1) improvement in POME-to-biogas conversion efficiency and (2) changes in FiT rate. Based on their simulation results, it is concluded that continuous technological upgrading is required to intensify the adoption of biogas technology in anticipation of annual degression in FiT rate. Precautionarily, more aggressive degression will lead to greater retirement of biogas production capacity and undermine FEW nexus.

In this work, we developed explicit linkages between components within FEW systems in which water is already being used as a circular resource. Unfortunately, the application of the model may be limited for exploratory purpose. Our fieldwork and interviews were dampened by the COVID-19 challenges and related movement controls. Model validation with stakeholders remains a work in future. Site visits and case studies are also essential to develop better understanding of their multidisciplinary interactions (from engineering to economics).

5.3.3.3 Three-Way Nexus Interactions: Hydropower and Dams

Dams are built as water storage in upstream reservoirs for various purposes. The purposes include for flood control, store water for irrigation, recreation, and drinking water, as well as for generating electricity. Sixteen percent of the world's power needs are generated through hydropower creating a nexus between water for energy production. This subsection looks at how hydropower is contextualised as a water-energy-food nexus is at various levels.

a. Background and the International Context

Dams can be single purpose or multipurpose. While dams are largely single purpose across the world, multipurpose dams, particularly for irrigation and hydropower creates a three-way nexus across water, energy, and food. While situational contexts differ, the WFEN often manifests itself across these purposes served by dams.

Previous studies often highlight that hydropower development has the potential to improve both energy supply as well as crop production. However, studies do demonstrate that it can also impact fisheries production negatively. This demonstrate that the impact of the WFE nexus in the context of hydropower can extend into other issue areas as well as being a critical issue in terms of sustainability.

Hydropower, which utilises the natural flow of water to convert it into electricity, is dependent on natural topography. In countries with high potential, such as Ethiopia, hydropower meets 90% of the final energy demand. Irrigation schemes are often seen as add-ons to hydropower rather than as a major purpose of hydropower previously. This has led to low agricultural water use previously. In this sense, efforts have been made, such as through the construction of Grand Ethiopia Renaissance Dam to realise more synergies across this dual function of irrigation and hydropower as well as providing revenue through selling to neighbouring countries. This demonstrates that the consideration of WFE nexus can both increase energy and food security as well as contribute to revenue if synergies are planned and realised. It also points to the potential differences of outcomes depending on planning and technologies adopted.

The Nam Ngum River Basin in the Lao PDR part of Mekong is situated where agriculture is the major economic activity. Ten hydropower projects are either in operation or will be constructed in the upstream basin. Findings on the impact of hydropower development is debated, with evidence in Nam Ngum sub-basin demonstrating that it may increase river flow during dry season, and therefore improve water availability and water security. However, various studies also demonstrate the opposite effect. In transboundary basins such as the Mekong, issues of the WFE nexus is a geopolitical hotspot with potential "resource wars" as a result of competition across scarce resources. This once again points to the significance of the WFEN as a security and economic issue.

b. Hydropower and Dams from the WFEN Perspective in the Context of Malaysia

Malaysia's natural geological conditions consists of a fair amount of sunshine, and a high rainfall rate which is distributed throughout the year. This poses a substantial potential for hydropower generation with the hydropower potential estimated at 29,000-MW. In particular, the potential in East Malaysia is high, with 85 percent compared to 15 percent in Peninsula Malaysia. Peninsula Malaysia has had only two major dams commissioned by 2016 (Hulu Terengganu 265 MW and Ulu Jelai 372 MW) and two multi-purpose dams in Kelantan under advanced planning. Energy Commission (2013) reported that by the end of 2013, only 3,931 MW (13.2 percent of total installed capacity) of the resource has been fully utilised (with the share of energy input in hydropower stations of 8.7 percent from the total 30,959 ktoe). This is due to the high capital investment required for its development.

Ismail (2014) and Aiken and Leigh (2011) report that Malaysia currently has 66 large single- and multi-purpose dams, with several more in development. In 2009, the Department of Irrigation and Drainage alone managed 16 dams for flood mitigation, providing adequate irrigation water and controlling silt while other dams are under the jurisdiction of other agencies. However, these different water uses come along with conflicting demands on water utilisation leading to trade-offs which highlight the need for an integrated management plan for all catchments.

The 11th MP emphasises water, energy, and food security, recognising the fact that actions in one area more often than not have impacts on one or both of the others. Hydropower development presents a quintessential three-way interaction of the nexus security challenge. The establishment and operation of hydropower dam are overwhelmingly complex because the issues are not only confined to the design, construction, and operation of dams themselves but embrace the issues of social, environmental, and political perspectives.

Dam development for hydropower therefore often involves many trade-offs. Although the generation of electricity impacts little on the quantity of water it may alter the timing of stream flows since the timing of water releases is determined by the demand curve for electricity managed by the National Load Despatch

Centre (NLDC). Conflicts can also arise between hydropower and downstream uses, including irrigation and supporting ecosystem services. In Malaysia, in the interest of energy security, hydropower dams such as Bakun have affected the food and water security of more than 9000 Sarawak indigenous communities (Aiken and Leigh 2011). The local communities resettled to Kampung Ganda from the remote villages of the Temengor Lake were provided with 11 acres of land with rubber trees to each household involved, as reported by Choy and Othman (1996).

Some people consider hydropower a type of renewable energy because it does not consume fossil fuels. Instead, it harnesses the power of renewable supplies of water by running through the turbines and discharging it downstream. While often praised for its low GHG emissions, it is widely accepted now that hydropower negatively affects water resources and river or lake ecosystems. By impounding a river or diverting its flow, dams alter the natural regime of a river, compromise the habitat functions the river plays for fish, modify water quality and change the river bed dynamics.

It is often said that consumptive water use does not happen in hydropower generation because what is required to generate power is water pressure and not the water itself. However, since water stored in a dam in a warm country faces regular temperature increase, water loss from the surface of hydro dams in Malaysia is inevitable. This evaporation process contributes to the consumptive aspect of dam storage which results in less flow for downstream uses. In a recent study of national water demand, total potential evaporation is estimated to be around 1.25 MCM/km/year or 3.42 MLD/km. Academy of Sciences Malaysia (2015) estimates total losses from hydropower surfaces in Malaysia to be 2000 MCM/year or 3.872 MLD.

On the positive side, hydropower can be a desirable form of electrical power generation from a power grid point of view. Its electrical power output can be changed within minutes, and this makes hydropower the preferred source for frequency control (around 49.75 to 50.2 in Peninsular Malaysia). Infrastructure costs aside, hydropower is economical since the fuel is rainwater from the sky, which is technically free. Both features render hydropower to be placed third in the electricity generation merit order in Malaysia. If hydropower plants are unable to provide electricity during peaking, power stations with the gas turbine open cycle will have to generate power at higher marginal costs to the national grid.

Alienating land for hydropower generation can be a lucrative source of income for state governments in Malaysia. As per TNB (1993), compensation from a utility company such as TNB to a state government is paid according to the units of electricity generated rather than by actual measurement of flow through the turbines.

At the state level, the Kenyir Dam in Terengganu acts as a case in point. The 400 MW Sultan Mahmud Power Station and its 155-metre height impounding Lake Kenyir is Peninsular Malaysia's largest storage hydropower scheme. TNB (1993) reported that Kenyir is a multi-purpose hydropower station which incorporates power generation, flood and drought prevention, recreation, tourism, and aquaculture. Before the construction of the dam, the East Coast used to flood each year around December to January. One of the benefits of regulating Sg. Terengganu is that the Kenyir dam has provided flood mitigation function successfully since the beginning of its operation. The other important function it provides is to minimise the interruption of the freshwater supply at Kuala Terengganu. Since the Sg. Terengganu river basin is mainly flat, it faces the risk of saltwater intrusion into the freshwater supply when high ocean tides coincide with low river flow. The Kenyir hydropower scheme showcases a best- practice attempt of both upstream and downstream Terengganu river basin stakeholders such as TNB and Syarikat Air Terengganu (SATU) to cooperate on issue of access to water and the regulation of the flow of Sg Terengganu.

The Kenyir scheme is being upgraded as a cascading system with the construction of two dams – Puah (250 MW) and Tembat (15 MW) – geared towards maximising the use of water resources upstream. The Puah dam is 78-metre high with a crest length of 800 metres with a lake size of 6,979 ha. The Tembat dam is smaller in comparison with the height of 36.5 metre and the crest stretching 210 metres in length.

The two dams are located in the Tembat and Petuang Forest Reserves as part of its Hulu Terengganu Hydroelectric Project; this is an environmentally-sensitive area known for its large elephant population. In meeting the requirements of Detailed Environmental Impact Assessment (DEIA), TNB is taking measures to ensure that the hydropower development will have minimum impact on the habitat of the elephants and other smaller mammals as well as their movement and distribution. To do this, TNB Research Sdn. Bhd. (TNBR) in collaboration with the Department of Wildlife and National Parks (Jabatan PERHILITAN) and Universiti Kebangsaan Malaysia (UKM) are currently carrying out a study to monitor the elephants' movement during the construction as well as the operational stages. In the study, the elephants in the area are fitted with GPS satellite collars, from which signals are obtained, and their movements are tracked and monitored online. Results from the study will assist in the development of a human-elephant conflict management plan which will be used for the project as well.

Under the Sarawak Corridor of Renewable Energy (SCORE), the state government of Sarawak has in recent years announced plans to develop several large hydroelectric projects. The development spanned over a period of 22 years to generate 28,000 MW of electricity once fully developed. The power generated by SCORE's complete energy nexus would be used to fuel the industrial development of 70,709 km^2 of Sarawak's central region. The Sarawak Government is using this dam-induced industrialisation strategy as a prospect to attract significant Foreign Direct Investment (FDI) in an attempt to achieve the Malaysian Government's vision of Sarawak as a 'developed state' by 2020. Amongst the projects to be developed are the Baram dam (1200 MW), Baleh dam (950 MW), and Pelagus dam (770 MW) in the upper reaches of the Rejang River, Sarawak. In 2013 the 944 MW Murum dam was completed. The Bakun hydroelectric project, one Asia's largest dams outside China, involves the construction of a 207 m high rock filled with concrete dam creating a reservoir of 69,640 ha, about the size of Singapore. Sovacool and Bulan (2011) report the cost for Bakun project to be around USD4,643 million.

The other nexus challenge for Bakun is encapsulated in the main criticisms from national and international bodies over the issue of the indigenous peoples (mostly Kayan, Kenyah, Lahanan, Kajang, Ukit, and Penan ethnic groups) being resettled by the impoundment of the lake, as found by Gabungan (1999) and Choy (2005). Concerning ethnic composition among the resettlers, the Kenyah population was the largest group consisting of 5313 people, followed by the Kayan, 3995 people, with the balance comprised of 910 peoples (Andre, 2012). The resettlement site, generally referred to as Kampung Asap is located approximately 40 km from the Bakun Dam site. People in some of the longhouses have also decided to move to other locations, not designated by the government. Most of the indigenous peoples involved were subsistence farmers for generations in a forest land of 107,000 ha with no previous participation in the Sarawak's economy. They also had a strong cultural attachment to the forest they left. Many studies claim that the communities' well-being as a whole was negatively affected. This was due to the fact that they have long depended on Sarawak's rivers and forests not only as a main source of livelihood but more importantly as their way of life. An ethnographic study by Choy (2005) found that the resettled communities had lost all four of the most important types of land: temuda, farmland around longhouses, menoa, land for game hunting and gathering, damp, cultivated land, and oipulau, or protected forest area. He concluded that ''the Sungai Asap resettlement area is environmentally unsuited to sustaining the social value and cultural identity of the indigenous communities affected by the Bakun Dam project'' (Choy, 2005: p. 66). To give a general sense of externalities associated with the major dams in Sarawak, Hartmann (2013) proposes simple criteria such as the numbers of hectares inundated per MW as environmental impact indicator and the number of resettled per MW as a measure of social impact.

In the Cameron Highlands in Pahang, there are two hydroelectric schemes cascading from the Peninsula's central mountain range. The Cameron Highlands-Batang Padang Hydroelectric Scheme includes seven power stations, five of which are mini hydro facilities such as Kampung Raja (0.8MW), Kuala Terla (0.5MW), Robinson Falls (0.9MW), Habu (5.5MW), and Odak (4.2MW). The other two power stations are high head underground schemes, namely Sultan Yussuf Power Station or Jor (100MW) and Sultan Idris II or Woh (150MW) (Kun and Saman 2004). The cascading scheme uses water resources from the states of Pahang (Sg. Telom and Sg. Bertam), Perak (Sg. Batang Padang and its tributaries) and Kelantan (diversion from Sg. Plau'ur) (TNB 1993). There are also three dams functioning as storage and flood control reservoirs:

- The Ringlet reservoir or Sultan Abu Bakar Dam is a lake about 3 kilometres long and up to half a kilometre wide, impounds the water from Sg. Bertam and Sg. Telom and provides a steady source of water for the Jor Power Station.
- The downstream Jor reservoir provides water for the Woh Power Station. It is created by two dams (main and saddle) which impound the water of Sg. Batang Padang and the water discharged from the Jor Power Station.
- The earthfill-construction Mahang Dam is designed to regulate the flow of the water released from the Woh Power Station and to create a small head for the Odak Power Station mini-hydro.

The Ringlet reservoir was designed for a gross storage of 6.3 million m^3 with an active/live storage of 4.7 million m^3. However, it is currently badly silted with sediment accumulation estimated to have reached 5.0 million m^3 by Kun and Saman (2004). This situation means that the live storage of the dam had been reduced to less than 2.0 million m^3, compromising its capacity to regulate flood flow. As sediments accumulate in the Ringlet reservoir, the dam gradually loses its ability to store water to drive the hydroelectric turbines, reducing the lifespan of the dam which was designed to last for at least 80 years, according to Jansen et al. (2013).

Not only that soil erosion inundated the Ringlet reservoir with silt, but it also impacted flows of the river system including the Ringlet, Bertam, Habu, and Telom rivers. The unregulated expansion of vegetable farming in Cameron Highlands, deforestation, and encroachment of settlements had caused land degradation on this important but sensitive water catchment ecosystem. Tenaga Nasional Berhad had spent over RM180 million over the past five years or RM40 million a year, cleaning up the Ringlet reservoir. However, the clean-up does not overcome the problem as the reservoir accumulates 500,000 cubic metres of sediment every year.

c. Conclusion

Increasing non-agricultural demands on water, growing food demands, and rapid urbanisation all place increasing pressure on water resources. This chapter shows that water resources play a vital role in not just the national economy, but also economic activities at the state level. Underpinning all aspects of development at the state level, water links together energy and food production. In some instances, as highlighted in the case of hydropower operation, upstream and downstream users often have conflicting needs. In the absence of water stress, like in some states, there is less competition for water and fewer trade-offs to be made. But this scenario does not necessarily mean there will not be any political trade-offs because water also holds great cultural and spiritual significance beyond physical and economic scarcity considerations. Also, high- level information uncertainty at the state level about water-energy-food linkages constrains the quest to frame appropriate strategies and policies. Finding solutions to secure water, energy, and food resources will require significant action – technological and non-technological – both of which cannot be pursued independently.

5.3.4 River Basin Assessment: Sg. Perak

The section of the report introduces in detail nexus interactions within the Sg. Perak river basin. It includes with a mapping of the nexus interactions within the basin, providing a schematic highlighting all major competing uses for water within the basin. It also provides a list of indicators required to successfully and richly analyse nexus issues pertinent to river basins, which has implications for the mooted development of a hydrological database and associated DSS.

a. WFEN Mapping within the Sg Perak River Basin

The Sg. Perak river basin was selected as the basin of interest for our WFEN assessment due to presence of various rich nexus interactions. This includes the water-energy nexus interactions within the energy sector (e.g., hydropower and thermal power generation), the water-food nexus (i.e., the irrigation of granary areas), the agricultural waste-to-energy nexus (e.g., biogas production, which can also be considered a food-energy nexus), and the energy-water nexus in the water sector (e.g., water supply and treatment).

Figure 14 below illustrates the coverage of Sg. Perak river basin within the state of Perak, as well as a mapping of the main economic actors from the water, energy, food, and industrial sectors located within the boundary of the river basin. These key actors include hydropower dams, thermal power plants, biogas power plants, water treatment plants, large-scale solar farms, granary areas, and agricultural lands, which are comprised of palm oil and rubber plantations, livestock farms, horticulture, and aquaculture. The major urban and industrial areas are also included in this WFEN mapping.

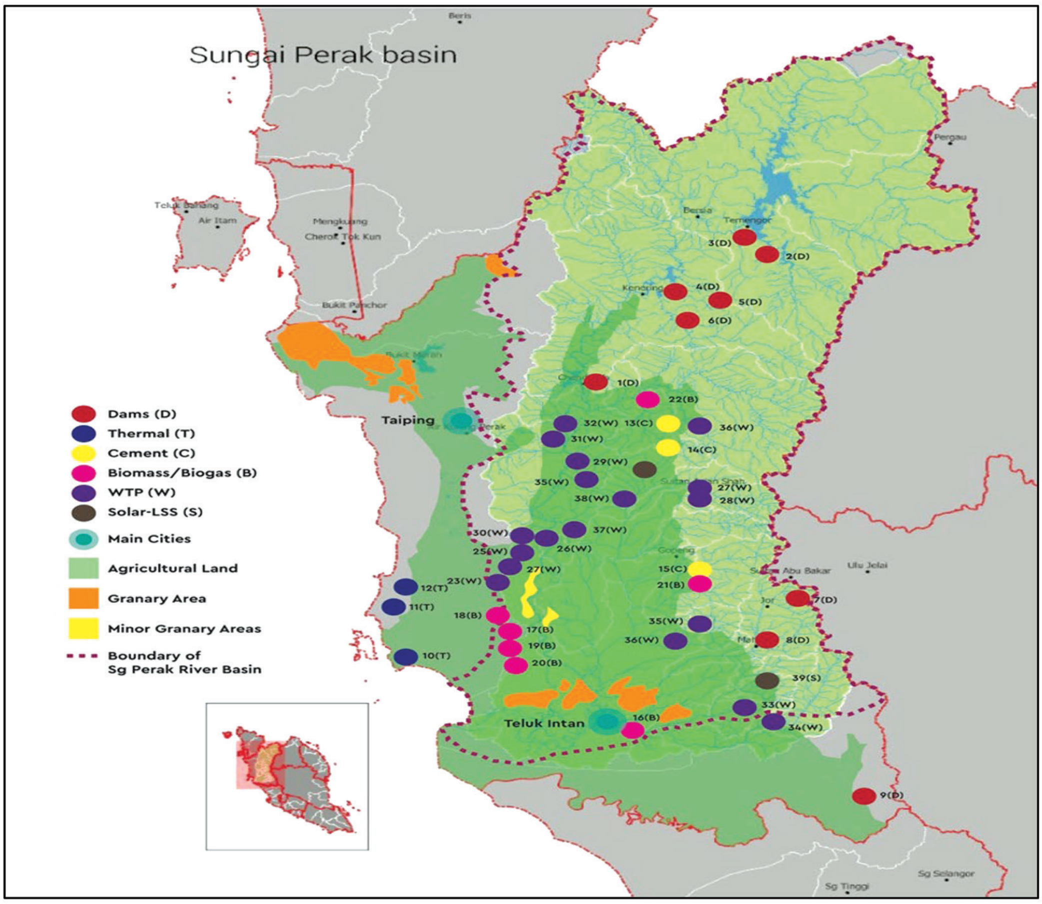


Figure 14. WFE Nexus Mapping in the Sg. Perak River Basin

As a general overview, Sungai Perak spans a length of roughly 427km, with the river basin covering an area of approximately 9,052km^2. Close to 60% of this landmass is forested, just over 30% is dedicated to agriculture, 8% is built-up, and the remaining 2% is made up of various water bodies, including lakes, rivers, and reservoirs. The Sg. Perak basin is one of the largest areas of cultivation in Peninsular Malaysia, with the dominant plantation crops including oil palm, rubber, horticulture, and paddy, and it is also a key energy-producing river basin. Power plants within its area provide a fifth of Peninsular Malaysia's power resources, including the Sg. Perak Hydroelectric Power Scheme (1,249MW) and TNB Janamanjung (4,100MW).

b. WFEN Schematic of the Sg. Perak River Basin

Water drawn from Sungai Perak is essential for the basin's economic development and sustainability, given its contributions to the local and national economy as well as the significant role it plays in ensuring the nation's energy and food security. In this section, water is highlighted and analysed as the centrepiece of WFEN interactions, with the schematic below illustrating the main uses and users of water within the Sg. Perak River Basin.

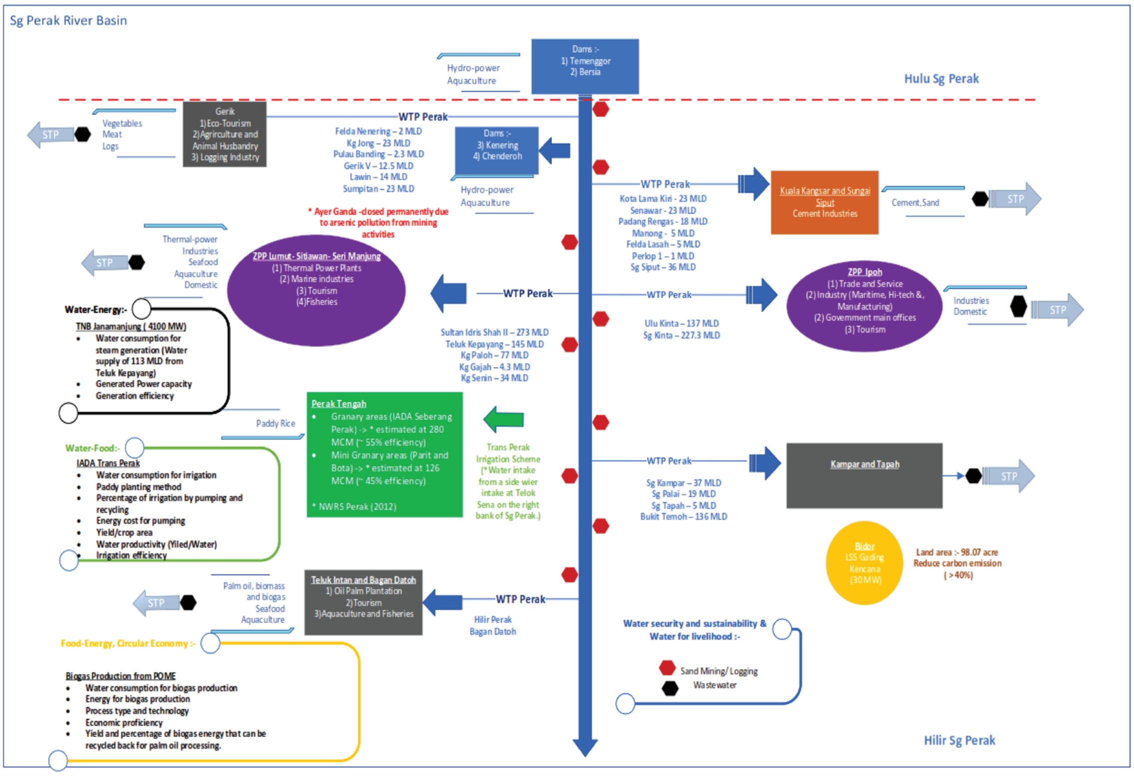


Figure 15. WFEN Schematic of the Sg. Perak River Basin

The schematic above identifies points of water withdrawal from Sg. Perak as well as its consumptive uses across the key economic actors within the river basin, particularly those which are involved intricately within the WFEN. This includes the Sg Perak hydropower dams (i.e., Temenggor Dam, Bersia Dam, Kenering Dam, and Chenderoh Dam). Water releases downstream from the Chenderoh Dam amount to approximately at 100 to 120 MCM on a daily basis.

Water withdrawals from Sg. Perak to the WTPs, operated by LAP, are later transported for domestic and industrial uses in areas such as Gerik, Kuala Kangsar, Manjung, Ipoh, Perak Tengah, Teluk Intan, Kampar, and Tapah. While Manjung may also withdraw water from Sg. Manjung to support its local water use requirements, water that is withdrawn from Sg. Perak and treated in WTP Teluk Kepayang is the main source of treated water supply to the several thermal power plants situated in Manjung and Lumut.

Water is also withdrawn from Sg. Perak for the purposes of irrigation in granary and minor granary areas in Perak Tengah through the Trans Perak Irrigation Scheme, operated jointly by JPS Perak and IADA Trans Perak. While oil palm and rubber plantations cover a large percentage of the agricultural land in Sg. Perak river basin and in the state of Perak in general, irrigation of these plantations depends mostly on groundwater sources. On the other hand, processing of palm oil is well known for also producing harmful wastewater. This problem can be reduced by using such wastewater to produce energy (e.g., through the production of biofuels).

c. WFEN Key Indicators and Interlinkages

Key indicators help to distinguish differences between resource bases, uses, and issues in the basin being assessed. The key indicators listed in Table 13 below allow for observation of the importance of the resources in a given river basin (i.e., the internal factors), as well as any impacts on external factors such as the economy, population, governance, and environment. In our analysis of the Sg. Perak river basin, it has been found that data covering the following indicators are critical requirements in the assessment of nexus issues and the generation of insights to address these challenges.

Table 13. Key Indicators and Relevant Nexus Interlinkages

Category	Key Indicators	Nexus Interlinkages
Total renewable reshwate resources	1) Annual total freshwater resource (million m3) 2) Annual total water withdrawal (million m3) i) Agriculture (%) - Irrigated areas (granary and mini granary schemes) ii) Energy (%) - Thermal (consumption and withdrawal) , Hydropower (evaporation loss and withdrawal). (iii) Industry (%) (iv) Municipal (%) 3) Associated energy for water transfer (pumping requirement) 4) Associated energy for wastewater treatment 5) NRW	W-F W-E W-Economy W-People E-W Waste-W E-W
Installed electricity generation capacity and hydropower	1) Annual installed electricity generating capacity (million kW) in the river basin 1a) Hydropower installed electricity generating capacity (million kW) 2) Generation of electricity based on fuel source: i) Hydropower ii) Fossil fuel iii) Other renewables - solar, biofuel, biomass, biogas 3) Area of land for electricity generating infrastructure (dams, thermal power plant, solar)	
Agricultural land	1) Total agricultural land area (km2) 2) Land under rice cultivation and percentage of irrigated area (granary and mini granary schemes) 3) Energy for irrigation (pumping - pump house or mobile pump) 4) Rice yield - yield/water demand, yield/energy for irrigation 5) Agricultural machinery 6) Fertiliser consumption 7) Associated percentage of oil palm plantation area in the river basin 8) Associated POME wastewater production from the oil palm plantations/ mills in the river basin area	W-F E-W-F W-F-E E-F F-W-E
Socioeconomic variables	1.1) Gross domestic product (GDP): (i) GDP; (ii) GDP growth (total, per capita) 1.2) Contribution of natural resources to GDP*: (i) total; (ii) oil; (iii) natural gas; (iv) coal; (v) mineral; (vi) forest 1.3) Contribution to total GDP by sector: (i) agriculture; (ii) industry; (ii) services 2) Population share in the basin, urban/rural 3) Employment by sector: agriculture, energy, industry, domestic/services	W-F-E-External Factors W-F-E-External Factors W-F-E-External Factors

5.4 TOR Scope 4: Transformation Strategy and Initiative Implementation Framework

5.4.1 Transformation Strategy

Taking into consideration the premise highlighted in the policy review as well as the guiding strategies of the overall WST2040, the study aims to chart out the pathways for Malaysia to become a regional water hub by 2040 through the utilisation of the nexus approach. The nexus approach is essentially a strategic approach supporting the implementation of two broad concepts that have often been challenging to implement due to its complexity and 'wicked' nature – IWRM and sustainability. Through bringing forward a sustainability paradigm early in the evolution of the sector, the shift towards water as an economic good will be addressed in a more holistic manner. Figure 16 highlights the nexus approach and strategies aligned to the WST2040 strategy and water paradigm. The report will delve into the details of each phase of the delivery.

Nexus is what is known as a wicked problem, where issues are defined by being complex. The salient features of the nexus challenges highlighted within the report are:

- **Nexus is highly contextual and dynamic**: The nature of nexus challenges is highly contextual, requiring institutions to be established at the appropriate scales to address the nexus phenomenon that occurs in the specific locality (i.e., river basin). Furthermore, the challenges are characterised by non-stationarity, with megatrends and pressures such as climate change and pollution resulting in the need for infrastructure and solutions to adapt to changes in hydrological systems.
- **Silo approach to cross-sectoral issues**: Cross-sectoral issues are addressed currently addressed in silos with little policy target, instruments or institutionally coordinated implementation found across sectors. Furthermore, each sector is also found to be fragmented within their own institutional structure.
- **Lack of capacity**: As a relatively new area that is complex and interdisciplinary, there is currently a lack of interdisciplinary capacity as well as transdisciplinary arrangements that not only cuts across knowledge in the three sectors (water, energy, and food) but also across technical expertise and policy knowledge.
- **Private sector innovation and investments lacking for nexus solutions**: The enabling environment is not conducive to attract investments to address cross-sectoral issues resulting in the lack of investments, particularly in the water sector. This includes low general awareness and capacity; lack of transparent cross-sectoral information to identify nexus flashpoints and related strategic challenges; absence of cross-sectoral policy targets and minimal use of economic instruments to provide incentives for innovation.

To address these nexus challenges, addressing the nexus will require characteristics that can address the challenges above. This requires an overall ecosystem approach that can respond to the wicked nature of the problem. Some features that are proposed include:

- **WFE Nexus indicator and monitoring**: As nexus challenges manifest themselves contextually, there needs to be a harmonised method and database at the river basin level to identify "nexus hotspots". It is proposed that the Water Stress Index (WSI) is utilised.
- **In-situ development**: To respond to the contextual nature of the nexus challenge from an institutional point of view, in-situ approaches such as establishing an integrated agency at the river basin is

proposed. This could be in the form of a River Basin Organisation which takes into consideration the competing uses of water as well as the preservation of water resources.

- **Integrated governance**: The nexus solutions should streamline water include the involvement of private sector to both attract investments and catalyse innovation. Previous examples from the palm oil industry provide an example of how commodity boards and associations can work in partnership.
- **Strategic planning**: There is a need to shift resources to focus solely on "livelihood" towards a focus on strategic and economic opportunities as well as longer term sustainability. In particular, the water sector has focused more on water for livelihood and water access while the agrofood sector has focused mainly on self-sufficiency levels. While these continue to be key concerns, it may come at a cost when strategic concerns are not taken into consideration.

The nexus approach aims to transition the industry from a silo approach to an integrated and strategic resource management approach by 2040. To achieve this, the overall ecosystem of the water sector will need to be reformed as below:-

5.4.1.1 Governance and Enabling Environment

In initiating a transition to IWRM and transforming to a regional hub, the water sector requires ensuring a conducive environment towards addressing the complex nature of WFE nexus. This includes ensuring evidence-based policymaking through enhancing monitoring and reforming institutional structures. The recommended strategies and initiatives are outlined below:-

- **Identify nexus hotspots and reduce 'Water Stress Index' (WSI) in relation to food and energy sectors**: To enhance identification and monitoring of WFE nexus, the WSI is proposed to be adopted as an indicator to identify nexus hotspots. The aim is to reduce river basins from 'Severe Stress' to 'Stress', 'Low Stress' or 'Not Stressed' in major granary areas.
- **Establish a multi-tiered institutional arrangement**: Four initiatives are proposed under this strategy to transform towards in-situ development and integrated governance and transitioning towards IWRM.
    - o Establish a National Water Department (NWD) to manage interactions between water and food, energy, and other sectors, encouraging a holistic view of water/water industries. This is in line with the 12MP's calls for better water resource governance, harmonisation of water-related legislation, and IWRM implementation. It can also play a role in addressing water pollution through administering smart monitoring systems and anti-pollution measures, also objectives under the 12MP.
    - o Establish a River Basin Organisation (RBO) at every state to better incorporate WFEN approaches within the water, food, and energy sectors including investment facilitation. This is in line with the 12^{th} MP plan to review water-related legislation in line with the Water Resources Bill 2016, including the establishment of water resources management authorities in all states (although our focus is at the river basin level).
    - o Establish a Centre of Excellence (CoE) on the WFEN, under the 12^{th} MP premise of institutionalising the WFE nexus approach. The WFEN CoE would be well positioned to meet the target of enhancing the technical expertise of the relevant ministries and agencies (alongside the WFEN Technical Guide and Manual).
    - o Develop informational policy instruments including a WFEN Technical Guide and Manual. This will assist the relevant agencies and departments in the implementation of nexus approaches, methods, and technologies and can be guided by the WFEN CoE. It fits with the theme of

improving the capacity of the relevant stakeholders with regard to mainstreaming nexus concepts.

5.4.1.2 Experimental Nexus Infrastructure

Towards developing nexus technologies and opportunities, enhancing information on WFE nexus is required. This will require the appropriate expertise to model nexus interconnections and facilitate interdisciplinary and transdisciplinary research. Furthermore, nexus technologies will be required to be piloted and tested. The strategies focused are outlined below:

- **Capacity building, communication, education, and public awareness**. To address the lack of capacity, two initiatives are proposed:-
  - o Establish a WFEN CoE consisting of technical and policy expertise; and
  - o Initiate and strengthen R&D in WFE Nexus/Nexus Modelling in Malaysia.

This is in line with the 12MP objective of implementing comprehensive awareness, advocacy, and capacity-building programmes, allowing stakeholders to access the information and knowledge required to mainstream nexus approaches and concepts into their operations.

- **Piloting infrastructure and technology to support WFEN approaches/initiatives** As a novel concept, pilot projects are required to test the nexus solutions in the context of Malaysia. This process should be bottom up and led by innovation from the private sector and facilitated by the government. For example, an establishment of a pilot project fund that accepts proposals from the private sector to address specific issues related to nexus challenges could be established. This is in line with the 12MP (Water Sector Transformation Strategy B4), where both public and private sector funding is channelled to promote WFE nexus innovation. This can be in the form of matching funds, government guarantee, and/or other forms of financing.

5.4.1.3 Integrated Ecosystem

The water-energy-food ecosystems are integrated through a conducive enabling environment. This includes the above-mentioned approaches as well as integrated information system where actors can make evidence-based decisions on cross-sectoral issues. The integrated ecosystem will require "integrators" to facilitate partnerships across the issue areas. These may be either issue/problem based or institutionalised actors. Beyond institutional integration, the focus on water use is made possible through an enabling environment that has identified the incentives and disincentives for water use efficiency technologies and innovation. The strategy is outlined below:-

- **Establish a database with usable information as a policy decision tool at the basin level**: Establish a DSS for WFEN, including the development of a hydrological database with improved monitoring of water catchment areas, alongside the development of modelling systems covering critical/stressed river basins. This is in line with the 12th MP objective of strengthening the water data ecosystem. In particular, it is in line with the goals to establish a local, data-driven DSS based on comprehensively collected data, and the use of this data and tool to undertake water-related analyses and provide strategic directions to the relevant stakeholders. The inclusion of indicators relevant to climate change, such as climate variabilities, sea-level rise, storm surges, high tides, and pollution would further the depth of this database and associated DSS, allowing climate impacts to also be taken into consideration in the implementation of evidence-based and risk-informed actions, as called for in the 12th MP.

- **Increase the use of economic instruments to promote resource efficiency and nexus approach**: This includes undertaking assessments on the economic value of water at river basin levels. From these assessments, the appropriate mechanisms that can enhance the economic value and potential of river basins will be identified. These instruments will also have implications for objectives described in the 12th MP, including those related to mitigating water pollution (e.g., through punitive economic instruments), and more broadly the objective of mainstreaming nexus considerations into water resource management to achieve greater resource security (in particular, water) across key sectors.

5.4.1.4 Strategic resource management

By 2040, as a regional hub for water, the aim is for the water sector specifically, and natural resources generally to be managed strategically. All the above strategies are designed to catalyse a transformation towards a holistic approach in governing WFE nexus.

5.5 TOR Scope 5: Consultations with Stakeholders and Experts

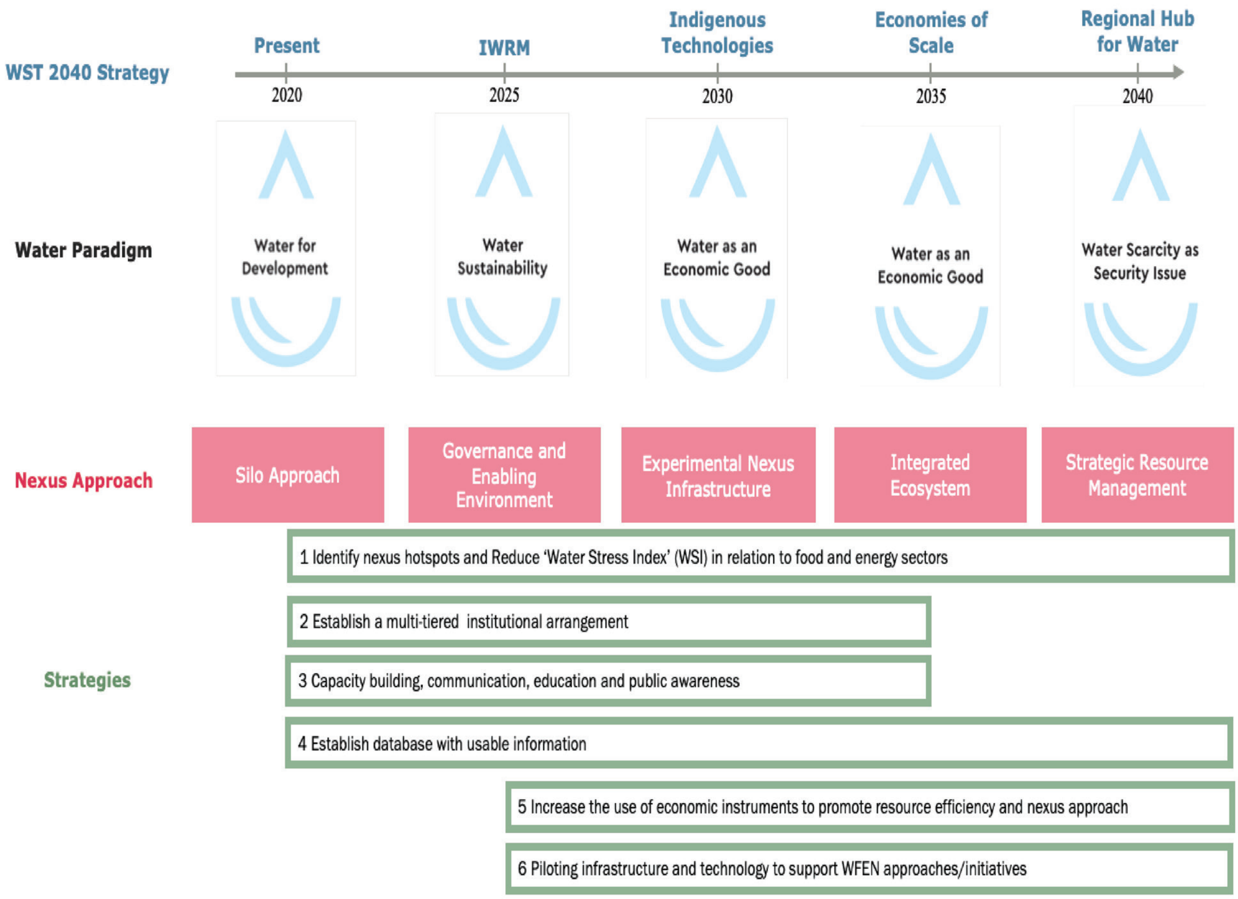


Figure 16. Transformation Strategy Aligned to WST2040 and Water Paradigms

5.6 TOR Scope 6: Roadmap for the National Agenda on WST2040

Table 14. List of Stakeholder Consultations Conducted

No	Agency	Date	Venue	Attendance
1.	MADA	10/3/2021	MADA Headquarters	Mr. Nik Kun Nik Man, Director of Planning Division Mdm. Siti Mariam bt. Md Rejab, Officer of Economic Affair Mdm. Siti Hajar, Paddy Division Mr. Khalil, Planning Division
2	LAP	10/3/2021	LAP Headquarters	Mr. Shamsul Kamar, Senior Engineer Mdm. Fadzillah, Operations DivisionB Mr. Lokman, Engineer Mdm. Balkhis, Operations Division
3	IADA Seberang Perak	11/3/2021	IADA Seberang Perak Headquarters	Mr. Nor Azlan Awaludin, Head o Engineering Division
4	JPS Perak	11/3/2021	JPS Perak Headquarters	Mr. Mohd Zaidi bin Mokhtar (Water Resources Management and Hydrology Division, BSAH) Ir. Sasitharan A/l Manikam (River Management Division) Miss Norzalina Anis bt. Mohd Ibrahim Miss Nordiana bt. Mohd Nor (BSAH)
5	Persatuan Aktivis Sahabat Alam (KUASA)	12/3/2021	KUASA Headquarters	Mr. Hafizudin Nasarudin, KUASA Consultant Miss Nurul Syuhada
6	WD Solar Sdn. Bhd.	15/3/2021	WD Solar Headquarters, Sepang	Miss Hafizah
7	TNB Hydro Generation Sdn. Bhd.	29/3/2021	Online	Mr. Kamal Hj. Azhar Mr. Mohd Rozi Mr. Wan Rafiq (TNB Sg. Perak) Mr. Farid (TNB Hq)
8	NUR Generation Power Plant	8/4/2021	NUR Generation Power Plant Headquarters	Mr. Khairil (Chief engineer), Mr. Jafry (Head of Operations), Mr. Chan (Distribution), Mr. Khoo (Engineering), Mr. Iswardi (Operations), Mr. Musri (Chemical)
9	IADA Pulau Pinang	9/4/2021	IADA Pulau Pinang Headquarters	Mr. Mohd Nor Hafiz Bin Noor Azmi (IADA Pulau Pinang) Mr. Fadhil (JPS Pulau Pinang)

6.0 WAY FORWARD: THE 8I ECOSYSTEM APPROACH

Strategy	Initiatives	Details	12MP (Accelerating IWRM)	13MP (Water Technology Innovation)	14MP (Economies of Scale)	15MP (Becoming the Regional Water Hub)
1 *Governance* Reduce 'Water Stress Index' (WSI) and 'Water Exploitation Index' (WEI) in relation to food and energy sectors, i.e., across nexus hotspots	1. Reduce water stress in areas with high water demand from irrigation, as measured by the Water Stress Index (WSI).	Coordinated by the proposed RBO in collaboration with KASA/ KETSA/MAFI	Reducing river basins from 'Severe Stress' to 'Stress', in major granary areas and/or where WSI is currently above 0.4 (out of 1) (Muda, Selangor, Johor)	Reducing river basins from 'Severe Stress' and 'Stress' to 'Stress', in major granary areas and/ or where WSI is currently above 0.3 (Muda, Selangor, Johor)	Reducing river basins from 'Stress' to 'Low Stress' in major granary areas and/or where WSI is currently at or above 0.2 (Muda, Selangor, Johor, Perak, Linggi)	Reducing river basins from 'Stress' to 'Low Stress' in major granary areas and/or where WSI is currently above 0.1 (Muda, Selangor, Johor, Perak, Bernam, Kelantan, Linggi, Padas, Pahang)
2 *Governance* Establish a strengthened, multi-tiered institutional arrangement to govern WFEN approaches across policy cycles and undertake policy reviews, assessments, and reviews related to WFEN	2. Establish a National Water Department (NWD) to manage interactions between water and food, energy, and other sectors, encouraging a holistic view of water/water industries	Establishment of a NWD under KASA	Organisational change management and transformation	Streamlining budgets to reduce redundancies and through strategic reallocations into new areas of growth	N/A	N/A
	3. Establish a River Basin Organisation (RBO) to better incorporate WFEN approaches within the water, food, and energy sectors, including investment facilitation	Encourage the establishment of RBOs under State Governments	Needs assessment of existing river basin/water authorities and establish policy and legislation to incorporate WFEN	Establishment of RBO (appropriate level of governance from the perspective of WFEN because issues are river-basin-specific) in remaining water-stressed states with major granary areas (e.g., IADA Penang, KADA (Kelantan), MADA, IADA Seberang Perak, IADA Terengganu Utara)	Undertake review and evaluation of RBO's performance in incorporating WFEN	N/A
	4. Develop informational policy instruments including a WFEN Technical Guide and Manual	Development of WFEN Technical Guide and Manual by National Water Department (NWD) along with WFEN CoE, KASA.	Development of a generic, national-level WFEN Technical Guide and Manual, covering data and technical requirements	Development of 3 river basin-level technical guides for Sg. Muda, Sg. Johor, and Sg. Selangor	Development of 2 river basin-level technical guides for Sg Perak and Sg Linggi	Development of 4 river basin-level technical guides for Sg. Bernam, Sg. Padas, Sg. Kelantan, Sg. Pahang

Strategy	Initiatives	Details	12MP (Accelerating IWRM)	13MP (Water Technology Innovation)	14MP (Economies of Scale)	15MP (Becoming the Regional Water Hub)
3 *People* Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus	1. Establish a WFEN Centre of Excellence (CoE) with cross-training programme with established CoE.	Establish a WFEN CoE at relevant GRI in Malaysia	Establish a pilot WFEN CoE at NAHRIM–ISIS	Assess pilot WFEN CoE and benchmark functions and performance against international and other established CoEs	Formalise permanent status of WFEN CoE	N/A
	2. Initiate and strengthen R&D in WFE Nexus/Nexus Modelling in Malaysia	River basin coverage of models/modelling systems developed, such as IIASA and CSIRO, covering critical river basins exhibiting high WSI by WFEN CoE (NAHRIM)	Perform needs and gaps assessments for WFEN nexus modelling. Three areas of focus: 1) requirements for data and database development, 2) requirements for human resource expertise development, 3) requirements for decision-support system development.	Development of WFEN modelling for 3 river basins (Muda, Johor, and Selangor)	Development of WFEN modelling for 2 river basins (Perak, Linggi)	Development of WFEN modelling for 4 river basins (Bernam, Padas, Kelantan, and Pahang). Commercialise expertise into WFEN modelling regionally and internationally
4 *Information & RDCI* Establish a database with usable information as a policy decision tool at the basin level	1. Establish a DSS for WFEN, including the development of a hydrological database with improved monitoring of water catchment areas, alongside the development of modelling systems covering critical/ stressed river basins	Development and maintenance of a hydrological database by KASA and WFEN CoE	Development of 1 national-level hydrological database covering WFEN indicators	Development of 3 river basin-level hydrological databases (Muda, Johor, Selangor)	Development of 2 river basin-level hydrological databases (Perak, Linggi)	Development of 4 river basin-level hydrological databases (Bernam, Padas, Kelantan, Pahang)

Strategy	Initiatives	Details	12MP (Accelerating IWRM)	13MP (Water Technology Innovation)	14MP (Economies of Scale)	15MP (Becoming the Regional Water Hub)
5 *Finance* Increase the use of economic instruments to promote resource efficiency and nexus approach	1. Undertake assessments on the economic value of water at river basin levels	Comprehensive studies conducted by WFEN CoE covering major/stressed river basins	Studies covering 2 river basins with significant economic value, selected by WFEN CoE	Studies covering 2 river basins with significant economic value, selected by WFEN CoE	Studies covering 2 river basins with significant economic value, selected by WFEN CoE	Studies covering 2 river basins with significant economic value, selected by WFEN CoE
6 *Infrastructure and Technology* Piloting infrastructure and technology to support WFEN approaches/ initiatives	1. WFEN CoE undertakes pilot projects to address WFEN challenges and opportunities in critical/ stressed river basins identified	Catalysing investment in indigenous infrastructure and technology related to WFEN (by WFEN CoE)	Up to six projects piloting the use of nexus-related infrastructure, materials, technologies to address WFEN issues and opportunities in Sg. Muda, Sg. Johor, Sg. Selangor river basins. Includes projects piloting drip irrigation, graphene, LSS, biogas, solar pumps, large-scale floating solar, depending on suitability (determined by WFEN CoE).	Develop economic incentives to encourage private investment in research, development, and deployment of nexus-related infrastructure, materials, technology.	Expand scope of projects to cover Sg. Perak, Sg. Linggi river basins (up to six projects each)	Expand scope of projects to cover Sg. Bernam, Sg. Padas, Sg. Kelantan, Sg. Pahang river basins (up to six projects each) Commercialisation and regional or international export of indigenous WFEN infrastructure, material, technologies.

The 8I ecosystem approach provides for a useful tool through which to measure the collective strength of the underlying WFE ecosystem in Malaysia. The 8Is, which are discussed in the context of the WFEN in this section, are complex in their interdependencies, and action in one area, or I, can drive improvements across key resource efficiency indicators. Using the water sector as an illustrative case, improvements to Malaysia's infostructure ecosystem, for example, through the use of big data analytics and advanced technologies in the water sector, can have positive effects on infrastructure and intellectual capital ecosystems. In positively influencing the integrity of the nation's water sector, institutions also benefit. Institutions are key to the development of appropriate economic incentives as well as the country's ambition to meet international best practices within the water sector. For the remainder of this section, attention is drawn towards the challenges faced in the development of a WFEN 8I ecosystem in Malaysia, as well as potential solutions to these challenges.

6.1 Institutions

A key institutional challenge in Malaysia at presence is the lack of a system or agency which facilitates WFEN governance at either state-, river basin-, or federal levels. The need for cross-sectoral coordination – especially important in the context of a nexus discussion – is typically unmet. Additionally, private sector supply chains are typically not taken into consideration. This siloed structure hampers the institutional ecosystem of the WFEN in Malaysia.

The WFEN subsector has identified two institutional arrangements that would enable and facilitate coordination across sectors and the public/private divide at state, river basin, and federal levels. First is the establishment of a National Water Department (NWD) tasked with managing interactions between water and food, water and energy, and water and other sectors, to encourage a holistic view of water and water industries and their relationships with other sectors. It is proposed that this NWD be institutionalised under the Ministry of Water and Environment (KASA), and incorporate the functions of the Department of Irrigation and Drainage; the Water Supply Department; the Sewerage Services Department; and the Department of Agricultural Irrigation and Drainage – of this group, the former three are already established under KASA, while the lattermost department is currently under the Ministry of Agriculture and Agrofood Industries. The second proposed institutional change is the establishment of river basin organisations (RBOs). It is proposed that this begins with the establishment of a single RBO, under KASA, to commence with a needs assessment of existing river basin or water authorities which establishes policy frameworks and legislation to better incorporate WFEN approaches within river basin management. Once these needs assessments are complete, it is proposed that RBOs be established in remaining water-stressed river basins which host major granary areas.

6.2 Incentives

There are two major challenges with Malaysia's incentive ecosystem in the context of the WFEN. The first is that fiscal and non-fiscal incentives do not encourage efficient water use in agriculture, energy, or domestic use. Water wastage is a particularly significant issue in paddy cultivation, and paddy development authorities have cited difficulties in altering resource conservation behaviour amongst farmers. The second challenge is the lack of incentives to encourage distributed RE adoption to reduce water and food sector's energy costs. Such incentives would also stimulate GHG emissions reductions and contribute to the achievement of climate change ambitions.

Solutions would therefore require a radical overhaul in Malaysia's incentivisation structure. Water must be valued appropriately to discourage its inefficient use. Economic instruments which promote sustainable resource use should be considered, such as payments for ecosystem services, the enforcement of polluter-pays principle, a uniform pricing model for water resources, amongst others.

6.3 Integrity

The most significant issue in Malaysia from the perspective of the integrity ecosystem is the lack of a system of governance for protection of its water resources, particularly water catchment areas. This is evidenced by the regular occurrences of anthropogenic pollution affecting the country's rivers, for instance. To illustrate this point, custodians of dams such as MADA or TNB Sg. Perak Hydro have no authority to penalise actors who cause siltation and sedimentation in their dams.

One way to circumvent this issue would be through the creation of an RBO, to ensure the quality – and effectively sustainability – of water resources at the river-basin level. The empowerment of such an institution, to strengthen pollution control and land-use planning would also be useful. These steps would be beneficial in combination too, and if guided by a singular river basin plan, which again could fall under the purview of the RBO.

6.4 Intellectual Capital

A significant challenge within the intellectual capital ecosystem relates to the lack of data science, or indeed data collection or access capabilities within and across the WFE sectors. Human capital standards also remain low, which is unsurprising given the nascency of WFEN understanding. Alleviating these issues requires actions such as greater capacity building, as well as CEPA initiatives. Broadening data science capabilities to monitor and analyse activities across WFE sectors would strengthen the data ecosystem and improve the ability of policymakers to engage better with nexus challenges and ultimately, achieve greater resource efficiency and security. Steps should also be taken to assess the impacts of new technologies on achieving greater resource security, particularly through the effects they have enhancing resource efficiency.

To further address the issues related to a lack of intellectual capital with regard to WFEN approaches and concepts, it is proposed that a WFEN CoE be established at NAHRIM – the nation's hydraulic research institute – in conjunction with ISIS. The functions and performance of this CoE, to be modelled after IIASA, CSIRO, and the GDI, as mentioned in Section 2 of this report, would be benchmarked against best practices adopted by other established international CoEs. It is proposed the CoE first be established on a pilot basis, with its permanent status formalised by 2030. Based on our analysis, it is proposed that the CoE be the lead authority in the initiation and strengthening of R&D into nexus modelling in Malaysia, as well as develop and maintain a hydrological database which acts as a decision support system to facilitate and improve monitoring of water catchment areas alongside the development of river basin-level WFEN models. It is further proposed that the CoE perform and later renew assessments of the economic value of water and other resources at the river basin level, and play a key role in the undertaking of pilot projects to address WFEN challenges and opportunities identified by the river basin-level models developed, as well as catalyse investment in indigenous infrastructure and technology related to the nexus.

6.5 Infostructure

Challenges to Malaysia's infostructure ecosystem can be analysed through the three nexus sectors individually. Within water a significant challenge is that technical information is maintained by the Department of Irrigation and Drainage but not shared across the various water stakeholders, such as the state departments of environment, forestry, or land. This ultimately hinders the proper protection of water catchment areas. Under energy, data is governed by the Energy Commission but data transparency remains an issue. Finally, within the food sector, an issue is the consistency of data that is collected: MADA collects data on the sources of water used for agriculture but IADA Seberang Perak does not.

There are several proposals for improving the domestic infrostructure ecosystem. Most importantly is to improve the collection and monitoring of data, particularly as it pertains to resource availability, quality, and use. Ultimately this can set the foundations for achieving resilience in water, food, and energy resource production. To this end, sharing of data across sectors and institutional levels as well as with resource users would also be beneficial in opening up the data ecosystem within the WFEN. Policy implementation barriers for cross-sectoral actions should also be identified, and standards should be introduced or improved upon to assist in the application of integrated planning principles and guidelines.

Ultimately the biggest change to Malaysia's infostructure ecosystem within the context of the WFEN would be the establishment of a decision support system (DSS) for the WFEN, including the development of a hydrological database to allow for monitoring of key indicators of resource use, security, and sustainability covering the various activities performed at the river basin level. Such a database would form the foundation for the various policies and legislations implemented to fortify nexus approaches in development planning and strategising.

6.6 Infrastructure

Within the paddy sector, the most significant challenge remains the fact that much of the infrastructure is ageing, including both pumps and roads, which causes increased energy costs and waste, as well as food losses. Cultivation processes as well as the quality and quantity of infrastructure varies greatly across states or even agricultural zones. This variation in the quality of natural and physical infrastructure plays out within the water sector too, and in many areas investment in the protection and improvement of infrastructure is necessary – this includes the installation of more pumps due to changes in flow regimes over time and across seasons.

Insofar as solutions to the infrastructure ecosystem in the Malaysian WFEN are concerned, the first is for investments and pilot projects be directed towards multi-purpose (or cross-sectoral), environmentally-sound infrastructure projects. These would improve resource efficiency by taking into account indirect and cross-sectoral impacts. For example, reducing water leaks within irrigation networks through improvements to infrastructure – as well as the digitalisation of infrastructure – can play a role improving efficiency as well as lowering energy consumption and any associated costs. It is proposed that the piloting of infrastructure and technology to facilitate and support nexus approaches and initiatives be undertaken by the WFEN CoE, whose focus would entail catalysing investment in these technologies. In order to achieve this, several steps are proposed. The first step involves the identification and piloting of relevant infrastructure, materials, and technologies to address WFEN issues and opportunities, such as drip irrigation, LSS, biogas, solar water pumps, and so on. The second stage involves incentivising private investment in these technological and infrastructural solutions; the successful implementation of this stage would enable the mainstreaming and expansion of the pilot projects introduced earlier on a larger scale. Finally, once Malaysia establishes itself as a regional leader in the adoption of nexus-related infrastructure and technology, steps can be taken to embark on the regional or more broadly international marketing and export of the indigenous infrastructure, materials, and technologies developed to address domestic WFEN issues and opportunities. This, importantly, would allow the WFEN CoE, which maintains ownership of these experimental infrastructure, materials, and technologies, to achieve financial independence and sustainability through the broader commercialisation of its initiatives and products.

6.7 Internationalisation

Due to the nascency of the WFEN approach in Malaysia, adherence to and awareness of global best practices on nexus thinking remains low, while the infrastructure, facilities, and information linking nexus opportunities are lacking. The first step that should be taken is to undertake a wide-ranging review of global best practices for resource efficiency – and particularly cross-sectoral resource efficiency – within each of the WFE sectors and the implementation of standards, guidelines, or incentivisation structures which align the country with best practices adopted in other countries.

As nexus approaches grow in their use and stature across Malaysia, in particular as expertise is developed within the WFEN CoE and disseminated across the relevant agencies, departments, and Ministries within the water, food, and energy sectors, and experimental or pilot nexus infrastructure, materials, and technologies are deployed, Malaysia will increasingly position itself as a regional and potentially even international leader in the application of nexus approaches in resource security and sustainability. This would allow for the international export of not only expertise and knowledge, but commercialised products in the form of infrastructure, material, and technology as well.

6.8 Interaction

As highlighted in the section on institutions most prominently, a key challenge within interaction is the lack of official avenues or processes to foster cooperation, collaboration, and knowledge sharing between the WFE sectors. There is also an absence of technical agencies or community organisations in the decision-making processes for development activities and this greatly compromises check-and-balance mechanisms and can cause missteps in the achievement of resource efficiency and security targets in favour of, for instance, private economic benefits.

To improve this situation, it is proposed that improvements be made to river basin-level data monitoring, verification, and ultimately exchange, as well as knowledge-sharing. The definition of areas of common areas for basin development, as well as potential complementarities of resource policy goals would also improve interaction across WFE sectors. Finally, consideration should be given to the development of common rules or guidelines for key sectors such as navigation, hydropower, and ecotourism.

It is proposed that the development of RBOs, as well as the establishments of the NWD and the WFEN CoE, will have an important role to play in facilitating interactions across sectors and a wide range of stakeholders to ingrain nexus approaches across institutions within a particular river basin – and indeed in the case of the WFEN CoE, to disseminate best practices and nascent technology related to the WFEN.

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

This report covers several aspects of the water-food-energy nexus as it pertains to Malaysia, highlighting the various WFEN interactions present across the country at the intersections of the water, agriculture, and energy sectors most prominently. These interactions sometimes involve, or are affected by, other key factors or variables such as land use or climate change. This analysis has contextualised the many challenges and opportunities facing the security and sustainability of Malaysia's key strategic resources from the perspective or lens of the WFEN ecosystem.

These nexus interactions, issues, and opportunities, as well as our reviews of international best practices within WFEN approaches and critical analyses of the water, food, and energy security issues facing Malaysia have been used to identify our policy recommendations. These recommendations have the objectives of enhancing resource efficiency and security, contributing to a future of water, food, and energy security and sustainability. These also aim to spearhead the transition of water into an economic good and the water sector as an economic driver, as well as enhance Malaysia's realisation of resource sustainability. Recommendations cover areas as varied as technological gamechangers and impacts, to governance and institutions, to economics, financing, and incentivisation, amongst others, that are relevant to the development of nexus solutions.

7.2 Recommendations

The transformation strategy recommended by the WFEN subsector is comprised of six strategies as described below:

1. **Identify nexus hotspots and Reduce 'Water Stress Index' (WSI) in relation to food and energy sectors**: To enhance identification and monitoring of WFE nexus, the WSI is proposed to be adopted as an indicator to identify nexus hotspots. The aim is to reduce river basins from 'Severe Stress' to 'Stress', 'Low Stress' or 'Not Stressed' in major granary areas.
2. **Establish a multi-tiered institutional arrangement**: Three initiatives are proposed under this strategy to transform towards in-situ development and integrated governance and transitioning towards IWRM.
   - o Establish a National Water Department (NWD) to manage interactions between water and food, energy, and other sectors, encouraging a holistic view of water/water industries;
   - o Establish a River Basin Organisation (RBO) at every state to better incorporate WFEN approaches within the water, food, and energy sectors, including investment facilitation; and
   - o Develop informational policy instruments including a WFEN Technical Guide and Manual
3. **Capacity building, communication, education, and public awareness**: To address the lack of capacity, two initiatives are proposed:-
   - o Establish a WFEN CoE consisting of technical and policy expertise; and
   - o Initiate and strengthen R&D in WFE Nexus/Nexus Modelling in Malaysia
4. **Piloting infrastructure and technology to support WFEN approaches/initiatives**: As a novel concept, pilot projects are required to test the nexus solutions in the context of Malaysia. This process should be bottom up and led by innovation from the private sector and facilitated by the government. For

example, an establishment of a pilot project fund that accepts proposals from the private sector to address specific issues related to nexus challenges could be established.

5. **Establish a database with usable information as a policy decision tool at the basin level**: Establish a DSS for WFEN, including the development of a hydrological database with improved monitoring of water catchment areas, alongside the development of modelling systems covering critical/stressed river basins.
6. **Increase the use of economic instruments to promote resource efficiency and nexus approach**: This includes undertaking assessments on the economic value of water at river basin levels. From these assessments, the appropriate mechanisms that can enhance the economic value and potential of river basins will be identified.

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9.0 APPENDIX

9.1 Project Organisation

Given the multi-sectoral nature of nexus challenges, the Study Team is comprised of multi-disciplinary members with expertise in the water, energy, and food sectors as well as in sociology, economics, and public policy.

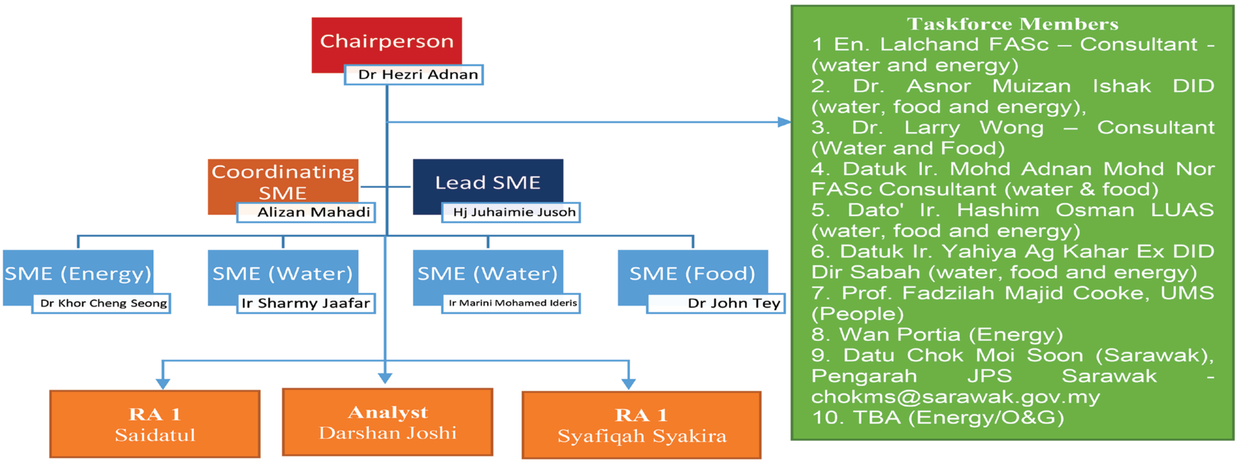


Figure 17. The WFE Nexus Sectoral Study Team

9.2 Workplan and Budget

The overall work plan for the nexus sectoral study is summarised in Table 15, which also provides indications of all the project deliverables and milestones (M1 to M6). The sectoral budget summary is provided in Table 16.

Table 15. Workplan for the WFE Nexus Sectoral Study

Activity / Year (Quarter)	2020			2021			
	Q2	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Project Inception and Mobilization							
Part 1: Current Scenario		M1					
Subpart 1.1: Nexus Mapping • Develop case study protocol • Conduct study on current status and critical issues • Identify nexus factors/variables • Collect data on other region's programmes and initiatives • Obtain best practices			M3				
Subpart 1.2: Findings/Outcomes Validation Conduct stakeholders workshop (SW) in Q1 2021				M3			
Progress Report #1 [31Aug 2020]							
Part 2 In-Depth Nexus Assessment							
Subpart 2.1 Internal-External Analysis • Develop case-study protocol • Evaluate nexus factors/variables • Modelling and scenario-building • Identify circular economy opportunities				M4			
Progress Report #2 [31 January 2020]							
Subpart 2.2: Recommendations Develop strategy guidelines for water-energy-food nexus				M5			
Draft Advisory Report [30 April 2021]							
Part 3: Roadmap Development							M6
Draft Final Advisory Report [30 August 2021]							
Final Advisory Report [30 November 2021]							

Table 16. Budgetary Summary for the WFE Nexus Sectoral Study

Item	Amount (RM)
1. Meetings	243,400
2. Task Force and Management Team	487,000
3. Administration	97,900
4. Contingency	41,415
Total	869,715

PART 2

1.0 BACKGROUND

1.1 Resource Challenges

Water is central to any nation's development. Cities, states, and even empires who have successfully harnessed water have thrived, while those who fail typically fall. History is filled with a litany of collapsed civilisations due to a scarcity of water. Today, many densely-populated cities, nations, and even regions suffer from this same issue, from the western United States to Southern Europe and the Sahel, to India, and even Australia, with this list highly likely to grow over the coming decades as the effects of climate change worsen. Water is an irreplaceable component for the sustenance of human, plant, and animal life, and beyond this, it acts as the unseen lubricant that drives entire economies. It is a fundamental element in food production and plays critical roles in the generation of the energy needed to power our economies.

It is consequently important to understand and analyse the many interactions between water, food, and energy in order to make policy decisions that have positive long-term effects on strategic resource security and sustainability in Malaysia. The failure to do so would leave the country ill-prepared to face the multitude of factors, such as climate change, and continued growth in incomes, population, and urbanisation, that will place further strain on the security of these very fundamental resources.

Emphases on nexus approaches themselves, focusing on precisely these interlinkages between water, food, and energy, have only been introduced and intensified in the past decade, primarily as a response to the realisation that business-as-usual resource security issues require a more holistic framing in their assessment and analysis. Indeed, nexus approaches and concepts are predicated on the idea that the pursuit of resource-level security in one single individual resource, such as food, or water, or energy security, can compromise the attainment of others, or cause net-negative costs in some other way. This has given rise to the idea of achieving nexus security; security across the water, food, and energy sectors which are intricately interrelated and interdependent.

At present, water, the heartbeat of the water-food-energy nexus, is abundant in Malaysia. The nation receives approximately 2,900mm of precipitation each year, spread over both space and time, although surface flow availability is confined only within river basins. Certain states, such as Sarawak and Terengganu, receive more than 3,000mm per year, while others, such as Malacca and Perlis receive only about 1,800mm annually. Despite the variance in precipitation across states, rainfall levels across the country are high when contrasted against the global average of approximately 800–900mm each year.

Water flows according to gravity and is confined within its basin unless transfer instruments, such as tunnels, are present. Of the water received through precipitation each year, roughly only 30% is available as surface water flow. Most water is lost to either evaporation or percolation. Almost half of Malaysia's surface water is lost to the seas, especially during periods of high flow. A high base flow within a river channel is what sustains not only the relevant ecosystems it directly supports, but also the needs of society and the economy, while base flow itself depends on forested catchment areas.

If water sustains life on Earth, energy drives nations forward. All nations have a fundamental need for reliable and affordable energy, with the World Bank's Development Indicators showing a strong relationship between energy use and almost every conceivable aspect of development. Wealth, health, nutrition, water, infrastructure, education, and even life expectancy itself, amongst many other variables, are strongly and significantly related to the per-capita consumption of energy. In terms of its interactions with water and food, energy is required throughout the processes of withdrawing and treating potable water, irrigating crops, and cleaning waste products.

Finally, human and animal life could not be sustained without food. Agriculture is the largest user of water globally, accounting for at least 70% of total surface- and ground-water consumption globally, and approximately 68% of total water consumption in Malaysia. The agricultural sector is a key driver of the Malaysian economy – and the economies of many other countries, regardless of income level.

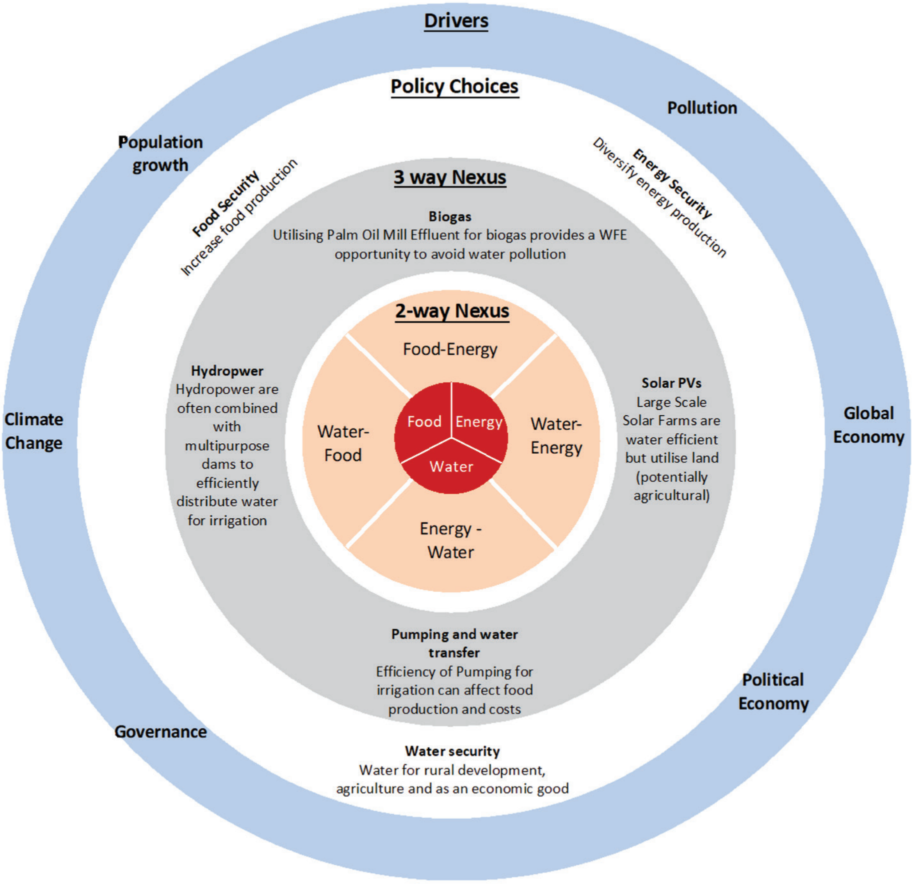
1.2 The Water-Food-Energy Nexus (WFEN)

Water, energy, and food are tightly interconnected strategic resources and emphasis has emerged in recent decades on the water-energy-food nexus (Vogt et al., 2010; Endo et al., 2020). Roughly 8% of global water withdrawals are used to generate energy. Energy, in turn, is needed to transport and fertilise crops: food production, and its associated supply chains, are responsible for approximately 30% of total global energy demand. Indeed, crops themselves can be used to produce biofuels (Hoff, 2011). Considering the increasing and varied demand of water resources from all sectors and the destruction of the utility value of water through pollution, it is now crucial and urgent that the whole spectrum of water-energy-food nexus be given attention and analysed.

There exist clear and significant interactions between water, energy, and food that may result in competition, synergies, and a multitude of trade-offs between different sectors or interest groups. However, current planning, foresight and implementation of policies that affect these strategic resources are performed separately (Ghodsvali et al., 2019). Given the aims of building a sustainable and inclusive future, current 'business-as-usual' policy and regulatory frameworks can no longer be considered viable models of economic development. Malaysia, and indeed many other nations, cannot rely on the same finite water, energy, and food resources far into the future without significant changes in existing policy and regulatory frameworks in ways that address the issues and opportunities that exist because of the deep synergies between these three resources.

The nexus approach provides a more integrated way to balance the various policy choices (see Figure 1). It must be noted that there is no single bullet and these policy choices are often contextual. The study design will analyse specific contexts of two-way nexus, and, if any, how they manifest themselves into three-way nexus. Additionally, these two-way and three-way nexuses interact with megatrends and pressures such as population growth, climate change, increase in pollution, increase in consumption, urbanisation as well as challenges related to governance and the wider political economy. Indeed, many nexus analyses in the academic and policy literature include variables such as land-use and climate as an additional nexus element, for instance focusing on three-way interactions of water-energy-climate, or even the four-way water-energy-food-climate nexus.

In the context of this study, many of the three-way nexus interactions analysed can be extended to include climate as a fourth nexus element; this is because the interactions analysed involve renewable energies such as solar, biogas, and hydropower, meaning the adoption of WFEN technologies would have implications for climate change mitigation – and in some cases, adaptation – as well. Nonetheless, by understanding this complex landscape, decision-making and policy choices can shift towards single resource to multiple resources. The outcome of the study will provide some of the policy choices to meet and balance the trade-off and synergies of current policy targets. On the one hand, it can ensure greater security across all three resources. On the other, it provides opportunities to take advantage over the economic potential of these strategic resources. The policy interventions will also address broad sustainability issues as the nexus approach also takes into consideration the drivers and megatrends that providing pressure to the earth's systems. This includes taking into consideration climate change as both a driver and a policy objective with Malaysia set to be carbon neutral by as early as 2050.



2.0 ACHIEVING RESOURCE SECURITY AND SUSTAINABLE DEVELOPMENT

There is no single approach of framing the nexus across water, food, and energy. This is notable in it being conceptualised as water-energy-food, water-food-energy or food-energy-water in various literature and reports. For the purpose of this study, it is conceptualised as water-food-energy due to a few reasons. Firstly, as part of the Water Sector Transformation 2040 study, the water sector becomes both the entry point as well as the focus. In this sense, there are some interactions that are not paid sufficient focus due to it being outside the scope of this study. For example, the two-way nexus across food-energy became a policy focus during the 2008 financial crisis due to the increased prices across both energy and food, as food requires to be grown, manufactured, and transported with high energy use and therefore is has a correlation with energy prices (Dodds, 2016). However, in the context of this paper, the focus is on the two-way and three-way nexus that interacts with the water sector, and therefore does not focus on interactions beyond the water sector. Secondly, in the overview study of water-energy food nexus in Malaysia, Hezri (2018) argued that whereby energy resources received highest-level policy attention from a security point of view, and food security, while receiving modest attention, water security is the most neglected in terms of policy focus and most critical in terms of security with challenges both on efficiency and sustainability evident.

From a water governance point of view, tracing its evolution has demonstrated many paradigms in the past, of which continue to evolve. The changes are driven by economic development, demographic growth, technological progress, social values, and environmental events like climate change. These changes have precipitated institutional reforms that causes variations in water paradigms, the dominant rules-in-use, and approaches for governing water resources (see Figure 5).

Malaysia first recognised the need to embark on a water reform journey way back in the 1990s when its economy was booming and the population fast increasing. By the 2000s it was evident that the water services industry must be financially viable and cannot continue as a social service. The shift in paradigm whereby water was considered an economic good underpinned the endorsement of the *Water Services Industry Act 2006* or the WSIA management reform programme. Arguably, Malaysia is still in the Type II reform with little emphasis on equity and sustainability. The nexus focus belongs to the Type IV and Type V reform. Interestingly, this study, part of the water sector transformation plan aims for Malaysia to transition the sector towards seeing water as an economic resource. Nonetheless, the Economic Planning Unit's overall objectives, aims for also addressing water security and sustainability within the transformation. For the purpose of this study, and towards achieving the overall objectives of the WST2040, the policy recommendations will be geared towards the transformations required to move to evolve water governance to address water from an economic resource point view (Type III); water from a security point of view; and sustainability of the water sector.

Ultimately, the aim of the nexus approach is to transition from governing a single resource to multiple resources. Towards this aim, there is a need to identify the interconnections within the nexus arena. It is important to note that the interactions across the different resources can be synergistic or consisting of trade-offs. Synergistic relationships, in theory, should be capitalised upon while trade-offs need to be managed. How the interactions manifest themselves are highly contextual. In this sense, the in-depth studies will be undertaken at the river basin level.

Beyond identifying the interconnections, more importantly, the objective of the study is to provide policy recommendations towards a transformation of the water sector. Cognisant of this, a hydrosocial perspective is adopted in this study. The term 'hydrosocial cycle', instead of the hydrological cycle, refers to the inseparable social and physical dimensions of water. The hydrological cycle points to the natural cycle of water or the water engine that is fuelled by solar energy, driven by gravity, and proceeds endlessly in the presence or absence of human activity. But water resources cannot be disentangled from human systems as was aptly argued by Bakker (2002: p. 774) as follows:

> "Whereas H2O circulates through the hydrologic cycle, water as a resource circulates through the hydrosocial cycle – a complex network of pipes, water law, meters, quality standards, garden hoses, consumers, leaking taps, as well as rainfall, evaporation, and runoff. ... Water is simultaneously a physical flow (the circulation of H2O) and a socially and discursively mediated thing implicated in that flow..."

Adopting the hydrosocial perspective has two major consequences for this study. First of all, is the understanding that we cannot manipulate water without profound social consequences. Within this study, the identification of the interconnections goes beyond the interconnections of natural systems and investigates the interlinkages across human systems as well as the consequences of such interactions from security, economic, and sustainability. Secondly, a hydrosocial perspective entails an institutional analysis that takes into consideration the various policy processes and responses and the political economy at various levels.

The following sections reviews the nexus challenge and its conceptualisation. First, we look at nexus from a policy challenge where nexus includes a focus on security, economy, and sustainability. Secondly, we focus on nexus identification, understanding how nexus are measured and accounted for to assist decision-making. Third, we focus on potential policy designs to provide incentives in addressing nexus. And finally, we review perspectives developed in literature towards governing WFE nexus.

2.1 The WFEN as a Policy Challenge

The idea of a WEF nexus was mainstreamed at the World Economic Forum (WEF) in 2011 following the Forum's publication of Water Security: The Water-Food-Energy-Climate Nexus. This report highlighted the scarcity of water in many locations around the world, as well as the fact that it is both an under-priced and increasingly depleted resource. Unlike energy, water does not have any substitutes. It is a finite good, and the indispensable nature of freshwater comes to the fore most prominently during periods of prolonged droughts – which are expected to occur with greater frequency and severity as the consequences of climate change are felt more acutely. Further, global demand for resources is likely to escalate as countries and populations grow larger and richer. Once the impacts of climate change are factored into the equation, the Earth may accurately be described as a "hot, hungry, crowded, and fast-evaporating planet".

In 2012, the United States' National Intelligence Council issued estimates of growth in demand for food, water, and energy by 2030, 2040, and 2050 of 35%, 40%, and 50%, respectively. The World Wildlife Fund (WWF) suggests that this is due to numerous factors that include a growing global population, increased levels of urbanisation, and the rise of the global middle-class (WWF & SABMiller, 2014). There also exist necessary aspirations to enhance the livelihoods of the poorest segments of society, who are undernourished and mostly without access to electricity and clean water (IRENA, 2015): achieving this will only add to the overall strain on water, energy, and food resources over time.

Due to these projected challenges, WFEN became a policy challenge towards addressing resource security. While most of the early literature focused on identification of the interactions across the resources, as a policy challenge, the focus shifted towards nexus solutions including governance and institutionalising the nexus. The focus on solutions also resulted in the nexus to focus on other policy objectives, namely nexus as an economic imperative as well as broadly as a solution to achieve efficiency both in terms of resource use and in terms of cost efficiencies.

As sustainability science and evidence become more prominent and urgent, the concept of nexus has also been linked to broader sustainability concerns. This includes the interactions of water-energy-food with climate change as well as land and biodiversity. These interactions create new configurations of nexus including potentially four- or five-way nexuses. Furthermore, from a sustainability perspective, the nexus challenge is seen from the lenses of the green and circular economy in efforts to balance economic and environmental objectives. These perspectives are elaborated further below towards understanding the different approaches and paradigms of nexus in achieving resource security and sustainable development.

2.1.1 Achieving WFEN Security to Support Livelihood

The WFE nexus had a strong focus on resource security in its early years (Simpson & Jewitt, 2019). With projections of increase in the global demand of water, energy and food, the nexus poses a challenge for both resource and human security (Simpson & Jewitt, 2019; UNESCAP, 2013; World Economic Forum, 2011). The securitisation of these three resources is underpinned by the idea of 'limits' which was first brought about in the 1970s and 1980s. More recently, work on the planetary boundaries demonstrate the biophysical limits of a "safe operating space for humanity" highlighting the link between natural resource security and human security (Rockström et al., 2009). This is also in line with the Ministry of Environment and Water's focus on using planetary health as a framework. To ensure water-food-energy security, the starting point is to build upon the three independent security frameworks. Bizkova et al. (2013) identified the elements of each independent security as can be seen in the figure below.

Table 17. Water, Food, and Energy Security Parameters (Bizikova et al., 2013)

Food Security	• Food availability: influenced by production, distribution, and exchange of food; • Access to food: including affordability, allocation, and preference; • Utilisation: nutritional value, social value, and food safety • Food stability over time
Water Security	• Water access; • Water safety; • Water affordability so that every person can lead a clean, healthy, and productive life while ensuring that the natural environment is protected and enhance
Energy Security	• Continuity of energy supplies relative to demand; • Physical availability of supplies; • Supply sufficient to satisfy demand at a given price

From the preceding study on WFE Nexus in Malaysia by Hezri (2018), it was found that water is the most critical in terms of security. In particular, the water sector performed poorly in relation to efficiency due to high rates in non-revenue water. Non-revenue water was 36.4 percent in 2020, which is above the World Bank's recommendation of being less than 25 percent of produced water. Sustainability is also compromised due to challenges related to pollution. In 2019, the Compendium of Environmental Statistics (2020) reported that 10 river basins (7 percent) were classified as polluted and 49 rivers (34%) slightly polluted out of 144 river basins monitored. Furthermore, in the past 30 years, in comparison with other countries, revenue of water utilities has only shown a slight increase despite cost escalations and rising operation costs. While the overall reserve margin at 16.3 percent is above the minimum threshold of 15 percent at the national level, some water utilities reserve margin is below 5 percent. These challenges demonstrate the vulnerability and challenges to address water security in Malaysia.

Globally, the Water-Energy-Food (WEF) Nexus Index is a tool that measures WEFN security in a composite manner. The index aggregates 21 globally available indicators. The WEF Nexus Index Value[5] for Malaysia is 67.8, placing the nation in the 18th position amongst countries assessed (see Figure 3). Malaysia has an index score of 79.4 for the water pillar, 64.1 for energy, and 59.9 for food. Under the Water pillar, Malaysia is ranked 4th in the world based on accessibility and availability. In terms of energy, Malaysia ranked 29th, while for the food pillar, Malaysia ranked 53rd in the world. This demonstrates the difference in assessment on security if it was based on availability and accessibility alone and does not take into consideration other factors such as efficiency, sustainability, and stability. Nonetheless, it highlights the abundance in natural resources generally, and in particular, for water in the context of Malaysia.

2.1.2 WFEN as an Economic Imperative

One of the major challenges of the nexus approach is to balance resource prospecting with creating new abundance. While security concerns have dominated nexus literature and approaches previously, on the other hand, countries with abundance of resources can utilise the nexus approach as an economic opportunity.

Globally, an emerging trend is the reframing of "wicked problems", or those which are complex, dynamic, and seemingly intractable, as opportunities rather than challenges. These opportunities are then taken through solution ecosystems, largely driven by businesses alongside networks of civil society, experts, and government. Through the fourth industrial revolution and greater volume, velocity and

[5] Water Energy Food, WEF Nexus Index website – https//wefnexusindex.org/

veracity of information, increased comprehension of the challenges and solutions are possible to address such wicked problems. It is driven partly by the need to internalise sustainability in businesses as well as creation of new forms of value. For example, Nestlé has undertaken efforts such as harvesting rainwater from their warehouse roofs, reducing sanitise flushes in cleaning circuits to address issues of water. Furthermore, efforts to address water-energy nexus has also been implemented such as reducing the blowdown rate of cooling towers in their manufacturing facilities in the Murray-Darling River basin in Australia to reduce energy losses and increase efficiency. Nonetheless, moving towards such a system requires developing an integrated ecosystem with various actors and integrators to bridge the disparate organisations together in a partnership arrangement. These includes business leaders, data holders and data analysts to inform decisions, civil society to promote action and monitoring and experts to provide strategic direction.

From a policy and perspective, the development of the nexus ecosystem also requires an enabling environment driven by progressive policies. The nexus approach looks at the possible policy tools that can address nexus issues. This includes fiscal tools that can potentially create interdependencies and synergies between the water-food-energy systems as well as tools that incentivise resource efficiency and technology adoption. The potential policy tools adapted from Brears (2018) are listed in Table 18.

Table 18. Policy Tools for Nexus Economics (Brears, 2018)

Policy Tools	**Objective**	**Mechanisms**	**Examples**
Market-based instruments and pricing	Integration of natural asset base to market decisions	Tariffs, levies, charges, tradeable permits, soft loans, etc.	Water tariff based on level of scarcity, payment for ecosystem services
Environmental taxes	To raise the cost of production or consumption as demand side management	Taxes on high consumption of energy, carbon, and/or water	Carbon tax, fuel tax
Financial and investments	Encourage synergies across WFE nexus	PPPs, Finance products, subsidies, and grants	Incentives for multiple resource innovations
Technological innovation	Improve performance resulting in higher efficiency	Innovation	Precision farming, pumping, etc.

In the context of Malaysia, the economic imperative is arguably lacking. As highlighted above, Malaysia's potential to become a hub for water is evident in its high ranking in terms of availability. Nonetheless, efforts will need to be undertaken to transform the ecosystem to be more in line with sectors such as energy and telecommunications. As an example, the revenue for the water industry in Malaysia is RM6bil, in comparison with RM60bil in the energy sector. Moving forward, the overall ecosystem needs to shift towards seeing water, and the nexus approach, as economic imperatives.

2.1.3 WFEN for Achieving Sustainability and Circularity

The WFE nexus approach is strongly linked to sustainability and sustainable development. The integrated and systems approach of nexus builds upon the need for addressing the balance between the social, economy, and environment. In many ways, the nexus approach is a quintessential sustainable development approach – whereby it promotes problem solving that is not piecemeal but rather taking into consideration the interactions and interdependencies in a holistic manner. In this sense, the nexus approach itself is a sub-set of sustainable development.

The green economy approach is also closely related to sustainability and sustainable development. Brears (2018) argues that the WFE nexus approach can reduce pressures towards achieving green growth. Some of the relevant areas highlighted include the following:

- Increase resource productivity – through increasing efficiency and decoupling resource use with environmental degradation
- Using waste as a resource – through a circular economy
- Economic incentives – improvements in resource productivity will require investment and incentives such as through pricing of resources (and ecosystem services)
- Ecosystem services – ecosystem conservation can lead to multiple benefits to other sectors

At the international arena, the Sustainable Development Goals (SDGs) was adopted by all the United Nations member states as the global development agenda. Although it consists of 17 individual goals, it is meant to be addressed in an integrated manner (United Nations, 2015). In the context of nexus, all three resources have their own individual goals. To achieve the SDGs in an integrated manner, the sustainability perspective will ensure that the achievement of one goal does not compromise the achievement of another (trade-offs) as well as promoting mutually beneficial solutions (synergies).

The 12th MP also targets the nation to be carbon neutral by as early as 2050. In this context, the nexus approach can also efforts to address both the mitigation of climate change through adoption of technologies that are both renewable (i.e., Large Scale Solar, solar pumps, hydropower) and/or through increasing resource efficiency.

2.2 Nexus Identification Challenge: Measurement, Accounting, Analysis, and Modelling

A key issue related to the analyses of water-food-energy nexus concerns relates to measurement. How do we measure threats to, or exploitation of these resources? What are the variables or metrics that need to be accounted for in measuring these threats? And how are these variables in turn affected by extraneous variables, from climate change and population growth, to legislation and policy? This section of the report is concerned primarily with the identification of the variables that would be required in order to effectively analyse nexus interactions, issues, and opportunities at the river basin level. This identification would consequently inform some of the policy recommendations put forth by this study, in particular the development of a database and linked decision support system to support policymaking initiatives with regard to water, food, and energy security in Malaysia. In this regard, this section sets forth prerequisites for the further immersion of nexus approaches into resource security initiatives in Malaysia.

Given the aforementioned centrality of water to the three-way WFEN nexus, as well as the fact that water scarcity or pollution are typically considered chokepoints in the context of nexus analyses internationally, a key metric of interest is the Water Stress Index, or WSI. The WSI is reflective of the ratio of total annual freshwater withdrawals relative to hydrological availability, with this figure typically falling within a scale of 0 to 1, with 0 representing no stress and 1 representing maximum stress, or represented by a percentage. Hydrological availability is determined by several factors, including water availability, surface runoff, groundwater recharge, and river discharge. Water use, meanwhile, is calculated by taking into consideration withdrawals and consumptive water use across domestic, industrial, and agricultural usage, with the latter encompassing water use in irrigation and animal husbandry. The WSI is further affected by dynamics variables such as variability in precipitation levels, which vary greatly between wet and dry seasons, for instance, and flow regulation, which can vary greatly within and across river basins. This renders critical the monitoring and collection of data across all river basins in Malaysia, particularly those with significant nexus interlinkages, of the many variables which feed into the calculation of the WSI.

Within the context of Malaysia, the National Water Research Institute of Malaysia, or NAHRIM, has conducted preliminary work into the establishment of a WSI for key river basins across the country. This data is reprinted in Table 19 below. As will be expressed within our policy recommendations, this study proposes the use of the WSI as a critical tool in assessing nexus pressures across river basins in the state, with action to incorporate nexus approaches to alleviate resource security pressures most imperative in the most-stressed basins. These typically occur where demand for water from one of the key sectors – usually food, and in particular paddy production – is significant, which creates competitive tensions between water required for irrigation and water required for other purposes, such as potable water, or for energy production. For this reason, river basins such as Muda and Selangor are considered to be stressed, while in Johor high rates of NRW as well as diversions of its water supply to Singapore are key factors contributing to its higher WSI. The Sg. Perak river basin, meanwhile, is considered to have a low WSI and this is due in large part to the high levels of water availability in the state. This situation, however, still needs to be managed due to the pressures on water resources in the state from economic and population growth, climate change and changing weather and rainfall patterns, and water pollution which occurs due to the myriad of agricultural and industrial activities that occur in the state (see Section 5 for an in-depth analysis of the Sg. Perak river basin).

Table 19. Water Stress Index for Key River Basins in Malaysia

River	Annual Water Volume (in MCM) (Availability)	Annual Water Abstraction (in MCM) (Withdrawals)	Water Stress Index, WSI (Index, %, and Ratio, 0–1)	Water Stress Level
Sg. Muda	2,606.80	1,962.31	75.3; 0.753	*Severe stress*
Sg. Kelantan	16,451.00	1,411.02	8.6; 0.086	*Not-stress*
Sg. Pahang	18,939.50	893.89	4.7; 0.047	*Not-stress*
Sg. Johor	2,049.50	847.86	41.4; 0.414	*Severe stress*
Sg. Linggi	1,234.20	227.65	18.4; 0.184	*Low stress*
Sg. Selangor	2,474.00	1,134.79	45.9; 0.459	*Severe stress*
Sg. Padas	7,593.40	249.4	3.3; 0.033	*Not-stress*
Sg. Sadong	5,667.70	128.81	2.3; 0.023	*Not-stress*
Sg. Perak	13,864.44	1,727.88	12.5; 0.125	*Low stress*

In addition to the WSI, several other indicators are useful in the context of analysing individual resources pressures, i.e., water, food, and energy security individually, as well as pressures across nexus systems. For water, this includes indices covering water quality (in addition to the WSI) and droughts; for food, irrigation efficiency and self-sufficiency; and for energy, water withdrawal and consumption factors, renewable energy capacity, and CO2 emissions avoidance are all factors of interest. In addition to this, data collection within river basins must be widened to include a host of indicators useful in the context of analysing two- and three-way nexus interactions. A summary list of these indicators is provided in Table 20 below.

Table 20. Summary of Indicators Relevant to WFE Nexus Analyses

	Resource Security (Availability and Demand)
Water Security	• Total water availability by state (in "mm rain fall per year") • Total water demand by sector (in "m/c/m per year" or in "mm rain fall per year") • Water stress index • Water consumption by sectors • Water exploitation index
Food Security	• SSL (by type of agriculture products) • Agricultural production
Energy Security	• Annual installed electricity generating capacity (million kW) in the river basin from which, the Hydropower installed electricity generating capacity (million kW) • Generation of electricity based on fuel source • i) Hydropower (%) • ii) Fossil fuel (%) • iii) Other renewables (%) - solar, biofuel, biomass, biogas • Energy demand by sector (Industry, Domestic, Services, Others including agriculture)
Land-Use	• Percentage of land use • Agriculture (Granary/ other type of agriculture) • Forest • Built-up (Domestic/Industry/Services) • Water Bodies • *Energy (Hydropower/Thermal power plant/LSS)
2-Way/3-Way Nexus Indicators	
Water for Food (Paddy Irrigation)	• Water yield or Volume of water from river source for annual irrigation (in m/c/m or in m3) • Paddy yield (in "tonne") • Paddy water footprint based on "Volume of water in m3/tonne of grain") • Irrigation efficiency
Energy for Food (Paddy Irrigation via pumping)	• Volume of water from river source for annual irrigation via pumping (in m/c/m) – value subject to factors such as water resources situation especially those related to rainfall and volume stored in the reservoirs. • Energy required to pump 1000 m3 of water (in "kwh/1000m3 of water") – calculation is a function of the average distance of water lift and the percentage of pump efficiency. • Total energy load to irrigate water via pumping (in kWh or in MWh) • Paddy energy footprint that is specific from pumping requirement for irrigation (in "MWh/tonne of grain")
Water for Energy	• Water consumption for Steam Generation in Thermal power plant • Water withdrawal for Hydropower Generation in Hydropower dam
Energy for Water	• Energy for Water Transfer via Pumping • Energy for Raw Water Treatment (WTP) • Energy for Sewage Water Treatment (STP)
External Factors in WFE Nexus	
Socioeconomic	• GDP Share in the basin (Possible to obtain If the basin region overlaps with an economically valuable region, it is otherwise difficult to estimate) - can try on industry, energy, granary, and palm oil" • Population share in the basin- (i) Total , (ii) Rural, (iii) Urban • Employment by sector: agriculture, energy, industry, domestic/services or just share in agriculture (paddy)"
Governance	• River Basin Authority/Organisational (availability)
Environment	• Water quality index
Economic Investment	• Future water investment • Water Value

2.3 Perspectives in Governing the Nexus

A review of the nexus literature in relation to governance demonstrates that generally, the nexus concept has focused largely on technological solutions. While governance of the nexus has been increasingly highlighted in the literature, much of the focus is on conceptualising the interactions rather than towards nexus solutions. Nonetheless, the review below highlights some of the approaches from international review.

Challenges in governing the nexus can be broadly based on three perspectives, namely, on risk and security; economic rationality; and on the political economy (Weitz, Strambo, Kemp-Benedict, & Nilsson, 2017a). These perspectives are in line with the conceptual framework of this report and the overall aim of WST2040 which aims to look ensure water for livelihoods (security) and water as an economic good. In addition, the political economy perspective can be seen as an enabler to achieve the two aims above.

The governance approaches and instruments differ in accordance with the perspectives undertaken. The first two perspectives are more technical or administrative in nature. For example, the adopting the nexus as a security perspective focuses more on coordination of information about cross-sector interactions. In the context of WFEN nexus, this requires cross-sector information to mostly identify what are the interactions across the three resources. For example, an indicator system to identify what are the nexus 'hotspots' or 'chokepoints' are proposed to address the security perspective. In this context, the governance responses is more on 'communicative instruments' which aims to "change the vision and mindset of decision-makers" (Scott, 2017; Weitz, Strambo, Kemp-Benedict, & Nilsson, 2017b).

The economic rationality perspective remains a technical and administrative approach. It often focuses on optimisation of resources, system performance and/or resource efficiency as measured by economic criteria. The purpose here is to improve policy cost-effectiveness and move towards a model that optimises resource allocation. It also focuses on creating new business opportunities and the overall enabling environment to facilitate innovation. The governance responses under this perspective is more varied, including addressing cross-sectoral and multi-stakeholder cooperation, increasing communication as well as economic instruments. In other words, the governance responses mainly adopt 'organisational' and 'communicative' instruments. Furthermore, economic based instruments to provide incentives and disincentives for WFEN are also proposed.

The final perspective goes beyond technical and administrative matters and focuses on the political process of decision-making. It acknowledges that the decision-making is not undertaken under a political vacuum where there are different interests, knowledge and practices across the critical stakeholders. Under this perspective, the focus is more on the local context or specific scales of decision-making where decisions are undertaken. It may include issues such as unequal distribution of power, asymmetrical resources and access to information (Weitz et al., 2017a). The governance responses in this context focuses not only on the institutional structure (organisational instrument), but also the 'procedural instruments', which seeks to change the "procedures, rules and standards for decision-making"(Scott, 2017; Weitz et al., 2017b). For example, regulatory instruments and major institutional changes such as the Water Sector Reform in Malaysia in 2006 can be seen to address some of the issues from the political economy perspective.

Table 21. WFEN Governing Approaches Review Framework

Perspective	Instruments	Examples of intervention	Stages of the Policy cycle
Security	Communicative	Communicative on risks – i.e., indicators and policy targets	Planning; monitoring and evaluation
Economic Rationality	Organisational, communicative, economic instruments	Multi-stakeholder coordination, Economic-based instruments	Planning; policy implementation
Political economy	Organisational and procedural instruments	Institutional structures, Regulatory instruments	Implementation

3.0 MAPPING OF NEXUS IN MALAYSIA

3.1 Two-Way Nexus Interactions

As highlighted in the review of nexus approaches and concepts, nexus interactions can exist across both two and three resources. Analyses of two-way resource interactions, such as those between water and energy, water and food, and food and energy, are important as they assist in the generation of deeper insights into resource use, security, and sustainability than can be provided an emphasis on single-resource security. This gives rise to the revealing of a set of potential cross-sectoral or cross-target solutions to contemporary resource security issues. A pertinent example can be found analysing the water-energy nexus; electricity generated through solar photovoltaics is significantly less water-intensive than that generated from coal, natural gas, or indeed biofuels, lending support to the notion that from a water security perspective, investment in improving Malaysia's solar capacity can assist in the addressing of issues that may arise due to water consumption in the energy sector. This line of inquisition is rendered more crucial by the various extraneous stresses on resource security, including climate change, income and population growth, and urbanisation, amongst others.

While the study of two-way nexus interactions is important in its own right, in some situations they are taken into consideration almost as 'stepping stones' to the analyses of three-way nexus interactions that encompass all three strategic resources – water, food, and energy. Such three-way analyses allow for the understanding of conflicts and synergies that arise across these strategic resources when, for example, steps are taken to boost the security of one resource. Analysing technologies and practices from the perspective of three-way nexus interactions then becomes an exercise in deepening our understanding of the holistic and interdependent nature of resource management and security. To build upon the example of solar photovoltaics, and particularly large-scale (or utility-scale) solar projects, these have an additional consequence beyond what an analysis from the water-energy perspective might illuminate. An emphasis on photovoltaics, whether to address water use in the energy sector, or simply to decarbonise electricity generation nationally, will intensify competition for land with other sectors. If land used to generate solar power comes at the expense of land used for agriculture, these solar projects can have unintended negative consequences for food security. These considerations are revealed only when approaching issues from a nexus perspective rather than through the existing focus on individual resource security, which we assume to be reflective of business-as-usual practices.

Such an approach reveals solutions, too. Photovoltaics can alleviate pressures on energy-sector water use, but may threaten agricultural output and consequently food security if considerations over land-use competition are not taken into account. Accordingly, methods to harness the benefits of solar power – from reduced water consumption to reductions in emissions that arise from replacing power generated by fossil fuels, for instance – must be balanced against these competing interests. This gives rise to a host of potential solutions that allow for a maximisation of the benefits – and minimisation of the costs – that arise from an increase in large-scale solar capacity. Most pertinently, these include agrivoltaic and floating solar farms, which allow for the co-production of crops and solar power on the same plots of land, and which circumvent the use of land by suspending photovoltaic panels on abandoned or unused water surfaces, respectively.

Two-way nexus interactions, between water and energy, energy and food, and water and food (and vice versa) are nevertheless important. In not all cases does a focus on two-way interactions tease out a potential three-way nexus solution; in some cases, the insights offered by these more limited nexus focuses offer direct solutions to issues that exist within the scope of the relevant interaction. Examples of these insights are provided in Table 22, which highlights interactions of water and energy, energy and water, water and food, as well as the three-way water-food-energy nexus interactions. It highlights specifically the activities within each interaction that has implications for resource use, security, and sustainability, and importantly, some of the opportunities that are revealed by a nexus-wide approach to resource use activities across these sectors. These opportunities typically refer to the utilisation of practices or technologies that can eliminate or mitigate the use of, or at least maximise the use efficiency of, one strategic resource as a factor of production for the other.

Table 22. Nexus Interactions, Activities and Opportunities between Water, Food, and Energy

Nexus Interaction	Activities	Nexus Conflicts and/or Opportunities
Water-Energy	Water consumption, use efficiency, and quality, energy generation	Opportunities from shifting to less water-intensive energy generation technologies, e.g., solar, biogas using POME.
	Water source, cooling, and condensation	Conflicts and opportunities arise where water used for cooling is drawn from freshwater resources.
	Water use, cooling, and condensation	Opportunities from shifting to less water-intensive cooling technologies, e.g., recirculating tower cooling, dry cooling.
Energy-Water	Energy efficiency, water supply Water losses, water supply	Opportunities through adoption of IR4.0 technologies, e.g., advanced sensor systems, remote monitoring of connected devices, big data analytics.
	Energy efficiency, water, and wastewater treatment, water pumping/lifting/ distribution	Opportunities from shifting to more energy efficient/less energy-intensive technologies, e.g., co-digestion, fuel cell systems; energy-efficient/renewable-powered/connected 'smart' pumping systems.
Water-Food	Water intensity, agricultural production Water efficiency, irrigation	Opportunities through modernisation of farming, i.e., precision agriculture, entailing digitalisation of farming processes to maximise efficiencies and minimise losses.
	Food losses, post-harvest	Opportunities through adoption of digital/connected technology, investment in on-farm/commercial storage and infrastructure (e.g., for transport), to minimise losses; improve financial and market access to benefit smallholders in particular.
Water-Food-Energy	Large-Scale Solar – agrivoltaics, floating solar	Opportunities to produce food and energy simultaneously with lower water intensity than other forms of energy generation.
	Waste-to-Energy – biofuels, particularly biogas	Opportunities for waste/wastewater to be converted into energy through biogas production, prominently in the oil palm industry.

The alleviation of many of these nexus conflicts or pressures can also be placed within the context of other intended policy outcomes, including but not limited to targets to enhance energy and water use efficiency, reduce greenhouse gas (GHG) emissions, minimise pollution, and enhance the circular economy. Within the water-energy nexus, for example, water consumption rates, use efficiency, and quality can all be impacted by changes in practices and/or technology use; the use of seawater for cooling and condensation purposes, combined with the use of low water-use cooling technologies, can minimise water supply pressures within the context of the energy sector. Better yet, perhaps, is encouraging the shift to less water-intensive energy technologies altogether, including solar and biogas, which have ancillary benefits in mitigating GHG emissions and aiding the low-carbon energy transition, and particularly in the case of biogas becoming an illustrative case of the circular economy in action. Managing strategic resources by analysing them in accordance with their interactions with each other can consequently aid the achievement of a broader and more diverse range of policy ambitions and targets beyond just fortifying individual, resource-level security.

3.2 Biogas

This section focuses on biogas as an application of the three-way water-food-energy nexus relevant within the context of Malaysia. It builds a system dynamics model mirroring an oil palm (food)-POME (water)-biogas (energy) (or the food-water-energy, or FWE) nexus, examining the base and possible spatial-temporal impacts arising from POME-to-biogas technologies in Malaysia. It presents a quantitative nexus assessment of renewable energy policy and innovation that considers the interactions of water, energy, food, and climate structures within a system. Based on system understanding, the FWE model enables simulations to help explore potential outcomes arising from technological upgrading and Malaysia's decreasing feed-in tariff (FiT) rates.

3.2.1 Background

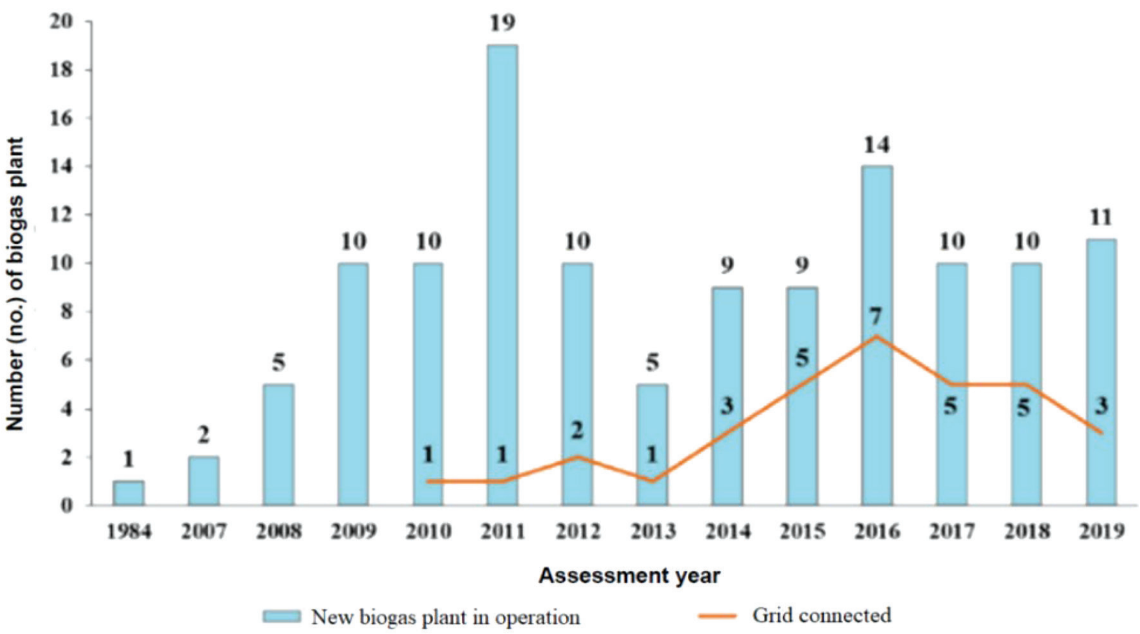
Malaysia produced approximately 19 million tons of crude palm oil (CPO, a milled product of fresh fruit bunches, or FFBs) from 5.9 million ha of registered planted area in 2020. Plantation firms accounted for 72.2% of the planted area, followed by 16.3% accounted for by independent smallholders and the remaining 11.5% by organised smallholders. These producers are the supply base to a total of 452 mills, which are typically located in vicinity for extracting the oil contents of FFBs at an optimal rate within 24 hours. It is this milling process that generates biomass products, including POME, empty fruit bunches (EFBs), mesocarp fibre, and palm kernel shell. In turn, physical biomass is burnt in modified boilers to generate steam for internal use. In this circular power system, EFBs and palm mesocarp fibre, which are of higher commercial values, are increasingly substituted by the biogas capture of POME (Vijaya et al., 2010). Policy attention has now expanded to promote biogas investments among palm oil mills in Malaysia.

Further to the Environmental Quality Act 1973, the POME discharge standard was enacted in 1978. As summarised in Kamyab et al. (2018), these standards are increasingly stringent. The Malaysian Palm Oil Board in 2011 issued guidelines for the National Biogas Implementation under the Entry Project Point 5 of the National Key Economic Areas (NKEAs), with its objective to encourage the uptake of biogas technologies across palm oil mills. Since 2014, new and existing palm oil mills requiring expansion have been mandated to install methane capture and avoidance facilities (MPOB, 2013). All mill licenses will only be extended if proof or plan of a biogas plant is submitted. It is a national target to have all palm oil mills equipped with biogas technologies.

Institutional efforts to promote biogas have gained momentum. At the international level, it is recognised as a clean renewable energy by the Clean Development Mechanism (CDM) for emissions reduction projects and allow for the earning of certified emission reduction (CERs) credits. These credits can be traded, sold, and used to meet emissions reduction targets under the Kyoto Protocol. In Malaysia, incentives are offered to companies generating renewable energy under the Promotion of Investments Act 1986. In 2012, the government began to implement the FiT system, with distribution licensees (such as Tenaga Nasional Berhad) obliged to buy the electricity produced from renewable resources from Feed-in Approval Holders.

Notwithstanding the mandate, biogas technology remains an economically productive option to palm oil mills. Tan and Lim (2019) found that an integrated POME technology can improve oil extraction rates by up to 0.3%. Yoshizaki et al. (2012)'s 10-year projection suggest a CDM can generate 25% internal rate of return, with a three-and-a-half-year payback period. Chin et al. (2013) find that biogas from POME can replace kernel shell and mesocarp fibre as boiler fuels and be upgraded to a gas engine for power generation. Such a combination can help a standard palm oil mill generate additional net profits of up to RM3.8 million per year. To what extent this may come true depends on the FiT rate locked for 21 years.

Plenty investment in a biogas plant by palm oil mills remains to be made. According to Loh et al. (2019), as at the end of 2019, a total of 125 biogas plants (see Figure 4 for their annual commencements) are in operation nationwide. This represents an 28% national biogas implementation. Thirty of these are connected to national grid and another three to local grid for external users. While the authors attributed the adoption gap to the unattractive economics of the biogas technology, Loh et al. (2017) clarify that the biogas initiative in meeting the nation's emission reduction target continues to be a long-term plan. Towards the same direction, Ghani et al. (2019) suggest that a system understanding helps optimise the potential of biomass.



(*Source*: Loh et al. (2019))

Figure 4. Number of Palm Oil Biogas Plants Established Annually in Malaysia

3.2.2 Methodology

In this study, the system dynamics approach was used for modelling WFE nexus. Howarth and Monasterolo (2017) and Markantonis et al. (2019) characterise a nexus as exhibiting non-linear understanding and dynamic feedbacks across sectors. The system dynamics approach meets these salient features. Supported by 35 years of empirical application, Forrester (1993) concluded that the system dynamics approach renders a plausible methodology to understand and influence how systems change through time using feedback loops and non-linear differential equations. He re-iterated that "…system dynamics process starts from a problem to be solved – a situation that needs to be understood, or an undesirable behaviour that is to be corrected or avoided."

Empirical Model

The empirical model developed for modeling WFE nexus that centers on POME issue in Malaysia is presented in Figure 5. Accordingly, the system dynamics model of the WFE nexus contains oil palm (food), POME (water), and biogas (energy) sub-systems as well as their feedback loops.

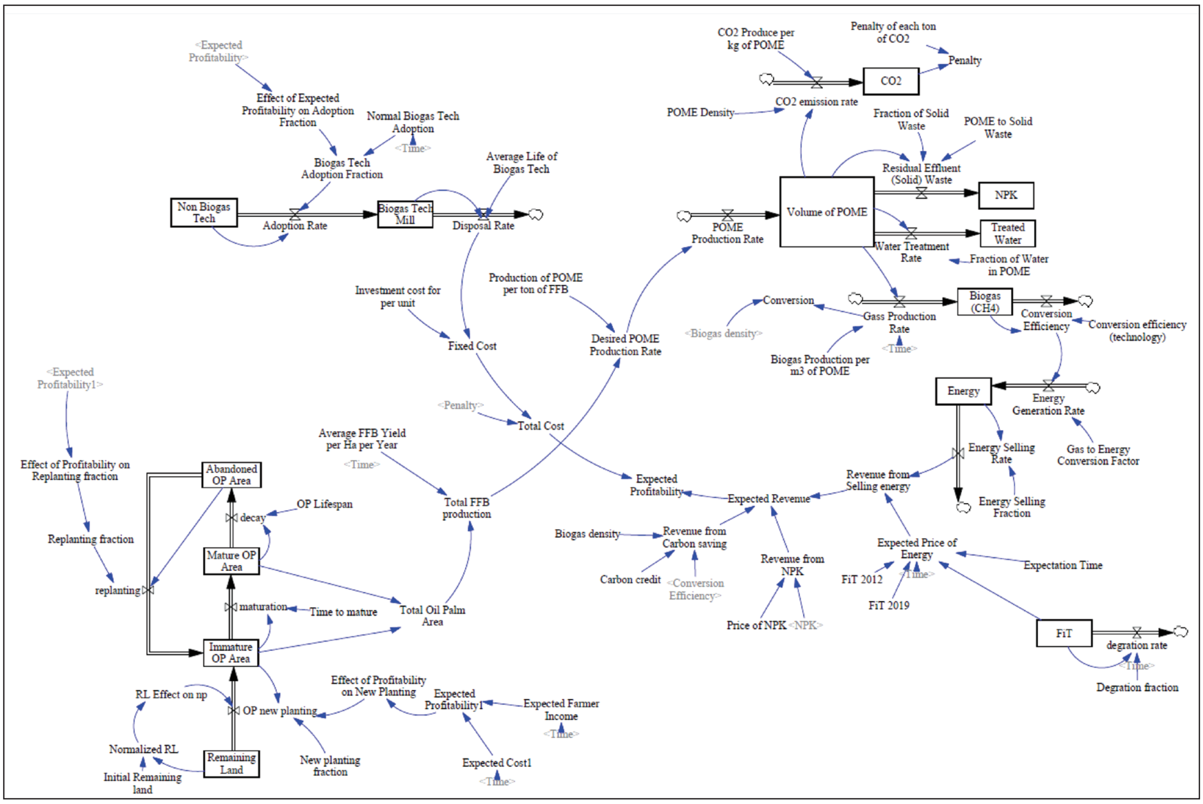


Figure 18. System Dynamics Model of Oil Palm-POME-Biogas

The Oil Palm (Food) Subsystem

The oil palm sub-system is built on Ibragimov et al.'s (2019) work. According to Arshad et al. (2020), the production of oil palm is influenced by its planted area, yield, and relative profitability. When higher relative profit is presented, growers are motivated to intensify the production loop, which, in the case of Malaysia, is characterised primarily by their decisions to expand and replant cultivated areas. This is because the national yield of fresh fruit bunches (FFBs) has been hovering around 20 ton/ha for decades. In 2019, oil palm trees were planted on 5.87 million ha (or more than 70%) of the arable lands in Malaysia. At the time of writing, there is a national cap limiting total oil palm planted area to 6.5 million ha.

In the terminology of system dynamics, Malaysia's oil palm planted area presents a change from an exponential growth to a gradual slow growth towards meeting its equilibrium. Sterman (2000) describes this trend as a S-shaped growth, reasoning that "as the capacity of the environment is approached, the adequacy of the required resources diminishes, and the fractional net increase rate must decline." Such a behaviour is relevant as the opportunity cost of land use prevails between food and non-food crops vis-à-vis agriculture and non-agriculture.

The POME (Water) Subsystem

POME is a liquid wastewater generated from palm oil milling activities. These span from (1) washing and sterilising FFBs, (2) clarification, separation, and cleaning, (3) pressing of empty fruit bunches and crude palm oil, and to (4) factory wash out. On aggregation, it is estimated that 1.5 m^3 of water is used for processing one ton of FFB. Approximately 50% of the water consumption is released as POME (Chan and Chong, 2018). The rest is lost as steam, boiler bow down, wash waters, and leakage.

After the palm oil milling activities, POME is discharged into a waste pond. One ton of POME contains 95%–96% water, 4%–5% of total solids, and 0.6%–0.7% of oil (Ahmed et al., 2015). Discharging the treated POME to a nearby river or stream is the cheapest disposal method (Hosseini and Wahid, 2015). However, because of its significant amount of organic matter, it still poses adverse effects on the environment (Ibrahim et al., 2017). In addition, each ton of POME can produce 28.13m^3 biogas, which otherwise is emitted as methane, carbon dioxide, a small amount of hydrogen sulphide, hydrogen, nitrogen, and trace amounts of carbon monoxide, and oxygen (Aziz et al., 2020). For conserving the environment, an integrated biogas technology presents an efficient management system in the treatment of these by-products.

Accordingly, in the empirical model, the POME sub-system is extended into three parts: treated water, production of organic fertilisers, carbon emission. In the terminology of system dynamics, these variables are stocks in representation of accumulation or storage takes place in the system. In this study, it is assumed that treated water, organic fertilisers, and carbon emission can be saved through the adoption of an integrated biogas technology. They accumulate in their respective stock balances.

The Biogas (Energy) Subsystem

Renewable energy is produced from anaerobic digestion process that turned POME into biogas, and biogas into electricity. Due to the abundance of by-products used in powering mill operations and/or estates, palm oil mills are self-sufficient in meeting their in-house energy consumption (Vijaya et al., 2008). Consequently, the capacity of biogas production points to a surplus production of energy.

The implementation process of a renewable energy begins with capacity acquisition in Malaysia (Ahmad et al., 2015). Capital outlay for a biogas plant is estimated to reach up to US$6 million (Lok et al., 2020) and to be utilised for up to 25 years (Mphtar et al., 2018). As energy sale is regulated, an application is necessary to secure a long-term contract with a utility company. The contract allows a biogas plant to sell the renewable energy at a fixed FiT rate for 21 years. As such, the revenue arising from the sale of the renewable energy is known throughout the contract period. Carbon credit and organic fertilisers provide additional incomes. They lead to the total expected revenue. After considering the cost of production (including both fixed (acquisition) and variable costs), the expected profitability of a biogas project is attained. A learning process will result in higher expectation towards profitability. In turn, this will reinforce the installed capacity of biogas.

In the terminology of system dynamics, Sterman (2000) indicates that the larger the capital outlay, the stronger the capacity acquisition loop will be. As investments in capacity are expensive and irreversible, palm oil mills would be reluctant to invest until a desired investment return is attained. Capacity is thus assumed to adjust to the desired level (rather than what it should be). This presents a delay, and the pressure to expand capacity has a non-linear effect on desired capacity.

Simulation Scenarios

Using secondary data, the study period began with 2000 and progressed annually into 2050. As the study period began prior to the implementation of FiT, the model renders an understanding of changes before and after the policy intervention as well as into the future. Two scenarios were hypothesised and simulated to understand their impacts on the FEW nexus in the long run.

Scenario 1: Changes in POME-to-biogas conversion efficiency

The first scenario explores improvement in POME anaerobic digestion for biogas production. The anaerobic digestion process is a complex mechanism involving hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Focused on interactions among microorganisms, the efficiency of biogas production depends on the temperature and pH. At a thermophilic (c.f. mesophilic) temperature, the entire process complete needs 7–14 (c.f. 30–40) days (Wang, 2016). Optimal pH range is 6.5–7.2 (Sitorus et al., 2013). Shortening the process and meeting these desired conditions will elevate the biogas production process. Considerable research and development attention is thus devoted to improving the biogas production through POME anaerobic digestion.

For shortening the process, pretreatment has been widely explored to prepare the raw material be readily consumable by microbial groups (Aziz et al., 2020). This includes acidified POME, addition of ash, co-digestion, coagulation-flocculation, de-oiling, dissolved air floatation, microwave irradiation, immobilisation media, ozonation, ultrasonication. They increase the rate of reaction in anaerobic digestion.

Bioreactors treating POME have been developed and continuously received improvisation (Aziz et al., 2020). Configurations of reactors include anaerobic fluidised bed reactors, anaerobic sequencing batch reactors, continuous stirred tank reactors, expanded granular sludge beds, up-flow anaerobic filtration, up-flow anaerobic sludge blankets, and up-flow anaerobic sludge fixed-film reactors. Benefitted from advances in bioprocess engineering, advanced anaerobic expanded granular sludge beds, anaerobic membrane reactors and up-flow anaerobic sludge blanket-hollow centred packed beds can improve biogas yields and efficiencies.

Other strategies to improve biogas production include inorganic and biological additive supplementations (Choong et al., 2018).

Scenario 2: Changes in the feed-in tariff rate

The second simulation scenario involves changes in FiT rates since, as discussed earlier, FiT is a key consideration determining the net benefit of a biogas investment project. In anticipation of progressive technological efficiency, the Malaysian Energy Centre (2009) proposed that an annual degression of 0.2% be imposed on the FiT of biogas. Degression of FiT rates is thus hypothesized to make a biogas investment project less viable in the long run. Chua et al. (2011) suggest that the degression is needed to promote cost efficiency for attaining grid parity. Accordingly, the feet-in tariff rates have begun to show a declining trend intermittently (see Table 23).

Table 23. Feed-in Tariff Rates (RM/kWh), Biogas

	01/01/12–31/12/12	01/01/13–31/12/12	28/01/19–to date
Basic FiT rates having installed capacity of			
<5MW			0.2210–0.2814
<4MW	0.3200	0.3184	
>4MW–10MW	0.3000	0.2985	
>10MW–30MW	0.2800	0.2786	
Bonus FiT rates having the following criteria (one or more)			
Gas engine technology with electricity efficiency > 40%	+0.0200	+0.0199	+0.0199
Locally manufactured or assembled gas engine technology	+0.0100	+0.0500	+0.0500
Landfill/sewage gas/agricultural waste fuel source	+0.0800	+0.0786	+0.0786

(*Source*: SEDA (2020))

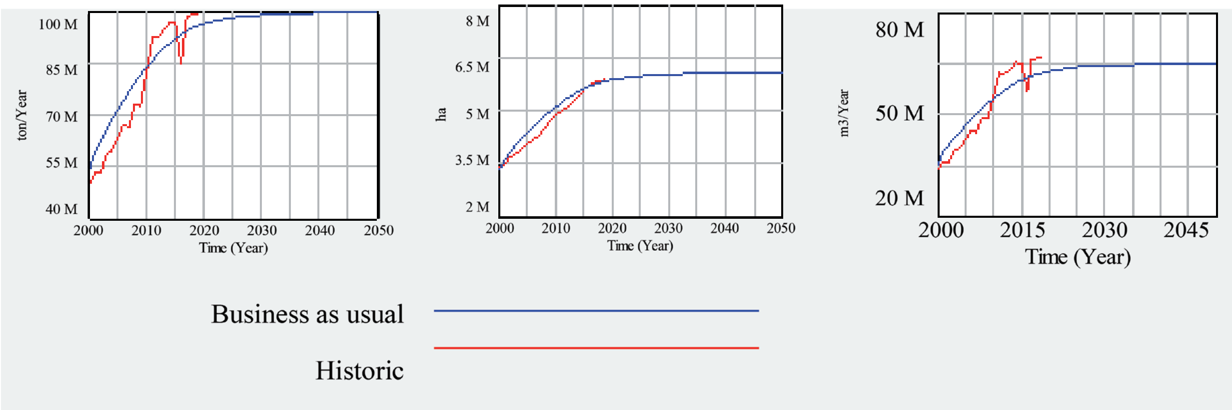
The present FiT rates range from RM0.2210 to RM0.2814 per kWh. Unlike the previous threshold system that catered up to an installed capacity of 30MW, the present system only allows a mill installed with a capacity up to 5MW to bid a FiT rate. The change in the FiT rates and systems was posited to release more quota for encouraging uptake while ensuring fund adequacy for FiT payments to biogas generators. However, the quota system will limit the growth of biogas plant (Chin et al., 2013). More critically, the range of FiT rates is approximate to the total replacement cost of a biogas technology (Loh et al., 2019). Consequently, higher FiT rates were explored to examine whether higher prices are necessary supports to the growth of biogas production.

3.2.3 Findings

After modelling, the work involved model validation to ensure that the model is fit for understanding the behaviours of oil palm-POME-biogas nexus, and scenario simulations for forecasting the future behaviours of the system.

Model Validation

The process of model validation generated a reasonable goodness-of-fit for the nexus model. Structural validation was initially conducted through inter-modeller reliability. Two independent modelers (co-authors Ibragimov and Ardiansyah) discussed and agreed on the structure of the nexus model with equation specifications. Interaction between variables was validated through actual observation and theoretical expectation. For example, it was verified that an improved POME-biogas conversion rate led to higher total revenues and expected profitability, and reinforced the capacity acquisition loop of biogas technology. System behaviour was validated when it was found to reproduce data series close to the historic data (see Figure 6). Importantly, synthesis of simulations was conducted and cross-validated model structure, interaction between variables, their behaviour. This validation method allowed us to observe changes in behaviour patterns through value adjustments in variables and variable interactions.



(a) FFB production (b) Total oil palm area (c) POME production

Figure 19. Model Validation through the Reproduction of Historic Data

Further confidence in the nexus model was obtained through multivariate sensitivity analysis. In this exercise, parameters that specified to vary included total FFB production, POME production, biogas production, and expected profitability – all of which are the underlying variables that control the system behaviour. As recommended by Sterman (2000), the variance used here was defined by +25% (best) and -25% (worst) from their respective base value. The best (worst) case scenario assumes strong (weak) conversion from POME to biogas, and high (low) profitability. Monte Carlo iterations built on the combination of these assumptions provide plausible range of uncertainties for the behaviour the palm oil industry is likely to face in Malaysia.

The outputs of the multivariate sensitivity analysis are presented in Figure 7. It shows the 50%, 75%, and 95% confidence bounds for biogas production in a sample of 1,000 iterations. There was a 95% chance that biogas production was between 75 million m^3 and 100 million m^3 in year 2012. It is noteworthy that confidence interval widens with the growth in biogas production throughout the first decade. This suggests an increasing range of uncertainly during the growth phase because the FiT rates, which faced intermittent review, dominate the expected profitability and the adoption of biogas technology.

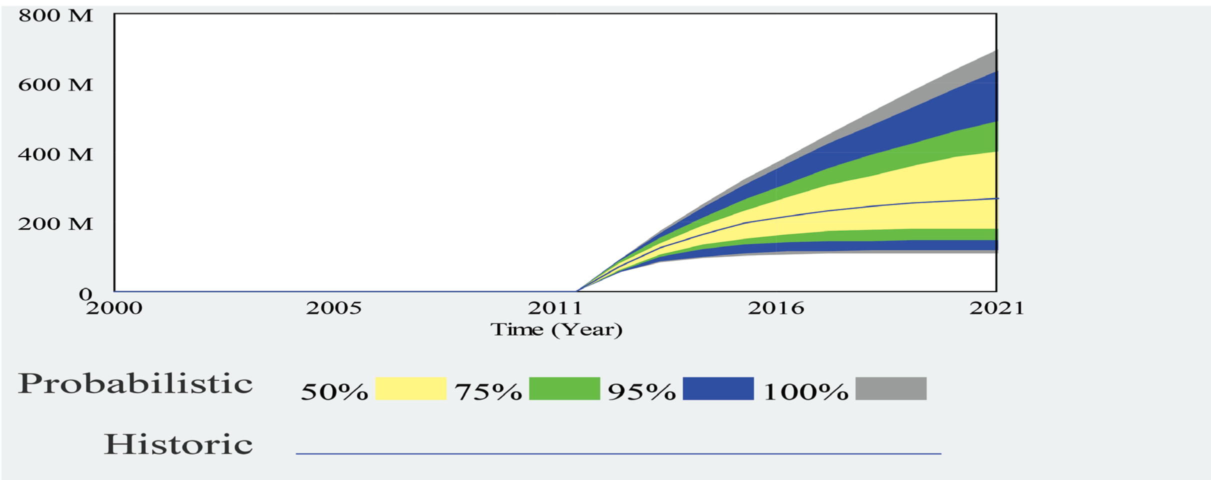


Figure 20. Monte Carlo Output of Biogas Production (m3) from Multivariate Sensitivity Analysis

Scenario Simulations

The simulation results are presented in Tables 24 and 25. As mentioned earlier, according to the sensitivity analysis, facilitation of the processing of POME into biogas is key to reinforcing the WFE nexus model. How much organic fertiliser (to reinforce oil palm production), biogas (to reinforce revenues arising from its sale) and treated water (to reinforce recycling) can be generated from POME is defined by the extent of biogas adoption, which is affected by the expected profitability. Therefore, the simulation results of annual expected profitability, annual rate of new of biogas, and annual biogas production (as a proxy to the production of organic fertilizer and treated water) were extracted.

Scenario 1: Changes in POME-to-biogas conversion efficiency

In Scenario 1, research and development initiatives were assumed to focus on technological upgrading. Simulations were made assuming 10%, 25%, and 50% improvement in the POME-to-biogas conversion efficiency from the present level (28m^3 of biogas produced from 1 ton of POME). In these simulations, suppose technological upgrading did not occur every year, but happened to be a one-time event. Other variables were assumed to remain unchanged.

Table 24. Simulated Results of Improvement in POME-to-Biogas Conversion Efficiency

Improved efficiency	Expected profitability (dimensionless)				Adoption rate of biogas (percentage per year)				Biogas production (million m^3 per year)			
	Base	+10%	+25%	+50%	Base	+10%	+25%	+50%	Base	+10%	+25%	+50%
2025	0.7061	0.7127	0.7210	0.7270	1.16%	1.20%	1.21%	1.22%	52.18	62.07	79.35	97.14
2030	0.6775	0.6768	0.6767	0.6771	1.17%	1.17%	1.17%	1.17%	52.42	62.34	77.90	93.54
2035	0.6618	0.6605	0.6604	0.6603	1.16%	1.16%	1.16%	1.16%	52.72	62.67	78.31	93.95
2040	0.6559	0.6548	0.6547	0.6547	1.15%	1.15%	1.15%	1.15%	52.69	62.83	78.52	94.21
2045	0.6569	0.6561	0.6561	0.6561	1.15%	1.15%	1.15%	1.15%	53.81	62.90	78.63	94.34
2050	0.6628	0.6624	0.6623	0.6623	1.16%	1.16%	1.16%	1.16%	52.59	62.95	78.68	94.41

Table 24 compares the defined changes in POME-to-biogas conversion efficiency to the base case. In the base case, all the selected variables are stable over time. The 50% (10%) improvement case sets the expected profitability to 0.7270 (0.7127) and the annual new adoption rate to 1.22% (1.20%) in 2025. While the impacts seem marginal, the annual production of biogas grows to 97.14 million m^3 (62.07 million m^3) in the same year. This suggests that the growth of biogas production is elastic to efficiency improvement.

With one-off improvement, the growth in the selected variables experience a rapid rise in the short run only to normalise in the long run. The normalised states of the expected profitability and the annual new adoption of biogas technology are the same as the base case. Research and development are implied to be a long-term commitment, continuously seeking technological upgrading for improving the POME-to-biogas conversion efficiency.

Scenario 2: Changes in the feed-in tariff rate

In Scenario 2, FiT rates were assumed to face annual review. Simulations were made assuming 1% growth as well as 1% and 5% degression from the present FiT rate (by taking the midpoint of RM0.2210–0.2814/kWh). To be conservative, other bonus FiT rates were excluded in the model. Other variables were assumed to remain unchanged.

Table 25. Simulation Results of Changes in Feed-in Tariff Rate

	Expected profitability (dimensionless)				Adoption rate of biogas (percentage per year)				Biogas production (million m³ per year)			
Yearly FiT rate	**Base**	**-5%**	**-1%**	**+1%**	**Base**	**-5%**	**-1%**	**+1%**	**Base**	**-5%**	**-1%**	**+1%**
2025	0.7061	0.7002	0.7049	0.7236	1.16%	1.19%	1.20%	1.21%	52.18	51.30	52.01	96.45
2030	0.6775	0.6067	0.6601	0.8280	1.17%	1.11%	1.16%	1.31%	52.42	50.61	50.95	98.98
2035	0.6618	0.5347	0.6100	0.9091	1.16%	1.05%	1.11%	1.38%	52.72	48.39	49.78	102.57
2040	0.6559	0.5250	0.5671	0.9473	1.15%	1.04%	1.07%	1.41%	52.69	46.22	49.01	103.61
2045	0.6569	0.5345	0.5463	0.9665	1.15%	1.05%	1.06%	1.43%	53.81	43.13	48.35	109.44
2050	0.6628	0.5493	0.5482	0.9773	1.16%	1.06%	1.06%	1.44%	52.59	40.91	45.20	117.40

Table 25 shows the simulation results arising from the defined changes in FiT rate. In the base case, all the selected variables show a declining trend over time. This is attributed to the 0.02% degression in FiT rate annually. The 1% (-1%) improvement case leads the expected profitability to 0.7236-0.9773 (0.7002-0.5482) and the annual new adoption rate to 1.21%–1.44% (1.20%–1.06%) in the 2025–2050 period.

As the positive price growth compounds, its impact on the annual biogas production becomes increasingly diverged from those of the degression cases. By 2050, annual 1% increment (degression) in FiT rate leads to a total of 117.40 (45.20) million m³ biogas production. The divergence becomes greater under the case of 5% annual degression. These are suggestive that any degression of FiT rate will lead to a significant reduction in production of biogas. Note is made that this is not a result of production adjustment, but rather a result of asset (capacity) retirement (at the end of the 21-year contract with the utility company) in anticipation of future degression.

3.2.4 Conclusion

This section on POME-to-biogas has revealed that an environmental/social threat is being translated into a nexus opportunity between food, energy, and water. Through integrated technology systems, biogas can be used to demonstrate WFE nexus at palm oil mills. It thus qualifies our exploratory work through a system dynamics approach to capture their non-linear interactions and examine the overall system behaviour through simulations.

With the aim to reinforce the circular economy, we simulated two scenarios – (1) improvement in POME-to-biogas conversion efficiency and (2) changes in FiT rate. Based on their simulation results, it is concluded that continuous technological upgrading is required to intensify the adoption of biogas technology in anticipation of annual degression in FiT rate. Precautionary, more aggressive degression will lead to greater retirement of biogas production capacity and undermine WFE nexus.

In this work, we developed explicit linkages between components within WFE systems in which water is already being used as a circular resource. Unfortunately, the application of the model may be limited for exploratory purpose. Our fieldwork and interviews were dampened by the COVID-19 challenges and related movement controls. Model validation with stakeholders remains a work in future. Site visits and case studies are also essential to develop better understanding of their multidisciplinary interactions (from engineering to economics).

3.3 Large Scale Solar

Renewable energy (RE) is a growing focus area for Malaysia particularly with the Fifth Fuel Policy (2001) that recognises RE as part of national power generation mix. The National Renewable Energy Policy and Action Plan (REPAP) is endorsed in 2010 to enhance indigenous RE contribution towards supply security and sustainable socioeconomic development.

The NREPAP also aims to enhance RE awareness while ensuring that environmental conservation remains a mainstream objective. Malaysia then enacted the Renewable Energy Act in 2011 to enable concerted RE development with financial support through a feed-in-tariff mechanism in developing RE-based power (electricity) generation for Malaysia. The RE act has accelerated RE development especially solar photovoltaic (PV) that sees its capital cost per kilowatt peak drop significantly over the years. More recently, solar PV development is enhanced especially through developing large scale solar (LSS) plants.

Background

For Malaysia, solar power generation is the fastest growing source of renewable energy, driven by drastic cost reductions, significant increase in efficiency, and encouraging government policies. LSS generation began its first operation in Peninsular Malaysia in 2018, producing about 32,000 MWh of electricity. In 2019, LSS electricity generation increased to about 646,000 MWh. This is in line with the government policy to achieve 20 percent RE capacity by 2025 (Energy Commission (ST) Malaysia, 2019b).

The Energy Commission's LSS programme (2017 to 2020) aims to accelerate Malaysia's RE production capacity as approved by the Planning and Implementation Committee of Electricity Supply and Tariff (JPPPET). The total capacity allocated for this programme is 1000 MW by 2020 with an annual capacity capped at 250 MW throughout the four-year period (Energy Commission (ST) Malaysia, 2019a).

The first LSS procurement cycle (dubbed "LSS Fast Track") is done via a direct negotiation award mechanism. A total of 250 MW capacity was awarded in this programme. Subsequent LSS tenders are done via a competitive bidding mechanism. There are now five LSS procurement rounds (or awards) with their capacities and planned commercial operational year summarised in Table 26 (Energy Commission (ST) Malaysia, 2017).

Table 26. Procurement Awards for LSS Plants in Malaysia

Procurement Cycle	Capacity (MW)	Start of Commercial Operation
Direct award (fast track)	250	2017
LSS1	401	2017-2018
LSS2	557	2019–2020
LSS3	500	2021
LSS4 (or MeNTARI)	1000	2022-2023

In 2018, nine LSS plants are operationalised with 260.5 MW of capacity. The planned LSS capacity is increased in 2020 with the new LSS4 or also called MeNTARI, which is the fourth LSS procurement cycle that offers a capacity of 1000 MW. The request for proposal is announced in May 2020 as part of a move by the government to revive and stimulate the economy following the COVID-19 outbreak (Zahratulhayat Mat Arif, 2020).

In general, all solar power technologies use a modest amount of water (approximately 20 gal/MWh (gallon per megawatt hour)) for cleaning solar collection and reflection surfaces like PV panels or mirrors and heliostats for concentrated solar power (CSP) technology (Macknick, Newmark, Heath, & Hallett, 2012; Meldrum, Nettles-Anderson, Heath, & Macknick, 2013). An example of the latter (CSP) is the Nevada Solar One parabolic trough plant that consumes 850 gal/MWh on a 360-acre site near Las Vegas (about 300,000 gal/acre annually). In comparison, agriculture in Nevada requires almost 1.2 million gal/acre of water per year, i.e., nearly four times of the solar power plant consumption (ACCIONA, 2021).

3.3.1 Nexus Arenas for LSS in Malaysia

Water Use

With growing renewable energy generation in Malaysia, the impact to water and food or land use ought to be taken into consideration. LSS in Malaysia mainly involves solar photovoltaic (PV) farms, with very low water demand. Solar PV arrays are connected to the grid inverter and into 132 kV substation to the grid network. Therefore, water for the farms is not used in direct electricity generation but mainly for cleaning and cooling, e.g., of PV panels.

Land Use

Land use is one of the biggest challenges impact of LSS projects. From our preliminary findings, LSS in Malaysia requires 2.5 to 3.37 acre of land per MWp. Meanwhile, coal-fired power plants require about 0.15 acre/MW and gas-fired power plants require about 0.04 acre/MW. To put in context, LSS requires 22.5 times more land to generate an equal electricity amount than that of a coal-fired power plant and 84.5 times more land than that of a gas-fired power plant (specifically compared with Tanjung Bin (coal) and Segari (gas) plants, respectively). This poses a land use challenge for LSS PV plants.

Innovative solutions are needed to reduce land use and potential environmental impacts of solar energy. One solution to increase land use efficiency is agrivoltaic (also called agrophotovoltaic) farms that use the same land for agriculture and solar PV. The concept involves mounting narrow rows of PV panels at wide spacing on high frames and undersown with food crops. The coexistence of PV panels and crops entails sharing the amount of sunshine and light received. This technology does not work for all types of products but is possible for shade-tolerant crops from fruit trees to peanuts, along with alfalfa, yams, taro, cassava, potatoes, sweet potatoes, and lettuce (Othman, Mat Su, & Ya'acob, 2018).

Japan pioneered the development of agrivoltaic technology: between 2004 and 2017, more than a thousand of these plants have been installed in open fields that are used simultaneously to cultivate the land occupied (Movellan, 2013). The concept was originally developed by Akira Nagashima in 2004, who is a retired agricultural machinery engineer who later studied biology and discovered the "light saturation point" effect: photosynthesis rate increases as the irradiance level is increased but beyond an appropriate point, any further increase in the amount of light that strikes the plant does not cause any significant increase to the rate of photosynthesis. Shading may be a benefit or a disadvantage, considering effects such as the impact of shade on evaporation rates.

Another solution to reduce land use of solar power is floating solar farms. In October 2020, a 13 MW floating solar farm is installed in Selangor, owned by WD Solar Sdn. Bhd. (which is part of Malaysian mining company called WD Group). The solar PV cell arrays cover an area of 53 acre (21.4 hectare or 0.214 km^2) on a pit lake in Dengkil, Sepang (Bellini, 2020). In 2018, only two floating LSS projects that were awarded and negated the need for ground-based installations. Cypark Resources Sdn. Bhd. is the developer for these floating solar panel projects at Empangan Terip (30 MW) and Empangan Kelinchi (50 MW), both in Negeri Sembilan.

Besides that, solar energy can be integrated with buildings through building integrated PV (BIPV). This generates smaller amounts of solar power capacities (usually less than 1 MW) and thus typically falls under distributed energy resources category. The solar PV panels can be retrofitted on top of agricultural farms, industries, and residential houses (Mak, 2018). The panels are installed close to the load demand centres, thus generating electric power at the point of consumption. It minimises a need to build new substations or reinforce distribution lines to get the clean solar power into the grid and to the consumers. Besides reducing the cost of building new facilities to transmit the energy, distributed solar generation will also decrease line losses and relieve grid congestion in certain area.

Energy Security and Other Issues

Solar power is dependent on climate conditions and solar irradiation. The solar PV panels are also subjected to effects of wind, dust, sand, and flood and may need higher maintenance for cleaning to ensure efficiency remains robust. Besides that, increase in surrounding temperatures reduces the power production of PV panels. The power output would see a decrease at every 0.4ºC increase in temperature.

A major challenge in solar power is its intermittency, which gives rise to the so-called "duck curve" phenomenon as illustrated in Figure 8. The 'duck curve' depicts the gap or deviation between total electricity demand of utility grid (the black curve) and net power load (the blue curve) due to a high penetration of solar electricity generation (the red curve) during the middle of a day. The peak sun hours in Malaysia are typically between three to five hours in a day (subject to changes in weather conditions) while the peak electricity demand is around middle of a day (noon) (which explains a somewhat shifted shape of the duck curve for the Malaysian case as compared to a western European or North American city or country). Solar power can assist to meet (or "shave off") peak demand load, but we still need to manage solar intermittency, e.g., via backup systems (e.g., peaking plants or batteries). Larger solar power capacity share connected to the grid makes it more challenging to ensure robust energy security for the nation.

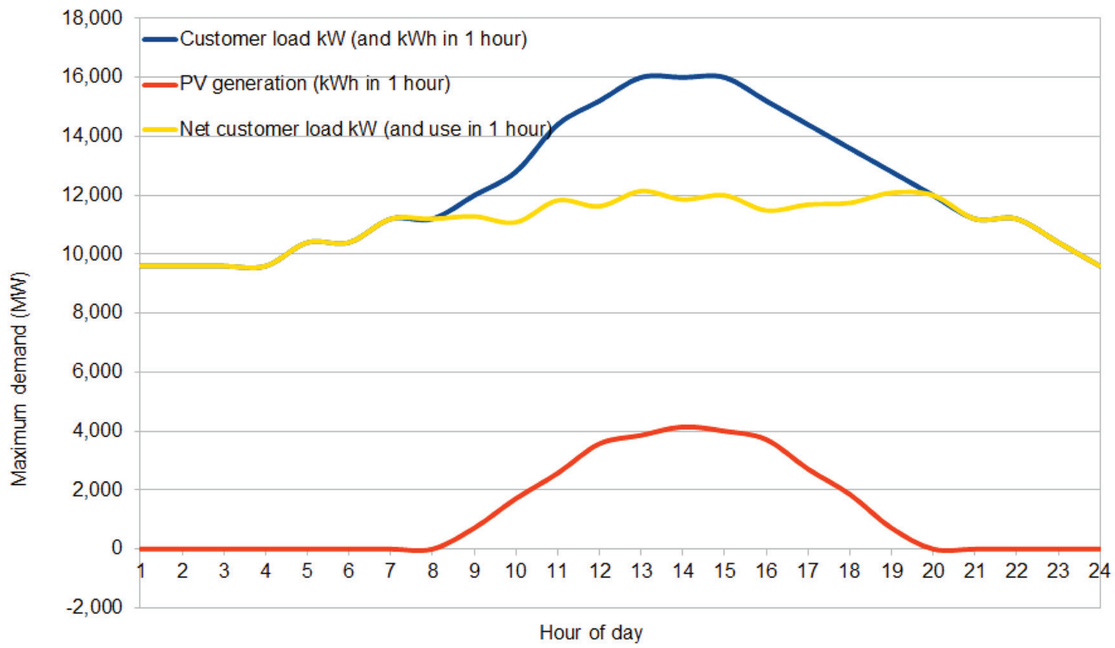


Figure 21. The 'Duck Curve' Phenomenon

The impact of high RE onto the energy system security is a critical component of study as Malaysia embarks on its low carbon generation plan. The integration of renewable generation technologies such as solar in the generation mix has introduced new challenges for managing operational security. First, the intermittency inherent in renewable resources can impact on key power system parameters such as frequency and voltage stability. Second, renewables interface with the grid through power electronics rather than mechanical elements, which means that the physical characteristics of turbine generation that have historically supported the stability of the grid start to become less dominant as the power system transitions away from fossil-fuel based thermal generation (Billimoria, Mancarella, & Poudineh, 2020).

Other issues to be studied include the microclimate effects of LSS. This will be very dependent on their location, i.e., whether near agriculture or forest areas versus near urban developments. This may also contribute to ecological implications caused by LSS. This study needs to further assess other environmental costs and benefits – the three-way nexus – to minimise any negative impacts and maximise ecosystem benefits.

3.3.2 Case Study: Floating LSS in Dengkil, Selangor

Wawasan Dengkil Sdn. Bhd. successfully bid for a LSS PV operating license through a special purpose vehicle called WD Solar as its operator. The site in Kuala Langat, Selangor is an ex-mining pond that prevents using the acidic water in its operation (pH level is about 3). Therefore, the LSS plant relies on piped water (i.e., utility supplied by Air Selangor, the state government's appointed service provider), which entails pumping energy requirement. An alternative is to withdraw water directly from Sungai Langat on a need basis to meet the plant operational needs.

Water is mainly used to wash the solar PV panels on monthly or quarterly (at minimum) basis that incurs regular operating costs in addition to daily checking of the panels (by an appointed contractor. According to the operator (WD Solar) solar PV capital cost has increased by about 30 to 40 percent in the past year (2020) although operating cost has reduced. In addition, the LSS farm faces risk of flood—its mitigation plan involves pumping out water from the pond. Other operational problems include algae growth on the pond particularly if the water condition (presently acidic) becomes more neutral.

A future expansion plan is to integrate the farm with operating a water treatment plant by using the available remaining area of this ex-mining pond (as indicated in Figure 9) as a private service provider, which would require obtaining permit from the state authority (Lembaga Urus Air Selangor, LUAS). WD Solar is also considering the option of aquaculture as supplementary activity to fully utilise the farm area.

3.4 Hydropower

Dams are built as water storage in upstream reservoirs for various purposes. The purposes include for flood control, store water for irrigation, recreation, and drinking water, as well as for generating electricity. A total of 16 percent of the world's power needs are generated through hydropower creating a nexus between water for energy production. This subsection looks at how hydropower is contextualised as a water-energy-food nexus is at various levels.

3.4.1 Background

Dams can be single purpose or multipurpose. While dams are largely single purpose across the world, multipurpose dams, particularly for irrigation and hydropower creates a three-way nexus across water,

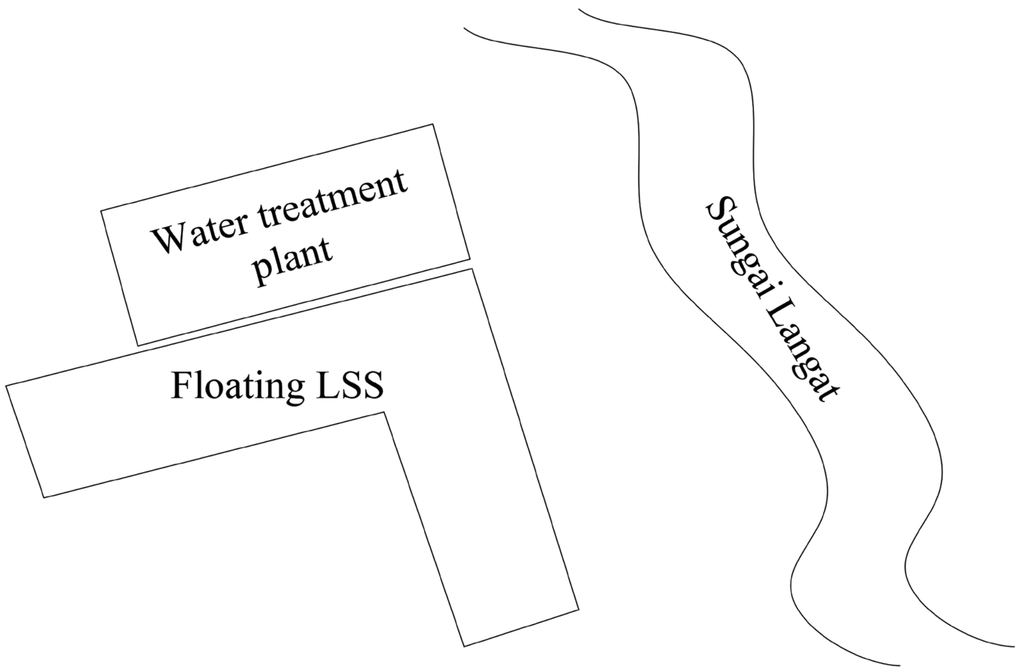


Figure 22. Schematic of WD Solar's Floating LSS Plant

Box: Facts on WD Solar's LSS Farm Plant in Dengkil

- Start of operation: August 2020
- Acreage: 110 m2
- Uses floating PV panels made from HDPE (high density polyethylene)-based double glasses technology
- Capacity: 9.98 MW (AC, alternate current) and 13 MW (DC, direct current)
- Energy generation: 45–50 MWh/day annual (based on 21-year power purchase agreement (PPA) with TNB)
- Capital expenditure: RM30 million (for construction and installation) including connection to the national grid (PMU) via 0.5 km transmission line (at cost of RM1 million/km); return on investment (ROI): 20 years

energy, and food. While context differs, often water-energy-food nexus manifests itself across these purposes, of which are the major purpose of dams.

Previous studies often highlight that hydropower development has the potential to improve both energy supply as well as crop production. However, studies do demonstrate that it can also impact fisheries production negatively. This demonstrate that the impact of the WFE nexus in the context of hydropower can extend other issue areas as well as be a critical issue in terms of sustainability.

Hydropower, which utilises the natural flow of water to convert it into electricity, is dependent on its natural topography. In countries with high potential such as Ethiopia, hydropower meets 90% of the final energy demand. Irrigation schemes are often seen as add-ons to hydropower rather than as a major purpose of hydropower previously. This has led to low agricultural water use previously. In this sense, efforts have been made, such as through the construction of Grand Ethiopia Renaissance Dam to realise more synergies across this dual function of irrigation and hydropower as well as providing revenue through selling to neighbouring countries. This demonstrates that the consideration of WFE nexus can both increase energy and food security as well as contribute to revenue if synergies are planned and realised. It also points to the potential differences of outcomes depending on planning and technologies adopted.

The Nam Ngum River Basin in the Lao PDR part of Mekong is situated where agriculture is the major economic activity. Ten hydropower projects are either in operation or will be constructed in the upstream basin. Findings on the impact of hydropower development is debated, with evidence in Nam Ngum sub-basin demonstrating that it may increase river flow during dry season, and therefore improve water availability and water security. However, various studies also demonstrate the opposite effect. In transboundary basins such as the Mekong, issues of the WFE nexus are a geopolitical hotspot with potential "resource wars" as a result of competition across scarce resources. This once again points to the significance of the WFEN as a security and economic issue.

3.4.2 Hydropower and Dams from a WFEN Perspective in Malaysia

Malaysia's natural geological conditions consists of a fair amount of sunshine, and a high rainfall rate which is distributed throughout the year. This poses a substantial potential for hydropower generation with the hydropower potential estimated at 29,000-MW. In particular, the potential in East Malaysia is high, with 85 percent compared to 15 percent in Peninsula Malaysia. Peninsula Malaysia has had only two major dams commissioned by 2016 (Hulu Terengganu 265 MW and Ulu Jelai 372 MW) and two multi-purpose dams in Kelantan under advanced planning. Energy Commission (2013) reported that by the end of 2013, only 3,931 MW (13.2 percent of total installed capacity) of the resource has been fully utilised (with the share of energy input in hydropower stations of 8.7 percent from the total 30,959 ktoe). This is due to the high capital investment required for its development.

Ismail (2014) and Aiken and Leigh (2011) report that Malaysia currently has 66 large single- and multi-purpose dams, with several more in development. In 2009, the Department of Irrigation and Drainage alone managed 16 dams for flood mitigation, providing adequate irrigation water and controlling silt while other dams are under the jurisdiction of other agencies. However, these different water uses come along with conflicting demands on water utilisation leading to trade-offs which highlight the need for an integrated management plan for all catchments.

The 11th MP emphasises water, energy and food security recognising the fact that actions in one area more often than not have impacts on one or both of the others. Hydropower development presents a quintessential three-way interaction of the nexus security challenge. The establishment and operation of hydropower dam are overwhelmingly complex because the issues are not only confined to the design, construction, and operation of dams themselves but embrace the issues of social, environmental, and political perspectives.

Dam development for hydropower therefore often involves many trade-offs. Although the generation of electricity impacts little on the quantity of water it may alter the timing of stream flows since the timing of water releases is determined by the demand curve for electricity managed by the National Load Despatch Centre (NLDC). Conflicts can also arise between hydropower and downstream uses, including irrigation and supporting ecosystem services. In Malaysia, in the interest of energy security, hydropower dams such as Bakun have affected the food and water security of more than 9000 Sarawak indigenous communities (Aiken and Leigh 2011). The local communities resettled to Kampung Ganda from the remote villages of the Temengor Lake were provided with 11 acres of land with rubber trees to each household involved, as reported by Choy and Othman (1996).

Some people consider hydropower a type of renewable energy because it does not consume fossil fuels. Instead, it harnesses the power of renewable supplies of water by running through the turbines and discharging it downstream. While often praised for its low GHG emissions, it is widely accepted now that hydropower negatively affects water resources and river or lake ecosystems. By impounding a river or diverting its flow, dams alter the natural regime of a river, compromise the habitat functions the river plays for fish, modify water quality and change the river bed dynamics.

It is often said that consumptive water use does not happen in hydropower generation because what is required to generate power is water pressure and not the water itself. However, since water stored in a dam in a warm country faces regular temperature increase, water loss from the surface of hydro dams in Malaysia is inevitable. This evaporation process contributes to the consumptive aspect of dam storage which results in less flow for downstream uses. In a recent study of national water demand, total potential evaporation is estimated to be around 1.25 MCM/km /year or 3.42 MLD/ km. Academy of Sciences Malaysia (2015) estimates total losses from hydropower surfaces in Malaysia to be 2000 MCM/ year or 3.872 MLD.

On the positive side, hydropower can be a desirable form of electrical power generation from a power grid point of view. Its electrical power output can be changed within minutes, and this makes hydropower the preferred source for frequency control (around 49.75 to 50.2 in Peninsular Malaysia). Infrastructure costs aside, hydropower is economical since the fuel is rainwater from the sky, which is technically free. Both features render hydropower to be placed third in the electricity generation merit order in Malaysia. If hydropower plants are unable to provide electricity during peaking, power stations with the gas turbine open cycle will have to generate power at higher marginal costs to the national grid.

Alienating land for hydropower generation can be a lucrative source of income for state governments in Malaysia. As per TNB (1993), compensation from a utility company such as TNB to a state government is paid according to the units of electricity generated rather than by actual measurement of flow through the turbines.

At the state level, the Kenyir Dam in Terengganu acts as a case in point. The 400 MW Sultan Mahmud Power Station and its 155-metre height impounding Lake Kenyir is Peninsular Malaysia's largest storage hydropower scheme. TNB (1993) reported that Kenyir is a multi-purpose hydropower station which incorporates power generation, flood and drought prevention, recreation, tourism, and aquaculture. Before the construction of the dam, the East Coast used to flood each year around December to January. One of the benefits of regulating Sg. Terengganu is that the Kenyir dam has provided flood mitigation function successfully since the beginning of its operation. The other important function it provides is to minimise the interruption of the freshwater supply at Kuala Terengganu. Since the Sg. Terengganu river basin is mainly flat, it faces the risk of saltwater intrusion into the freshwater supply when high ocean tides coincide with low river flow. The Kenyir hydropower scheme showcases a best- practice attempt of both upstream and downstream Terengganu river basin stakeholders such as TNB and Syarikat Air Terengganu (SATU) to cooperate on issue of access to water and the regulation of the flow of Sg. Terengganu.

The Kenyir scheme is being upgraded as a cascading system with the construction of two dams – Puah (250 MW) and Tembat (15 MW) – geared towards maximising the use of water resources upstream. The Puah dam is 78-metre high with a crest length of 800 metres with a lake size of 6,979 ha. The Tembat dam is smaller in comparison with the height of 36.5 metre and the crest stretching 210 metres in length. The two dams are located in the Tembat and Petuang Forest Reserves as part of its Hulu Terengganu Hydroelectric Project; this is an environmentally sensitive area known for its large elephant population. In meeting the requirements of Detailed Environmental Impact Assessment (DEIA), TNB is taking measures to ensure that the hydropower development will have minimum impact on the habitat of the elephants and other smaller mammals as well as their movement and distribution. To do this, TNB Research Sdn. Bhd. (TNBR) in collaboration with the Department of Wildlife and National Parks (Jabatan PERHILITAN) and Universiti Kebangsaan Malaysia (UKM) are currently carrying out a study to monitor the elephants' movement during the construction as well as the operational stages. In the study, the elephants in the area are fitted with GPS satellite collars, from which signals are obtained, and their movements are tracked and monitored online. Results from the study will assist in the development of a human-elephant conflict management plan which will be used for the project as well.

Under the Sarawak Corridor of Renewable Energy (SCORE), the state government of Sarawak has in recent years announced plans to develop several large hydroelectric projects. The development spanned over a period of 22 years to generate 28,000 MW of electricity once fully developed. The power generated by SCORE's complete energy nexus would be used to fuel the industrial development of 70,709 km^2 of Sarawak's central region. The Sarawak Government is using this dam-induced industrialisation strategy as a prospect to attract significant Foreign Direct Investment (FDI) in an attempt to achieve the Malaysian Government's vision of Sarawak as a 'developed state' by 2020. Amongst the projects to be developed are the Baram dam (1200 MW), Baleh dam (950 MW), and Pelagus dam (770 MW) in the upper reaches of the Rejang River, Sarawak. In 2013 the 944 MW Murum dam was completed. The Bakun hydroelectric project, one Asia's largest dams outside China, involves the construction of a 207 m high rock filled with concrete dam creating a reservoir of 69,640 ha, about the size of Singapore. Sovacool and Bulan (2011) report the cost for Bakun project to be around USD4,643 million.

The other nexus challenge for Bakun is encapsulated in the main criticisms from national and international bodies over the issue of the indigenous peoples (mostly Kayan, Kenyah, Lahanan, Kajang, Ukit, and Penan ethnic groups) being resettled by the impoundment of the lake, as found by Gabungan (1999) and Choy (2005). Concerning ethnic composition among the resettlers, the Kenyah population was the largest group consisting of 5313 people, followed by the Kayan, 3995 people, with the balance comprised of 910 peoples (Andre, 2012). The resettlement site, generally referred to as Kampung Asap is located approximately 40 km from the Bakun Dam site. Some people in some of the longhouses have also decided to move to other locations, not designated by the government. Most of the indigenous peoples involved were subsistence farmers for generations in a forest land of 107,000 ha with no previous participation in the Sarawak's economy. They also had a strong cultural attachment to the forest they left. Many studies claim that the communities' well-being as a whole was negatively affected. This was due to the fact that they have long depended on Sarawak's rivers and forests not only as a main source of livelihood but more importantly as their way of life. An ethnographic study by Choy (2005) found that the resettled communities had lost all four of the most important types of land: temuda, farmland around longhouses, menoa, land for game hunting and gathering, damp, cultivated land, and oipulau, or protected forest area. He concluded that ''the Sungai Asap resettlement area is environmentally unsuited to sustaining the social value and cultural identity of the indigenous communities affected by the Bakun Dam project'' (Choy, 2005: p. 66). To give a general sense of externalities associated with the major dams in Sarawak, Hartmann (2013) proposes simple criteria such as the numbers of hectares inundated per MW as environmental impact indicator and the number of resettled per MW as a measure of social impact.

In the Cameron Highlands in Pahang, there are two hydroelectric schemes cascading from the Peninsula's central mountain range. The Cameron Highlands-Batang Padang Hydroelectric Scheme includes seven power stations, five of which are mini hydro facilities such as Kampung Raja (0.8MW), Kuala Terla (0.5MW), Robinson Falls (0.9MW), Habu (5.5MW), and Odak (4.2MW). The other two power stations are high head underground schemes, namely Sultan Yussuf Power Station or Jor (100MW) and Sultan Idris II or Woh (150MW) (Kun and Saman, 2004). The cascading scheme uses water resources from the states of Pahang (Sg. Telom and Sg. Bertam), Perak (Sg. Batang Padang and its tributaries) and Kelantan (diversion from Sg. Plau'ur) (TNB, 1993). There are also three dams functioning as storage and flood control reservoirs:

- The Ringlet reservoir or Sultan Abu Bakar Dam is a lake about 3 kilometres long and up to half a kilometre wide, impounds the water from Sg. Bertam and Sg. Telom and provides a steady source of water for the Jor Power Station.
- The downstream Jor reservoir provides water for the Woh Power Station. It is created by two dams (main and saddle) which impound the water of Sg. Batang Padang and the water discharged from the Jor Power Station.
- The earthfill-construction Mahang Dam is designed to regulate the flow of the water released from the Woh Power Station and to create a small head for the Odak Power Station mini-hydro.
- The Ringlet reservoir was designed for a gross storage of 6.3 million m^3 with an active/live storage of 4.7 million m^3. However, it is currently badly silted with sediment accumulation estimated to have reached 5.0 million m^3 by Kun and Saman (2004). This situation means that the live storage of the dam had been reduced to less than 2.0 million m^3, compromising its capacity to regulate flood flow. As sediments accumulate in the Ringlet reservoir, the dam gradually loses its ability to store water to drive the hydroelectric turbines, reducing the lifespan of the dam which was designed to last for at least 80 years, according to Jansen et al. (2013).
- Not only that soil erosion inundated the Ringlet reservoir with silt, but it also impacted flows of the river system including the Ringlet, Bertam, Habu, and Telom rivers. The unregulated expansion of vegetable farming in Cameron Highlands, deforestation, and encroachment of settlements had caused land degradation on this important but sensitive water catchment ecosystem. Tenaga Nasional Berhad had spent over RM180 million over the past five years or RM40 million a year, cleaning up the Ringlet reservoir. However, the clean-up does not overcome the problem as the reservoir accumulates 500,000 cubic metres of sediment every year.

3.4.3 Conclusion

Increasing non-agricultural demands on water, growing food demands, and rapid urbanisation all place increasing pressure on water resources. This section shows that water resources play a vital role in not just the national economy, but also economic activities at the state level. Underpinning all aspects of development at the state level, water links together energy and food production. In some instances, as highlighted in the case of hydropower operation, upstream and downstream users often have conflicting needs. In the absence of water stress, like in some states, there is less competition for water and fewer trade-offs to be made. But this scenario does not necessarily mean there will not be any political trade-offs because water also holds great cultural and spiritual significance beyond physical and economic scarcity considerations. Also, high- level information uncertainty at the state level about water-energy-food linkages constrains the quest to frame appropriate strategies and policies. Finding solutions to secure water, energy and food resources will require significant action – technological and non-technological – both of which cannot be pursued independently.

3.5 Nexus Modelling

Governments rely on hundreds of models for a huge variety of critical activities, from forecasting spending plans to guiding operational decision making. The section outlines and identifies the needed capability to understand and act upon the interlinkages among water, energy, and food sectors in undertaking a nexus-based approach for policy-related decision-making.

3.5.1 Review of Current Practices

This brief review presents current practice of systematic modelling focusing on contribution towards government policy-making in Malaysia. At the outset, modelling use and its associated capacity building is still largely contained within the academia particularly universities with research-based postgraduate programmes. Formal modelling use by government agencies perceivably involves ad-hoc implementation of such model-based solution for decision making with minimal long-term follow through actions for its continuous use. Although value of modelling might be acknowledged, the capability of using and maintaining the related components including regular updating of data and refreshing IT (information technology) systems (supported by necessary manpower and budget allocation for such activities) remains an area for development or improvement in government institutions.

3.5.2 Nexus Modelling Overview

Nexus modelling for engineering applications or policy-related undertakings is still relatively new across government, private, and academic institutions. A cursory sampling of modelling purpose and examples of representative work is summarised in Table 27.

Table 27. Purposes of Modelling and Examples of Representative Work

Sector	Purpose (Main)	Example of Representative Work
Finance	Fiscal and development planning (national scale)	Malaysian Government's Treasury (for fiscal planning) and EPU/Economic Planning Unit (for development planning)
Agriculture	Production of food/crop or non-crop materials and other products (including as feed, fibre, and fuel)	United Nation's Food and Agriculture Organisation/ FAO (2014); Nie (2019)
Energy	Power (electricity) generation planning on fuel mix	PLEXOS by Energy Exemplar (2021)—used by Single Buyer (TNB entity for electricity generation); Prof. Haslenda Hashim's research group at UTM Skudai (Hashim et al., 2014; Tan et al., 2014); Giampietro and co-workers (Giampietro et al., 2006; Aragão and Giampietro 2016)
Water	Water allocation and management, hydrological simulation and/or optimisation modelling	(e.g., Zhang and Vesselinov (2017); Leung et al. (2016; 2017)

A potentially useful framework for modelling of nexus interactions to support, enhance, and sustain the operation of a large scale solar photovoltaic (LSS-PV) plant is by adopting a whole-systems approach (Murray, 2009; Hechinger et al., 2010). Such an operating philosophy can be in the form of a hierarchical structure as generally illustrated in Figure 10. This framework covers a lowest level of material acquisition (including piped or other sources of water as a cleaning utility besides raw materials of solar PV panels) to measurement and actuation (involving sensor and actuator validation using analysers and databases) that eventually leads to a highest level of logistics optimisation (including dispatching the generated electricity) (Khor and Elkamel, 2013). The heart of this framework lies in several key profitability-related middle layers of the hierarchy given by the following multiscale modelling levels:

Nexus Modelling for Large-Scale Solar Photovoltaic Operations

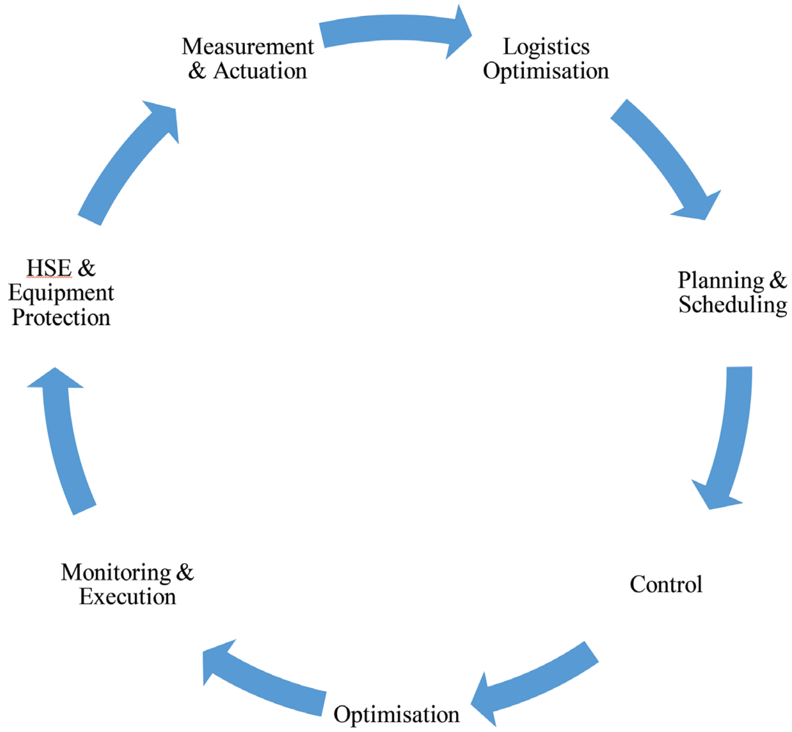


Figure 23. Generic Modelling Framework for LSS Operations

1. Planning and scheduling to optimise activities pertaining to raw material inputs, unit operations, and end-products including power demand forecasting to support supply chain management (Elia et al., 2011);
2. Control and optimisation to maximize throughput (e.g., sunlight or radiation supply and utility water), quality (e.g., conversion efficiency from direct to alternate current of electricity), and performance (e.g., amount of power generated and water used; the latter including water reused) as well as possible redesign for debottlenecking (Khan and Go, 2020);
3. Monitoring and execution to ensure smooth operation and abnormal event detection (including alarm management and emergency shutdown).

A main goal of these modelling activities is to capture the nexus elements and analyse their interactions towards optimising values (e.g., in per unit monetary terms) at various levels up to an entire supply chain. Such a holistic, comprehensive modelling framework serves to sustain performance, extend equipment or plant lifetime, enhance operation, and improve profit margin over the whole LSS-PV asset lifecycle. Ultimately, modelling can help to attain a highest possible financial return while meeting the triple bottom line of safer, greener, and faster as well as longer operations.

Nexus Modelling Applications for the Agricultural Sector

This example (prototype) proposes a framework to show and analyse the relations and potential interactions among entities in the agricultural sector contained in a region within a state. It serves to highlight the complexity of the interrelations among the entities that calls for applying a systems approach. A main goal is to capture and portray the interactions, dependencies, and implications involved for decision-making. Subsequently, a suitable model can be developed to address the possible conflicting goals due to limiting resources, socioeconomic demands, and environmental impact (including waste generation and treatment) on the value (e.g., profitability or revenue including cost) of such localised agricultural sector.

We briefly illustrate an example of nexus modelling application through a simplified case study on agricultural sector around Perak Tengah region. This example considers focusing the WFEN approach on the economic aspect of Perak Tengah's agricultural activity for food, feed, and fibre production as a core sector supported by available water and energy resources demand.

A geographical area is identified first in devising an appropriate model representation (such as a superstructure form) of all possible alternatives for the nexus elements and their interactions. In this regard, a wide range of spatial dimensions are available for a localised area (e.g., district, state, region, or country/nation, even up to global scale if intended). The model input data include human population and natural resources (mainly water, energy, and food) of the selected area. A superstructure is then constructed to delineate the interconnections among subsystems of the units involved. To construct the superstructure, the subunits existing in the geographical scope have to be defined and classified accordingly (e.g., for resources, production, and products). The interconnectedness of the subunits in the superstructure is exemplified in Figure 11 for a district-level agriculture sector (e.g., Perak Tengah).

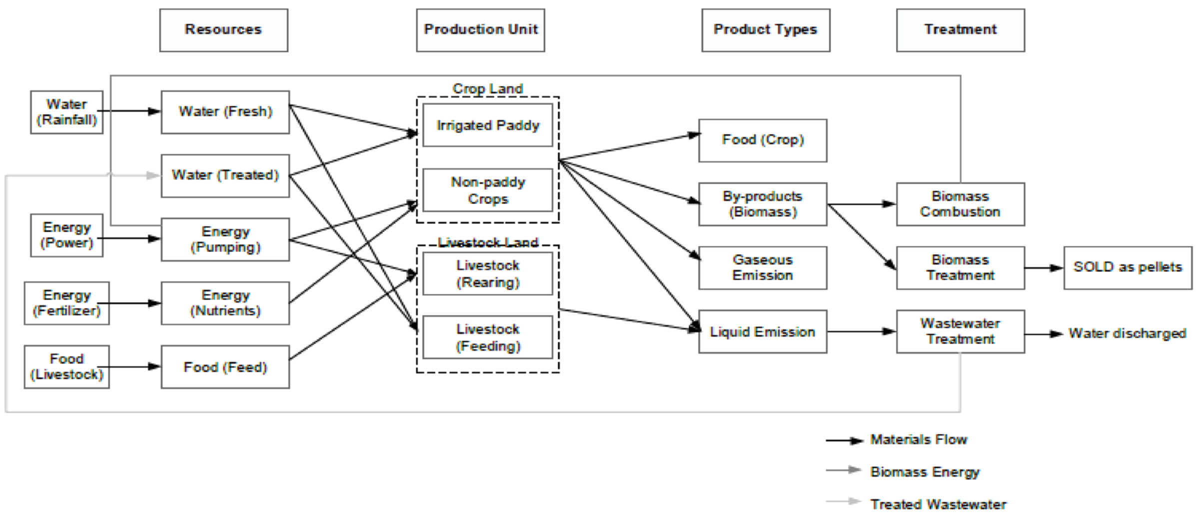


Figure 24. Model-based Representation of the WFEN for a District-Level Agricultural Sector

Relevant data for Perak Tengah are obtained from the open literature (mainly online sources for ease or pervasiveness), which include population (natural), resources (e.g., freshwater, land, livestock feed, electrical energy (electricity), biomass, fertiliser, and waste emissions such as liquid effluents and carbon dioxide (CO_2)), and crop production, among others. Land use mainly involves industrial buildings and forest reserve besides agriculture. The main resources available in Perak are water and energy. We consider two water resource types, namely freshwater and treated water for agricultural, industrial, and domestic use. The main freshwater source is from rivers mainly Sungai Perak (about 45%) as well as Sungai Kinta and Sungai Sungkai.

Energy use for agriculture is modelled in terms of supply of power and fertilisers (as nutrients). As Perak Tengah's geography is not that of a flat surface land, energy is needed to pump water from the source (i.e., instead of relying on gravitational force) to be distributed for land irrigation and livestock rearing. In addition, cultivating livestock needs feed intake while that of crops need fertiliser, both of which use energy. The main crop activities in Perak Tengah involve irrigated paddy besides oil palm and rubber plantations. Oil palm has the highest production followed by paddy and rubber. The main livestock types involve cattle, goat, swine, poultry, and duck. The model also considers available land for agricultural expansion in the area. In this regard, limited agriculture-ready land makes it more important to determine an optimal land distribution that simultaneously caters for crops and livestock cultivation.

A superstructure representation is constructed for Perak's agricultural sector nexus encompassing its associated activities with resources consumed and products generated in general. The superstructure elements or entities consist of subsystems called "resource", "production", "product", and "treatment", which are named according to their functional properties, e.g., production subsystem comprises industrial crops and livestock in the model. For ease of computation, the superstructure adopts a source–and–sink structure as shown in Figure 12.

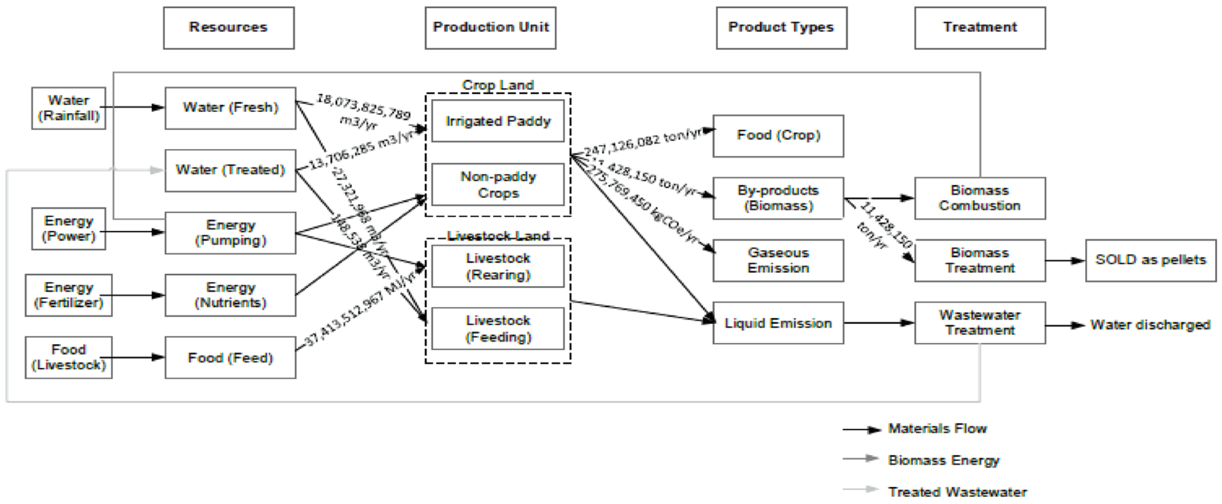


Figure 25. Superstructure Representation of Perak Tengah's Agricultural Nexus Systems

The formulated model aims to maximize the local agricultural sector returns by considering profit-contributing sources from crops production and potential revenues from palm oil biomass upon subtracting cost items comprising (fresh) water, energy, fertiliser or feed cost, and CO2 emissions. The main decision variables are crops production and freshwater rates and amounts for irrigated paddy, non-irrigated crops, and livestock, which are identified as degrees-of-freedom in the model.

The linear programming (LP) model can be solved using a standard algorithm such as simplex for LP, and the solution interpreted in tandem with performing sensitivity analysis on the data that form the model parameters or coefficients. For example, model results can be used to compare a solution run obtained with existing data (see Figure 13 referred to as initial values) with that prescribed by the LP optimisation procedure (see Figure 14).

3.5.3 Summary and Recommendations for Future Directions in Nexus Modelling

A nexus modelling approach as presented here can be potentially adopted for utilisation or upscaling for the following purpose or activities: (a) perform systematic planning and/or scheduling in optimising resource allocation and use, (b) give advisory support in policy making (e.g., developed as an automated tool in the form of decision support systems), and (c) elicit non-intuitive solutions to issues arising due to uncertainty or unexpected (abnormal) departure from conventional situations. Further work to formalise this modelling approach can involve undertaking systematic and sustained capacity development for modelling (i.e., human resource aspect) and infrastructure (hardware and software aspects) and building a dedicated team (or a standalone agency) capable of performing various modelling activities. It is

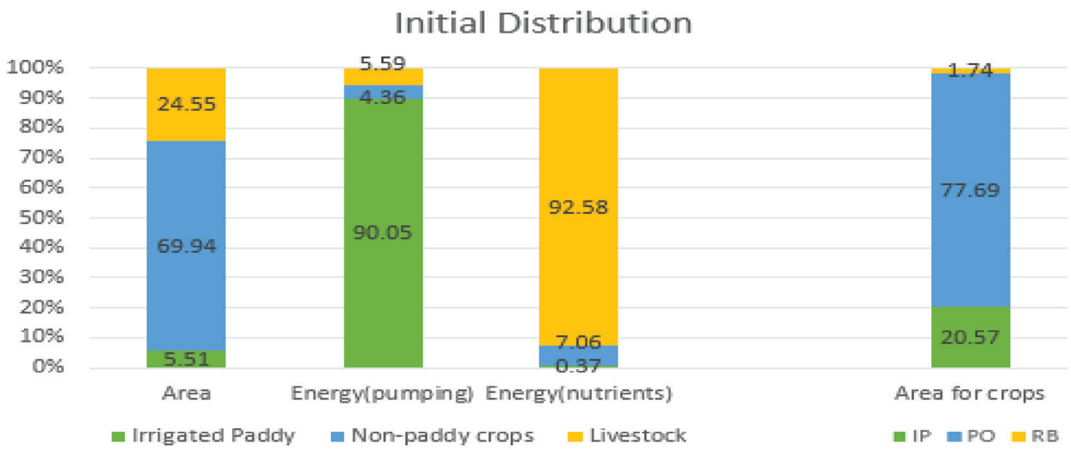


Figure 26. Solution for Model Applied with Existing Dataset used in Model

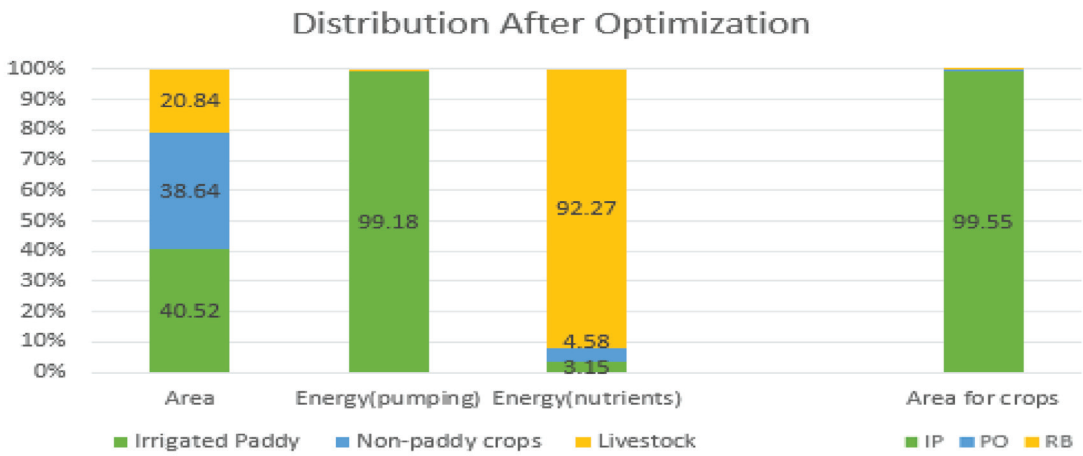


Figure 27. Solution (Optimal) for Model with Identified Degrees-of-Freedom as Decision Variable

important to maintain a continuous use of such modelling applications with periodic refreshing of the associated data and IT systems, which have become increasingly easy with ongoing advances in big data analytics, Internet of Things, and IT/OT tools as spurred by Industry Revolution 4.0.

4.0 STATE-LEVEL NEXUS INTERACTIONS

4.1 Kedah

Kedah is located in northern Peninsular Malaysia and is bounded by the state of Perlis, and Thailand, in the north; Perak in the east and the south; and the Straits of Malacca in the west. With a land size of 9,477km^2, Kedah's eastern side is dominated by highlands, with coastal plains comprising much of the western region, towards the Straits of Melaka.

Agriculture accounts for roughly 55% of land use across Kedah, with the most dominant crops being oil palm and paddy. While paddy plantations are widespread across the state, these are predominantly concentrated within the MADA granary areas, which cover an area of approximately 830km^2, or almost 9% of Kedah's total landmass. A similar proportion of land is dedicated to oil palm plantations; total acreage in 2016 was roughly 877km^2. A further 38% of Kedah's landmass is forested, especially in its the upper catchment areas. These forests serve a crucial role as a catchment for water used in irrigation and for the domestic water supply.

4.1.1 Water in Kedah – A Background

Kedah has a tropical monsoon climate with relatively uniform temperatures, ranging between 21°C and 32°C. Between January to April, weather is generally dry and warm. Humidity is consistently high on the lowlands, ranging between 82% and 86%. Average annual rainfall in Kedah is approximately 2,310mm (NWRS, 2011), most of which falls in the southern part of the state. Northern Kedah displays distinct wet- and dry-period patterns, with the wettest periods occurring between September and November, and the driest between December and March. These features are similar to those of Perlis and Southern Thailand, while the central and southern regions of Kedah typically receive about 10% more rainfall than the north each year.

Gunung Jerai receives the most rain within Kedah, with an annual average of 3,528mm, whilst the lowest was recorded in the area of Kuala Nerang, which recorded a total average rainfall of 1,874mm. The Pedu rainfall station, located on the embankment of Pedu Dam, recorded an average annual rainfall of 2,156mm. In terms of rainfall depth, Kedah receives an annual average of 2,310mm, of which 1,430mm (60%) is lost back to the atmosphere through evapotranspiration, 130mm (5%) infiltrates as groundwater, and only 750mm, or 35% of the total, remains as surface flow. In terms of volume, Kedah receives 21.95bil m^3 of rain, of which 13.6bil m^3 evaporates back to the atmosphere, 1.2bil m^3 seeps into the ground and only 7bil m^3 turns up as surface flow.

Kedah hosts three major river systems. The Muda River Basin is the largest, with a catchment size of 4,150km^2, comprising 43% of the state's area, and the river stretches a total of 180km in length. A catchment area roughly 984km^2 in size, or 24% of the basin area, is located upstream of Muda Dam. The Muda Dam also diverts water to the Pedu River catchment via the Saiong Tunnel. Except for impoundment at Beris Dam, a tributary of the Muda River, all rainfall that falls within Muda River basin flows downstream, unregulated, until the Sg. Muda Barrage at the river mouth. For a 25km downstream stretch, Muda River forms the boundary between the states of Kedah and Penang.

The 2nd largest river basin is the Kedah River Basin, which has a catchment area of 2,972km^2 and accounts for almost a third of Kedah's total landmass. It has a length of 130km and in the middle is connected to the Northern and Southern Canals of the Muda Irrigation Area at Pelubang. Some of the major tributaries of the Kedah River include the rivers Pedu, Pendang, and Padang Terap. The Pedu and Ahning Reservoirs are located within the Kedah River Basin. The Kedah River drains the northern part of the state whilst the Muda River drain the southern portion of the state. The third-largest catchment is the Merbok River Basin, which is 439km^2 in size and has a length of 45km. Merbok drains the central part of the state.

Kedah has several large reservoir storages constructed mainly for irrigation and water supply. NWRS (2011) reports Kedah as having a total storage volume of 1,606MCM, which represents about 169mm or 7% of the annual rainfall received. Table 28 below presents the full list of reservoirs in Kedah, with those with smaller storage capacities located on the island of Langkawi.

Table 28. Major Dams in Kedah

Dam	Catchment Area (km^2)	Active Storage (MCM)	Gross Storage (MCM)
Muda	984	154	170.7
Pedu	171	1080	1205
Ahning	122	275	318.5
Beris	116	114	122.4
Padang Saga (Langkawi)	12	0.14	0.2
Bukit Malut (Langkawi)	3.4	6.9	7.2

The Muda and Pedu reservoirs are connected, via the 6.8km Saiong Tunnel making this one of the earliest water basin transfer in the country and serves to supplement water to the Pedu reservoir for irrigation and water supply. The inter-basin linkage at the upper river catchment involves a catchment area of 984km^2, which accounts for a substantial 25% of the Muda River Basin. Further downstream, the development of the Naok and Reman dams, and other related developments allowing for the transfer of water from the Muda River to the southern of the MADA area, are reported to be underway. Currently, these projects are in their initial phases and are projected to be completed in across phases in line with the Malaysia Development Plans. Both the Naok and Reman dams are to be constructed as storage reservoirs to hold water that will be diverted from the Muda River at Kampung Kota Bukit via the Jeniang Barrage. Naok is planned to have an impounded storage of 27MCM and a small catchment size of only 18km^2.

Table 29 below, meanwhile, provides an overview of water demand in the state of Kedah, including projections up to 2050, according to its various uses. Irrigated paddy is by far the most significant user of water, accounting for more than two-thirds of total water demand on an annual basis, making this a key determinant of water security and sustainability in the state. Serious considerations therefore have to be made with regard to enhancing the water-food nexus in particular in order to enhance water use efficiencies within the food sector. This is the subject of the remainder of this section.

Table 29. Actual and Projected Water Demand in Kedah, 2010 to 2050

Sectors	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
	Water Demand in MCM per year					Water Demand in mm rainfall per year				
Potable Water Demand	486.5	558.1	595.0	634.4	677.1	51.2	58.7	62.6	66.8	71.3
Irrigated Paddy	2,283	2,263	2,089	2,076	2,030	240.3	238.2	219.9	218.5	213.7
Non-Paddy Crops	145.9	146.1	146.5	147.0	148.0	15.4	15.4	15.4	15.5	15.6
Livestock	6.5	8.4	11.2	15.2	21.3	0.68	0.89	1.18	1.60	2.24
Total consumptive demand	2,921.9	2,975.6	2,841.7	2,872.6	2,876.4	307.6	313.2	299.1	302.4	302.8
*Fisheries	136.1	157.9	183.2	212.7	246.8	14.3	16.6	19.3	22.4	26.0
Total demand	3,058.0	3,133.5	3,024.9	3,085.3	3,123.2	321.9	329.8	318.4	324.8	328.8

4.1.2 Two-Way Nexus Interactions in Kedah

The focus on nexus interactions within Kedah deals predominantly with the water-energy, water-food nexus, and the three-way water-food-energy nexus, which are the most significant across the state. The energy-food nexus is only covered in brief. Generally speaking, the water-food-energy nexus is an important feature for Kedah because it is the most significant producer of rice across the country; this consumes a sizeable volume of water, especially for paddy irrigation activities. Through its irrigation networks as well as water withdrawals from its rivers, Kedah also provides about 80% of the water needs in Perlis and 70% in Penang (NWRS, 2011).

This section analyses areas where major nexus interactions occur across the state and attempts are made to assess the strength of these interlinkages based on available information and assumptions derived from other studies. The water-energy nexus covers four interactions – energy use in water treatment, energy use in water distribution, energy use in wastewater services, and water use in both thermal and solar energy production. The water-food nexus is primarily concerned with water use requirements in agricultural production, most prominently paddy; other, non-paddy, edible crops (e.g., fruits and vegetables); oil palm; and animal husbandry.

4.1.2.1 Water-Energy Nexus in Kedah

The first emphasis is on the water-energy nexus. Most prominently, this covers energy use in water treatment and distribution, as well as wastewater treatment, and water use in energy production. These will be covered in turn.

Energy Use in Water Distribution and Water and Wastewater Treatment

The water-energy nexus is crucial as the treatment and distribution of water, as well as wastewater services and treatment, are heavily energy-intensive activities. Annual water production in Kedah in 2015 was approximately 1,316MLD according to the then-Ministry of Water and Energy, while NWRS (2011) estimates water demand to be approximately 1,451MLD, slightly higher than production. Domestic use accounted for approximately 523MLD of this total, non-domestic uses roughly 272MLD, with the remaining 575MLD lost as non-revenue water. This makes Kedah the state with the fourth-highest rates of NRW after Kelantan, Perlis, and Sabah. Meanwhile, SPAN reports Kedah's water service factor in 2017 as being 100% in urban areas and 96.5% in rural areas, contributing to a statewide average of 98.3%.

Studies, including those conducted by ACEEE (2014), Capodaglio (2020), Dhakal et al. (2013), Siatou (2020), an UNEP (2015), examining energy usage in water treatment generate a wide range of results. In the EU in 2019, for instance, average energy usage for a water treatment plant (WTP) was roughly 0.59 kWh/m^3. In China, where numerous studies elucidate at length several aspects of water treatment and energy requirement, key findings include energy demand of approximately 0.29kWh/m^3 to treat potable water for supply to urban areas. Data from the United States, provided by ACEEE (2014), meanwhile provides several ranges of the energy requirements per million gallons of water sourced, treated, and distributed; for the purposes of this study these have been converted into energy-intensity in terms of kWh per m^3. For larger facilities, the average energy requirement is approximately 0.43 kWh/m^3 (or 1,621 kWh/MG) while medium-sized systems require roughly 0.41 kWh/m^3. Smaller WTPs are found to be the most energy-intensive, requiring a mean energy intensity of 0.76 kWh/m^3.

The range of results found across these studies, which cover varying geographical regions with numerous differences in exogenous characteristics such as the natural and built environment, distance from water sources to water lifting needs in terms of height, as well as more endogenous characteristics which include the size and efficiency of WTP technologies. This review nonetheless confirms a range of between 0.20–0.80 kWh/m^3 of energy needed to treat water, and this range will be compared to water treatment systems in Malaysia.

Our attempts to estimate energy requirements for the abstraction, treatment, and distribution of potable water in Kedah utilises a value of roughly 0.29kWh to treat and supply each cubic metre of water, amongst the smallest values derived from the literature review and reflective of the situation in China. This figure generates a total daily energy requirement of 397,000kWh to treat and distribute 1,370MLD of water. Of this, NRW alone accounts for 188,575kWh of energy daily, a significant proportion that contributes adversely to energy efficiency and security, and brings with it significant costs.

Typical household potable water consumption of approximately 40m^3 would consume about 12kWh of energy, equivalent to about RM2.50 of electrical usage based on a tariff rate of RM0.218/kWh. Meanwhile, and particularly given the importance of decarbonisation and climate action, CO2 emissions are also an important consideration. Given that most energy in Kedah is drawn from combined-cycle power plants, which emit roughly 490gCO2e/kWh, a total of about 95 tons of CO2e is estimated to be emitted on a daily basis for the purposes of energy use for water treatment. NRW accounts for almost half of this total.

Wastewater treatment is another significant component of the water-energy nexus for livelihood. Kedah was reported to have 785 WWTPs across the state in 2017, with these varying greatly in terms of capacity, from as low as 2,000 persons-equivalent (PE) to over 50,000 PE. Assuming an urban population proportion of roughly 80%, which equates to roughly 900,000 people, that is served by a centralised wastewater treatment system using energy to treat wastewater, with the remainder of the population assumed to be served by septic tank or other pour-flush systems. This estimate of 900,000 inhabitants served by centralised treatment services tracks closely data reported by SPAN, which reported a PE of 950,000 served by such centralised services in 2016.

Assuming typical wastewater production of 150 litres per person daily, it is estimated that Kedah produces an aggregate of roughly 135MLD of wastewater a day, or 135,000m^3/day. To determine a 'reasonable' energy usage rate for WWTPs, estimates are again drawn from evidence in China, the EU, and US. The lower bound of each of these estimates is roughly 0.25kWh/m^3, rising to up to 0.87kWh/m^3 in the US and as high as 2.1kWh/m^3 in Europe. The differences across these figures are typically accounted for by variations in endogenous and exogenous factors, such as those described previously in the analysis of WTPs; most prominently in the context of WWTPs, technology and system design are important considerations. For the purposes of this analysis, the figures derived from studies in China, indicating energy consumption of 0.25kWh/m^3 is used to estimate the energy requirements for WWTPs in Kedah and can be considered to be a lower-bound estimate. These assumptions suggest energy requirements for WWTPs in Kedah are approximately 57,150kWh per day, but an important caveat is that this refers to only wastewater produced by households – it does not cover wastewater treatment for industrial runoff. These figures do not account for embedded energy in wastewater either; estimates indicate embedded energy content of roughly 9.7kWh/m^3, of which perhaps 2.7kWh/m^3 can be 'extracted' back out. Ultimately, as a result, the water-energy nexus in Malaysia requires a daily energy load of approximately 431,290kWh, or 157,420MWh on an annualised basis.

Water Use in Energy Production: Thermal Power Plants, Solar Farms, and Biofuels

Water is also required in the production of energy. There is currently only one thermal power plant located in Kedah, operated by Nur Power Generation, which is located at the Kulim Hi-Tech Park in the southern region of the state and not housed within any major river basin of Kedah. It is an independently operated power plant featuring a combined cycle gas and steam turbine and an installed production capacity of 220MW. At this stage, the quantity or volume of water required for energy production at this power plant is unclear. Estimates, however, can be derived through comparisons with a power plant located in Perlis with a production capacity of 650MW and which requires roughly 28MLD of clean water, it is estimated that this power plant would need about 10MLD for the generation of steam and for its cooling purposes. Based on these assumptions, total water requirements for the operation of Nur's Kulim power plant is estimated at roughly 3.65 MCM per year, or 10,000m^3 per day. The source of the treated water for this power plant would likely be from the SADA-owned Kulim Hi-Tech WTP, which is located along Sg. Muda some 32km away from the power plant.

Kedah is also seeing the development of another thermal power plant, to be built in Gurun. This plant is to be comprised of two power blocks of high-efficiency gas and steam turbines, with a generation capacity of 1,200MW. It will rely predominantly on natural gas as its fuel and features a wet cooling tower system (WCT). Assuming that this plant will be operational for 18 hours a day, producing a total of 19,200MWh, it will require roughly 35MLD to be extracted from the Muda River which will then be channelled to the plant via a 17km pipeline. Estimates of the water-intensity of energy production at similar thermal power plants in China and the United States have been used to derive this figure; a comparison between these figures indicates that water requirements for energy production in Malaysia pale in comparison to requirements in China (0.06m^3/kWh) and the US (0.095m^3/kWh).

It is estimated that by the time these two power plants are operational, by 2025 at the earliest, the total volume of treated water needed for power generation would be between 45 and 53 MLD, or roughly 3.3–3.8% of total water requirements across the state. This is a negligible quantity except during extreme situations of water stress; for instance, when clean water supply cannot be guaranteed for a period of more than 10 days, operations at Gurun might be affected in order to secure supplies for domestic, commercial, and industrial activities.

Water use is not limited to thermal power production. Kedah is one of Malaysia's leaders in solar energy production, accounting for an estimated 19% of total Malaysia production capacity. Kedah hosts seven solar farms installations, with installed capacities ranging from 30–50 MW that are either being developed or are already operational. Among the largest of these are solar farms operated by TNB, Edra, Quantum, Leader, and Solarpack, with total installed capacity estimated at 195 MW. In contrast to requirements in thermal power plants, most studies assume modest usage of water at solar farms. In comparison to the typical requirement of 4,250 litres per MWh in thermal power plants, solar farms require only 90 litres per MWh – this indicates the significant potential of solar power not just as a tool to mitigate carbon-based GHG emissions that arise from the use of fossil-fuel powered thermal power plants, but as a method of alleviating water-related resource constraints that may arise from the use of thermal power plants. Given high levels of solar irradiation in Kedah, too, policies should be in place to address the twin concerns of resource sustainability and climate change by taking advantage of available, clean energy-generation technologies.

Finally, the prevalence of oil palm cultivations in Kedah opens the door to the possibility of using this as a fuel source for power generation through the production of biofuels. Biodiesel production in Malaysia in 2019 reached approximately 1.56 billion litres, and Malaysia is well-placed to also support global demand for vegetable-based biofuels, particularly given the increased prominence of biodiesel as a renewable energy source used to substitute for diesel use in transport- and industrial-based applications.

Oil palm cultivations in Kedah, as mentioned previously, occupy an area of just under 88,000ha, representing 38% of the state's landmass. Oil palm plantations in Kedah typically do not require irrigation, relies mostly on green water, through rainfall, for its growth. This creates other uncertainties, however, which might worsen as the impacts of climate change on temperature and weather patterns are felt, particularly as they affect rainfall. This is because of the relationship between rainfall and oil palm yields; dry and hot weather conditions over long periods, typically associated with El Nino events, have been reported to reduce yields by as much as a fifth. Such climatic events, which have occurred 1997, 1998, 2014, and 2016, are only likely to become more common over time due to climate change.

Oil palm is also a highly water-intensive crop, consuming water from the root zone and playing a major role increasing average levels of evapotranspiration. Safitri (2017), in a study conducted in West Kalimantan, Indonesia, reports an evapotranspiration rate of between 3.07–3.73 mm/day for various oil palm plantations, across age and soil type. The study reported similar results in Johor and Borneo, of 3–3.70 mm/day, and 2.7–2.8 mm/day, respectively. Based on this, each hectare of oil palm plantations loses about 0.9 mm of water more than a tropical forest, and in total, the close to 88,000ha of oil palm plantations in Kedah causes excess water losses of 800,000m^3 of water relative compared to water loss from a tropical forest.

4.1.2.2 Water-Food Nexus in Kedah

The second emphasis is on the water-food nexus in Kedah; this is the most significant aspect of the water-food nexus within the state in large part due to the dominance of paddy cultivation within agriculture. Kedah is the nation's rice bowl; in 2018, it produced over 1.1MT of rice accounting for almost two-fifths of national production (Department of Agriculture, 2018). NWRS (2011) estimates that this level of rice production consumes approximately 2,283MCM of water, or 72.6% of the total estimated demand for water across all sectors in 2020, of 2,996MCM.

In terms of water efficiency of rice production, Kedah produces approximately 0.497kg of rice per m^3 of water used, or 2,010m^3 of water per ton of rice produced. Considering the annual volume of rainfall received across the state, along with losses through evapotranspiration, groundwater percolation and sea-flow, Kedah is considered to be a water-deficient state and during certain hot, dry periods is increasingly unlikely to be able to fulfil water demand across all sectors. In some situations, and particularly given the dependence of the paddy sector on water, the foregoing of paddy planting becomes unavoidable in order preserve water resources for use across other sectors and purposes.

This clearly illustrates a continuing conflict across the water-food nexus within Kedah, and comprehensive studies are needed to accurately quantify the economic and social impacts of such situations, especially given the tight export supply of the global grain market. Such conflicts are lent more gravity because of the general socioeconomic context – and importance – of paddy farmers in Kedah. In 2017, these numbered approximately 57,013, making them the single largest population of paddy farmers in the country, accounting for 29.4% of the total number of 194,000 across Malaysia. KRI (2016) finds that most of these farmers are within the B40 income category, with the average monthly household income of farmers in the MADA granary area approximately RM2,527, in contrast to the national average of RM6,958 per month. Any disruption to the planting of paddy due to water security considerations would therefore not only have an impact on the national food supply but have direct socio-economic and socio-political consequences.

With water consumption in Kedah significantly influenced by the irrigation needs of paddy cultivation, its role as the nation's rice bowl, and it being a relatively water-deficient state, interactions across the water-food nexus are amongst the most crucial strategic resource interlinkages across Malaysia. Food security measures, policies, and targets which impact rice production will likely impact Kedah, and in particularly the security of its water resources. This can have knock-on effects on other sectors; risking further conflict over water. Curtailing water consumption by withholding its use within paddy production will have both food security and socioeconomic repercussions. And as this paper discusses, the importance of Kedah's river basins – and in particular the Muda river basin – is also felt in other states such as Perlis and Penang. Kedah represents a quintessential example of the failures of single-resource focuses and by extension the importance of incorporating nexus-wide considerations when dealing with strategic resources.

Beyond paddy, many other water-food nexus interactions and interlinkages exist within Kedah. The first of these is the interactions water has with non-paddy food crops in Kedah. In this report, we assume that only fruits, vegetables, herbs, flowers, and sugar cane require irrigation, with farmers assumed to over-irrigate their crops due to their high value. Fruits, herbs, and sugar cane, therefore, are assumed to be irrigation to 150% of their evaporative water loss. Vegetables, meanwhile, require even more water – they require persistently wet soil to maximise water absorption and consequently growth, and in the context of this analysis are assumed to be irrigated to 200% of their evaporative capacity. Data on rainfall and evaporation in three locations in Kedah – Alor Setar, Chuping, and Lubok Merbau – between 2002 and 2008 is averaged out in Table 30 below, while past and projected monthly water requirements for non-paddy crops are provided in Table 31.

Table 30. Rainfall and Evaporation in Kedah

Month	Rainfall	Evaporation
Jan	39.3	5.5
Feb	59.8	6
Mar	144.6	5.6
Apr	210.7	4.9
May	160.5	4.1
Jun	185.4	3.9
Jul	225.6	3.7
Aug	210.5	3.9
Sep	258.5	3.8
Oct	295.4	3.6
Nov	202.7	3.8
Dec	137.5	4.3
Total	2,130.50	4.4

Table 31. Monthly Water Requirements for Irrigated Non-Paddy Crops in Kedah

Month/Year	**2007**	**2020 (proj.)**	**2050 (proj.)**
Jan	48,029	48,095	48,564
Feb	43,488	43,549	43,985
Mar	26,428	26,472	26,788
Apr	3,693	3,711	3,846
May	7,968	7,898	8,139
Jun	738	749	820
Jul	87	88	96
Aug	483	489	536
Sep	0	0	0
Oct	0	0	0
Nov	400	405	444
Dec	14,535	14,563	14,764
Total	145,847	146,109	147,981

NWRS (2011) reports Kedah as having one of the lowest levels of rainfall across Peninsular Malaysia, along with some of the highest rates of evaporation. Combined, this makes Kedah one of the driest states in the country, with rainfall exceeding evaporation by only 30 percent across a typical year. Given the uneven distribution of rainfall across time, however, evaporation considerably exceeds rainfall between the months of January and March, and the two are relatively equal during a typical December. Kedah can therefore be considered to be in drought between the months of December and March – or a quarter of the year.

Fruits and sugar cane together form over 90% of the irrigable areas, and if irrigation is not applied across these crops during these months to allow for optimal growth (particularly of fruits and sugar cane), Kedah's water needs for irrigation are reduced by approximately 46%. NWRS (2011) also reports Kedah as requiring approximately 146MCM of water in 2020 to produce non-paddy irrigated food crops, relative to the state-wide overall water demand of 2,283 MCM. Enforcing such compromises, however, is not ideal, and steps must be taken to address the water deficits faced by Kedah, including the adoption of technological, practical, and even institutional advancements which contribute to increases in water use efficiency, as well as the use of alternative water sources and/or storages, such as streams, wells, ponds, or even groundwater.

The third significant water-food interaction in Kedah comes from animal husbandry, with the water requirements of livestock production reported in Table 32 below. This includes projected water requirements every ten years through 2050.

Table 32. Water Use in Animal Husbandry in Kedah

Year	Wash Water Requirement	Drinking-Water Requirement	Abattoir Water Requirement	Total Water Requirement
2010	2,555,524	3,589,287	322,156	6,466,967
2020	3,283,910	4,730,731	432,736	8,447,377
2030	4,312,189	6,328,625	582,690	11,223,504
2040	5,814,990	8,628,489	787,065	15,230,544
2050	8,156,102	12,051,341	1,067,581	21,275,024

In summary, the total water required for livestock production of 6.5 million cubic metres in the year 2010 is projected to increase to 21.3 million m^3 in 2050. Drinking water accounts for the most followed by wash water and abattoir water. NWRS (2011) also reports that most of the water used to maintain livestock is derived from the water supply system. As a result, no attempts have been made to calculate energy requirements from water usage; these are instead assumed to have been captured in our earlier assessments of energy requirements for water services.

4.1.3 Water-Food-Energy Nexus in Kedah

The most complex resource nexus at play in Kedah relates to the three-way water-food-energy nexus interaction which exists in the context of paddy cultivation in Kedah, and in this subsection we delve into the two main areas where paddy plantations are located across the state – the MADA region, and smaller-scale paddy schemes housed within the Muda River Basin. In MADA areas, roughly 52% of irrigation is rain-fed, with a further 42% gravity-fed from the Pedu and Ahning reservoirs, as well as other river sources. The remaining 6% of the water requirements of MADA paddy plantations, however, utilise water pumped from river sources to augment the water already within the distribution network. This is where the three-way interaction comes into play, with energy being a crucial requirement in the process of pumping water (water) to supply these paddy cultivations (food).

MADA reports a seasonal volume of water of roughly 1,545MCM; of this, it is estimated that a typical season would require roughly 94MCM of water to be recycled through pumping (based on the 6% ratio highlighted above). This water requirement fluctuates based on two factors – the volume of rainfall received, and the volume of water stored in the reservoirs supplying MADA's paddy schemes, given the importance of these two sources of water in supplying MADA's needs. These fluctuations are reported by Jamil (2016), who estimates total water consumption of 2,758MCM for MADA areas in 2014 in comparison to NWRS (2011) which estimated total water use of only 1,726MCM for MADA areas just four years prior.

In terms of energy requirements for the pumping of the typically-required 94MCM of water, the physics of lifting water by a pump specifies an energy use of 0.002725 kWh per metre of lift required under 100% pump efficiency (CottonInfo, 2015). For our purposes, assuming an average lift requirement of 3m and a pump efficiency of 60%, energy requirements amount to roughly 13.625kWh in order to pump 1,000m^3 of water. The required pumped water volume of 94MCM to irrigate these paddy cultivations would consequently utilise an energy load of 1,280,750kWh or 1,280MWh, per season.

As was previously mentioned, these values are likely to vary between seasons. During dry seasons, such as the first season of 2016, the share of water supplied through recycling (and which required pumping) increased to about 15%; this would increase energy requirements by approximately 2.5 times, to roughly 3,550 MWh per season. Extrapolating these results further allows us to estimate the energy requirements per tonne of rice produced. Each year consists of two planting seasons; assuming energy requirements of 2,560MWh per year and rice production of 1.19MT annually (for reference, 1.19MT of rice was produced in 2018), each ton of grain produced requires roughly 2.55kWh of energy.

The Muda River Basin also hosts 20 smaller paddy schemes, with some 16 of them irrigated through pumping. For these smaller schemes, total annual pumping withdrawals totalled roughly 122 MCM, and if assumptions are maintained from the previous analysis, this equates to a total energy requirement of just over 2,000MWh would be needed for irrigation.

4.2 Perak

Perak is the second-largest state in Peninsular Malaysia with a land area of 20,976km^2. Located along the Straits of Malacca on the west of the Peninsula, it borders the state of Penang to the north, Kelantan and Pahang to the east, Thailand to the northeast, and Selangor to the south. Terrain in the eastern reaches of Perak is typically mountainous, with coastal plains dominating the west.

Forests account for just over 52% of land in Perak, followed by agriculture, which in 2015 accounted for a further 37.2% of land use. The remaining 10.8% is comprised of a combination of the built environment and water bodies. The majority of Perak's forests are gazetted under various categories of conservation; areas designated specifically as water catchment areas account for just under 160,000ha of the almost 1.1 million ha of forested land across the state (a share of around 14.5%). As far as agricultural land is concerned, the most commonly-grown crops in Perak are oil palm, paddy, and rubber. In 2016, oil palm acreage amounted to 398,314ha (6.9% of the total area of oil palm cultivations nationwide) while rubber accounted for another 205,764ha. Together, these two crops account for 29% of Perak's total landmass (Perak Structural Plan 2040, 2017).

Relative to land use by oil palm and rubber, paddy acreage is small. Just over half of Perak's paddy cultivations by area are concentrated within the three granary areas of Kerian, Seberang Perak, and Sg. Manik, which utilise 35,112ha of land. The remainder is accounted for by smaller-scale and in some cases independent irrigation schemes along the rivers Kerian and Perak. These cover an area of 30,356ha. With a total of 65,648ha of paddy cultivations, Perak produced 336,395MT of grain, accounting for around 11% of national production, in 2018.

As with paddy production, Perak in 2018 was the third-largest producer of other food crops in Malaysia. The state accounts for 7.1% of national fruit production, 10.7% of vegetable production, and 31.3% of the nation's 'cash crops', which include oil palm and rubber. Table 33, derived from statistics provided by the Department of Agriculture, overviews agricultural production in Perak in 2018. It includes the total acreage and land use shares, as well as the total production and national production shares, of each crop produced in Perak.

Table 33. Agricultural Production in Perak, 2018

Paddy		Fruits		Vegetable		Cash Crops	
ha	MT	ha	MT	ha	MT	ha	MT
81,208	336,395	10,951	116,747	8,956	113,260	4,290	74,546
11.8%	11.0%	5.2%	7.1%	13.4%	10.7%	19.8%	31.3%

4.2.1 Water in Perak: A Background

Perak, like Kedah, has a tropical monsoon climate with relatively uniform temperatures ranging between 21°C and 32°C. Between January and April, the weather is generally dry and warm. Humidity is consistently high in the lowlands, ranging between 82% and 86%.

NWRS (2011) reports mean annual rainfall in Perak of approximately 2,480mm; variation across the state is vast, from as low as 1,660mm in Sitiawan to a high of 4,373mm in Bukit Larut. Generally, the west of Perak receives high annual rainfall, in the range of 3,200mm to 4,300mm. In the southeast, meanwhile, rainfall averages between 2,600mm and 3,400mm a year.

Of the average of 2,480mm of rainfall Perak receives annually, 1,320mm (or 53.2% of the total) is lost through evapotranspiration, 170mm (6.9%) infiltrates as groundwater, with the remaining 990mm, just under 40% of the total, remaining as surface flow. Perak receives some of the highest volumes of surface runoff across the country, receiving a total of over 52 billion cubic metres of water, with 20.77 billion m^3 remaining as surface runoff. NWRS (2011) projects Perak to be in a water surplus through to 2050.

The four main river basins in Perak are that of Sungai Perak, Kerian, Kurau, and Bernam. All four river systems flow from the highlands that form the spine of Peninsular Malaysia and flow westward through to their discharge in the Straits of Malacca.

There are four major dams located along Sungai Perak; these are Temenggor, Bersia, Kenering and Chenderoh. Two off-river schemes can be found along Sungai Piah, one of Perak's tributaries, while there are three storage dams across the state. One of these was developed for irrigation purposes in Bukit Merah, within the Kurau river basin, and two water supply dams are operating in Ulu Kinta and Larut. These dams are overviewed in Table 34.

Table 34. Major Dams in Perak

Dam	Catchment Area (km²)	Storage Volume (MCM)	Details
Temenggor	N/A	6,050	348 MW hydropower and water supply dam
Bersia	3,650	-	72MW hydropower dam
Kenering	N/A	352	120kW hydropower dam
Chenderoh	6,560	84.4	40.4kW hydropower dam
Bukit Merah	484	65	Irrigation and water supply dam
Ulu Kinta	146	28.6	Water supply dam
Kuning	9.63	1.13	Water supply dam

Moving from water availability to water consumption, Table 35, provided below, overviews actual and projected water demand in Perak between 2010 and 2050. This table, derived from NWRS (2011), provides data on demand for water across various sectors and uses, including breakdowns for water consumption accruing to paddy and non-paddy crops, as well as livestock, which are all pertinent in the context of the WFEN analysis.

Table 35. Actual and Projected Water Demand in Perak, 2010 to 2050 (NWRS, 2011)

Sectors	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
	Water Demand MCM per year					Water Demand mm rainfall per year				
Potable Water Demand	386.2	476.7	533.6	598.2	661.4	18.4	22.7	25.4	28.4	31.4
Irrigated Paddy	1,476	1,352	1,160	1,084	1,010	70.2	64.3	55.1	51.5	48.0
Non-Paddy Crops	65.0	65.0	66.0	68.0	70.0	3.1	3.3	3.1	3.2	3.3
Livestock	22.1	28.6	38.5	51.2	69.4	1.1	1.4	1.8	2.4	3.3
Total consumptive water demand	*1,949*	*1,927*	*1,798*	*1,801*	*1,811*	*92.7*	*91.6*	*85.5*	*85.6*	*86.1*
Fisheries	325.4	416.6	533.3	682.6	873.8	15.5	19.8	25.4	32.5	41.5
Total demand	**2,275**	**2,344**	**2,331**	**2,484**	**2,685**	**108.1**	**111.4**	**110.8**	**118.1**	**127.6**

4.2.2 Two-Way Nexus Interactions in Perak

The focus on nexus interactions within Perak deals predominantly with the water-energy, water-food, and the three-way water-food-energy nexus, which are the most significant across the state. The energy-food nexus is only covered in brief. Generally speaking, the three-way nexus interactions between water, food, and energy are most significant because of their prevalence and strategic importance across the state. Perak hosts three major granary areas: Kerian, Seberang Perak, and Sg. Manik. In addition to this, there are at least 5,481 mini granary areas across the country. Within the Perak river basin, there are six hydropower plants with an installed capacity of 649MW, 24 WTPs with a capacity of 1,150MLD, two major granary areas covering 14,847ha and producing roughly 116,000 metric tonnes of paddy, and three thermal power plants with a capacity of over 5GW.

The Perak river basin is the second-largest in Malaysia, with a catchment size of 14,908km^2, and it hosts various agricultural cultivations. This section of the report looks into areas of major two-way nexus interactions in Malaysia and attempts to analyse the strength of these interlinkages based on available information and assumptions derived from other studies. The water-energy nexus covers energy usage in water and wastewater treatment and distribution, as well as water use in energy production. The water-food nexus is primarily concerned with water use requirements in agricultural production, most prominently paddy; other edible crops (including fruits and vegetables); oil palm; and animal husbandry.

4.2.2.1 Water-Energy Nexus in Perak

The first focus is on the water-energy nexus in Perak; this relates to energy used in water distribution, and water and wastewater treatment, but also encompasses water use in energy generation, including at thermal power plants, solar plants, and biofuels. The first point of focus is energy use in water and wastewater services. Similar assumptions have been made in this section as were made in the context of Kedah with regard to energy requirements per cubic metre of water treated – 0.29kWh/m^3 for water supply treatment, and 0.254kWh/m^3 for wastewater treatment.

Energy Use in Water Distribution and Water and Wastewater Treatment

Lembaga Air Perak (LAP) reported serving 687,941 domestic users in 2018, who utilise 71.4% of the total water supply volume. Non-domestic users comprise the remaining 28.6% of water demand. LAP operates 44 WTPs with a production capacity of 1,887MLD, with reserve capacities of this plants totalling 566MLD, or 40% of present production, in 2018. Total water production, by comparison, was between 1,333MLD that same year. Non-revenue water accounts for roughly 31%, or 412MLD, of daily production.

Urban areas of Perak have complete water coverage, with rural coverage lagging slightly behind at 99.3%. Almost all water is withdrawn from surface sources, including rivers and storage from two dedicated impoundments located in Kinta and Larut Matang. Over 45% of Perak's water supply is derived from Sg Perak, upon which ten WTPs are located with seven of these drawing more than 100MLD each.

Table 36. Overview of Water Statistics in Perak

		2017	2018
1	Domestic Connection (#)	676,619 (87.5 %)	687,941 (%)
2	Non-Domestic Connections (#)	96,730(12.5%)	98,733 (%)
3	Production Volume (MLD)	1,321	1,333
4	Production Capacity (MLD)	1,887	1,839
5	Production Utilised (MLD)	908	933
6	NRW	30.9%	30.0%

Given an assumed energy consumption rate of 0.29 kWh/m^3 and daily production of 1,321MLD, total energy requirements are 397,000kWh/day. Out of this, NRW alone accounts for 109,333kWh of energy. Given the average domestic water consumption of 0.96m^3/day, a typical household which uses 30m^3/day consumes around 9kWh of energy, equivalent to roughly RM1.96 of electricity based on a tariff of RM0.218/kWh.

With regard to energy use in wastewater treatment, Perak was reported by SPAN to have a total of 997 regional WWTPs in 2017 covering 1,787,334 PEs. Perak's 2017 population was estimated at roughly 2.49 million; as a result, the estimated percentage of the population covered by centralised WWTPs is roughly 71.8%. Assuming typical usage of 150 litres per person per day of wastewater (as reported by NWRS, 2011), the volume of wastewater produced and treated in a regional WWTP in Perak is approximately 268,100m^3/day. Following similar assumptions made for energy requirements in WWTPs in Kedah, daily energy requirements to treat wastewater in Perak are roughly 68,097kWh. This refers to energy requirements for domestic purposes only, not accounting for energy requirements for industrial wastewater treatment – these are government by the Environment Quality Act (EQA).

In total, daily estimated energy requirements for both water and wastewater treatment in Perak amounts to roughly 465,097kWh, for an annual volume of 169,760MWh/year.

Water Use in Energy Production

The next stage of our analysis into the two-way water-energy nexus interactions in Perak focus on the use of water in energy generation. Most prominently, this involves TNB Janamanjung, which obtains treated water from the Teluk Kepayang WTP drawing from Sg. Perak, located some 50km away from the power plant. This WTP had a production capacity of 113.5MLD in 2014, upgraded recently to 145.6MLD.

Hezri (2018) reports the maximum withdrawal in 2011 as being roughly 6.87MLD, representing about 6% of the water treatment plant capacity. Although this represents a small share of the production capacity of the WTP plant, the significance of the TNB Janamanjung power plant within the context of the water-food-energy nexus is emphasised further when accounting for the very central location of the thermal plant, its large installed capacity of 4,100 MW, and the fact that it supplies between 18 and 20% of total national demand for electricity. In other words, water security issues that affect Sg. Perak, and by extension the water needs of TNB Janamanjung – particularly for cooling and condensation activities – may have enormous implications for national energy security and depending on the interlinkages with agriculture, potentially food security as well.

The water-energy nexus next considers water use in palm oil activities. Perak in 2016 had the fifth-highest palm oil acreage in the country after Sabah, Sarawak, Johor, and Pahang, with 397,908ha, representing around 6.9% of the total acreage of oil palm cultivations of 54,400km^2 nationally, and just under 19% of total land use in the state (Khusairi, 2016).

Oil palm plantations, as mentioned previously, do not typically rely on irrigation and draw most of their water needs from on rainfall. Zulkilfli (2016), gathering data from 281 plantations covering an area of 440,000ha, reported a water footprint of 1,165.6m^3 per ton of fresh fruit bunches (FFBs) produced. Additionally, it is found that just under 91% of oil palm water requirements are met by green water (i.e., rainfall), with the majority of the rest from grey water (i.e., polluted water sources).

With regard to water use in the production of crude palm oil, Sabriyah et al. (2017) compiled and analysed information from a 65,000ha oil palm plantation in South Sumatra in 2016, and found a volume of 1.36m^3 of water use per ton of oil palm produced in total. This study also isolated the main user of water as being boilers, with 66% of all water requirements dedicated to this activity.

Due to its enormous production capacity for oil palm, being the second-largest producer in the world, Malaysia also has the potential to be a major global supplier of biofuels of vegetable origin. Palm oil-based biodiesel is also gaining prominence as a valid renewable energy fuel source, which will lend further weight to the importance of the oil palm industry and in particular to this study, the interactions and interlinkages present between water and energy – indeed, given that oil palm is a crop, this could very well represent a three-way nexus interaction from the perspective of biofuels.

Our final exploration into the two-way water-energy nexus in Perak relates to solar power. Perak is the second-largest producer of solar power nationally, with an estimated production capacity of 198.87MW, representing close to a fifth of Malaysia's installed capacity. Again, however, as with the case of Kedah, solar offers a tremendous opportunity through which Malaysia can not only address concerns associated with climate change and the need to embark on a sustained decarbonisation drive within electricity generation, but it can address any issues associated with water use within the energy sector because it doesn't require very much of it; in comparison to the typical requirement of 4,250 litres per MWh in thermal power plants, solar farms require only 90 litres per MWh.

4.2.2.2 Water-Food Nexus in Perak

This section looks into the interlinkages between water and food in Perak by establishing elements of the water-food nexus across the state, as well as attempting to analyse the water-energy nexus within food production. Perak accounts for 11.8% of land used for paddy cultivation in Malaysia, accounting for 10.98% of national production. It also produces 7.1% of the fruit produced nationally, 10.7% of vegetables, and around 31% of cash crops, including sweet corn, groundnut, cassava, sweet potato, sugar cane, and chestnuts.

Water and Paddy Cultivation in Perak

The strong linkages between water and paddy production in Perak are based on the presence of three granary areas across the state, along with 11 mini-granary areas, which in total cover an area of roughly 42,882ha. Perak's production of 336,395MT in 2018 made it the third-largest rice producer nationally (DOA, 2019). Perak's main granary areas are the Kerian Irrigation Scheme, covering an area of 23,559ha, and the IADA Trans Perak Schemes which cover two areas: Seberang Perak (8,529ha) and Sg Manik (6,318ha). Both of these utilise different water sources – Seberang Perak utilises water from Sg Perak via a headwork and canal, while Sg. Manik uses headworks from its namesake. Kerian, meanwhile, relies mostly on the Bukit Merah reservoirs, with only around 15% of its water requirements met by the Sg. Bogak pumphouse; this translates into volume requirements of around 36.8MCM annually. Jamil (2016) estimates seasonal water use of 255.5MCM, of which 176MCM is gravity-fed from Bukit Merah. The remainder of these water requirements are met by the Sg. Bogak pumphouse and seven water recycling locations; based on this information, it is assumed that around 82MCM of water needed for irrigation would require the use of energy to supply.

Much of the water supply for IADA Seberang Perak is drawn from Sg. Perak itself, and pumping at the field level is only necessary if water levels fall below 8.6m. A dry year, such as 2014, requires an estimated RM400,000 worth of fuel to run mobile pumps for this very purpose (Hezri, 2015). The Sg. Manik irrigation scheme, meanwhile, obtains most of its water requirements from Sg. Batang Padang and the Chikus pumping station, where a volume of around 3.84MCM is withdrawn annually using energy. Perak also houses a further 11 mini-granary areas with a total area of 5,841ha, particularly alongside the rivers Perak and Kerian. These are also assumed to be irrigated through pumping, requiring a total volume of roughly 140MCM, as reported by NWRS (2011). In total, Perak consequently requires approximately 222MCM to be lifted for the irrigation of paddy plantations on an annual basis.

Given that in 2018 Perak produced 336,395 MT of paddy grain and used 1,377MCM of water for irrigation, average water use for paddy in Perak is estimated at 4,093m^3 per ton of grain produced, significantly higher than the national average water requirement of 2900m^3/MT of rice.

Beyond water, Perak is also an important producer of other crops in Malaysia, ranking third amongst all states in terms of its share of total production of fruits, vegetables, and cash crops nationally. Producing

304,553MT of these crops in 2018, the Department of Agriculture reports Perak as accounting for just over 10% of total production in the country. Of this produce, fruits and vegetables account for roughly 30% each, with other significant crops being cash crops and coconuts, which together account for most of the remaining 40%. Farmers are assumed to irrigate fruits and herbs to 1.5x their evaporative loss of water, while for vegetables the factor is 2x.

This section derived all its information National Water Resource Study that was carried out in 2011. The volume of water shall cover water required for the fruits, vegetables, herbs, and flowers. In this report, the farmers are assumed to over-irrigate their crops because their product is of high value; fruits and herbs are therefore assumed to be irrigated to 1.5x their evaporative loss of water. Vegetables are reported to require even more water. The soil has always to be wet so that the plants can take up as much water as possible for faster and greater growth. They are assumed to be irrigated to 2.0x their evaporative loss of water. With this in mind, the monthly water requirements for non-paddy crops in Perak are presented in Table 37.

Table 37. Monthly Water Requirements for Non-Paddy Crops in Perak, 2007 to 2050 (projected)

Year (Base)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	6,429	15,557	5,847	2,037	11,504	11,640	4,429	5,151	2,171	0	0	0	64,774
2010	6,442	15,585	5,860	2,045	11,520	11,656	4,440	5,163	2,180	0	0	0	64,889
2020	6,499	15,672	5,919	2,081	11,594	11,727	4,491	5,217	2,218	0	0	0	65,418
2040	6,746	16,037	6,173	2,237	11,909	12,030	4,705	5,448	2,384	0	0	0	67,668

The final element within the water-food nexus for Perak relates to water use in animal husbandry. Perak is amongst the largest producers of meat and animal products in the country and correspondingly has one of the highest rates of water consumption for these purposes. Taking into account water requirements for abattoir, washing, and drinking, livestock water requirements are estimated by NWRS (2011) to have been 22.1MCM in 2010; and are projected to reach 28.6MCM in 2020 and up to 51.2MCM in 2040. Drinking water for livestock accounts for the largest proportion of this figure, with a share close to half of all water requirements in animal husbandry statewide. Given, however, that NWRS (2011) reports that water use for livestock is drawn directly from the water supply system, no attempts have been made to quantify the associated energy requirements of this water as they are assumed to have been captured by previous assessments of energy requirements for water services.

4.2.3 Water-Food-Energy Nexus in Perak

The three-way water-food-energy nexus in Perak relates primarily to situations where the use of pumps is required to lift water; most prominently, this occurs in the context of irrigated crops, such as paddy and some fruits, vegetables, and cash crops. These relationships have been described in the context of the two-way water-food nexus in the previous section. As has been described, pumping may be required during periods of low flow or during droughts for irrigation at IADA Seberang Perak (if water levels in Sg. Perak fall below 8.6m), while the Sg. Manik irrigation scheme and the 11 mini-granary areas along Sg. Kerian and Sg. Perak rely regularly on pumping to meet their water requirements. This equates to a total need of roughly 480MCM of water to be lifted.

In order to estimate the energy requirements for this quantity of water that requires pumping, the same assumptions are made as in the analysis of the three-way WFE nexus in Kedah, namely that average lift requirements are 3m and that pumps operate at an efficiency of roughly 60%. This equates to roughly 13.625kWh required to pump 1,000m^3 of water. By extension, the energy requirement to lift 480MCM per year is roughly 6,536.2MWh, over five times the energy requirements for irrigation in Kedah despite the fact that Perak produces a significantly lower quantity of paddy than the former.

It is here that nexus opportunities exist which can mitigate in particular the energy needs of irrigation across the state of Perak. This challenge is lent further urgency due to the fact that climate change, in causing a steady increase in average surface-level temperatures, is expected to cause significant changes to rainfall patterns, including rainfall received, and will likely render more imperative the use of water pumping to meet water demands for irrigation over the coming decades. Unless steps are taken to further incorporate nexus approaches and concepts into resource security matters, this issue may not be addressed to the degree it has to. Emphasis must therefore be placed on implementing not only nexus approaches but the utilisation of nexus-related technologies; these are discussed throughout this paper, and in the context of Perak, and specifically the WFE nexus challenges that are present in the state, this involves the deployment of technologies which enhance the efficiency of pumping as well as reduce the energy requirements – efficient, smart pumps are one option, as are solar- or other RE-powered pumping technologies.

4.3 Perlis

Perlis is the smallest state in Malaysia, with an area of 821km^2. It is bordered by Thailand in the north, Kedah on the east and south, and the Straits of Malacca to the west. It is largely a flat state, with its highest point being Gunung China near the Thai border. Land use in Perlis is dominated by agriculture, which accounts for 61,217ha, or 75% of state land. Paddy accounts for 51,500ha of this total; of this, 17,717ha falls under the MADA granary area. In fact, the entirety of the state's paddy land south of the capital of Kangar is under the administration of MADA. The remaining paddy plantations are located in the fringes of villages outside of Kangar, Utan Aji, and Beseri. Forests make up the second-largest land-use category, accounting for 18% of state land, followed by built-up areas. These built areas are concentrated mainly in Kangar, Arau, Padang Besar, Kaki Bukit, Beseri, Mata Air, and Kuala Perlis. Finally, the remainder of state land is accounted for by water bodies; these are largely represented by the Timah Tasoh lake.

4.3.1 Water in Perlis: A Background

Perlis has a tropical monsoon climate, much like Kedah and Perak, with distinct dry spells occurring between the months of January and April. Temperatures are in the range of 21 to 31°C, with humidity consistently high between 82% and 86%. Mean annual rainfall is approximately 1,880mm annually; while this is almost double the global average of 990mm, it is the lowest in Malaysia. Coupled with its small catchment size, limited surface flow, and intense droughts – which are akin to those in southern regions of Thailand – Perlis frequently faces issues related to water scarcity. NWRS (2011) labels Perlis a water-deficient state.

NWRS (2011) reports average annual rainfall in Perlis to be in the region of 1,704–2,005mm, with the wettest months being April, May, and August through September. The driest months, meanwhile, are January and February. Of the rainfall received by Perlis, which amounts to 1,545 million m^3 of rainfall annually, 69% returns to the atmosphere through evapotranspiration, while a further 6% infiltrates as groundwater. The remaining 25% remains as surface runoff, and of this, NWRS (2011) assumes only 15% is available for use for the various activities across the state – a total of 15MCM. Further, Perlis is endowed with several productive groundwater wells where production ranges from 1.52MLD to 2.2MLD. Two WTPs operating in Perlis draw water from these groundwater wells, and are used to service between 1,000 and 1,500 premises depending on water loss rates within the delivery network. Total water demand for potable water as well as food production between 2010 and projected through to 2050 is provided in Table 38 below.

Table 38. Actual and Projected Water Demand in Perlis, 2010 to 2050

Sectors	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
	Water Demand MCM per year					Water Demand mm rainfall per year				
Potable Water Demand	54.8	61.3	65.3	70.1	75.2	66.7	74.7	79.6	85.4	91.6
Irrigated Paddy	198.0	184.0	165.0	155.0	141.0	241.2	224.1	201.0	188.8	171.7
Non-Paddy Crops	52.0	52.0	52.0	52.0	52.0	63.3	63.3	63.3	63.3	63.3
Livestock	0.9	1.7	3.3	6.5	12.8	1.1	2.1	4.1	8.0	15.6
Total consumptive water demand	*305.6*	*299.0*	*285.7*	*283.6*	*281.0*	*372.3*	*364.2*	*348.0*	*345.5*	*342.3*
Fisheries	9.4	10.4	11.5	12.7	14.1	11.5	12.7	14.0	15.5	17.1
Total demand	**315.1**	**309.5**	**297.2**	**296.4**	**295.1**	**383.8**	**376.9**	**362.0**	**361.0**	**359.4**

Perlis hosts two river basins, Perlis and Arau. The Perlis river basin has a catchment area of 724km^2, while that of Sg. Arau has an area of 110km^2 – some of this falls within the state of Kedah. Perlis has only one major impounded reservoir, Timah Tasoh, which with a capacity of 70.3MCM primarily supports flood mitigation and irrigation, but this scope has been expanded to include meeting water supply requirements as well.

4.3.2 Two-Way Nexus Interactions in Perlis

The focus on nexus interactions within Perlis deals predominantly with the water-energy, water-food nexus, and the three-way water-food-energy nexus, which are the most significant across the state. As with the analyses of Kedah and Perak, this section analyses areas where major nexus interactions occur across Perlis and attempts are made to assess the strength of these interlinkages based on available information and assumptions derived from other studies. The water-energy nexus covers four interactions – energy use in water treatment, energy use in water distribution, energy use in wastewater services, and water use in both thermal and solar energy production. The water-food nexus is primarily concerned with water use requirements in agricultural production, most prominently paddy; other, non-paddy, edible crops (e.g., fruits and vegetables); oil palm; and animal husbandry. Finally, an attempt is made to classify nexus issues inherent to the state in the context of water security.

4.3.2.1 Water-Energy Nexus in Perlis

The first emphasis is on the water-energy nexus in Perlis. Most prominently, this relates to energy use in water and wastewater treatment and distribution, as well as water use in thermal and non-thermal energy production, with each of these interlinkages described in turn.

Energy Use in Water and Wastewater Treatment and Distribution

As of 2019, Perlis hosted seven WTPs, five of which draw their supply from surface-level sources, with the remaining two drawing theirs from groundwater sources. Of the five which draw water from the surface, one draws from Timah Tasoh, while two each draw from Sg. Arau and Sg. Baru respectively. With the exception of withdrawals from Timah Tasoh, all withdrawn water is from unregulated surface flow from the Arau and Kedah river catchments, as well as storage at the Ahning and Pedu dams via the Northern Kedah Canal System. Water production in Perlis is reported to have been 242MLD in 2017, up from 216MLD in 2014.

The WTP which withdraws from Timah Tasoh is located along Sg. Jarum and is reported to have an operational capacity of 54MLD. A second WTP, expected to be operational in 2023, will also have a capacity of 54MLD and will also draw from Timah Tasoh. These WTPs are designed with the aim of supplying the northern areas of Perlis, in particularly Beseri. Two WTPs are located along Sg. Baru; one of these, belonging to SADA, supplies potable water to the island of Langkawi via a submarine pipeline. The second was constructed in 2007 as a source of water for energy generation at Teknologi Tenaga Perlis Consortium (TTPC), and has a capacity of 56MLD. Half of this figure is dedicated to energy production, with the remainder servicing areas south of Kangar – namely Simpang Empat and Sanglang. Due to issues related to water coverage and weaknesses in the water supply infrastructure, however, only 14MLD of the remaining 28MLD can be tapped into to supply potable water needs. Finally, the two WTPs which draw from groundwater sources are located in Chuping and Semandung, and have a capacity of 3.6 and 1.4MLD respectively. These WTPs supply potable water to the local areas.

In gauging energy requirements for the treatment of water at these WTPs, the same assumptions are made as in previous analyses of Kedah and Perak with regard to energy requirements per cubic metre of water treated – 0.29kWh/m^3 for water supply treatment, and 0.254kWh/m^3 for wastewater treatment. The only exception is in the estimation of energy requirements in treating water from groundwater sources; this process requires energy for treatment, but before that requires energy use in the lifting of water to the surface. For this, evidence is considered from three groundwater wells located in the cities of Qingdao, Beijing, and Tianjin, in China. Information on the depth of these wells and the associated energy requirements to lift a cubic metre of water from these sources is reported in Table 39. In addition to this, ISAWWA (2012), in a survey of energy intensities for groundwater withdrawals in the United States reports an average requirement of 0.75kWh per cubic metre of water.

Table 39. Energy Requirements to Lift Water from Groundwater Sources

	City	Depth (m)	Energy (kWh/m3)
1	Qingdao	58	0.40
2	Beijing	39	0.44
3	Tianjin	58	0.66
4	USA	N/A	0.75

In applying these figures to the context of Perlis, groundwater depth is assumed to be 50m, and this final figure of 0.75kWh/m^3 is taken to be the energy requirement per unit of water. Given that the daily groundwater extraction rate is roughly 5MLD, this equates to an energy need of about 3.75MWh daily, or 1,368MWh on an annual basis. For the production of treated water from surface-level sources, which amounts to 240MLD, daily energy requires are far more significant at 69.6MWh, or 25,404MWh on an annualised basis. With NRW rates in Perlis roughly 58% in 2017, this means energy losses amount to 14,734MWh per year, or 960 litres per person per day in terms of water and 0.278kWh per person per day in terms of energy.

As far as wastewater is concerned, Perlis has a population of roughly a quarter of a million, with 58,000 connected to a public sewage treatment plant. For this study, it is assumed that the persons-equivalent (PE) of wastewater service coverage is 60,000. With these figures in mind, assuming energy requirements of 0.254kWh/m^3 of water, and a daily wastewater volume of 9MLD, energy requirements for wastewater treatment in Perlis are assumed to be 2.3MWh per day.

Water Use in Energy Production

Perlis hosts one combined-cycle gas power plant and several solar farms. The CCGT power plant has a capacity of 650MW, and utilises seawater in its cooling system as well as drawing on 28MLD from the WTP located on Sg. Baru. This volume represents 7.5% of Perlis' total water production capacity, while the power plant accounts for roughly 2% of Malaysia's power production capacity of 34GW. As with our previous analyses, it is assumed that a thermal power plant requires between 0.06m^3 and 0.095m^3 of water per kWh of energy produced. Assuming a load factor of 64.4%, as reported by TTPC, and taking the lower bound figure for water requirements in energy production, water requirements at this power plant equate to roughly 28,000m^3.

Solar generation capacity in Perlis, meanwhile, is roughly 5MW. Most reports assume modest water usage for photovoltaic power generation, with the average being roughly 90 litres per MWh, in contrast to 4,250 litres/MWh for thermal power plants. The annual production potential of these solar plants, of 97MWh, consequently requires approximately 9,000 litres of water, a significant quantity in comparison to Perlis' water production capacity. As a result, it can be concluded that Perlis' energy sector is not a significant user of water and energy security is unlikely to be affected by water-related issues across the state. This finding is likely to be further reinforced as the state continues its energy transition towards renewable forms of energy, particularly solar, given its significantly lower water intensity.

4.3.2.2 Water-Food Nexus in Perlis

As with Kedah and Perlis, the dominant crop in Perlis is paddy. Roughly 23,700ha of land is cultivated for rice production, with another 8,700ha, or just over a quarter of the total, devoted to other food crops. MADA granary areas account for about 17,700ha of total paddy land across the state, with the remaining 6,000ha located along river fringes. Much of this – roughly 4,900ha – is accounted for by the small paddy schemes downstream of the Timah Tasoh dam. The biggest of these are Sg. Karok/Sg. Abi, at 4,200ha, and Sg. Batu Pahat, at 750ha. Total paddy production in Perlis in 2018 is estimated to be 270,702MT, accounting for 8.8% of total national production despite Perlis' small landmass.

NWRS (2011) estimates annual water demand of 315MCM for food production in Perlis in 2010, with paddy activities accounting for 63% (or 198MCM) of this total. A breakdown of water demand by activity across Perak is provided in Table 40 below.

As with MADA areas in Kedah, most of the water needs for irrigation are met by rainfall or other surface sources via gravitational means. Only 6% of the water requirements of these granary areas are met by recycling. Perlis hosts about 16.3%, or 17,700ha, of the land under the administration of MADA, and assuming constant supply across all MADA areas, each cropping season for MADA land within the vicinity of Perlis would require around 252MCM of water. Given that only 6% of water is recycled, 15MCM of water used for irrigation in Perlis would require the use of energy in lifting. Assuming that pumps operate at 60% efficiency, and that water needs to be lifted a total of 3m, each cropping season utilises 204.4MWh of energy.

Table 40. Actual and Projected Water Demand in Perak, 2010 to 2050 (NWRS, 2011)

Sectors	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
	Water Demand MCM per year					Water Demand mm rainfall per year				
Potable Water Demand	54.8	61.3	65.3	70.1	75.2	66.7	74.7	79.6	85.4	91.6
Irrigated Paddy	198.0	184.0	165.0	155.0	141.0	241.2	224.1	201.0	188.8	171.7
Non-Paddy Crops	52.0	52.0	52.0	52.0	52.0	63.3	63.3	63.3	63.3	63.3
Livestock	0.9	1.7	3.3	6.5	12.8	1.1	2.1	4.1	8.0	15.6
Total consumptive water demand	*250.9*	*237.7*	*220.3*	*213.5*	*205.8*	*305.6*	*289.5*	*268.4*	*260.1*	*250.6*
Fisheries	9.4	10.4	11.5	12.7	14.1	11.5	12.7	14.0	15.5	17.1
Total demand	**315.1**	**309.5**	**297.2**	**296.4**	**295.1**	**383.8**	**376.9**	**362.0**	**361.0**	**359.4**

4.3.3 The Water-Food-Energy Nexus and Water Security in Perlis

This section discusses briefly key nexus-related issues pertinent to the state of Perlis. These are split into three dimensions: water resource availability, water use in food production, and non-revenue water.

Water Resource Availability

NWRS (2011) reported Perlis as being a water-deficit state based on the assumption only 25% of its received rainfall remains as surface flow. Considering losses to the sea during storm events and saltwater intrusion limiting withdrawals from some stretches of its rivers, NRWS (2011) only considers 15% of its received rainfall to be available for use by all activities within the state. This translates into just 57MCM of water relative to demand of 377 MCM in 2020, projected to rise to 360MCM in 2050.

As far as water storage is concerned, the Timah Tasoh reservoir has a capacity of 70.3MCM and this – along with its catchment size that accounts for 23% of the state's landmass – allows it to capture and retain a substantial proportion of the rainfall the state does receive. This plays a significant role in determining the state's water security. The reservoir, however, faces conflicting issues, particularly between its responsibilities of storing water for irrigation, and the need to provide volume for flood mitigation purposes. Simulations conducted under the purview of NWRS (2011) report that even with additional volumes made available by increases in storage, supplies to minor granary schemes would be insufficient to cater for two planting seasons. In this regard, food production is sometimes sacrificed in favour of ensuring smooth functioning of water services delivery.

Water Use in Food Production

Despite its small size, Perlis contributes 9% of Malaysia's total paddy production, hosting a significant acreage of 51,491ha of paddy cultivations producing roughly 270,702 tonnes of rice. Its average yield of 5,257kg/ha is almost equal to the figures in Kedah. Given the aforementioned competition for water between water service provision and food production, and the fact that food production is sometimes sacrificed to ensure sustained water supply, it is assumed that irrigation is sometimes reduced to cover only 2,500ha of paddy cultivation. As a result, around 3,500ha of paddy land would be denied double-cropping, curtailing national production by an estimated 17,500 tons per year.

Non-Revenue Water

Perlis is reported to have serious issues concerning NRW losses. In 2016, NRS was reported to be approximately 60.7%, increasing to 63.1% in 2018. With production of 245MLD in 2019, a total of 56.3 MCM of treated water is lost through the distribution system annually. This is equivalent to almost 80% of the total volume impounded by Timah Tasoh at full storage. This renders imperative the implementation of measures to mitigate instances of NRW losses in the state, especially considering its already strained state of water security.

4.4 Sabah

Sabah is the second-largest state in Malaysia, with a land mass of 73,904km2. Located in the north of the island of Borneo, in East Malaysia, Sabah borders Sarawak to the southwest and the Indonesian region of Kalimantan to the south. The Federal Territory of Labuan, an island, lays just off the Sabah coast. NWRS (2011) reports that as of 2010, the largest uses of land across the state were forestry (71.6%) and agriculture (19.1%). Water bodies comprised of only 0.06% of Sabah's surface area. Agricultural land accounted for over 1.4 million hectares, a figure that has grown in recent years – as of 2016, it was found that oil palm plantations covered an area of over 1.5 million hectares. Oil palm is the state's dominant crop, taking up over 21% of the state's landmass and 27% of the total planted area of the crop in Malaysia. Typically when these plantations expand, they come at the expense of forest cover.

4.4.1 Water in Sabah: A Background

Sabah, in contrast to the western coast of Peninsular Malaysia, has an equatorial climate with uniform temperatures throughout the year (between 20 and 32°C), high humidity, and copious rainfall. Most areas of Sabah receive at least 2,000mm of rainfall annually, from a low of 1,240mm in some areas to a high of 5,250mm in others. Different regions of Sabah are endowed with wildly differing rates of rainfall, and rainfall patterns. The east and northeast regions have their wettest periods between the months of October and February due to the effects of the northeast monsoon. Conditions are slightly drier (although rainfall is still prominent) between May and September, while April is considered the driest month. In the west, southwest, and northwest regions of Sabah, the northeast and southwest monsoons bring moderate rainfall between May and December, while the driest months occur from January through March.

Sabah is reported by NWRS (2011) as having abundant water resources across its rivers, lakes, and wetlands. Mean annual rainfall statewide is around 2,560mm, of which 1,180mm, or 46%, remains as surface flow. Sabah is considered a water-rich state, receiving a volume of 11,700MCM in 2020 against demand of 1,380MCM, making it the state with the third-highest rainfall depth surplus nationally after Sarawak and Terengganu. There are 25 major river basins across Sabah, with the Sg. Kinabatangan river basin, located on the east coast, being the largest with an area of 16,755km^2. The second-largest is the Sg Padas basin, with a catchment size of 9,180km^2. Five river basins are larger than 1,000km^2 and the others are comprised of smaller areas. Five lakes across the state – Babagon, Pinangsoo, Sepagaya, Tenom, and Timbangan – are utilised for water supply and hydropower purposes, with a total storage volume of approximately 29.6MCM. Finally, the actual and projected water demand by sector is provided in Table 41 below.

Table 41. Actual and Projected Water Demand in Sabah, 2010 to 2050

Sectors	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
	Water Demand MCM per year					Water Demand mm rainfall per year				
Potable Water Demand	382.9	618.7	731.8	821.3	877.8	5.2	8.4	9.9	11.2	11.9
Irrigated Paddy	450	655	575	533	496	6.1	8.9	7.8	7.2	6.7
Non-Paddy Crops	72.6	73.3	74.2	75.2	76.6	1.0	1.0	1.0	1.0	1.0
Livestock	6.9	8.5	10.7	12.8	18.5	0.1	0.1	0.1	0.2	0.3
Total consumptive demand	912.4	1,355.5	1,391.7	1,443.3	1,468.9	12.4	18.4	18.8	19.6	19.9
Fisheries	21.1	25.3	30.4	36.5	43.8	0.3	0.3	0.4	0.5	0.6
Total demand	**933.5**	**1,380.8**	**1,422.1**	**1,479.8**	**1,512.7**	**12.7**	**18.7**	**19.2**	**20.1**	**20.5**

4.4.2 Two-Way Nexus Interactions in Sabah

The most prominent nexus interactions playing out in Sabah related to the water-energy and water-food nexuses. This section begins by introducing and discussing the water-energy nexus, where primary activities of interest include energy use in water and wastewater treatment and distribution, as well as water use in energy generation, including thermal power, hydropower, and solar power. The water-food nexus analysis considers water usage in irrigation for paddy and non-paddy crops, as well as in oil palm production and animal husbandry.

4.4.2.1 Water-Energy Nexus in Sabah

Energy Use in Water and Wastewater Treatment and Distribution

Once again the same assumptions are made in the analysis of energy use in water and wastewater treatment – that the former requires 0.29kWh per cubic metre of water treated, and that the latter requires 0.254kWh/m^3. A total of 73 WTPs are in operation in Kedah, with these managed by the Sabah State Water Department, an agency under the purview of the Sabah Ministry of Infrastructure Development. Almost all the water treated at these WTPs are drawn from surface sources, including rivers, dam storage, or off-river dam storage. An issue in Sabah persists over water coverage – while urban areas are fully covered, only 69% of rural areas across the state receive access to clean and treated piped water.

Annual water production, as of 2017, was 1,261MLD, of which 323MLD, or just over a quarter, is devoted to domestic use. 259MLD is reserved for non-domestic uses, and NRW accounts for much of the remainder, at almost 54% of the total. This makes Sabah have some of the highest rates of NRW nationally, second only to Perlis. This is especially concerning given recent reports that Sabah's water services industry is not generating enough revenue to cover its capital and operational expenditures. Given the state's production, nonetheless, and given the assumptions made previously, it is estimated that energy requirements for water treatment in Sabah amount to 366MWh per day, with NRW accounting for the use of 196MWh of this total.

Insofar as wastewater is concerned, this is managed by the Sabah Public Works Department as well as local authorities. While the design and implementation of wastewater-related projects are handled by the PWD, operations and maintenance are handled by local authorities. NWRS (2011) reports a PE capacity of around 726,500 in Sabah; given that these figures are almost a decade old, for this analysis we assume a PE of 1 million serviced by a centralised WWTP, as well as usage of 150 litres per person per day (as reported by NWRS, 2011), this equates to the treatment of 150,000m^3 in a regional WTP on a daily basis, using 45MWh of energy. Energy consumption in Sabah is subdued relative to other states owing to the higher proportion of the population that is not serviced by a centralised WWTP.

Water Use in Energy Generation in Sabah

Electricity distribution in Sabah and Labuan are operated and managed by the Sabah Electricity Sdn. Bhd. (SESB), with the state relying on a combination of diesel, hydropower and natural gas for the majority of its energy needs. A list of all thermal power plants in Sabah is provided in Table 42.

Table 42. List of Thermal Power Plants in Sabah

No.	Name	Districts	Capacity (MW)
1	Kimanis CCGT	Papar	367
2	SPR Energy -Kimanis CCGT	Papar	108
3	Ranhill Powertron CCGT	Kota Kinabalu	208
4	Ranhill Powetron II (GT&ST)	Kota Kinabalu	214
5	Sepanggar Bay (GT&ST)	Kota Kinabalu	113
6	SESB SJ-Metawa (DG&GT)	Kota Kinabalu	344
7	Libaran Stravest MFO	Sandakan	64.4
8	SESB Sandakan – Batu Sapi (DG)	Sandakan	58
9	SESB SJ Kubota	Tawau	64

Most of these power plants are located coastally; as a result, it is expected that the majority of cooling processes utilise seawater. In contrast to Peninsular Malaysia, it is assumed that the usage of fresh water for steam generation to drive the turbine is minimal.

Hydropower potential, meanwhile, is limited in Sabah relative to its neighbouring state of Sarawak. There is only one significant hydropower plant in the state, located in Tenom Pangi, with a capacity of 75MW, with the others being off-river schemes that bring total hydropower capacity in the state to 76MW. Studies, however, indicate hydropower potential in Sabah upward of 200MW, which brings forward the possibility of further projects in the coming years to enhance the state's energy security. These projects will have to be mindful of nexus interlinkages across the state, particularly as they pertain to water use and potentially damage to biodiversity and local ecosystems.

As highlighted in previous sections, water use for solar power generation is limited, with the typical solar farm utilising around 90 litres of water per MWh of electricity produced. In total, based on LSS awards during the first and second national LSS auctions in Malaysia, Sabah hosts a total solar capacity of 42.8MW. These are presented in Table 43.

Table 43. List of Large-Scale Solar Plants in Sabah

No.	Name	Districts	Capacity (MW)
LSS 1	Nusantara Suriamas	Kota Marudu	5.9
	Beau Energy	Beaufort	6.0
LSS 2	TTL Energy	Sipitang	5.0
	Amled Solar/Bumisinar JV	Papar	2.3
	Amled Solar	Keningau	7.0
	Suria Capital	Papar	2.0
	BP Energy	Kunak	5.0
	Gaya Besar/Constant	Beaufort	5.0
	Sun Energy	Sandakan	10.00

4.4.2.2 Water-Food Nexus in Sabah

Relative to many states – especially those analysed previously in this report – water-food nexus interlinkages are rather limited in Sabah. This owes to the fact that Sabah is not a significant producer of rice nationally, with its agricultural sector dominated by the production of oil palm. Paddy production in Sabah amounted to 122,390 tons in 2018, just 4.6% of total national production. For vegetables, Sabah ranks fifth, producing 4.3% of the national total, while for fruit Sabah accounts for just under 7% of national production. The largest granary area in Sabah is located in Kota Belud, with an area of 3,735ha. Its production of 30,096MT in 2018 gives it a yield of 3,112kg/ha, significantly lower than the national average of over 4,600kg/ha. Several other mini-granary areas make up the remainder of rice production in Sabah; these cover an area of around 14,000ha. For animal husbandry, Sabah is again not a significant national producer. NWRS (2011) projects that Sabah would require roughly 8.5MCM of fresh water in 2020 for the purposes of washing and drinking, as well as water use in abattoirs.

The most significant food crop produced in Sabah is oil palm. Using assumptions made in previous state reviews, it is assumed that the 4.64 million MT of oil palm produced in the state in 2019 required the use of roughly 6.32MCM of potable fresh water.

5.0 NEXUS AT THE RIVER BASIN LEVEL: A FOCUS ON SUNGAI PERAK

The main objective of this section of the report is to conceptualise and develop an analytical framework for a Revenue Stream Model for the Sg. Perak basin, and to quantify both direct and indirect value of water used by economic and non-economic sectors. This report is structured as follows: section 2 – geographical profile of Sg. Perak, section 3 – total economic value framework, section 4 – Sg. Perak ecosystem dynamics, section 5 – economic activities and output, section 6 – valuation method, section 7 – WFE nexus schematic of the Sg. Perak river basin, and section 8 – water quality analysis.

5.1 Introduction

Sg. Perak is the second largest river system in Peninsular Malaysia, flowing from the mountainous Perak-Kelantan-Thailand into the Straits of Malacca in Bagan Datoh with a length of around 427 km and a catchment area of 15,180 km^2. The major tributaries converging with Sg. Perak at the upper basins are Sg. Rui, Sg. Belum, Sg. Temenggor, and Sg. Piah. Meanwhile, Sg. Pelus, Sg. Kinta, and Sg. Bidor are the major tributaries at the lower basins. There are seven administrative districts within the river basin, which are Hulu Perak, Kuala Kangsar, Kinta, Perak Tengah, Batang Padang, Manjung, and Hilir Perak.

The Sg. Perak Basin is separated into three sections, each with its own set of terrain and land cover. Except for isolated hills and ridges in the North-South direction of the Kg. Gajah-Tanjung Tualang route, the lower parts of Sg. Perak consist of flat to gently undulating terrain and swampy areas. The second part lies between Parit and Chenderoh Dam with well-drained, moderately steep land that is largely planted with rubber trees. The catchment areas above Chenderoh is mountainous and mostly covered with forest. There is little cultivation along this part of the river course except for a small area around Gerik.

5.2 Total Economic Value Framework

Water can be valued using the total economic value framework as depicted in Figure 15. In general, total value of water can be divided into two broad classes, use value and non-use value. The use value of water can be further divided into direct use, indirect use, and option value. Direct use value refers to the explicit use of water resources for consumptive and non-consumptive purposes. Consumptive usage includes the use of water for agriculture, manufacturing, mining and quarrying, construction, domestic purposes. On the other hand, non-consumptive uses include water usage in recreation, cultural activities, and generating hydroelectric power. Indirect use value represents the indirect environmental services provided by water such as nutrient cycling, water purification, hydrological function, and also flood control. Option value represents the value of maintaining future options for water usage. It reflects the values of all services, including supporting activities that would be available for future use, either directly or indirectly.

Non-use value of water can be classified into existence and bequest values. Existence value relates to the intrinsic value of water and water ecosystem that includes supporting services such as biodiversity. Subsequently, bequest value refers to the value of water-related ecosystems left or preserved for future generations.

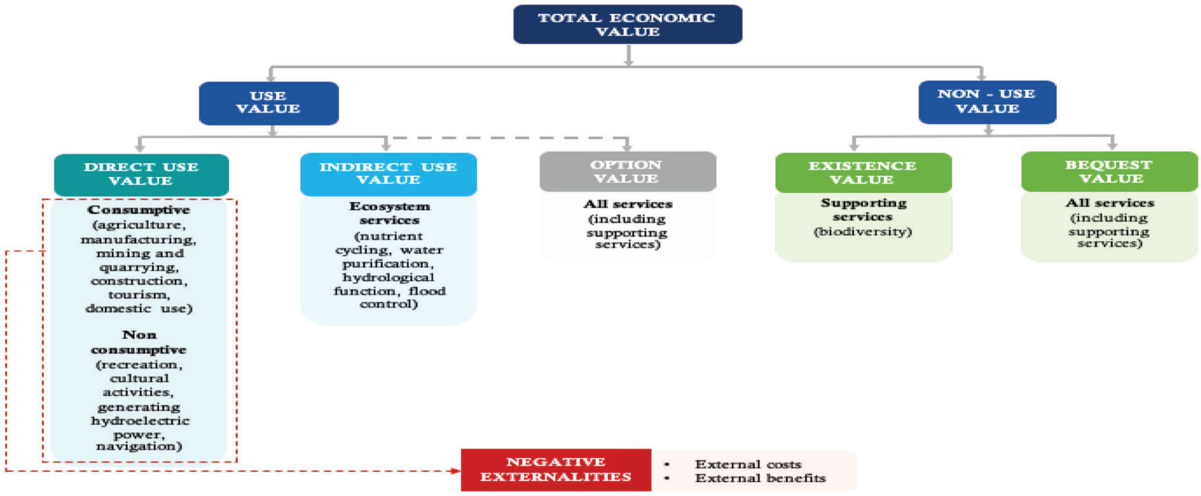
It is important to note that consumptive and non-consumptive use of water can cause externalities. Externalities refer to the external costs or external benefits to a third party that are not related to the production or consumption of that particular product or service. An example of externalities from consumptive use of water can be illustrated using the mining and quarrying sector. This sector produces external benefits such as job creations and improvements to infrastructure. However, there are also external costs associated to mining and quarrying such as flooding, water pollution, loss of land, reduced access to food, reduce groundwater recharge, and loss of vegetation. The damage to the ecosystem will affect not only the parties involved in the mining and quarrying activities, but also the people in the surrounding area that have no direct nor indirect involvement.

Externalities from non-consumptive use of water can be illustrated using the case of hydroelectric generation. The hydroelectric sector produces external benefits such as lower greenhouse gas emission when compared to coal-fired power stations, increase the environmental capacity of water, conservation of freshwater habitats, and flood and drought protection. Conversely, hydroelectric generation also leads to external costs such as reducing the aquatic system connectivity (affects the migration of fish and other animal species), and altered the flow regimes (change in sedimentation levels), which can lead to rapid changes in water temperature. These externalities need to be addressed to improve social well-being as well as to preserve the environment.

5.3 Sg Perak Ecosystem Dynamics

The ecosystem dynamics framework provides a brief description of the hydrological system of Sg. Perak and its interactions with the economy (Figure 16). The main sources of water for the river system, which spans a length of 427km, come from precipitation and ground water discharge. Sg. Perak is the main source of income and food for more than 2.51 million of Perak's inhabitants by providing essential input for the agriculture, manufacturing, mining and quarrying, construction, and tourism industries. It also provides potable and non-potable water for the domestic sector.

The main agriculture sectors in Perak are oil palm, paddy, rubber, coconut, fruits, vegetables, aquaculture, and livestock. Sg. Perak contributes approximately RM240 millions to the state's paddy production and RM1.94 billion for fishery/aquaculture production (WST2040 Model Study).



Source: Adapted from UNESCO (2021)

Figure 28. Total Economic Value Framework, Sg. Perak River Basin

The direct and indirect use of water generate negative externalities such as contamination and pollution, which can affect the availability of water resource needed, thereby reduce the water supply for future use. However, the contaminated and polluted water will go through the wastewater treatment process, which lead to CO2 emission to the air, or natural ecosystem treatment services (water purification, nutrient cycling) before it can be released back into the groundwater inflow and surface water inflow, for the purpose of domestic and economic uses.

Similarly, the untreated water will also be channelled back to groundwater inflow and surface water inflow. These polluted and contaminated water contains saline intrusion and chemical (organic, organic, microbiological pollution) and could lead to backwater effect. The detail reporting on water quality analysis is provided in Section 5.7 using Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Ammoniacal Nitrogen (NH3-N), Suspended Solids (SS), and pH. Therefore, maintaining the current water consumption especially for direct water usage is important, as highlighted in the option value.

The water resources of Sg. Perak are comprised of raw water and alternative water, namely grey water, recycled water, wastewater, as well as storm water. As the Sg. Perak is an open basin, spillage represents water that cannot be stored and flows. All the residual storage capacity is transferred to spillage. Moreover, the reservoirs storage capacity is constructed to store the water in the rainy season and release it when the river flow is low to ensure an adequate and dependable water supply. It is also important for the function of flood control and the generation of hydroelectric power with a total installed capacity of about 1249MW.

The groundwater inflow and surface water inflow also reflects the non-use values in the total economic value framework. Therefore, it should be well preserved and conserved, as it will determine the future consumption.

5.4 Economic Activities and Output

Perak is the second largest state in Peninsular Malaysia with a geographical size of 20,976 sq. km. In comparison with other states, Perak is the 7th largest economy in Malaysia, which contributes about RM76 billion GDP with 4.1% annual growth rate in 2019 (DOSM, 2021). The agriculture sector contributed 14.9%

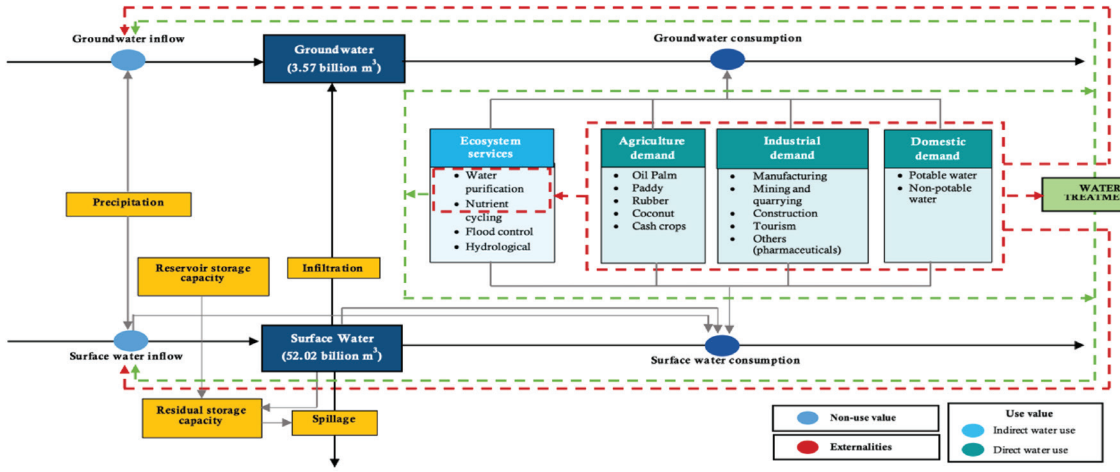


Figure 29. Sg. Perak River Basin Ecosystem Dynamics

(RM11 billion) to total GDP, followed by services sector – 63.1% (RM48 billion), manufacturing sector – 18% (RM13 billion), construction sector – 3.3% (RM2 billion), and mining and quarrying sector – 0.7% (RM505 million).

The economic performance in Perak could partly be associated with adequate water supply from Sg. Perak. Apart from being the main source of water supply to the majority of Perak's 2.48 million population, Sg. Perak plays a vital role for economic and ecosystem services in the state. It provides major input for the economic sectors in Perak such as agriculture, mining and quarrying, manufacturing, construction, tourism, as well as utilities (Figure 17), and its contributions are further discussed in the next section.

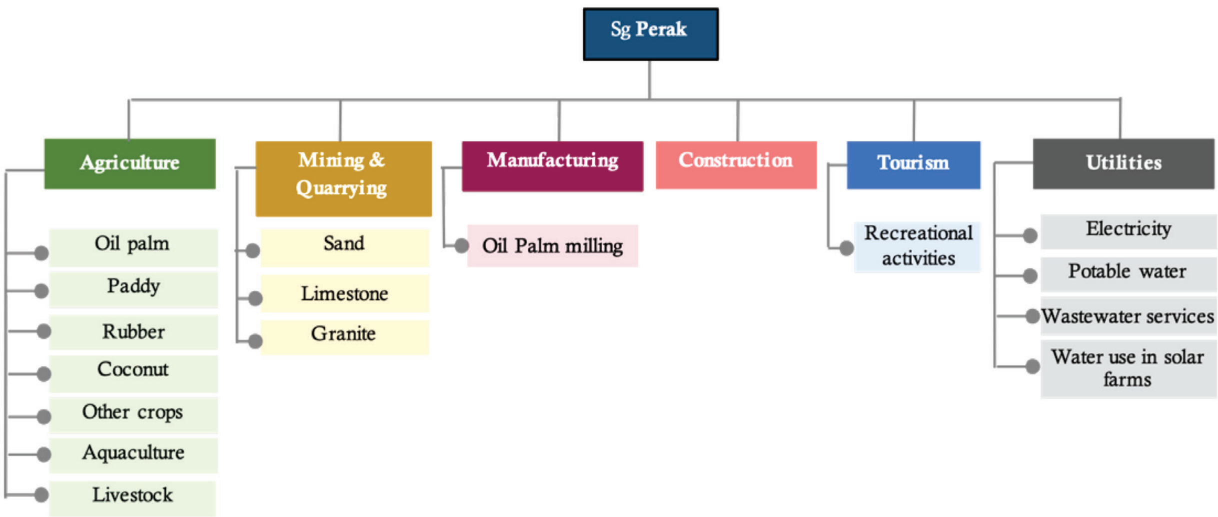


Figure 30. Economic Activities and Outputs in the Sg. Perak River Basin

5.4.1 Agriculture

Agriculture plays a crucial role in supporting the economic performance of Perak. The major crops are oil palm, rubber, coconut, paddy, and horticulture, occupying an area of 780,850 hectares (ha), which accounts for 37.2% of the state's total land use of 2,099,808 hectares (Perak Draft Structure Plan Study for Perak 2040, 2015).

Oil Palm

Perak, has the fifth highest acreage of oil palm cultivation in the country after Sabah, Sarawak, Johor, and Pahang. In 2020, the total planted area for oil palm in Perak is about 391,768 ha, with 19.51 tonne/ha FFB yield and 3.75 tonne/ha oil yield (Table 44). The state oil palm production in 2016 was 26,983 MT and valued at approximately RM13.5 million (Table 2945).

Table 44. Oil Palm Production Statistics in Perak, 2018 to 2020

Year	Total Planted Area (ha)	FFB Yield (tonne/ha)	Oil Yield (tonne/ha)
2018	413,311	19.38	3.72
2019	407,603	19.40	3.75
2020	391,768	19.51	3.75

(*Source*: MPIC (2020))

Table 45. Value of Oil Palm Production in Perak, 2014 to 2016

Year	Quantity (MT)	Value (RM)
2014	-	-
2015	27,290	13,645,000
2016	26,983	13,491,500

(*Source*: Malaysian Palm Oil Board (MPOB) in Basic Data Negeri Perak Darul Ridzuan 2016)

Oil palm cultivation is water-intensive, sipping water from the root zone and contributing to higher evapotranspiration level. A study by Hashim et al. (2014) in 281 plantations covering an area of 440,000 ha reported that oil palm plantation relies 90.5% on rainfall (green water) for its growth, followed by 9.18% from grey water, and 0.31% from blue water.

Paddy

Perak is the 3rd largest paddy producer in Malaysia. In 2018, the state produces 336,395 metric tonnes of paddy, which accounts for 11.4% of the country's total paddy production. The crop is cultivated in Kerian, Trans Perak schemes (Seberang Perak, Sg. Manik), and 11 other mini granaries with a total area of 42,882 ha. The water source for irrigation for Kerian is mainly from Bukit Merah. Sungai Perak provides irrigation for the Trans Perak schemes, which is around 14,847 ha, and 7,000 ha of small irrigation areas.

Energy requirement for irrigation in the Trans Perak scheme is usually low, since the area depends on Sungai Perak for water supply without the need for pumping. Pumping at the field level would only be necessary if the water level in Sg. Perak falls below 8.6 m. Nonetheless, drought would increase the irrigation cost. For example, in a dry year like 2014, the cost of fuel to run the mobile pumps is estimated to be around RM400,000 (Hezri, 2015).

In total, Perak needs about 480 MCM of water to be lifted for paddy irrigation annually. Taking into consideration case studies in other states, it is also assumed about 13.625 kWh energy use to pump 1,000 m^3 volume of water with an average lift of 3m and 60% pump efficiency. Thus, to irrigate the fields in Perak, a volume of 480 MCM of water would require an annual energy volume of 6,540,000 kWh.

Table 46. Paddy Schemes, Production, and Yield in the Sg. Perak River Basin, 2018

Scheme	Acreage (ha)	2018 Production (MT)	Average Yield (kg/ha)
Kerian	23,5591	184,617	4,414
Seberang Perak	8,529	115,661	4,169
Sg Manik	6,318	(Included in above)	(Included in above)
11 Mini Granaries	5,841	50,280	4,344
Total	42,882	336,395	

(*Source*: DOA, 2019 and NWRS,2011 - 1 Include Sg. Acheh in PP 1,365ha)

2014	278,950	361,350,221
2015	339,759	520,985,938
2016	320,648	497,004,400

(*Source*: Perak Agriculture Department in Basic Data Negeri Perak Darul Ridzuan 2016)

Rubber

Rubber plantation areas in Perak are located in Manjung, Kuala Kangsar, Larut Matang/Selama/Kerian, Batang Padang/Hilir Perak, Hulu Perak, and Perak Tengah/Kinta. As of 2016, Hulu Perak remains the largest rubber plantation area occupying 38% of the 39,494 ha of rubber plantation area in Perak (Table 47).

Table 47. Rubber Plantations and Production in Perak, 2014 to 2016

District	Area (ha)		
	2014	2015	2016
Manjung	2,475.44	2,562.68	2,570.92
Kuala Kangsar	7,226.11	7,635.83	6,834.03
Larut Matang/Selama/Kerian	9,403.04	9,555.31	6,634.47
Batang Padang/Hilir Perak	4,047.02	4,229.39	4,037.45
Hulu Perak	14,466.92	15,017.25	15,186.54
Perak Tengah/Kinta	4,273.05	4,445.20	4,230.87
Total	**41,891.58**	**43,445.65**	**39,494.28**

(*Source*: Rubber Industry Smallholders Development Authority (RISDA) in Basic Data Negeri Perak Darul Ridzuan 2016)

Rubber production in 2016 was reported at 4,962 MT with an estimated value of RM11,661,955 (Table 48).

Table 48. Value of Rubber Production in Perak, 2014 to 2016

Year	Quantity (MT)	Value (RM)
2014	-	-
2015	4,646.86	8,829,034
2016	4,962.53	11,661,955

(*Source*: Rubber Industry Smallholders Development Authority (RISDA) in Basic Data Negeri Perak Darul Ridzuan 2016)

Coconut

In 2019, Perak is the 3rd largest coconut producer in Malaysia with 78,644 tonnes of output, after Selangor (99,760 tonnes) and Johor (99,375 tonnes). The planted area in the state is 7,594ha, which accounts for 9% of the country's total planted area of 86,466.3ha.

Table 49. Coconut Production in Perak, 2017 to 2019

Year	Planted Area (ha)	Harvested Area (ha)	Production (tonnes)
2017	9,337	9,142.90	82,466.30
2018	7,835*	7,584.10*	65,900.60*
2019	7,594	7,404.90	78,644.30

(*Source*: Industrial Crop Statistic, DOA (2019))

Table 49 present the coconut production and its corresponding value in Perak in according to district in 2016. The highest coconut production is from the Hilir Perak district with 80,702,541.48 MT valued at RM 79,246,083 (Table 9). Overall, the coconut production value in Perak during that year was RM88,955,328 with more than 87 MT of production.

Table 50. Value of Coconut Production in Perak, 2014 to 2016

District	Production (MT)	Production Value (RM)
Batang Padang	331,117.00	457,356.40
Hilir Perak	80,702,541.48	79,246,083.35
Hulu Perak	13,502.00	14,414.00
Kerian	349,212.03	552,972.00
Kinta	922,521.00	1,575,057.60
Kuala Kangsar	563,480.00	721,708.20
Larut Matang & Selama	3,718,974.00	4,646,632.80
Manjung	924,289.11	1,338,324.70
Perak Tengah	364,218.00	402,779.00
Total	**87,889,854.62**	**88,955,328.05**

(*Source*: Perak Agricultural Department in Basic Data Negeri Perak Darul Ridzuan 2016)

Other Crops

Cultivation of fruits, vegetables, and cash crop in Perak occupies 10,951, 6,956, and 4,290 hectares of land in state with 116,951, 113,260, and 74,546 MT respectively (Table 51). Tables 52, 53, and 54 report the quantity and value of fruits, vegetables and cash crops production in the state from 2014 to 2016.

Table 51. Other Crop Production in Perak, 2018

Scheme	Quantity (MT)	Area (ha)	% National
Fruits	116,951	10,951	7.12
Vegetable	113,260	6,956	10.69
Cash crops	74,546	4,290	31.31

(*Note*: Cash crops include sweet corn, groundnut, cassava, sweet potato, sugar cane, and chestnut.
(*Source*: DOA (2019))

Table 52. Quantity and Value of Fruit Production in Perak, 2014 to 2016

Year	Quantity (MT)	Value (RM)
2014	97,501	174,504,220
2015	127,872	254,224,748
2016	112,633	298,443,959

(*Source*: Perak Agriculture Department in in Basic Data Negeri Perak Darul Ridzuan 2016)

Table 53. Quantity and Value of Vegetable Production in Perak, 2014 to 2016

Year	Quantity (MT)	Value (RM)
2014	58,777	112,118,580
2015	69,568	145,348,305
2016	88,910	184,838,687

(*Source*: Perak Agriculture Department in in Basic Data Negeri Perak Darul Ridzuan 2016)

Table 54. Quantity and Value of Cash Crop Production in Perak, 2014 to 2016

Year	Quantity (MT)	Value (RM)
2014	36,583.58	53,809,070.01
2015	41,357.73	58,316,574.03
2016	53,111.50	101,377,507.83

(*Source*: Perak Agriculture Department in in Basic Data Negeri Perak Darul Ridzuan 2016)

Considerable amount of water is needed for the production these crops. The water requirement for vegetables is reported to be high. The soil needs to always be wet so that the plants can take up as much water as possible for faster growth. The irrigation need for vegetables is assumed to be to two times its evaporative loss of water. The volume of water required to produce other crops is also high. Fruits and herbs need to be irrigated to 1.5 times their evaporative loss of water. It is estimated that Perak will require around 70 MCM of water for the production of other food crops by 2050 (NWRS, 2011).

Aquaculture

In 2008, Perak was Malaysia's largest freshwater aquaculture producer and the second largest brackish/ marine water aquaculture producer. There is a total of 2,698 aquaculture farmers in the state with various production technologies including pond culture (55.1%), ex-mining pool (10.1%), river cage culture (2.9%), pen (7.1%), cement tank (5.6%). The remaining 9.6% are ornamental pond farmers. There main districts for aquaculture are Kerian, Selama, Larut Matang, Kuala Kangsar (U), Kuala Kangsar (S), Kinta, Kampar, Perak Tengah, Manjung, Batang Padang, as well as Hilir Perak. In 2019, Perak produces about 72,620 tonnes of aquaculture products valued at RM 708,958,943 (Table 55).

Table 55. Quantity and Value of Aquaculture Production in Perak, 2017 to 2019

Year	2017		2018		2019	
District	Quantity (tonnes)	Value RM)	Quantity (tonnes)	Value (RM)	Quantity (tonnes)	Value (RM)
Kerian	10,279	150,387,470	10,626	160,275,891	12,435	211,006,163
Selama	39	1,396,564	67	2,480,468	16	884,058
Larut Matang	9,535	84,465,746	10,728	97,976,526	10,856	104,939,249
Kuala Kangsar	732	9,721,499	815	11,159,771	785	9,627,905
Hulu Perak (U)	1,894	9,564,914	2,605	13,565,229	1,534	13,352,688
Hulu Perak (S)	131	1,671,367	139	1,818,515	149	2,062,122
Kinta	7,839	35,946,821	7,895	37,322,549	11,110	57,164,849
Kampar	8,498	33,486,597	9,936	40,363,111	10,480	44,832,817
Perak Tengah	228	2,463,384	231	2,567,590	268	2,743,078
Manjung	7,054	141,992,815	6,811	141,342,742	8,621	152,997,045
Batang Padang	12,781	74,754,165	15,297	92,235,786	13,254	83,445,298
Hilir Perak	2,445	20,961,615	2,339	20,671,104	3,113	25,903,672
Grand Total	61,456	566,812,957	67,489	621,779,281	72,620	708,958,943

(*Source*: Basic Data Negeri Perak Darul Ridzuan 2017 – 2019)

Livestock

Perak produces 57,961 MT of livestock output in 2019, with pork being the highest (56,548 MT), followed by cattle (799 MT), raw hides skin and leather (251 MT), buffaloes (202 MT), goat (108 MT), sheep (35 MT), deer (14 MT), and milk (4 MT).

Table 56. Livestock Production in Perak, 2017 to 2019

Year	Quantity (MT)	Value (RM million)
2017	54,774	649.57
2018	55,134	652.53
2019	57,961	692.3

(*Notes*: Livestock including beef cattle, beef buffaloes, mutton goat, mutton sheep, mutton deer, milk, pork, raw hides skin and leather.)
(*Source*: Basic Data Negeri Perak Darul Ridzuan 2017 – 2019)

Table 56 reports the water consumption by the livestock industry in Perak. Livestock water consumption can be divided into wash, drinking, and abattoir water requirements. The total amount of water required for livestock production in 2010 is 6.5 million m^3 and it is projected to increase to 21 million m^3 by 2050.

Table 57. Livestock Water Requirements in Perak (m^3 per year)

Year	Wash Water Requirement for Livestock	Wash Water Requirement for Poultry	Drinking Water Requirement for Livestock	Drinking Water Requirement for Poultry	Abattoir Water Requirement	Total Water Requirement
2010	6,985,849	5,015,098	3,092,967	6,206,019	842,677	22,142,610
2020	8,793,596	6,510,601	4,019,332	8,170,055	1,136,496	28,630,080
2040	14,319,673	11,046,504	7,147,680	16,553,868	2,098,486	51,166,211

(*Source*: NWRS (2011))

5.4.2 Mining and Quarrying

Granite and Limestone

Water is an important requirement for the mining and quarrying sector. Perak was the seventh largest quarry rock producer in Malaysia in 2016 with the production of 24.61 million tonnes of granite and 15.78 million tonnes of limestone (Appendix: Table 17a).

Tin

Perak is the most important tin producer in Malaysia (Ahmad and Jones, 2013), producing 82% of the country's tin output of 3,895 tonnes in 2019 (Appendix: Table 18a). Kinta district has the most ex-mining land with 47,614 ha (58.2%), followed by Batang Padang 21,064 ha (25.8%), Perak Tengah 5,095 ha (6.2%), Larut Matang 4,610 ha (5.6%), Kuala Kangsar 1,581 ha (1.9%), Hulu Perak 982 ha (1.2%), Manjung 661 ha (0.8%), and Hilir Perak 143 ha (Osman and Ishak, 2012).

Sand

River sand is a major component in construction materials. In Perak, the demand for these materials continues to rise where 110 cases of illegal sand mining activities were recorded up to May 2015. In comparison to the previous year, it was only 99 cases of illegal sand mining were caught. Other than causing negative impact to sand revenue, increase in the volume of extracted sand also caused river bed degradation. This worse case is happening at the Jambatan Iskandar station (Ministry of Natural Resources and Environment 2010). By incisions and deep down-cutting into the canal bottom, this in-stream mining operation lowers the river bed level, which may lead to worsening bank collapse and erosion, endangering the structural integrity of the river banks.

Based on the 10–50 year data period, the likely river aggradation or degradation along Sg. Perak was assessed modest, with less than 0.5 m. However, if the trends and scale of sand mining and theft continue, river bed erosion may intensify in the future years (Hezri, 2018). Currently in Perak Tengah, seven operators have been approved for a total 1,100,000 m^3 for one year and 660,000 m^3 for two years, which located at Kg. Baru, Tanjung Aur, Kg. Pulau Pisang, Pulau Juar, Padang Tenggala, Kubang Chandong, as well as Wilayah Jalan Gudang. Meanwhile in Daerah Hilir Perak, the amount of sand mining is even higher, which is about 2,300,000 m^3 for a total number of three operators approved in Muara Sg Bagan Datuk, Kg. Sg Sengkoh, Kg. Sg Suli, and Muara Sg. Bidor.

5.4.3 Manufacturing

Palm Oil Milling

Perak has established a strong industrial base, depending on manufacturing as a powerful economic engine that contributes about 4.3% (RM14 billion) to total GDP, focusing on automotive, high tech manufacturing, and heavy industries (NCER, n.d.). Perak is the fifth largest state in Malaysia for palm oil manufacturing. It contributes about 10% of FFB processed by mills in 2019, which is equivalent to 9,582,173 tonnes. There are 45 mills in the state with annual FFB processing capacity of 10,215,000 tonnes and 4 palm oil kernel crushing mills with 820,000 tonnes processing capacity.

5.4.4 Tourism

Perak is well known for tourism due its cultural heritage and also attractive sites, many of which centres around the Sungai Perak Basin. In 2019, the state receives 21.07 million domestic visitors and 10,113 million domestic tourists, where 5.4 million arrivals were reported for the Sg Perak Basin (Perak Draft Structure Plan 2040). The Perak River Basin comprises the Royal Belum, Ulu Geruh, Lenggong, Sg. Perak and major cities and towns that includes Ipoh, Kuala Kangsar, and Teluk Intan (RSN, 2040). Sg. Perak provides spectacular settings, water-based recreational opportunities, adventure, and other tourist attractions. There are 9,151 hotel rooms in cities and towns within the Sg. Perak Basin representing 64% of the total 17,742 rooms in the state. Sustaining the Sg. Perak ecosystem is significant, as the tourism value in Sg. Perak is estimated about RM 5.53 billion.

5.4.5 Utilities

Electricity

Sg. Perak has a series of hydroelectric dams that produce power for Peninsular Malaysia with a total installed capacity of about 1249MW. It provides about RM 6 billion worth of energy value, with 152,960,000 MWh electricity generation in 2019 (MEIH, 2018). The four main dams are located at the upstream part, known as Temengor, Bersia, Kenering, and Chenderoh. Other than hydroelectric power generation purpose, these dams also act as flood control structures. Temengor, the largest of the four dams, has a 239 metre average water level. Meanwhile both Chenderoh and Kenering have the average depth of 60.2 and 110 metre, respectively.

Power is proportional to the height of the water in the dam. Thus, it is important to keep the dam level at the maximum level, because any reduction in the dam level will create the cost of lost generation. For example, Temengor dam, the minimum operating level is 237m and the water will automatically spill when it reaches 248.2m level.

In Perak, the total electricity supply capacity in 2019 is about 5,775 MVA with 1,448.56 MVA maximum load, and 25.1% usage (Table 58). Manjung power plant, also known as the Sultan Azlan Shah power station delivers about 2100MW of net power from three units of 700 MW generators. The plant runs on bituminous and sub-bituminous coal as fuel. In 2015 a new unit utilising supercritical technology started its operation resulting in a total design capacity of 3100 MW. Its operation also requires a lot of water for condensing steam purpose, which is demonstrated in Table 13. The water supply for Janamanjung station comes from Teluk Kepayang water treatment plant, which is operated by Lembaga Air Perak (LAP).

Table 58. Water Consumption and Associated Costs for Janamanjung Thermal Power Plants, 2011 to 2015

Year	Station Total Capacity (MW)	Water Consumption (m^3)	Annual Water Bill (RM)
2011	2,100	2,506,022	4,034,695.42
2012	2,100	1,684,057	2,711,331.77
2013	2,100	2,076,208	3,342,694.88
2014	2,100	2,336,761	3,762,185.21
2015	3,100	na	na

(*Source*: Tenaga Nasional Berhad in an Overview Study of Water-Food-Energy Nexus in Malaysia.)

Potable Water

The water supply penetration in urban coverage is 100% while rural coverage is 99.3%, where almost half (45%) of the supply is from Sg. Perak. It is about 87.5% water supply used for domestic connection and 12.5% used for non-domestic connections (Table 59).

Table 59. Water Supply Statistics in Perak, 2017/18

	2017	2018
Domestic Connection (nos)	676,619 (87.5 %)	687,941 (%)
Non-Domestic Connections (nos)	96,730(12.5%)	98,733 (%)
Production Volume (mld)	1,3211,333	
Production Capacity (mld)	1,887	1,839
Production Utilise (mld)	908	933
NRW	30.9%	30.0%

Table 60 indicates the availability and demand for water resources from various sectors from 2010 to 2050. It can be seen that the future potable water demand in 2050 is about 677.1 MCM per year, which is 119 MCM higher than potable water demand in 2020. Meanwhile, it is about 71.3 mm water demand from rainfall needed in 2050, compared to 58.7 mm water demand from rainfall in 2020.

Table 60. Actual and Projected Potable Water Demand in Perak, 2010 to 2050

Sectors	2010	2020	2030	2040	2050	2010	2020	2030	2040	2050
	Water Demand m/c/m per year					Water Demand mm rainfall per year				
Potable Water Demand	486.5	558.1	595.0	634.4	677.1	51.2	58.7	62.6	66.8	71.3

(*Source*: NWRS (2011))

The water resource in Perak is always sufficient to support the local needs, as the water demand is lower than the water supply. Therefore, there is always water surplus and the amount is estimated to increase by 0.14% in 2050.

Based on the rate of 0.29 kWh/m^3 with 1,321 MLD volume of daily production, the total daily energy requirement is equal to 397,000 kWh. Furthermore, it is about 0.96 m^3 average of daily domestic consumption, given the amount of water used and number of connections. A typical 30m^3 of potable water usage per household of 5 people per month would consume about 9kWh of energy and this is equivalent to about RM1.96 of electrical usage based on recent TNB's tariff of RM0.218/kWh.

Wastewater Services

Of Perak's population of 2.49 million in 2017 (DOSM, 2020), around 71.8% is covered by a central wastewater plant. In total, Perak is reported to have 997 regional wastewater treatment plants which cover a PE of 1,787,334.

By assuming a typical usage of 150 litres/person/per day of wastewater (NWRS, 2011), the volume of wastewater produced and treated in a regional wastewater treatment plant in Perak would be approximately 268,100 m^3/day.

The rate of energy used per volume of water treated in Perak is 0.254 kWh/m^3. This value is taken from China cases, since it have the lowest rate compared to EU and US that provide a rate range between 0.3 to 2.1 kWh/m^3 and 0.41-0.87 kWh/m^3, respectively. However, the rate 0.254 kWh/m^3 should also be referred to the main national wastewater management operator, namely Indah Water Konsortium (IWK) for the purpose of this report. From all the assumptions made, the energy required to treat wastewater in Perak given below (68,097 kWh/day) is just for or domestic treatment purposes only and does not include the energy required to treat wastewater from industrial premises which are governed by the Environment Quality Act (EQA). In summary, Perak's anticipated daily energy demand for combined water and wastewater treatment is 465,097 kWh per day, with an annual volume of 169,760 MWh per year.

Water Use in Solar Farms

Perak is said to be one of the two leading states in terms of solar energy production. It represents 19.6% of the national solar installed capacity by producing 198.87 MW solar energy. In the case of water use, most studies assumed that solar farms only consume 90 litres per MW/hr, as compared to that used for thermal power plants.

5.5 Valuation Methods

In general, this study has identified several valuation methods from five published reports in the context of several countries such as European Union (EU), Armenian, and Turkey, as well as from international organisation including United Nations (UN), Ecorys, International Union for Conservation of Nature (IUCN), World Bank, The Nature Conservancy, European Water Initiative (EUWI), and United Nations Economic Commission for Europe (UNECE). The methods can be organised into the following categories:

5.5.1 Market-Based Approaches

The data from actual markets is used in these approaches to represents the actual preferences or costs to individual. Usually, the data for these approaches are easily to obtain. However, the fundamental drawback of these approaches is, many ecosystem services do not have markets, or if they do, they are often distorted. There are several approaches that belongs to this category, which are:

Market price-based approaches is the most basic approach to valuation, in which the value of items is estimated based on their market price. These methods are mostly used to determine the worth of provisioning services, as commodities generated by provisioning services are frequently traded on markets (e.g., residual value - changes in net income). It reflects the difference between the value of the output and the costs of all non-water inputs to production (UNESCO, 2021). Several applications exist in the United States (Loomis, 1992; Brown, 2006), Australia (Grafton et al., 2011), and Chile (Loomis, 1992; Brown, 2006) to estimate the economic value of water for irrigation (The World Bank Group, 2016).

Cost-based approaches is based on the costs estimations that would be incurred if ecosystem service benefits had to be replicated artificially. For instance, the avoided cost method, the replacement cost method, and the mitigation or restoration cost method (OECD, n.d.).

Production function-based approaches is used to calculate how much a particular ecosystem service contributes to the delivery of another service or commodity that is exchanged on existing markets. In other words, these approaches calculate how much ecosystem services contribute to an increase in income or productivity (OECD, n.d.). However, instead of market-based approaches, the World Bank Group (2016) and the IUCN, the Nature Conservancy, and the World Bank (2004) has categorised these approaches under revealed preference methods, that can be constructed based on econometric models - crop water production functions, or mathematical programming or general equilibrium approaches (Johansson, 2005).

In China, these methods have been used to estimate the value of crop water yields (Liu, 2007). Meanwhile in Poland, the methods have also been used to analyse industrial water demand for power plant (Stone & Whittington, 1984). The limitations found in these approaches are the lack of data that measured the change in service and consequent impact on production (IUCN, the Nature Conservancy, & the World Bank, 2004).

Avertive expenditures or so called defensive expenditures assuming that individuals spend money for the purpose of mitigating and elimination damages caused by environmental degradation. In the context of water resources, there are several applications that reflect different cost aspects: household-level costs associated with groundwater contamination in the United States, such as the purchase of bottled water or water filters, and cleaning and repairing water systems (Abdalla, 1994); and the additional cost of purchasing bottled water in Lebanon (Sarraf et al., 2004).

5.5.2 Revealed Preference Techniques

These techniques are based on non-market values or the analysis of individual choices in existing markets, related to the ecological service being valued, such as change in the value of real estate of an area when the surrounding landscape improves or deteriorates (Schellekens et al., 2018). Commonly used methods in the water context include:

Travel cost method is based on recreational value of ecosystems. It assumes that recreational experiences are associated with a direct expenses and opportunity cost of time to visit the site. The travel cost reflects preferences for the ecosystem function from which site demand is derived. Direct queries about customers' WTP can be used to acquire information on the value of an environmental benefit (The World Bank Group, 2016). Since it is limited to recreational benefits, therefore, it is hard to use for multiple trips that involved with multiple destinations (IUCN, the Nature Conservancy, & the World Bank, 2004).

Hedonic pricing is associated with the for an environmental attribute to the demand for a marketed commodity. The application for this method is more towards air quality, scenic beauty, as well as cultural benefits. As a result, the value of a change in the environmental good will be reflected in a change in the value of property, which can be inferred through estimating the demand function for property (OECD, n.d.).

This method has been discussed under revealed preference methods by The World Bank in Turkey context and it have been used in the United States (Petrie and Taylor, 2007; Mukherjee and Schwabe, 2012), Greece (Latinopoulos et al., 2004; Mallios et al., 2009), and Iran (Esmaeili and Shahsavari, 2011; Kakhki et al., 2010) to estimate the economic value of water for irrigated agriculture (The World Bank Group, 2016). Usually, it requires vast quantities of data and very sensitive to specification (IUCN, the Nature Conservancy, & the World Bank, 2004; The World Bank, 2016).

Cost of illness method is considered as a type of production function approach for estimating the monetary value of an environmental modification based on its impact on illnesses. It can be used to value the benefits of pollution reduction by estimating potential savings in direct out-of-pocket expenses (e.g., medicine, doctor, and hospital bills) and opportunity costs (e.g., loss of earnings due to illness); or actual health impacts from environmental degradation through WTP to avoid illness (The World Bank Group, 2016). In other words, this method measures any changes in the ecosystem that lead to health impacts such as water pollution.

Replacement cost method is usually applied to estimate the ecosystem service value. It is frequently applied when the market or shadow price of water cannot be determined or to represents any loss of goods and services. It reflect the price of that particular entity would have to pay to replace an asset at the present time, based on its current value. Therefore, the price should be carefully estimated to avoid overestimation. This technique is considered as one of the market-based methods by The World Bank Group (2016) in valuing water resources in Turkey. It is assumed that environmental harm is quantifiable, and the value of an ecosystem service should not be higher than the cost of replacing it.

Derived demand functions used a demand curve based on actual water sales or the contingent valuation approach, coupled with econometric analysis to determine total economic value. (UNESCO, 2021). Specifically, this method represents the user's WTP for water. Water transactions are observed between water utility suppliers and individual water users at specific prices to obtain the WTP and demand for water. Application of this method is found to obtain the demand and value of municipal water consumption in several countries such as Honduras, Madagascar, as well as Vietnam (Nauges and Whittington, 2010).

Alternative cost method or known as "substitute" cost method is basically the cost of available alternatives for a particular non-priced good (e.g. consumer good or input factor) or service. For example is an input factor in the context of water resources are surface water for irrigation (which could be substituted by groundwater), water for hydropower generation (which can be replaced by thermal or renewable energy), or water for navigation (which can be substituted by rail or trucking). This method posits that if the two options provide the same service, the value of the non-priced good (water) is equal to the saved cost from selecting the alternative (The World Bank Group, 2016).

5.5.3 Stated Preference Approaches

These methods use surveys on hypothetical (policy-induced) changes in the ecosystem service provision to simulate a market and demand for ecosystem services. It can be used to estimate both the use and non-use values of ecosystems. Moreover, these methods are frequently the only methods for non-use values estimation (OECD, n.d.). The main techniques are:

Contingent valuation method is simply obtain by asking a sample of people how much they would be willing to pay for the item in given questions. This method is usually applied to determine the value of ecosystem goods and services that have no-market price. For instance biodiversity, good water quality or recreation (UNESCO, 2021). It can be done by distributing questionnaires to random people in selected sample areas. For example, the list of CVM studies in Perak are as the following:

Table 61. List of CVM Studies in Perak

Authors	Title	Area	Objective	Results
Ramli et al. (2017) *Malaysian Forester*	Willingness to pay for conservation fee using contingent valuation method: The case of Matang Mangrove Forest Reserve, Perak, Malaysia	Matang Mangrove Forest Reserve, Perak	To estimate the WTP for the conservation fee among consumptive direct users (Fishermen) and non-consumptive direct users (Visitors) of the mangrove forest	WTP for the conservation fee is RM17.60 and RM8.38 per year for visitors and fishermen.
Ahmad (2009) *Journal of Tropical Forest Science*	Recreational values of mangrove forest in Larut Matang, Perak	Larut Matang, Perak	The study was aimed at estimating recreational benefits (direct service values) of the mangrove ecosystem.	The recreational values of the mangrove forest to local recreationists were estimated at RM44.58 per visit, and at the mean, the WTP function indicated the recreational value of RM41.18 per visit.
Kamil, & Tech (2019) *Doctoral Thesis*	Management strategy choices: An integrated evaluation for Pulau Sembilan State Park, Perak, Malaysia.	Pulau Sembilan State Park, Perak (May to August 2014, for 237 recreational anglers and 230 non-fishing recreational users)	To evaluate the closing strategy proposed and explore other alternative management strategies to manage Pulau Sembilan State Park	Recreational anglers are willing to pay RM6.75 (USD1.72) to get one extra targeted fish and RM1.92 (USD0.49) for one extra non-targeted fish. When multiplied to the average number of fish usually caught by one recreational angler in a trip and aggregated by the number of anglers in a year, these values are substantial, reaching RM 1,158,874 for targeted fish, and RM 187,359 for non-targeted fish.

Choice modelling method is also similar to contingent valuation method, except that each respondent can have more than one choice and it can be more than two alternatives. Moreover, rather than being asked their willingness to pay for one scenario, respondents are given a variety of alternative descriptions of a good, each characterised by its level and attributes, and asked to rank, rate, or choose their most favoured option (Hanley et al., 2001).

Group valuation method combines stated preference procedures with political science aspects of deliberative processes (OECD, n.d.).

Other than the evaluation of overall value of an environmental resources, the ***Choice experiment method*** also allows for evaluation on the implicit value of its attributes, their ranking, and the value of modifying multiple attributes at once (Hanley at al., 1998; Bateman et al., 2003). Furthermore, as reported by The World Bank Group (2016), the application of this method is found in estimating the WTP for improved water quality, quantity and biodiversity conservation in Cyprus (Birol et al., 2010).

5.5.4 Other Valuation Methods

Benefit transfer is a technique for estimating economic values for ecosystem services by transferring available information from previous research conducted in a different area and/or context. In other words, the value estimation at another "policy site" can be determine using the estimation value at the "study site". It is considered the most reliable method, especially when the characteristics of both sites are similar, such as quality, location, and population characteristics. For instance, recreational fishing values in a certain state can be approximated by using measures of recreational fishing values from another state's study (King et al., 2000).

Mathematical programming models is used to inform decisions on water allocation and infrastructure development. It specifies an objective, such as maximising output value, while taking into account production inputs such as water supply, institutional and behavioural constraints (UNESCO, 2021).

Tradeable water right is a technique to capture markets in the derivation of the value of water. The application of this method is found in the water trading schemes such as in Australia, Chile, Iran, South Africa, and Spain's Canary Islands, and in some of the western states of the United States of America (UNESCO, 2021).

Water footprint measures the amount of freshwater consumption for both direct and indirect purposes by an individual or group/producers. It can be calculated in terms of both water volume and monetary unit. For instance, the water footprint per unit of time is divided by income for consumers or turnover for businesses (UNESCO, 2021).

From the published reports that have been reviewed earlier, there are numerous approaches for valuing water. Each of the methods has both advantages and limitations. The categorisation of some methods is different for market-based approaches, revealed preference techniques, and stated preference approaches in certain reports. The application of these techniques should be guided by the availability of the data and the study's objectives. Moreover, "making apples and oranges comparable" is significant in valuing the ecosystem services (IUCN, the Nature Conservancy, & the World Bank, 2004, p.10). Therefore, most of the reports are suggesting expressing the valuation techniques results in monetary units which are widely recognised and readily understood by decision makers and public.

5.6 WFEN Schematic of the Sg. Perak River Basin

The schematic framework in Figure 18 shows that water resources play a crucial role for agriculture, hydropower operations, and for other economic sectors. The framework depicts the water withdrawal stations from Sg Perak, as well as their consumptive uses by several economic actors within the river basin, which are intricately involved within the WFEN. The flow of the Sg. Perak is drawn from the upper part (Hulu Sg Perak), to the lower part of the river (Hilir Sg. Perak). There are 4 major dams located at the upper areas, namely Temenggor, Bersia, Kenering, and Chenderoh that release approximately 100 to 200 MCM water downstream on a daily basis.

Water withdrawn from Sg. Perak is treated at the LAP before being channelled for both domestic and industrial usage in areas such as Gerik, Kuala Kangsar, Manjung, Ipoh, Perak Tengah, Teluk Intan, Kampar, and Tapah. Local water use requirement in Manjung areas is withdrawn from Sg. Manjung, and water withdrawn from Sg. Perak and treated in WTP Teluk Kepayang is the primary source of for the various thermal power plants in Manjung and Lumut.

Both granary and minor granary areas in Perak Tengah is also irrigated by Sg. Perak through the Trans Perak Irrigation Scheme, which is run jointly by Jabatan Pengairan dan Saliran (JPS) Perak and IADA Trans Perak. Even though oil palm and rubber plantations represent a major portion of the agricultural land in the Sg. Perak river basin and the state of Perak in general, these plantations also rely on ground water for irrigation. Palm oil processing, on the other hand, is widely known for producing harmful wastewater. This problem can be alleviated by using wastewater to generate energy (for example, through the production of biofuels).

Furthermore, the need for river sand as a construction material has increased due to rapid development. This has resulted in a mushrooming of river sand mining activities especially in Perak Tengah with a total of 1,760,000 m^3 sand mining occurred, as well as in Hilir Perak (2,300,000 m^3), causing a slew of issues including deterioration of river water quality from suspended sediment loading. Overall, the water quality index (WQI) in 2017 along the Sg. Perak river basin is recorded between the ranges of 81 to 92, or known as class II.

The effect of sand mining activities in Perak Tengah and Hilir Perak is shown schematically in Figures 19 and 20. For example in Figure 6, the sand mining activities that effect the downstream flow of the Sg. Perak river basin through Sg. Kinta are Tanjung Aur (400,000 m^3), Padang Tenggala (80,000 m^3), Kubang Chandong (80,000 m^3), Kampung Baru (200,000 m^3), and Pulau Juar (500,000 m^3). As a result, the amount of suspended sediment in Sg. Kinta is higher at 790 tonne/km^2/year. Moreover, the suspended sediment in Sg. Pari (564 tonne/km^2/year), Sg. Raya (256 tonne/km^2/year) and Sg. Chederiang (862 ton/km^2/year) also contributes to the higher amount of suspended sediment in Sg. Kinta.

Similarly in Figure 7, higher amount of suspended sediment in Sg. Bidor (147 tonne/km^2/year) and Sg. Perak (170 tonne/km^2/year) is due to the sand mining activities occurred in Kg. Sg. Sengkoh (200,000 m^3), and Kg. Sg. Suli and Muara Sg. Bidor (100,000 m^3). Both Sg. Batang Padang and Sg. Sungkai also suffered from higher suspended sediment at 313 tonne/km^2/year and 116 tonne/km^2/year, respectively. However, it should also be noticed that the sand mining activities in Muara Sg. Bagan Datuk is even higher at 2,000,000 m^3 than other areas.

5.7 Water Quality Analysis

Sg. Perak is a major valuable resources for industries and cities in Perak. It is about 60% of the state's water supply originates from Sg. Perak river basin (The Sg Perak River Basin as WST2040 Model Study). However, direct consumption, especially for consumptive that involves agriculture, mining and quarrying, manufacturing, construction, tourism, and utilities lead to externalities.

Both Table 62 and 63 show the status of river water quality in Perak in terms of 6 major parameters namely DO, BOD, COD, NH3-N, SS, and pH from 2014 to 2017. It can be seen that most of the rivers were categorized as clean, except for Sg. Kuang and Sg. Kangsar that are slightly polluted in 2016. Since majority of these rivers are in class 2, therefore, it indicates the requirement of conventional treatment.

Taken from DOSM glossary A-Z, the water quality parameters are significant factors in determining the quality of water, where:

- SS - Caused by soil erosion and sedimentation from the development in highlands and clearance of land for logging and mining.
- DO – Amount of gaseous oxygen (O2) actually present in water expressed in terms either of its presence in the volume of water (milligrams of O2 per litre) or of its share in saturated water (percentage).
- BOD - Dissolved oxygen required by organisms for the aerobic decomposition of organic matter present in water. This measurement is usually taken over five days.

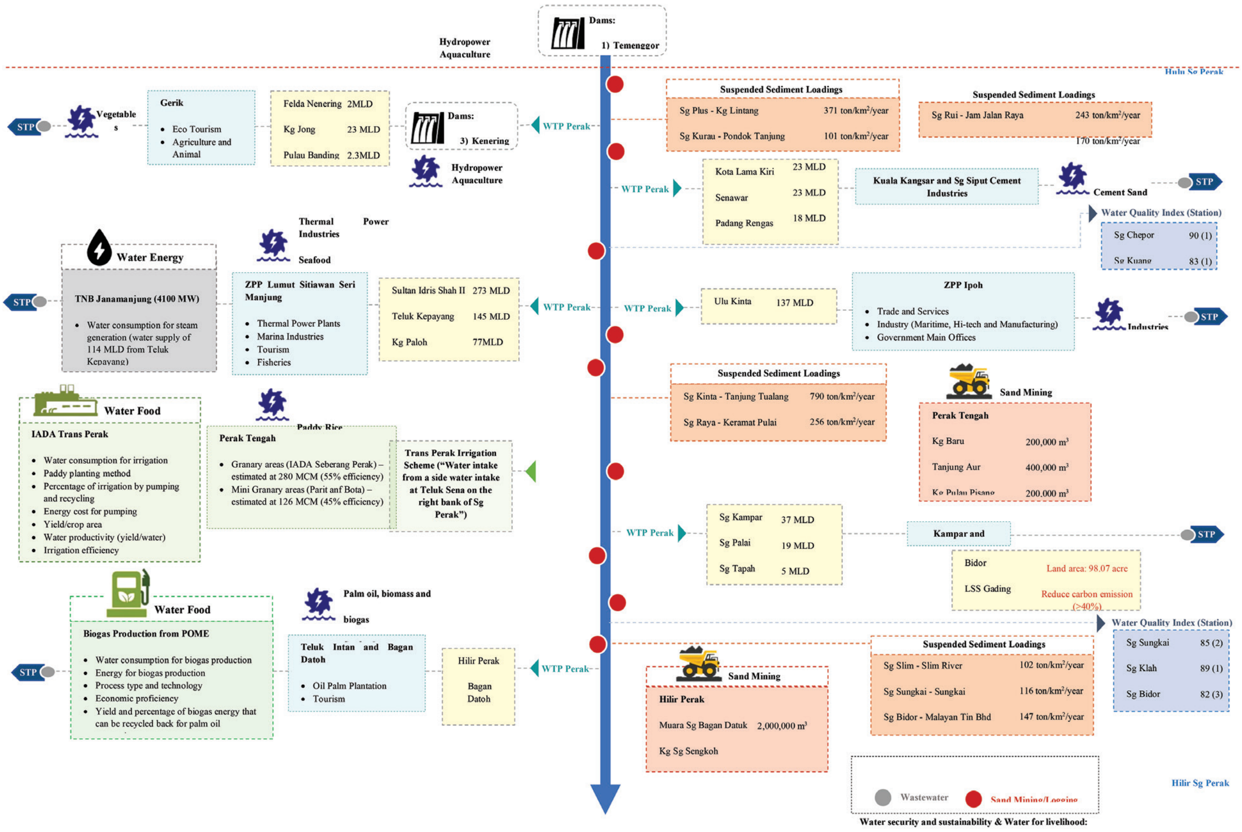


Figure 31. WFE Nexus Schematic for Sg Perak River

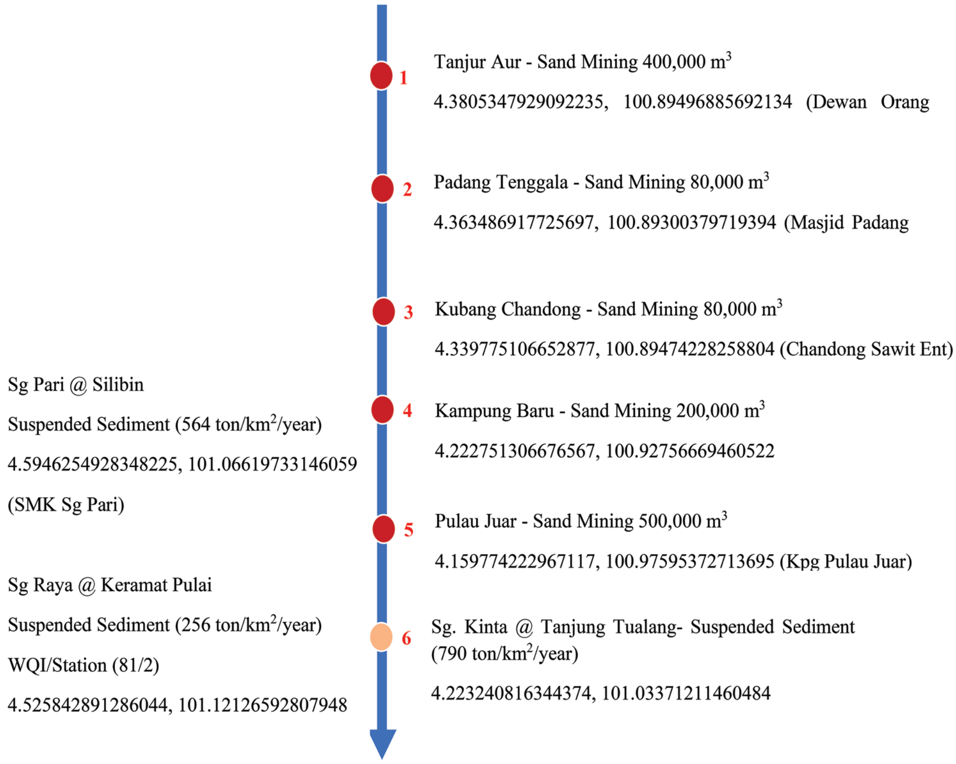


Figure 32.

Figure 33.

Table 62. Water Quality in Sg. Perak, 2014/15

Year	2014				2015		
	Number of Stations	Water Quality Index (WQI)	Category	Class	Water Quality Index (WQI)	Category	Class
Sg. Chepor	1	85	B/C	2	91	B/C	2
Sg. Chenderiang	1	84	B/C	2	81	B/C	2
Sg. Kuang	1	86	B/C	2	84	B/C	2
Sg. Klah	1	90	B/C	2	88	B/C	2
Sg. Kinjang	1	89	B/C	2	88	B/C	2
Sg. Kampar	2	90	B/C	2	88	B/C	2
Sg. Batang Padang	3	87	B/C	2	84	B/C	2
Sg. Kangsar	1	84	B/C	2	82	B/C	2
Sg. Sungkai	2	87	B/C	2	86	B/C	2
Sg. Bidor	3	83	B/C	2	83	B/C	2
Sg. Raya	2	87	B/C	2	88	B/C	2
Sg. Perak	8	85	B/C	2	84	B/C	2

Table 63. Water Quality in Sg. Perak, 2016/17

Year	2014				2015		
	Number of Stations	Water Quality Index (WQI)	Category	Class	Water Quality Index (WQI)	Category	Class
Sg. Chepor	1	90	B/C	2	90	B/C	2
Sg. Chenderiang	1	87	B/C	2	87	B/C	2
Sg. Kuang	1	79	ST/SP	2	83	B/C	2
Sg. Klah	1	86	B/C	2	89	B/C	2
Sg. Kinjang	1	90	B/C	2	92	B/C	2
Sg. Kampar	2	85	B/C	2	86	B/C	2
Sg. Batang Padang	3	82	B/C	2	82	B/C	2
Sg. Kangsar	1	73	ST/SP	3	81	B/C	2
Sg. Sungkai	2	86	B/C	2	85	B/C	2
Sg. Bidor	3	85	B/C	2	82	B/C	2
Sg. Raya	2	81	B/C	2	81	B/C	2
Sg. Perak	8	82	B/C	2	85	B/C	2

(*Source*: River Water Quality Report DOE)

- COD - Index of water pollution measuring the mass concentration of oxygen consumed by the chemical breakdown of organic and inorganic matter.
- NH3-N - A component of nitrogen which is adopted as an indicator to determine pollution by sewage. It is formed from microbiology activity and usually exists inside surface water and groundwater. The main sources of NH3-N were domestic sewage and livestock farming.
- pH - Measure of the acidity for alkalinity of a liquid. A pH value in the range of 0 to 7 indicates acidity, a pH value in the range of 7 to 14 indicates alkalinity, and a pH value of 7 signifies neutrality.

In Malaysia, the main source of pollution identified as contributing to SS loading include construction operations such as earthmoving and land clearing. Meanwhile, domestic sewage, livestock farming, other liquid organic waste products are the main sources of NH3-N (Huang et al., 2015). Similarly, agriculture-based industries (e.g., natural rubber and palm oil production), manufacturing industry, and livestock industry are blamed for the deterioration in BOD status (Global Environmental Forum, 2000). Furthermore, the depletion of DO concentration may have occurred with an increase in the organic matter and nutrients released into the river (Abd Wahab et al., 2018). The evidence also shows that domestic waste and recreational activities could results in high COD status (Mohmadisa Hashim et al., 2018).

6.0 INSTITUTIONALISING AND GOVERNING THE WATER-FOOD-ENERGY NEXUS

This section begins with a review of the nexus practices that have been adopted internationally to govern water, food, and energy sectors in an integrated manner. Adopting the framework identified in Section 2.4, the rest of this section focuses on the status gaps in the Malaysian context. Included is a section that reviews the status of nexus governance in Malaysia by assessing these perspectives and instruments (Section 6.2). The section concludes with recommendations on the necessary interventions to institutionalise WFEN in Malaysia (Section 6.3). The focus on institutionalising the WFEN is in line with strategies contained in 12MP (in particular Strategy B2 under Chapter 9). The next sub-section reviews the international best practices towards governing the nexus.

6.1 Governing the Nexus: International Review

As highlighted in Section 2.4, nexus perspectives can be seen from a security, economic rationality, or political economy perspective. In addressing these three perspectives, various instruments were found. These can be categorised as communicative instruments such as information instruments that aid the identification and understanding of nexus hotspots; economic instruments that focuses on increasing efficiency and incentives for adopting nexus solutions; and organisational and procedural instruments that address the institutional arrangements, in particular, the silo approach in both planning and implementing nexus solutions. The adoption of these instruments is reviewed internationally.

6.1.1 International Case Studies

6.1.1.1 Governing Nexus Security Through Communicative Instruments

The first step in addressing the nexus at the policy planning level is the identification of nexus hotspots. The identification is undertaken through various communicative instruments. The level of sophistication falls on a wide spectrum from identification through integrated goals or aspirations, through long term and future planning, identification of specific indicators or more comprehensive hydrological databases tied to Decision Support Systems (DSS). These approaches that have been adopted internationally are reviewed below.

At the macro planning level, there are a few examples that identify nexus as integrated policy goals or aspirations. This is in contrast of identifying the risks based on science or evidence. The attention is paid to the synergies and trade-offs towards ensuring water, food, and energy security from an overall development planning point of view. This can be done through national level development plans. For example, in Ethiopia within the Growth and Transformation Plan (GTP) I (2010–2015), there was an aim of accelerating the development of agricultural and energy sectors for export, it aims to concurrently scale up agricultural productivity (by 30%), energy production (by 300%) as well as sugar and meat production (UNESCO, 2019). Within the plan, there is also a focus of increasing energy generation through biofuels as well as hydroelectricity via the Gran Ethiopian Renaissance Dam. It was highlighted that close attention was paid to the individual targets and its synergies and trade-offs. For example, an increase in biofuel production may require large amounts of water resources for irrigation and as well as potentially land (and watersheds). Understanding the competing demands in the planning process can help mitigate these challenges. The example here in Ethiopia highlights how information in the form of broad policy targets are used as a communicative instrument.

Nexus approaches also advocate for a long term planning, including through envisioning future landscape scenarios (Bizikova, Robinson, & Cohen, 2007). This can be done by identifying critical uncertainties and crafting plausible scenarios. For example, in the Middle Eastern and Northern African (MENA) region, countries such as Saudi Arabia, Qatar and Kuwait that are dependent on oil exports within their economy, a long-term nexus approach is required whereby a global energy transition towards renewables will result in impacted revenues. Related to that, in Saudi Arabia, for example, 70% of the country's total water use, including for food production is sourced from desalination, which is cost and energy intensive (UNESCO, 2019). Understanding and planning for a future scenario of a global green energy transition is crucial to understand how this impacts the interconnected nature of water-energy-food. Recent work on integrated scenarios can analyse the future dynamics and recommend response strategies including on climate policies, higher agricultural yields, dietary change and reduction of food waste (Van Vuuren et al., 2019). Similarly, in Tonle Sap, four alternative futures were articulated through scenario formulation process took place to addressing the changing flood regime and increased dry season. These hydrological and environmental changes, in turn, affect fish production. Envisioning of future landscape scenarios was adopted to understand the potential future pathways that will impact the resource security of Tonle Sap (Keskinen et al., 2015). As part of wider development planning, there is also a need to link nexus opportunities with new job opportunities. For example, investment on research and development on nexus approaches could create jobs, as well as technological solutions (Markantonis et al., 2019). The examples above demonstrate how scenario analyses and scenario planning can be used as communicative instruments for future development planning.

In identifying more immediate WFEN risks, another approach is more towards a science and evidence-based approach to identify nexus hotspots. However, the challenge is that it integrating three resources into a single measure is highly complex and international indices of nexus does not assist in identifying the nexus hotspots from a spatial and urgency (i.e., security) point of view. International review highlights that often water scarcity is the choke point for both agriculture and energy production (Sarni, 2015). Therefore, various nexus security challenges focus on the information systems that can identify the contexts of water scarcity in relation to its consumptive and non-consumptive uses. How the information system is designed, including its scale and overall use will be dependent on its use. In the context of governance, the literature review of international best practices was more for policy planning purposes. Specifically, this included for long term and future planning purposes as well as for immediate identification of nexus hotspots through in-depth hydrological database. One of the approaches that has been highlighted in other sections of this report is through the identification of Water Stress Index at the river basin level. The focus on measuring water stress is come into significance by being a specific target under the SDGs (SDG6.4). An application of this is highlighted in a study in China where WSI is used in combination with scenario analysis to assess the WSI. It found that coal-based electricity production can exacerbate water stress in the long term and by 2030 (Niva, Cai, Taka, Kummu, & Varis, 2020). A study in Thailand also highlighted the importance of WSI for agriculture land-use planning. It found that the conversion of rice planted areas to sugarcane could reduce water withdrawal for agriculture, which would increase the water stress of the watersheds (Gheewala et al., 2018). It proposes to use WSI for land use planning, planning of cropping system and crop calendar at the watershed level. While these examples demonstrate potential rather than implemented schemes through academic papers, it clearly highlights the potential of policymakers to adopt WSI as a nexus tool.

The Asian Development Bank, in a review of river basin management planning in Indonesia, highlights numerous requirements for a hydrological database to be suitable for use in river basin management, including an analysis of the data requirements (such as space, time, and relation-oriented data); and the processing tools required for processing (including data entry, data validation, calibration tools, and the use of models to address potentially missing data), analysing (such as for rainfall, rainfall-runoff relationships, evapotranspiration, and other key indicators), applying the data gathered (such as through statistical computations, the development of distribution functions, data interpretation, forecasting, and so on); and processing tools to manage the database itself. The ADB suggests that these databases be supported by a decision support system (DSS) which links the hydrological database to the various nexus-related concerns within a particular river basin, for example in assessing water demand for irrigation and competing uses.

Beyond information systems, policy targets can translate the evidence or indicators into concrete policy actions. Internationally, while policy targets vary and are more at the river basin level (as opposed to national), there are various policy targets that can be designed for the water-food nexus, including (OECD, 2010):-

- Financial target to improve water use efficiency in agriculture (i.e., water charges)
- Sustainable limits on the use of water
- Policy targets related to water use efficiency in irrigated agriculture
- Measuring and setting water use efficiency targets, for example, the relationship between accumulated yield (kg DM ha-1) and water use (mm)
- Irrigation efficiency, crop productivity, etc.
- Water availability, including water level, reserve margin, etc.

6.1.1.2 Governing Nexus Through Economic Instruments

An economic rationality approach focuses on a range of instruments including communicative (i.e., valuation studies, covered elsewhere in this report), organisational and economic based instruments. Economic based instruments in particular provide an incentive for resource efficiency and optimisation. In particular, the tool has been used to regulate water demand strategies. These can be done through setting of water abstraction of allowance rates, capital accounting, or incentives for water use efficiency and technology adoption.

In California, economic based instruments were combined with regulatory instruments. Specifically, two water conservation bills became subject to permanent legislation in May 2018 after the seven-year drought (2011–2017) in which a state of emergency was declared, and infrastructure, legislation, and social reforms took place in California's water management system. Although no clear nexus linkages are addressed, the state's response to securing water security under extreme drought is reviewed as a resource management best practice to reduce nexus pressure. The new laws require cities and water districts to set strict annual water budgets by 2022 and set mandatory usage targets on standardised water allowance. Failure to meet these targets will be met with punitive action; fines for non-compliance of $1,000/d in normal conditions and $10,000/d in drought conditions. In France, improving agricultural water use efficiency is also done through the introduction of a water abstraction charge (OECD, 2010; Oosterhuis et al., 2004). The water charges have been introduced since 1964, where a water abstraction fee is paid by those that abstract water above a certain threshold, determined by the six regional water agencies (Oosterhuis et al., 2004).

Cross-sectoral policy targets also strengthen the development of nexus management. In China, the National Development and Reform Commission (NDRC) expressed the need to develop a good way of undertaking capital accounting of the country's natural resources by 2020. It focuses on studying the implementation of wastewater tariffs to reflect the actual cost of wastewater treatment and develop strategies for water reuse financing.

Incentives promote the adoption of resource-efficient technologies and shaping behavioural change, which in turn influence the development of sustainable technical solutions. Additionally, energy and water tariffs must be set accordingly to reflect the true cost of wastewater treatment. For example, the city of Zaragoza in Spain saw a 27% reduction in overall water consumption between 1996 and 2008 after the city implemented a water-conserving tariff supported by economic incentives. Consumption-based tariffs could guarantee the business case for nexus investment while simultaneously ensuring socially equitable tariffs, especially for low-income groups. In Iran, an increase of electricity tariffs in the agriculture sector was implemented for water withdrawal from underground resources through pumping (Tahami Pour Zarandi & Rahmani, 2018).

Incentives for technology adoption has also proven to be effective. During and after California's century drought, the Metropolitan Water District of Southern California (MWD) initiated a mass scale infrastructure investment to ensure water reliability to California's densely populated south and expand the region's water recycling capacity, set to be the largest in the US. MWD is a state-owned cooperative of 26 cities and water agencies serving nearly 19 million people. One of the initiatives was revising 'The Local Resources Programme' in 2014 to provide economic incentives for water recycling, groundwater recovery, and clean-up projects, including seawater desalination efforts. As an outcome, the Regional Recycled Water Program recharged local groundwater sources with 567,759 m^3/d of treated effluent. From July 2016–June 2017, the program collected a daily average of 608,000 m^3 of recycled water, putting more than 597,000 m^3/d into groundwater recharge. Another example for adoption is 'SoCal Water$mart'. Aligned with water efficiency measures, it is implemented to reduce Californian water demands by improving community outreach and behavioural change. The program offers rebates for high-efficiency appliance installation, irrigation controllers, rain butts, and turf removal. The utility provided rebates of $1 for every square foot of turfgrass converted to California native flora (up to a maximum $1,500 rebate). Another example is in Morocco, where efforts were in place to improve water use efficiency in agriculture. Drip irrigation as a technological solution was incentivised through subsidy of 80 percent rising to 100 percent for farms smaller than 5 hectares (Jobbins et al., 2015).

6.1.1.3 Establishment of Nexus Ecosystems Through Public-Private Institutional Arrangements

As the nexus literature is mostly focused on technological solutions, beyond incentivising technological adoption, the review also highlighted the need for facilitation of innovation, and in particular, public-private-partnership through innovative institutional arrangements as an organisational instrument. The focus is to develop nexus ecosystems that involves and coordinate across various stakeholders (Eggers & Muoio, 2015; Sarni, 2015; Stephan et al., 2018). This can be in the form of establishment of water funds, economic agreements, or through ecosystem integrators.

The nexus discourse and solutions have received attention from the private sector and resulted in many private led initiatives. One approach is to create water funds through pooling of resources. One such effort is in Colombia where the partnership between The Nature Conservancy (TNC), a global environmental NGO, and SABMiller, a multinational brewing and beverage company, partnered with other stakeholders to create a water fund (Sarni, 2015). TNC, a global leader in providing water funds (see https://waterfundstoolbox.org/), established the Water for Life and Sustainability Fund to address water conservation efforts along Cauca River (near Cali, Colombia), where one of SABMiller's brewery withdraws water from. The river is also one of the largest sugarcane-producing area which is water intensive, along with other uses such as irrigation and industrial use, threatening water scarcity and pollution. The water fund pools money from downstream water users (including municipalities, water and power utilities and companies) as well as donors. These funds are then channelled to upstream stakeholders that impacts availability and water quality to undertake projects that contribute to water, energy and food security and needs. This includes farmers, ranchers, community organisations, and environmental groups.

Another private led initiative approach is through economic agreements. The EDF group in France, demonstrated this approach in the Serre-Ponçon dam and reservoir, located in the Durance and Verdon River system in southeast France (Sarni, 2015). The system includes 21 hydropower plants to produce energy, and at the same time irrigates over 150,00 hectares of farmland, resulting in a perfect water-energy-food nexus case study. As concerns rise on the optimal use of water for producing electricity, EDF developed a Water Saving Convention as an agreement between EDF and two main agriculture irrigators. In essence, the agreement established for the irrigators to reduce their water usage, while EDF will remunerate the irrigators for the amount of water saved.

While the above instruments utilise economic incentives as the primary instrument, there has also been various efforts to address these wicked problems through coordination. In particular, ecosystem integrators that are capable of "holding the whole" has been established to address complex challenges such as nexus (Eggers & Muoio, 2015). While not directly addressing nexus, for example, the MDG Health Alliance and the Roll Back Malaria Partnership are considered ecosystem integrators in the fight for Malaria where they coordinate with multiple stakeholders. While not without criticisms, the Global Alliance for Vaccines and Immunisations (GAVI) is another example of private-public partnership that includes WHO, UNCEF, academics, pharmaceutical companies and funders to have one roof in shaping the vaccine market.

6.1.1.4 Institutional Coordination

In addressing the political economy challenges of the nexus and the need to balance power asymmetries and varied interests across three sectors much of the focus of the nexus literature has been on institutional coordination. It is important to highlight that there is no silver bullet and that different approaches are undertaken at the different scales, for example, national level or river basin level. Furthermore, the interventions are highly dependent on the prevailing structure such as more centralised or decentralised mode of governance. Nonetheless, the international best practices highlight that the institutional coordination can be in the form of organisational instruments that address vertical and/or horizontal integration, as well as procedural instruments that aim to set the "rules of the game" such as through establishment of formal or informal laws to regulate behaviour. In particular, the literature review has highlighted the need to break down silos through consolidation, as well as to establish River Basin Organisations (RBOs) at the appropriate scales.

The major institutional challenge of governing the nexus is to break down silos and move towards an integrated approach. This requires institutional coordination and cooperation across sectors and governance levels. Horizontally, this entails coordination across the different sectors, namely, water, energy, and food. Vertically, it requires coordination across the various governance levels including national and sub-national levels. This is required to ensure the nexus approach is transferred into decision-making processes.

Efforts to address vertical coordination is often proposed through institutional arrangements where many challenges of a silo approach were identified in literature. For example, in Kenya, whereby the lack of vertical cooperation across functions at the national and county level resulted in conflicting plans and duplication of efforts (Aboelnga, Khalifa, McNamara, Ribbe, & Sycz, 2018). Similar findings have been documented in Indonesia and the Amazon River basin (Scott, 2017). Similarly, approaches for vertical coordination should take into account upstream and downstream dynamics. In the Hindu Kush region in India, cross-sectoral integration was proposed to govern and integrate upstream and downstream areas that are critical to food, water, and energy security. This is due to the high dependency of downstream communities on upstream ecosystem services (Golam et al., 2014). Options to improve coordination and integration have focused on changes in institutional structure that forms 'nexus groups' consisting of key decision makers across the three sectors.

One approach to address the silo approach is through consolidation. The Korean government, for example, has viewed water insecurity as a big challenge in achieving the water energy food land (WELF) nexus on a national and basin scale and made steps towards consolidation. In 2018, Korea revised its national water management system that had fragmented responsibilities among ministries into an integrated structure with the Ministry of Environment as the single authority. The reform optimized the administrative efficiency in water management to ensure cost-effective, equitable, and sustainable use of the country's limited water resources. Under the presidential water commission, they have established water commissions in four river basins. According to the new Framework Act on Water Management, Korea will build a National Water Management Plan every ten years. The first was formulated in 2020, defining policy goals and specific measures on comprehensive water issues, including water quality, water resources, water disasters, conflicts, and water industry.

Another approach is through the establishment of River Basin Organisations at the appropriate scales. From the perspective of the WFEN, river basins are the appropriate level at which to govern nexus issues because they involve competition between various sources of demand for resources, and these dynamics typically play out at the scale of a river basin. For this reason, the establishment of river basin organisations can play a significant role ameliorating the various challenges that make WFEN analyses and solutions complicated to administer. Indeed, Kittikoun and Schmeier (2020), in an analysis of over thirteen significant river basins across developing and developed countries, find that RBOs play a key role as vessels of water diplomacy in the presence of competing interests, provided they are given the appropriate legal and institutional powers, and their ability to influence strategic resources. Keskinen et al. (2016) summarise some of the benefits associated with a river basin approach to addressing nexus concerns and mainstreaming nexus approaches. Although their analysis focuses on transboundary river basins, i.e., those which cross state or national borders, it is still relevant in the context of the cross-sectoral boundaries that exist between the three resources in question within river basins at a whole. Indeed, management of nexus issues at a river basin-level is more effective and efficient than, for instance, at the state or national level because of the dynamic and contextual nature of nexus issues. Keskinen at al. (2016) cite that the introduction of nexus considerations in a cross-sectoral context has the potential to "provide new resources and approaches, alter existing actor dynamics, and portray a richer picture of relationships".

Further, The Global Water Partnership's Integrated Water Resources Management Toolbox highlights specific characteristics of sustainable river basin management; among these are for river basin-wide planning and coordination which enables a balancing of the needs of various water users from a demand-side perspective, and to facilitate and monitor agreements between the many stakeholders within the ecosystem. RBOs can also facilitate public and stakeholder participation in decision-making within river basins, adding a layer of democracy to these processes by empowering stakeholders to become decision-makers; indeed the GWP cites successful RBOs as having broad stakeholder involvement and the determination of solutions that are at the very least acceptable to all parties involved.

Much of the literature focuses on RBOs to mitigate transboundary issues that arise between countries, such as in the Nile river basin. In Central Asia, River Basin Organisations (RBOs) are set up in each country, accompanied by Water Codes that dictate how various uses will be regulated. Its establishment is in response to transboundary agreement and institutional arrangements to regulate water withdrawal from the main river basins (Amu Darya and Syr Darya). Reliance on agriculture and being one of the most water intensive economies in the world, there is competing uses from various countries, including Tajikistan, Uzbekistan, Turkmenistan, Kyrgyzstan and Kazakhstan (Barchiesi, Carmona-Moreno, Dondeynaz, & Biedler, 2018). While communication and coordination across the RBOs remains a challenge, it provides the institutional and legal basis for governing the nexus. In 1998, the "Agreement on the Use of Water and Energy Resources of the Syr Darya Basin" was signed by Kazakhstan, Kyrgyzstan and Uzbekistan, and later Tajikistan. It required annual protocols to define the exact discharge times and amounts of water, as well as the price of energy to be sold to the downstream countries. Although its implementation faced challenges, the legal framework as a tool for institutional coordination provides an example and basis for applying the nexus approach in a transboundary setting. More specifically, it highlighted the hybrid between organisational instrument in the form of the establishment of RBOs and procedural instruments in the form of agreements.

The literature on procedural instruments focus mainly on regulatory instruments. However, a study in Dartmoor, United Kingdom, where there are 17 micro hydroelectric plants, a regulatory mapping exercise found fragmented and overlapping regulations across various jurisdictions including sectoral, national, local, and even non-state regulations. Despite the complexity across the regulatory landscape, it was found that procedural justice – via planning permissions, impact assessments and consultations – were sufficient to address nexus issues. As above, in combination with organisation instruments, formal procedural instruments including regulatory, contractual as well as procedural justice mechanisms can form the basis for institutionalising the nexus.

6.2 Governing the Nexus in Malaysia: Review of Current Status and Gaps

Based on the framework produced above, this section reviews the current status of governing the nexus in Malaysia. This includes addressing the nexus at both the national and state levels.

6.2.1 Governing Nexus at the National Level

6.2.1.1 Nexus Communicative Instruments

The WFE Nexus is a relatively new area and one that is complex and contextual. Complex due to the fact that it cuts across three sectors, water, energy and food and; contextual as WFE nexus issues are not the same in every location and are dependent on a variety of internal and external factors including availability of resources, consumption patterns, climate, pollution and infrastructure. As a result, it is critical that a tool to identify nexus hotspots is available to inform policy. This will ensure that an evidence-based approach is utilised in the policy landscape. The review highlighted the importance of *information systems* towards identifying nexus hotspots. This can be in the form of indicators, such as the Water Stress Index or comprehensive hydrological databases that can be used as a cross-sector communication tool on the status of nexus. To further translate these communicative instruments into implementation, sectorial policy targets can be institutionalised. A review of the status of nexus related information system, indicators and *policy targets* are further investigated below.

In terms of *information systems*, a review of the national landscape highlights little evidence of a WFE Nexus monitoring or identification tool being used in the policy landscape. The National Water Balance Study (NAWABs) does include a chapter to assess the Water-Food-Energy Nexus at the river basin level. However, much of the analysis focuses on the security of supply for the three sectors individually. This information is not sufficient to identify the criticality of the WFE Nexus at the river basin level. Most of the information is based on global literature review rather than specific to the river basin. As a result, it does not assist in identifying or projecting whether the WFE Nexus is a priority policy issue as there is no index or indicator that indicates, for example, the threshold in terms of WFE Nexus security.

Beyond NAWABs, there is no comprehensive hydrological or hydrosocial database[6]. In the context of nexus, it is crucial for a comprehensive cross-sector water demand accounting to be in place that includes both hydrological data, which captures physical water scarcity, as hydrosocial data, which captures the interactions between water resources and social phenomena (Bozorg-Haddad, Baghban, & Loáiciga, 2021). These include data related to water uses such as for irrigation, dams, mining as well as its relationship with external factors such as climate change, population density and growth and technological impacts. These factors demonstrate high correlation with water availability such as per capita renewable water (Bozorg-Haddad et al., 2021). In Malaysia, there is no such integrated database. To regulate water demand, a previous study by ASM found that there is no threshold or capping of water abstraction for human use (Academy of Sciences Malaysia, 2016). The study also highlighted that the current approach to data and information is still sectoral and information such as rainfall, flow, water levels and water quality is not available for all sectors to forecast and plan future demands, warning systems and as decision support systems specifically. This was corroborated during site visits undertaken as part of this report where hydrological data at granaries were not available to project the impact of future water availability with water demand for irrigation, taking into consideration the competing uses of future water demand.

To translate information into policy actions such as towards improving water resources allocation, water abstraction thresholds or regulate water stress levels more generally, there is a need to set *policy targets*. The international review demonstrates that various policy targets can be set such as through allocation, abstraction thresholds or efficiency/optimisation levels. A review of relevant policies highlighted that that while various policy targets exist, there are very few nexus related and cross-sector policy targets.

The water sector, through the **NWRP**, and the associated actions plans IWRM Management Best Practices and the NWRP Action Plans (2013–2020) provided various strategies towards demand side management. However, there are no policy targets for water usage such within sectors such as for irrigation or for energy production. In the food sector, the **NAP4** aims to optimise land use by increasing yield but reducing overall land use for agriculture. In relation to water use efficiency, while it aims to increase efficiency, its policy targets aim to increase the irrigation intensity from 20 to 50 metres per hectare. No policy targets on irrigation efficiency or water use efficiency were found. This demonstrates the focus is on increasing productivity rather than efficiency of water use. The energy sector has had a stronger focus on demand side management and improving resources efficiency. Nonetheless, no cross-policy targets such as increases in water usage efficiency in energy production or energy-land nexus optimisation that can affect food production were found in the energy target.

A brief mapping of the national level policies is conducted in Table 64 below. The three sectors demonstrate that there may be trade-offs in achieving the various policy targets within the sector (nexus pressure). Existing policy targets are mainly related to efficiencies and resource optimisation that may have indirect consequences to the nexus. The energy sector focuses mainly on policy targets on energy production (i.e., installed capacity) as well as on increasing energy efficiency and reducing intensities. The food sector does demonstrate cross sector policy targets on resource optimisation, specifically related to land. At the national level, the water sector also includes policy targets on non-revenue water (NRW). These policy targets will indirectly impact the nexus through increasing resource efficiency as a whole. However, there are few direct cross-sector policy targets. The National Agrofood Policy (2011-2020) does focus on land use optimisation including reduction in land use for agriculture from 922,000 hectare (2010) to 841,000 hectare (2020). However, there are no policy targets found across the nexus between water and food and energy production. Arguably, demand management strategies are utilised less from the food and water sectors with no notable policies and initiatives. In the food sector, recent focus on food waste and

[6] A more comprehensive assessment of the hydrological database is covered under another sub-sector in the Water Sector Transformation (WST) 2040. This assessment is only focused on data relevant to WFEN nexus

Table 64. Policy Targets Across Water, Food, and Energy Sectors

Policy	Policy Target	Nexus Pressures	Nexus Opportunities
		Water Security Policy Targets	
All shall have access to safe, adequate, and affordable water supply, hygiene, and sanitation (NWRP 2012).	• No policy targets	Insufficient allocation due to pollution from food production Availability for energy production	Set integrated and cross-sector standards relating to food and energy security
Water for food and rural development (NWRP 2012)	• No policy targets	Competing priorities	Opportunity to link to food and development issues
Water for Economic development (NWRP 2012)	• No policy targets	Competing priorities	Opportunity for provision of water to link to food and energy production
		Food Security Policy Targets	
Increase in SSL from 2010 – 2020 (National Agrofood Policy 2011–2020)[7]	• Paddy from 71.4% – 69.8% (reduction) • Fruits from 65.8% to 76.3% • Vegetables from 41.2% to 67.6% • Fish from 101.7% to 110.4%	Increase in water for irrigation Increase in land for fruits and vegetables Increase in pollution due to aquaculture	More optimum usage of resources including water for paddy Hybrid systems for food and energy production
Optimum land use (National Agrofood Policy 2011–2020)	Reduction in land use for agriculture from 922,000 hectare (2010) to 841,000 hectare (2020).	Risk of reduction in production and not meeting SSL	More optimum usage of water and energy
Increase land size for commodity plantations (National Commodities Policy 2011–2020)[8]	Increase in land use from 5.9 hectares (2010) to 6.9 hectares (2020)	Competing land for food and energy production (including biofuels and biogas production)	Integrated and circular economy approaches such as through utilising by products and waste (biomass) for biogas production
Increase in irrigation intensity (National Agrofood Policy 2011–2020)	Cap oil palm to 6.5 hectares by 2023 (now 5.8 hectares) Increase in irrigation intensity from 20 to 50 metres per hectare	Ability to increase energy production through biofuels Competing priorities. Increased water consumption for food production	Policy target on irrigation efficiency in granary areas
		Energy Security Policy Targets	
Increase renewable energy mix	Achieve 20% Renewable Energy Mix by 2025 Produce 2.5 GW through Large Scale Solar (LSS), (10% of electricity demand) 4% of energy from hydro by 2022	Competing priorities, including land for LSS versus land for agrofood production Impacts of hydro to downstream activities, including food production	Floating solar and other technological solutions Nexus approach for multi-purpose dams

[7] Please note that the National Agrofood Policy 2021-2030 is currently being drafted

[8] Please note that the National Commodities Policy 2021–2030 is currently being drafted

food loss has been introduced in the policy landscape. In the water sector, efficiency is often related to non-revenue water, but not less in terms of consumer demand management.

6.2.1.2 Nexus Economic Instruments

The economic instruments review highlighted practices related to water abstraction charges, including, capital accounting and through incentives for water use efficiency and technology adoption. The information system based on valuation of water is covered in other parts of this report.

In terms of water abstraction charges, there is no regulation found to have included specific thresholds on water abstraction to provide incentives, either generally or for specific sectors. The State of Selangor began charging and licensing of ground and surface water abstraction in 2005 at a rage of RM0.01/m^3 for public utilities and RM 0.05/m^3 for commercial users (parallel to Section 41(2) SWMA Enactment 1999). The Water Resources Abstraction (State of Selangor) Regulation 2021 was also enforced to control water abstraction. Nonetheless, no economic instruments were found to provide for efficiency such as including thresholds on water abstraction charges based on volume.

In terms of capital accounting, the Department of Statistics has established a System for Environmental Economic Accounting (SEEWA) specifically for water and published the MySEEA PSUT Water Account, 2015. The information included abstracted water and wastewater and was divided across water for distribution and for own use. It found that Agriculture was the largest supply of abstracted water for own use of 6,194 million of cubic metres (72.2%); followed by Electricity, gas, steam and air conditioning supply, 1,969 millions of cubic metres (23.0%); Water supply and sewerage, 277 millions of cubic metres (3.2%); and Manufacturing, 80 millions of cubic metres (1.0%)[9]. This provides a good platform to include water as an important consideration for example, towards water abstraction charges based on sectors and/or sectoral water resources allocation. However, while SEEA-Water internationally also aims to produce hybrid and economic accounts that describe the supply and use of water-related products in monetary terms, including identifying the costs associated with the production of related products, the income generated by them, the investments in hydraulic infrastructure and the cost of maintaining it, the focus in Malaysia is supply and use accounts. The supply and use accounts describe water flows within the economy and between the environment and the economy. It is unclear if the aim is to move towards hybrid and economic accounts through SEEA-Water.

Similarly, there is lack of economic incentives to encourage either efficiency directly or technology adoption. In terms of efficiency, while various energy sector in particular has focused on demand side management, incentives for cross-sectoral efficiency with water and food is not found. Within the agro-food sector, and in particular the rice sector, the economic instruments utilised is more towards achieving rice self-sufficiency. In 2017, it was found that 45 percent of the total budget of the Ministry of Agriculture and Agro-based industries went to supporting rice production through subsidies as well as trade policy (World Bank, 2019). Meanwhile, the water sector has seen little use of economic instruments with Malaysia's water tariffs for irrigation being one of the lowest in the world. Incentives for technology adoption are not explicitly to address nexus solutions. Nonetheless, existing incentives such as the Green Technology Financing Scheme (GTFS), the Green Investment Tax Allowances (GITA) and Green Income Tax Exemption (GITE) can be utilised under each of the sectors towards sustainability and resource efficiency in general.

Within the sectors, as highlighted before, the energy sector in particular has a range of policy instruments to implement its policy aspirations to facilitate energy efficiency. Specifically, for demand

[9] See:
https://www.dosm.gov.my/v1/index.php?r=column/ctheme&menu_id=NWVEZGhEVlNMeitaMHNzK2htRU05dz09&bul_id=Q2R0WG8yQWlxanNqK1RYNGZHNWZOdz09

side management, various action plans and instruments have been included such as the **National Energy Efficiency Action Plan (NEEAP)**, **Minimum Energy Performance Standards (MEPS)** and the **Green Investment Tax Allowances (GITA)** and **Green Income Tax Exemption (GITE)** to provide economic incentives. Within the agro-food sector, and in particular the rice sector, the economic instruments utilised is more towards achieving rice self-sufficiency. In 2017, it was found that 45 percent of the total budget of the Ministry of Agriculture and Agro-based industries went to supporting rice production through subsidies as well as trade policy (World Bank, 2019). Meanwhile, the water sector has seen little use of economic instruments with Malaysia's water tariffs for irrigation being one of the lowest in the world. If one adds to these costs what consumers pay through trade policy (which raises domestic prices) and what taxpayers pay through subsidies and compares the total with the total production value of rice, the cost is also high. This measure of the transfers from consumers and taxpayers is known as the producer single commodity transfer.

6.2.1.3 Nexus Public-Private Institutional Arrangements

The international review highlighted the importance of facilitating private actors both in terms of attracting investment as well as catalysing innovation. More broadly, nexus, as a wicked problem requires multistakeholder coordination. To address this water funds, economic agreements and the role of ecosystem integrators were highlighted.

In terms of water funds, there is no evidence of funds being created for nexus and/or for addressing competing uses across upstream and downstream users[10]. While the plantation sector in Malaysia, in particular, the oil palm industry levies a cess for R&D activities undertaken by MPOB, there is no cross-sector establishment of funds identified. In particular, as water is often the choke point of nexus challenges, no water funds were found in the context of Malaysia.

The interviews highlighted economic agreements were in place in terms of abstraction of water for example for hydropower facilities or for energy production from state authorities. However, it is unclear if these are based on regulations, institutionalised, or based on one-off agreements. Furthermore, the agreements are understood to be more in the form of payment based on volume and do not incentivise innovation for efficiency or reduction of usage.

In terms of ecosystem integrators, while various stakeholders including NGOs, academia and government agencies have demonstrated working in partnership, there has particularly been a lack of private sector partnership or private actors that act to coordinate both public and private entities. One of the major challenges is due to the lack of information and low water tariffs making it unattractive for investors to establish such institutional arrangements in the context of Malaysia.

The experience of the palm oil sector demonstrates that this has been implemented in Malaysia. In particular, the role of commodity boards is also supportive as ecosystem integrators. For example, the Malaysian Palm Oil Board (MPOB), alongside the Malaysian Palm Oil Council (MPOC) and the Malaysian Palm Oil Association (MPOA) provide a comprehensive ecosystem to address the oil palm industry. This includes R&D initiatives of MPOB that are informed by MPOC and MPOA, who in turn, disseminate the results to stakeholders. MPOB also acts as an incubator, for example, through establishing pilot commercial plants with the private sector (see World Bank 2019). While the structure differs in the agrofood sector, the "horizontal" integration towards including multistakeholders and private participation is an example of best practice being implemented in Malaysia.

[10] The assessment is only based on water funds related to nexus. A more comprehensive assessment on water financing is covered under the alternative water financing sub-sector of the WST2040.

6.2.1.4 Nexus Institutional Coordination

As highlighted in the National Water Resources Management Plan and in other parts of the report, water governance is fragmented across water resources management and water supply management as well as differs across states. The silo approach is exacerbated in the WFE Nexus where fragmentation occurs both across and within sectors. International review highlighted the need to have organisational instruments that coordinate across multiple sectors. This is usually undertaken through a process of consolidation. The institutional coordination is required to be consolidated at various stages of the policy cycle including planning and implementation.

The water sector is complex and multi-layered with no single agency responsible for strategic planning and management of water resources. The National Water Resources Council (Majlis Sumber Air Negara) was established as the apex body for coordinating water resource body. However, challenges remain both horizontally and vertically. Horizontally, water resource management and water supply and more generally water use is governed by various sectors. Vertically, the state still maintains powers and authority over water resources management. The **Water Industry Act 2006** and the **National Water Services Commission Act 2006** provided a mechanism for the federal government to acquire water-related assets and leased back to water industry operators. However, the laws do not provide link to the planning and management of other sectors. In terms of strategic planning, much has been written on the challenges to govern water resources as a whole, let alone, including planning across other sectors that are prominent for resources use including agriculture and energy (i.e., hydropower and other uses).

The structure of agrofood sector is complex and highly dependent on the crop and commodity. It consists of agrofood sector, plantation, and commodities sector as well as rural and land development. There is an evident dualism in agriculture which is reflected in federal institutions, between plantation and non-plantation agriculture. The plantation industry is more advanced in terms of structure, where for instance in the palm oil industry, federal level ministries work with the private sector towards diversification and research and development (World Bank, 2019).

Strategic planning in the agrofood sector is driven by the Ministry of Agriculture and Food Industries. The **NAP4** included the establishment of the *Majlis Pembangunan Industri Agromakanan Strategik*, which includes members from the private sector. It also highlighted the role of the Prime Minister's Office that previously provided strategic direction via the Economic Transformation Programme (ETP). National Key Economic Areas (NKEA) were identified in the agriculture sector including on paddy, swiftlet nest, aquaculture, herbs, fruits, organic vegetables, seaweed, feedlot cattle and dairy sectors. A total of 16 Entry Point Projects were included under the supervision of PEMANDU. NAP4 also highlighted the dynamic clusters, led by the economic growth corridors. However, it is unclear how these institutions interact with wider strategic and long-term issues beyond specific sectors and commodities.

For the water-food nexus and agriculture water more specifically, the Division of Irrigation and Agricultural Drainage (BPSP) is placed under MAFI which is mandated to oversee agriculture water development and management. Institutionally, the agriculture sector has had a mechanism for an integrated approach since the 1970s in granary areas through the Integrated Agriculture Development Areas. The establishment of MADA, KADA and IADAs consolidated relevant implementing agencies under one institution, including for irrigation. In terms of regulations, there is no special act to accompany the agricultural water management. For paddy specifically, the Irrigation Areas Act 1953 regulates matters on irrigation while the Drainage Works Act 1954 covers drainage matters for the Peninsular Malaysia. These acts are only applicable to areas gazetted as granary areas and do not cover water resources aspects. From a legal perspective, one of the challenges is that there no specific regulations to avoid water use wastages for agriculture end users (i.e., farmers).

The energy sector is governed by the federal government and therefore does not face issues towards the vertical integration of the sector (except for the case of Sabah and Sarawak, where the Economic Planning Units play a significant role in energy related matters). Nonetheless, similar to the water sector, demand side management falls under the purview of various ministries including the Ministry of Housing and Local Government for building energy efficiency as well as waste, Ministry of Transport for transportation, in particular for fuel, Ministry of Trade and Industry for industrial processes, and the Ministry of Domestic Trade and Consumer Affairs for household consumption. The Ministry of Environment and Water also addresses energy efficiency through, for example, the Green Technology Master Plan. In the context of WFE Nexus, the focus is mostly water usage at the energy production stage and therefore the focus will largely be at the federal sector with the Ministry of Energy and Natural Resources

The challenge of addressing silos is also apparent in the strategic planning of the oil and gas industry, whereby vertically, the **Petroleum Development Act 1974**, which effectively led to the states to surrender their rights to petroleum resources in lieu of cash payments and annual royalties. In the context of WFE nexus, however, the strategic direction provided by the various energy policies, do not focus on cross sectoral impacts (horizontally) generally. Nonetheless, since the **National Energy Policy in 1979**, followed by **Five-Fuel Diversification Policy (2000), the National Biofuel Policy (2006)**, **National Renewable Energy Policy and Action Plan (2010)** and the **New Energy Policy (2010)**, there has been a focus on environmental sustainability. However, the main focus is on renewable energy and towards reducing dependency on fossil fuel rather than on impacts to the water sector specifically and adaptation more generally. Institutionally, the oil and gas sector consist of the **Malaysian Petroleum Resource Corporation (MPRC)** under the purview of EPU. It was established towards building a thriving regional hub for the oil and gas sector. This includes providing trade and investment facilitation, support technology innovation, human capital development, market access and access to finance. Recently, it launched the National OGSE Blueprint 2021–2030 with the aim of catalysing an energy transition. No similar institution was found for the water sector or for planning and managing strategic resources as a whole in Malaysia. In terms of the water-energy sector, no institutional link was found for regulating water usage for energy production.

In terms of the energy-water nexus, and in particular, energy to move water, pumping is a major part of the cost to bring drinking water to the consumers as well as for irrigation. Furthermore, inter-basin transfers also require significant energy to move water. Currently, transporting of water is largely governed internally by water treatment companies. While the costs are not insignificant, market forces will most likely incentivise energy efficient practices. In the context of nexus, inter-basin transfers as well as granary areas (i.e., IADAs) also play a very important role in ensuring energy efficiency. Institutionally, river basin organisations can play a role to improve energy efficiency. A major gap is that there is an absence of National Water Services policy encompassing both water supply and sewerage sectors. For planning purposes, there is a need to integrate water supply and demand including for food and energy sectors which addresses issues such as energy efficiency in producing potable water.

In terms of overall development planning, Malaysia's resource mobilisation at the federal level is based on the five yearly Malaysia Development Plans. In the context of the WFE nexus, the **Eleventh Malaysia Plan** emphasises the need to move beyond the sector-based approach to advance water, energy, and food security:

> "In the Eleventh Plan, Malaysia is breaking free from the conventional wisdom of development at all costs to green growth, which is a more sustainable path of growth. This will see Malaysia enter the ranks of advanced economies in 2020 with an economy resilient to the adverse impact of climate change and with a secure and sufficient supply of natural resources such as water, food, and energy. Partnership and shared responsibility across all levels of society, including individuals, will be key to safeguarding the environment and biodiversity. Successful green growth will not only expand

> economic opportunities, but also enhance inclusivity and reduce disaster risks." (Malaysia, 2015: pp. 6-30)

This was further strengthened in the 12th MP where a specific focus on "Institutionalising the Water-Energy-Food nexus Approach was included as a strategy (Chapter 9, Strategy B2) which states:-

> The water, energy, and food sectors will be managed integrally to address challenges related to urbanisation, land-use and climate change. The water-energy-food nexus is a vital element in ensuring comprehensive water resource management and water security across the sectors. This nexus will provide a framework that determines the appropriate distribution of water resources to all sectors. Going forward, the water-energy-food nexus approach will be institutionalised, while technical expertise of relevant ministries and agencies will be enhanced to ensure effective implementation. (EPU, 2021: pp. 9–19)

This marks that at the development planning level, there is a focus on addressing interactions, synergies and trade-offs across sectors including the water, food, and energy sectors. However, there is little clarity on how this will be implemented in an integrated manner. Generally, in terms of overall strategic resource planning, while this review highlighted elements are evident within sectors, there is little evidence of a cross-sectoral strategic organisational arrangement to plan from a multi-sectoral point of view. Furthermore, there is little evidence of long-term capabilities to undertake cross-sectoral assessment such as through strategic foresight.

From an institutional point of view across the three sectors, the review notes no institutional arrangement exists for governing WFE Nexus. The implementation consists of only specific nexus trade-offs (and synergies) or weak policy integration and coherence between different sectors and mainly focuses on resource optimization. Where water transfers inter-state, such as in the case of Penang and Kedah (Sg. Muda), the agreements do not take into consideration nexus factors or drivers such as ecosystem services preservation beyond the raw water transfer. Furthermore, in the water sector, as highlighted previously, there is no single institutional framework to streamline the governance of water use across water resource management and water supply management. The Majlis Sumber Air Negara is the apex body for the water sector but does not address nexus issues specifically. In the context of water-food nexus, while BPSP is under the Ministry of Agriculture and Food Industries.

In summary, as fragmentation occurs within each sector, it is not plausible to consolidate institutions across all three sectors. Nonetheless, consolidation should occur within each sector, and with water identified as the choke point for nexus challenges, consolidation across the water sector, and in particular, across significant resource users is recommended.

6.2.2 Governing at the River Basin Level

6.2.2.1 Nexus Institutional Coordination and Public-Private Facilitation

At the river basin level, three states have established the *Majlis Sumber Air Negeri* (MSANg), namely, Selangor (LUAS), Sabah, and Kedah. Challenges remain at the river basin level where there are no river basin authorities that acts to integrate and coordinate activities in a river basin including implementing IWRM. LUAS has arguably progressed towards ensuring integrated management at the water basin level. However, a river basin authority will also need to engage multi-stakeholders to take into account various competing uses of water, including its impacts downstream. This will require taking into account a nexus approach in any multi-tiered institutional arrangement.

The nexus approach will need to take into consideration the complexities and fragmentation within each sector. Nonetheless, implementing the nexus approach requires a multi-tiered structure that coordinates across the levels of government, including at the river basin (vertically); and across the different sectors and stakeholders (horizontally). While each individual sector (water, energy, and food) is already complex and fragmented, the review demonstrates that two potential successful models, in situ initiatives (such as the integrated agriculture development areas), that are able to take into consideration the contexts at the appropriate scale; and an integrated approach that facilitates partnership, including with the private sector (i.e., palm oil industry). In the context of nexus and the water sector, two frameworks are required to be established, an institutional framework at the federal level that integrates the water sector including the DID and a governance structure at the river basin that incorporates nexus thinking.

Currently LUAS provides an example where it adopts various instruments for IWRM. This includes (as highlighted before), issuing licenses for water resource abstraction, diversion of water for generating electricity (amongst others) as well as adoption of Payment for Ecosystem Services (PES). These provide a good starting point for governing nexus at the river basin level. The experience in LUAS demonstrates the importance of state and river basin level governance for addressing issues that range from water resource management to water demand management, of which is require in the context of governing the nexus.

6.3 Institutionalising the nexus ecosystem in Malaysia

Taking into consideration the premise highlighted in the policy review as well as the guiding strategies of the overall WST2040, the study aims to chart out the pathways for Malaysia to become a regional water hub by 2040 through the utilisation of the nexus approach. The nexus approach is essentially a strategic approach supporting the implementation of two broad concepts that have often been challenging to implement due to its complexity and 'wicked' nature – IWRM and sustainability. Through bringing forward a sustainability paradigm early in the evolution of the sector, the shift towards water as an economic good will be addressed in a more holistic manner. The 12th MP (under Chapter 9, Strategy B2) identified a strategy that "going forward, the water-energy-food nexus approach will be institutionalised". While the review found that it would not be plausible to consolidate all three sectors under one organisational arrangement, the recommendations in this sub-section provide the building blocks in institutionalising nexus in Malaysia.

Nexus is what is known as a wicked problem, where issues are defined by being complex. The salient features of the nexus challenges highlighted within the report are:

- **Nexus is highly contextual and dynamic**: The nature of nexus challenges is highly contextual, requiring institutions to be established at the appropriate scales to address the nexus phenomenon that occurs in the specific locality (i.e., river basin). Furthermore, the challenges are characterised by non-stationarity, with megatrends and pressures such as climate change and pollution resulting in the need for infrastructure and solutions to adapt to changes in hydrological systems.
- **Silo approach to cross-sectoral issues**: Cross-sectoral issues are addressed currently addressed in silos with little policy target, instruments or institutionally coordinated implementation found across sectors. Furthermore, each sector is also found to be fragmented within their own institutional structure.
- **Lack of capacity**: As a relatively new area that is complex and interdisciplinary, there is currently a lack of interdisciplinary capacity as well as transdisciplinary arrangements that not only cuts across knowledge in the three sectors (water, energy, and food) but also across technical expertise and policy knowledge.

- **Private sector innovation and investments lacking for nexus solutions**: The enabling environment is not conducive to attract investments to address cross-sectoral issues resulting in the lack of investments, particularly in the water sector. This includes low general awareness and capacity; lack of transparent cross-sectoral information to identify nexus flashpoints and related strategic challenges; absence of cross-sectoral policy targets and minimal use of economic instruments to provide incentives for innovation.

To address these nexus challenges, addressing the nexus will require characteristics that can address the challenges above. This requires an overall ecosystem approach that can respond to the wicked nature of the problem. Some features that are proposed include:

- **WFE Nexus indicator and monitoring**: As nexus challenges manifest themselves contextually, there needs to be a harmonised method and database at the river basin level to identify "nexus hotspots". It is proposed that the Water Stress Index (WSI) is utilised.
- **In-situ development**: To respond to the contextual nature of the nexus challenge from an institutional point of view, in-situ approaches such as establishing an integrated agency at the river basin is proposed. This could be in the form of a River Basin Organisation which takes into consideration the competing uses of water as well as the preservation of water resources.
- **Integrated governance**: The nexus solutions should streamline water include the involvement of private sector to both attract investments and catalyse innovation. Previous examples from the palm oil industry provide an example of how commodity boards and associations can work in partnership.
- **Strategic planning**: There is a need to shift resources to focus solely on "livelihood" towards a focus on strategic and economic opportunities as well as longer term sustainability. In particular the water sector has focused more on water for livelihood and water access while the agrofood sector has focused mainly on self-sufficiency levels. While these continue to be key concerns, it may come at a cost when strategic concerns are not taken into consideration

  The sections below highlight the key recommendations arising from the review.

6.3.1 Communicative or Informational Instruments

6.3.1.1 Institutionalise the Water Stress Index (WSI)

One of the major challenges is the lack of information for decision-making in identification of nexus hotspots. The nexus flashpoints are highly contextual and there is a need for accessible and usable data to be available to further identify the phenomenon and problems in the first place, and subsequently identifying the responses through an evidence-based approach. Identifying water as the choke point, the proposal is to adopt the Water Stress Index (WSI).

This includes the establishment of a monitoring and evaluation system on WSI. The NWRP should include a policy target on the feasible and targeted level for WSI in Malaysia. For example, the policy target should target to have all river basins defined as 'low stressed' or 'not stressed' in accordance with the WSI methodology adopted internationally. The focus on measuring water stress is also an indicator under the SDGs (Target16.4).

6.3.1.2 Develop a Hydrological and Hydrosocial Database

One of the key challenges is the absence of a database that can be accessible to all sectors and particularly end users for resource planning. There is a need to develop a comprehensive hydrological and/or hydrosocial database that can guide decisions including for resource allocation and for resource planning. The database should be linked to a decision support that can both identify WFE nexus challenges through an improved monitoring of water catchment areas, as well as support decisions at the river basin level through development of databases and modelling systems covering critical/stressed river basins, at the river basin-level in addition to the national-level hydrological database. The DSS can be part of a broader M&E system for the NWRP.

The MySEAA-Water Account by DOSM should be leveraged and explored to be expanded to include hybrid and economic accounts. The accounting will also provide the starting point for the strategy to "determines the appropriate distribution of water resources to all sectors" as part of the strategy under the 12th MP.

6.3.1.3 Establish Cross-Sectoral Policy Targets in Sectoral Policies

Cross sectoral policy targets should be included in latest iteration of sectoral targets in water, food and energy policies. This includes a revised National Water Resources Policy, a National Water Services Policy, National Agrofood Policy 2021–2030 and the National Energy Policy. The policy targets should focus on water and energy use efficiency targets. This includes considering policy targets in the National Water Resources Policy on abstraction thresholds for irrigation and utilities sectors, energy efficiency targets for National Water Services Policy (for water treatment and wastewater treatment), irrigation efficiency and water use efficiency targets in the National Agrofood policy and water use and land use efficiency and optimisation in the National Energy Policy. This is in line with SDG6.4 towards on enhancing water use efficiency.

6.3.1.4 Develop a WFEN Technical Guide and Manual

As part of informational instruments to enhance nexus delivery, a WFEN Technical Guide and Manual should be developed. The technical guide and manual is required to guide relevant agencies on WFE nexus implementation and is in line with the 12th MP intention for increasing the technical expertise of relevant ministries and agencies.

6.3.2 Economic-Based Instruments

6.3.2.1 Establish Incentives for Water Use Efficiency in Agriculture and Energy Sectors

Following on from better information systems through the databases highlighted above, incentives based for efficiency based on water usage should be explored. A study should be conducted on water abstraction rates should be conducted to establish incentive mechanisms. This can be based on differentiated tariffs and/or thresholds for water abstraction, charge by metering and/or other feasible mechanisms. Any such as incentive should also be explored to be institutionalised through regulatory mechanisms.

6.3.2.2 Establish Incentives for Resource Efficient Technology Adoption

While specific incentives are currently available such as through GTFS, incentives for adoption for resource efficiency relevant to nexus should be established. For example, this can include System of Rice Intensification adoption, drip irrigation, solar pumps, and any other relevant nexus technologies. Larger and integrated nexus infrastructure projects should also be supported, for example, floating LSS, POME biogas capture, multipurpose dams, and hydro and/or other innovation that contributes towards resource security of the three sectors.

6.3.2.3 Facilitation of Private Participation, Investment, and Innovation

River Basin Organisations (see organisational instruments) should be tasked to be ecosystem integrators and facilitate multi-stakeholder participation including the private sector. This includes facilitating investment through ensuring availability of information, ensuring a platform for communication with key stakeholders, and also incentivising innovation. For example, the feasibility of water funds to support upstream activities that reduce water usage should be explored.

To facilitate innovation, a mechanism for promoting innovative financing, in line with the Twelfth Malaysia Plan (Water Sector Transformation Strategy B4), where both public and private sector funding is channelled to promote WFE nexus innovation should be explored. This can be in the form of matching funds, government guarantee, and/or other forms of financing. These funds should support pilot projects towards nexus solutions.

6.3.3 Organisational Instruments

6.3.3.1 Establish a National Water Department

In line with the NWRP and IWRM, the review highlighted the importance of consolidation to address the fragmentation in governing the nexus. Although international review as well as the domestic review highlighted that it is not plausible to consolidate all three sectors as fragmentation exists even within the sectors, it is proposed that the water sector is consolidated. In the context of nexus, this is to ensure that water supply, services and water demand are being coordinated and planned by a single authority at the federal level. This would provide better coordination for water resource allocation and identification of nexus hotspots.

The proposal is to consolidate and establish a single National Water Department consisting of all water related agencies including JPS, JBA, and JPP. Particular attention should be paid to BPSP, which is currently under MAFI, and is not proposed to be part of the National Water Department. This is because it focuses specifically on regulating water use in the agriculture sector. This is because water services within agriculture requires specific sets of expertise from agricultural engineers and scientists. Opening established and institutional coordination mechanisms between the NWD and BPSP will allow for the avoidance of conflicting objectives between increasing yield and water use efficiency that may currently take place. The agency will be responsible, amongst others, to manage interactions between water and food, energy, and other sectors, and encouraging a holistic view of water/water industries.

6.3.3.2 Establish River Basin Organisations Governing Each State

One of the major gaps found in the review is that lack of integrated management at the river basin level. Although examples such as LUAS has demonstrated the potential of state and river basin level management, nexus approaches are still nascent with little evidence of implementation. Nonetheless, RBOs provide the best level of management of nexus to address the contextual and dynamic (non-stationarity) nature of nexus challenges.

A revised NWRP policy should explicitly aim to support states establishment of RBOs at the state level including providing federal support in its establishment. This is in line with the Twelfth Malaysia

Plan focus on Water Sector Transformation with Strategy B2 explicitly review the respective water-related legislation in line with the Water Resources Bill 2016, including the establishment of water resources management authority in all states.

6.3.3.3 Establishment of a Centre of Excellence (CoE) for WFE Nexus

WFE Nexus is still a relatively new area requiring technical expertise and support towards both identification and implementation of nexus challenges and opportunities. To support this transition, it is proposed that a CoE is established as a resource and technical centre. This is also in line with 12th MP, where under Strategy B2, a specific focus on Institutionalising the Water-Energy-Food Nexus Approach was defined, as follows; "the water-energy-food nexus approach will be institutionalised, while technical expertise of relevant ministries and agencies will be enhanced to ensure effective implementation". Under this strategy, it is proposed that a CoE on WFEN Nexus is established to support the technical expertise component, with NAHRIM and ISIS recommended as co-hosts.

6.3.4 Procedural Instruments

6.3.4.1 Revise Laws on Water Demand Management

Laws related to water demand management should be revised. While various laws such as the Irrigation Areas Act and Drainage Work Act do exist, there needs to be a review to update the acts in accordance with the current situation. A review and consideration of establishing new acts at the sectoral level should also be considered and explored. This includes studying the feasibility for a single Agriculture Water Management Act that covers all sectors of agriculture. Beyond specific acts, policies to govern water services should also be formulated, including for water treatment and wastewater treatment, taking into consideration efficiency targets for nexus challenges such as energy efficiency.

7.0 CONCLUSION AND SYNTHESIS OF RECOMMENDATIONS

7.1 Conclusion

This report covers several aspects of the water-food-energy nexus as it pertains to Malaysia, highlighting the various WFEN interactions present across the country at the intersections of the water, agriculture, and energy sectors most prominently. These interactions sometimes involve, or are affected by, other key factors or variables such as land use or climate change. This analysis has contextualised the many challenges and opportunities facing the security and sustainability of Malaysia's key strategic resources from the perspective or lens of the WFEN ecosystem.

These nexus interactions, issues, and opportunities, as well as our reviews of international best practices within WFEN approaches and critical analyses of the water, food, and energy security issues facing Malaysia have been used to identify our policy recommendations. These recommendations have the objectives of enhancing resource efficiency and security, contributing to a future of water, food, and energy security and sustainability. These also aim to spearhead the transition of water into an economic good and the water sector as an economic driver, as well as enhance Malaysia's realisation of resource sustainability. Recommendations cover areas as varied as technological game-changers and impacts, to governance and institutions, to economics, financing, and incentivisation, amongst others, that are relevant to the development of nexus solutions.

7.2 Recommendations

The transformation strategy recommended by the WFEN subsector is comprised of six strategies as described below:

7. **Identify nexus hotspots and Reduce 'Water Stress Index' (WSI) in relation to food and energy sectors**: To enhance identification and monitoring of WFE nexus, the WSI is proposed to be adopted as an indicator to identify nexus hotspots. The aim is to reduce river basins from 'Severe Stress' to 'Stress', 'Low Stress' or 'Not Stressed' in major granary areas.
8. **Establish a multi-tiered institutional arrangement**: Three initiatives are proposed under this strategy to transform towards in-situ development and integrated governance and transitioning towards IWRM.
   - o Establish a National Water Department (NWD) to manage interactions between water and food, energy, and other sectors, encouraging a holistic view of water/water industries;
   - o Establish a River Basin Organisation (RBO) at every state to better incorporate WFEN approaches within the water, food, and energy sectors including investment facilitation; and
   - o Develop informational policy instruments including a WFEN Technical Guide and Manual
9. **Capacity building, communication, education, and public awareness**: To address the lack of capacity, two initiatives are proposed:-
   - o Establish a WFEN CoE consisting of technical and policy expertise; and
   - o Initiate and strengthen R&D in WFE Nexus/Nexus Modelling in Malaysia
10. **Piloting infrastructure and technology to support WFEN approaches/initiatives**: As a novel concept, pilot projects are required to test the nexus solutions in the context of Malaysia. This process should be bottom up and led by innovation from the private sector and facilitated by the government. For example, an establishment of a pilot project fund that accepts proposals from the private sector to address specific issues related to nexus challenges could be established.
11. **Establish a database with usable information as a policy decision tool at the basin level**: Establish a DSS for WFEN, including the development of a hydrological database with improved monitoring of water catchment areas, alongside the development of modelling systems covering critical/stressed river basins
12. **Increase the use of economic instruments to promote resource efficiency and nexus approach**: This includes undertaking assessments on the economic value of water at river basin levels. From these assessments, the appropriate mechanisms that can enhance the economic value and potential of river basins will be identified.

8.0 ACKNOWLEDGEMENTS

This report has benefitted from the contributions of numerous individuals, government agencies, and private corporations. The study team would like to thank the following individuals, agencies, and corporations for their invaluable input during the various stakeholder discussion sessions that were held throughout 2021.

Table 65. List of Stakeholder Discussions

No	Agency	Date	Venue	Attendance
1.	MADA	10/3/2021	MADA Headquarters	Mr. Nik Kun Nik Man, Director of the Planning Division Mdm. Siti Mariam Bt Md Rejab, Economic Affairs Officer Mdm. Siti Hajar, Paddy Division Mr. Khalil, Planning Division
2	LAP	10/3/2021	LAP Headquaters	Mr. Shamsul Kamar, Senior Engineer Mr. Fadzillah, Operation Division Mr. Lokman, Engineer Mr. Balkhis, Operation Division
3	IADA Seberang Perak	11/3/2021	IADA Seberang Perak Headquarters	Mr. Nor Azlan Awaludin, Chief of Engineering Division
4	JPS Perak	11/3/2021	JPS Perak Headquarters	Mr. Mohd Zaidi bin Mokhtar (Water Resources management and Hydrology Division, BSAH) Ir. Sasitharan A/l Manikam (River Management Division) Miss Norzalina Anis bt. Mohd Ibrahim Miss Nordiana bt. Mohd Nor (BSAH)
5	Persatuan Aktivis Sahabat Alam (KUASA)	12/3/2021	KUASA Headquarters	Mr. Hafizudin Nasarudin, KUASA Consultant Miss Nurul Syuhada
6	WD Solar Sdn Bhd	15/3/2021	WD Solar Headquarters, Sepang	Miss Hafizah
7	TNB Hydro Generation Sdn Bhd	29/3/2021	Online	Mr. Kamal Hj Azhar Mr. Mohd Rozi Mr. Wan Rafiq (TNB Sg. Perak) Mr. Farid (TNB Hq)
8	NUR Generation Power Plant	8/4/2021	NUR Generation Power Plant Headquarters	Mr. Khairil (Chief engineer), Mr. Jafry (Head of Operations), Mr. Chan (Distribution), Mr. Khoo (Engineering), Mr. Iswardi (Operations), Mr. Musri (Chemical)
9	IADA Pulau Pinang	9/4/2021	IADA Pulau Pinang Headquarters	Mr. Mohd Nor Hafiz Bin Noor Azmi (IADA Pulau Pinang) Mr. Fadhil (JPS Pulau Pinang)

9.0 APPENDIX

Strategies, Targets, and KPIs for the 12th to 15th Malaysia Plans

12th Malaysia Plan

Table 66. Strategies, Objectives, and KPIs for the 12th Malaysia Plan

Strategy	Initiatives	Objectives	KPI
Establish a strengthened, multi-tiered institutional arrangement to govern WFEN approaches across policy cycles and undertake policy reviews, assessments, and reviews related to WFEN	**Establish a National Water Department** (NWD) Establish a **River Basin Organisation (RBO)** Develop informational policy instruments including a **WFEN Technical Guide & Manual (TGM)**	Reorganise institutional mandates to position the NWD as the lead authority on water-related matters in Malaysia. Needs assessment of existing river basin- or state-level water authorities and establish policy and legislation to incorporate WFEN Development of a generic, national-level WFEN TGM	Reducing river basins from 'Severe Stress' to 'Stress', in *major granary areas* and/ or where WSI is currently above **0.4 (out of 1)** (Muda, Selangor, Johor)
Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus	Establish a pilot WFEN Centre of Excellence (CoE) Initiate the development of an ecosystem to support **WFEN Modelling** in Malaysia	Institutionalise the pilot WFEN CoE at NAHRIM to engage in activities related to the WFEN (refer to Roadmap and recommendations) Identify priority areas/river basins and perform needs and gap assessments to identify the required expertise, covering requirements for the development of a database, decision support system (DSS), and human resources Development of the required expertise/ human capital, in areas such as coding, programming, machine learning, in the context of the water sector and all associated activities (i.e. covering all interlinkages with energy, and food).	
Establish a database with usable information as a policy decision tool at the basin level	**Establish a DSS for WFEN**, including the development of a hydrological database	Development of a national-level hydrological database, system integration and user interface by consultants with the required expertise	
Increase the use of economic instruments to promote resource efficiency and nexus approach	Undertake **assessments on the economic value** of water at river basin levels	Undertake studies covering two river basins with significant economic value (or high levels of resource interactions).	
Piloting infrastructure and technology to support WFEN approaches/initiatives	Undertake pilot projects to address WFEN challenges and opportunities in critical/stressed river basins identified through infrastructure, materials, and technology	The experimentation/piloting of six projects featuring the use of WFEN-related infrastructure, materials, technologies. Examples may include drip irrigation, graphene, agrivoltaic LSS, biogas, solar pumps, floating LSS.	

13th Malaysia Plan

Table 66. Strategies, Objectives, and KPIs for the 13th Malaysia Plan

Strategy	Initiatives	Objectives	KPI
Establish a strengthened, multi-tiered institutional arrangement to govern WFEN approaches across policy cycles and undertake policy reviews, assessments, and reviews related to WFEN	Establish a National Water Department (NWD)	Streamlining budgets to reduce redundancies and through strategic reallocations into new areas of growth	Reducing river basins from 'Severe Stress' and 'Stress' to 'Stress', in major granary areas and/or where WSI is currently above 0.3 (Muda, Selangor, Johor)
	Establish a River Basin Organisation (RBO)	Establishment of RBO (appropriate level of governance from the perspective of WFEN because issues are river-basin-specific) in remaining water-stressed states with major granary areas (e.g. IADA Penang, KADA (Kelantan), MADA, IADA Seberang Perak, IADA Terengganu Utara)	
	Develop informational policy instruments including a WFEN Technical Guide & Manual	Development of 3 river basin-level TGMs for Sg Muda, Sg Johor, and Sg Selangor	
Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus	Establish a pilot WFEN Centre of Excellence (CoE)	Assess pilot WFEN CoE and benchmark functions and performance against international and other established CoEs	
	Initiate the development of an ecosystem to support WFEN Modelling in Malaysia	WFEN modelling for 3 river basins (Muda, Johor, and Selangor)	
Establish a database with usable information as a policy decision tool at the basin level	Establish a DSS for WFEN, including the development of a hydrological database	Development of 3 river basin-level hydrological databases (Muda, Johor, Selangor)	
Increase the use of economic instruments to promote resource efficiency and nexus approach	Undertake assessments on the economic value of water at river basin levels	Undertake assessments on the economic value of water covering 2 RBs with significant economic value, to be determined by the WFEN CoE	
Piloting infrastructure and technology to support WFEN approaches/initiatives	Undertake pilot projects to address WFEN challenges and opportunities in critical/stressed river basins identified through infrastructure, materials, and technology.	Develop economic incentives for private investment in WFEN infrastructure, materials, and technology.	

14th Malaysia Plan

Table 67. Strategies, Objectives, and KPIs for the 14th Malaysia Plan

Strategy	Initiatives	Objectives	KPI
Establish a strengthened, multi-tiered institutional arrangement to govern WFEN approaches across policy cycles and undertake policy reviews, assessments, and reviews related to WFEN	Establish a National Water Department (NWD)	Completed under 13MP	Reducing river basins from 'Stress' to 'Low Stress' in major granary areas and/or where WSI is currently above 0.2 (Muda, Selangor, Johor, Perak, Linggi)
	Establish a River Basin Organisation (RBO)	Undertake review and evaluation of RBO's performance in incorporating WFEN	
	Develop informational policy instruments including a WFEN Technical Guide and Manual	Development of 2 river basin-level TGMs for Sg. Perak and Sg. Linggi	
Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus	Establish a pilot WFEN Centre of Excellence (CoE)	Formalise permanent status of WFEN CoE	
	Initiate the development of an ecosystem to support WFEN Modelling in Malaysia	WFEN modelling for 2 river basins (Perak, Linggi)	
Establish a database with usable information as a policy decision tool at the basin level	Establish a DSS for WFEN, including the development of a hydrological database	Development of 2 river basin-level hydrological databases (Perak, Linggi)	
Increase the use of economic instruments to promote resource efficiency and nexus approach	Undertake assessments on the economic value of water at river basin levels	Undertake assessments on the economic value of water covering 2 RBs with significant economic value, to be determined by the WFEN CoE	
Piloting infrastructure and technology to support WFEN approaches/initiatives	Undertake pilot projects to address WFEN challenges and opportunities in critical/stressed river basins identified through infrastructure, materials, and technology	<6 projects each for Sg. Perak, Sg. Linggi river basins	

15th Malaysia Plan

Table 68. Strategies, Objectives, and KPIs for the 15th Malaysia Plan

Strategy	Initiatives	Objectives	KPI
Establish a strengthened, multi-tiered institutional arrangement to govern WFEN approaches across policy cycles and undertake policy reviews, assessments, and reviews related to WFEN	**Establish a National Water Department** (NWD)	Completed under 13th MP	Reducing river basins from 'Stress' to 'Low Stress' in major granary areas and/or where WSI is currently above **0.1** (Muda, Selangor, Johor, Perak, Bernam, Kelantan, Linggi, Padas, Pahang)
	Establish a **River Basin Organisation (RBO)**	Completed under 14th MP	
	Develop informational policy instruments including a **WFEN Technical Guide & Manual**	Development of 4 river basin-level TGMs for Sg. Bernam, Sg. Padas, Sg. Kelantan, Sg. Pahang	
Capacity Building and Communication, Education and Public Awareness (CEPA) on WFE Nexus	Establish a pilot **WFEN Centre of Excellence (CoE)**	Completed under 14MP WFEN modelling for **4** river basins (Bernam, Padas, Kelantan, and Pahang).	
	Initiate the development of an **ecosystem to support WFEN Modelling** in Malaysia	Commercialisation and export of developed expertise into WFEN modelling.	
Establish a database with usable information as a policy decision tool at the basin level	**Establish a DSS for WFEN**, including the development of a hydrological database	Development of **4** river basin-level hydrological databases (Bernam, Padas, Kelantan, Pahang)	
Increase the use of economic instruments to promote resource efficiency and nexus approach	Undertake **assessments on the economic value of water** at river basin levels	Undertake assessments on the economic value of water covering **2** RBs with significant economic value, to be determined by the WFEN CoE	
Piloting infrastructure and technology to support WFEN approaches/initiatives	Undertake pilot projects to address WFEN challenges and opportunities in critical/stressed river basins identified through infrastructure, materials, and technology	<**6** projects each for Sg. Bernam, Sg. Padas, Sg. Kelantan, Sg. Pahang river basins Commercialisation and international export of indigenously-developed infrastructure, materials, and technology.	

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