DEVELOPMENT OF WATER-ENERGY-FOOD NEXUS CONCEPTUAL FRAMEWORK FOR BANGLADESH

By

Partha Protim Biswas

MASTER OF SCIENCE IN WATER RESOURCES DEVELOPMENT

Institute of Water and Flood Management

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

October, 2018

DEVELOPMENT OF WATER-ENERGY-FOOD NEXUS CONCEPTUAL FRAMEWORK FOR BANGLADESH

A Thesis
By

Partha Protim Biswas

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN WATER RESOURCES DEVELOPMENT

Institute of Water and Flood Management

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

October, 2018

BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

Institute of Water and Flood Management

APPROVAL

The thesis titled **'DEVELOPMENT OF WATER-ENERGY-FOOD NEXUS CONCEPTUAL FRAMEWORK FOR BANGLADESH'** submitted by Partha Protim Biswas, Roll No. 0416282008 F, Session: April/2016, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of M.Sc. in Water Resources Development on 31 October, 2018

BOARD OF EXAMINERS

Dr. G. M. Tarekul Islam — Chairman
Professor
IWFM, BUET, Dhaka.
(Supervisor)

Dr. Sujit Kumar Bala — Member (Ex-Officio)
Director
IWFM, BUET, Dhaka.

Dr. Sujit Kumar Bala — Member
Professor
IWFM, BUET, Dhaka.

Dr. Md. Munsur Rahman — Member
Professor
IWFM, BUET, Dhaka.

Dr. M. Mozzammel Hoque — Member (External)
Former Professor of IWFM, BUET.
92, Maszid Road, Old DOHS, Dhaka.

CANDIDATE'S DECLARATION

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any degree or diploma.

Partha Protim Biswas
Roll No.: 0416282008
Session: April 2016

ACKNOWLEDGEMENT

I wish to express my sincere gratitude to my thesis supervisor Dr. G. M. Tarekul Islam, Professor, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology for his invaluable guidance, encouragement, and support in performing the thesis work. I am deeply indebted to Dr. G. M. Tarekul Islam for the knowledge and various aspects of the thesis I learned from him during my research work.

I would like to thank Dr. Sujit Kumar Bala, Director and Professor, Institute of Water and Flood Management, Bangladesh University of Engineering and Technology for his guidance and giving me the opportunity to fulfill the thesis work.

I also render my gratitude to those authors whose works in the related field gave me relevant information and to interviewees who rendered their valuable time in answering in the key informant interview.

I am greatly indebted to my parents who rendered their immense support during my M.Sc. course and I dedicate my accomplishment to them.

ABSTRACT

The Water-Energy-Food (WEF) Nexus is a useful concept to apprehend the complex and interrelated characteristics of vital natural resources that are indispensable in the achievement of sustainable development for Bangladesh. The WEF nexus approach expounds interdependency of three interfaces of energy-water, energy-food, and food-water and through integrating nexus perspectives into national plans, policies and strategies, becomes a policy and resource management instrument. A Water-Energy-Food (WEF) Nexus framework is developed for Bangladesh through evaluating water, energy and agricultural resource management conflicts, expounding interrelations by demand assessment and assessing prevailing WEF nexus frameworks. The WEF nexus framework for Bangladesh depicts that in one hand food production is water intensive due to irrigation requirements that draws vast electricity that is also dependent on water supply for both thermal and hydro plants whereas water management systems are run by electricity. Water-induced disasters bring devastation to both food and power production while fertilization in agriculture and criticality in land acquisition for setting up of power plants along with their discharged effluents in rivers cause damage to water quality, agriculture, and fisheries of particular locations. Solar irrigation, crop diversification, biomass electricity, micro-hydro power generation, organic fertilization are responses to the criticality of WEF nexus being practiced in Bangladesh. Despite national plans and policies of Bangladesh tremendously focus on implementation measures to accomplish sustainability in water, energy, and food security, their lacking in incorporating the WEF nexus would result in impeding eco-system sustenance. It is evident from this study that, the institutionalization of the synergy between water and agriculture is issued in major plans and policies whereas interconnection between water and energy, food and energy is not addressed to required extent whilst the WEF nexus perspective is absent. Divergent sectarian experts have strongly agreed on efforts to improve institutional and financial coordination along with international technology transfer and capacity building training programmes to be initiated to adopt a nexus approach in the process of SDG implementation. Given growing criticality in resource management in water, energy and food sector, foremost ratiocination derived is to harnessing the WEF nexus in policymaking is of utmost importance for achieving sustainable development ensuring ecosystem and environmental balance.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BBS	Bangladesh Bureau of Statistics
BDP	Bangladesh Delta Plan
BPDB	Bangladesh Power Development Board
BWDB	Bangladesh Water Development Board
CPD	Center for Policy Dialogue
CSIRO	Commonwealth Scientific and Industrial Research Organization
CO_2	Carbon Dioxide
DOE	Department Of Environment
EIA	Environmental Impact Assessment
ERD	European Report on Development
EU	European Union
FAO	Food and Agriculture Organization
GBM	Ganges-Brahmaputra-Meghna
GED	General Economic Division
HKH	Hindu Kush Himalayan
ICIMOD	International Centre for Integrated Mountain Development
IISD	International Institute for Sustainable Development
NAP	National Agriculture Policy
NWPo	National Water Policy
NEMAP	National Environmental Management Action Plan
NCA	Net Cultivable Area
NWMP	National Water Management Plan
MDG	Millennium Development Goals
SDG	Sustainable Development Goals
SLR	Sea level rise
TA	Technical Assistance
UN	United Nations
WEF	Water Energy Food
WARPO	Water Resources Planning Organisation
WEL	Water Energy Land
7FYP	7^{th} Five Year Plan

CHAPTER 1

INTRODUCTION

1.1 General

Ensuring endurability in water, energy and food supply is the most critical feature to ensure sustainable development for human life. Global projections indicate that over the next decades demand for freshwater, food, and energy will increase significantly under the pressure of population growth and mobility, economic development, international trade, urbanization, diversifying diets, cultural and technological changes, and climate change presuming demand for food and energy will jump 50% by 2030 and for fresh water by 30% (Hoff, 2011; Parry, 2012). Increasing competition for food, water, and energy resources demand is interwoven for their natural interdependency whereas general trend to deal with isolation has resulted into lack of integrated approach regarding technical and policy issues of food, water and energy.

The Water-Energy-Food Nexus has emerged as a useful concept to apprehend the complex and interrelated nature of our global resource systems that are indispensable in the achievement of different social, economic and environmental goal (FAO, 2014). The nexus approach expounds the interdependencies of water, energy, and food production and aims to systemize the interconnections to erect a framework for assessing the use of all resources and to manage trade-offs and synergies (Hellegers et al., 2008; Bazilian et al., 2011; Scott et al., 2011; Hermann et al., 2012; Hussey and Pittock, 2012; Sharma and Bazaz, 2012). This holistic approach will not only provide a significant contribution to obtain national and regional sustainable development targets but will also be effective for espousing equity amongst individuals and communities in local and global development agendas (Biggs et al., 2015).

Bangladesh has established a new development paradigm through outstanding progress in MDGs achievement. Its remarkable achievement of consistent average economic growth rate has led to the ambition of being a middle-income country by 2021. In thriving for development, the country has incorporated Sustainable Development Goals generally known by their acronym SDGs as a priority issue and striving to achieve greater success than MDGs. SDGs are considered to be integrated by synergy leading to the fact that aiming to achieve individual goals will be in vain if synergy among them is not considered. Among proposed goals, Goal 2, Goal 6 and Goal 7 focus on the security of three basic elements of food, water, and energy respectively. SDG-2: zero hunger, SDG-6: clean water & sanitation & SDG-7: affordable & renewable energy are interconnected and their nature of interdependence, which is well reflected through WEF nexus, is critical in overall SDG implementation. The water-energy-food nexus perspective can be useful as a policy and management instrument in dealing with adversaries to the implementation of Sustainable Development Goals.

1.2 Water energy food nexus

Burgeoning population, rapid urbanization, economic prospect, and climate change have brought in complex synergy within supply-demand management of water, energy and food resources on the context that their universal storage is on a descending trend. Any strategy focusing on the single part of the water energy food nexus without considering its interconnections may risk serious unintended consequences (WEF, 2011). The WEF nexus is a non-linear interacting process illustrated by three bilateral interfaces of energy-water, energy-food and food-water comprising linkages as resource supplies, end-use demands and requirements and natural and human-engineered technologies, processes and infrastructures essential to produce, supply and deliver the resources to meet the end-user demand (Kumar et al., 2015). The Bonn 2011 Conference, "The Water, Energy and Food Security Nexus- Solutions for the green economy" is recognized as the initial international effort to institute the WEF nexus approach in attaining sustainability in water, energy, and food security in a manner reducing adverse impacts on nature that eventually leads toward a green economy. Later the Bonn 2014 Conference, "Sustainability in the Water-Energy-Food Nexus" emphasizes on the coherence of cross-sector policy efforts and cross-border cooperation as integral for the successful governance of the complex risks to sustainable supply of water, energy, and food (Kumar et al., 2015). The key areas for intervention in promoting the WEF nexus includes stakeholder involvement, policy integration, governance through resource planning and promoting innovation while an ecosystem-based spatially explicit nexus framework is required for implementing these issues to increase water, energy and food security (Bizikova et al., 2013).). In the process of incorporating WEF nexus perspective in national planning, formulating a nexus framework in Bangladesh for a better understanding of the issue and analyzing the country‟s strategic plans and policies to accommodate the approach is of utmost importance.

1.3 Objectives of the study

This study is expected to provide a comprehensive overview of water-energy-food nexus in the context of Bangladesh and create an approach to incorporate the nexus in SDG achievement. In this regard the objectives of this study can be described as followed;

1) Develop a WEF nexus framework in the context of Bangladesh through evaluating water, energy and agricultural resource management conflicts, expounding interrelations by demand assessment and assessing prevailing WEF nexus frameworks

2) Analyze existing national plans, policies and strategies of Bangladesh regarding water, energy and food resources to evaluate their prospect to incorporate WEF nexus perspective

3) Evaluate existing national executive structure of SDG implementation and assess government‟s concerns and possibilities to incorporate a WEF nexus approach in the planning process

CHAPTER 2

LITERATURE REVIEW

2.1 Interconnections among water, energy and food

Enormous inter-linkage prevails in water, energy and food systems illustrated by three bilateral interfaces of energy-water, energy-food and food-water comprising linkages as resource supplies, end-use demands and requirements and natural and human-engineered technologies, processes and infrastructures essential to produce, supply and deliver the resources to meet the end-user demand (Kumar et al., 2015). Water is integral to biomass production and biomass is the central resource for energy and food security in a Green Economy (Hoff, 2011). Food production and supply chain are accounted for around 30% of total global energy demand as well as responsible for 80% to 90% of consumptive blue water usage making it the largest water consumer (Hoff, 2011). Water consumption for energy generation amounts to about 80% of global water withdrawal (SOER, 2010) whereas some countries consume up to 40% of total energy use for groundwater irrigation (WEF, 2011).

2.2 Importance of water, energy and food nexus

The tremendous synergy between water, energy and food systems derives extreme significance in the accreditation of a nexus approach to the integrated management of these resources. A nexus approach is capable of transforming climate mitigation to be water smart, less energy-intensive and avoiding damaging consequence for food production sustaining vital ecosystem services (Hoff, 2011). In this context, the water-energy-food nexus has emerged as a useful approach to balance different resource user goals and interests maintaining the integrity of ecosystems apprehending complex and inter-related nature of our global resources systems (FAO, 2014). The WEF nexus was commenced at the Bonn 2011 Nexus Conference and subsequently conferred to World economic forum 2011, 6th World Water Forum, World Water Week 2012 and Rio +20 Declarations. The WEF nexus can be particularized through (1) ability to incorporate management approaches beyond being water-centric (Giupponi et al., 2016); (2) emphasizing security concerns for three interrelated resources important for society and economy (Bakker, 2012); (3) provisioning sustainable business solutions through public-private partnership (Benson et al., 2015; Bizikova et al., 2013). European Report on Development, ERD, 2012 specified several characteristics underlining the importance of water, energy and food nexus including firstly imminent global scenario of absolute resource scarcity presenting challenges and opportunities for integrated solutions. Secondly, interrelation among water, energy and food resources may draw negative impact if coordination failure takes place in addressing the inter-linkages within policies. Thirdly, the inadequacy of clear property rights and data on resource conditions in developing countries. Finally, nexus affects poorest population groups disproportionately pressurizing their livelihoods.

Overall resource use efficiency, sustainable resource management, and equitable benefit sharing can be achieved by provisioning more integrated policies and decisions (Hoff, 2011). Despite the inherent interconnections among water, energy and food systems, fragmented and isolated approach incorporating poor sectoral coordination and institutional fragmentation by concerning agencies has triggered an unsustainable use of resources and threatened the long-term sustainability of food, water, and energy security in the region posing challenges to achieving the Sustainable Development Goals (SDGs) (Rasul, 2014). For instance, designing of agricultural policies and subsidy programmes without taking into account the complexity between energy and water along with providing energy subsidies without considering groundwater depletion and degradation is a recurrent act by governments (Bhaduri et al. 2015). Existing institutions need to be adaptive, cooperative and flexible accompanied by the provision of the further establishment of institutions to facilitate policy adaptation and amendment to forge ahead with accelerated development (Walker et al., 2009; Hoff, 2011). The players underpinning greater policy coherence to the implementation of WEF nexus are public, private and civil society at local and broader human scales (Bhaduri et al., 2015).

2.3 Water, energy and food nexus framework

The WEF nexus is a non-linear interacting process that comprises a conceptual and analytical approach to socio-economic systems and offers a framework for coordination management and use of natural resources across sectors and scales (FAO, 2014). The nexus comprises of three bilateral interfaces of energy-water, energy-food, and food-water forming a dynamic set of nonlinear interacting processes linked through a complex network of feedbacks, rendering the analysis of sector-to-sector interfaces insufficient to capture the complexity of the WEF system as stated by Hibbard et al., 2014. It can be defined as an approach to assessment, policy development and implementation focusing simultaneously on water, energy and food security (Bizikova et al., 2014) recognizing their interdependencies and systemizing interconnections to provide a framework for assessment and management of synergies and trade-offs (Kumar et al., 2015). WEF nexus thinking permits governance considerations at the global level by recognizing interregional spillover effects of national and regional policies as a manifestation of global interdependences due to trade, production, consumption, climate and the movement of people. It forges improved coordination of energy, water and agricultural priority setting, and planning at the regional level while at water basin level it provides a rationale for regional policy formulation and infrastructure development. At the national and local levels, WEF nexus calls for coherence in planning achieved through cross-sectoral consultation and decision processes (ESCWA, 2015). In recent years various conceptualization of the WEF Nexus has emerged divergent in their structuring of the nexus in spite of commonly leading towards an effective management approach for natural resources. Major conceptual frameworks for WEF nexus are FAO water-energy-food nexus framework, Bonn 2011 WEF nexus framework, European Development Report (EDR) nexus framework, water–energy–food security nexus framework by IISD, WEF nexus framework by ICIMOD etc. WEF nexus frameworks primarily embodied interdependencies among water, energy and food resources assessing regional and global trends and different organizations seeking to expand scopes to include additional issues of particular concern to their specific mandates (ESCWA, 2015).

CHAPTER 3

METHODOLOGY

3.1 Water energy food resources data assessment

Assessment of conceptual frameworks for WEF nexus provides with the theory of developing a Water-Energy-Food (WEF) nexus framework with its working areas comprising of determining nexus drivers through evidence, scenario development and discovering response options. Water resources management conflicts with agricultural and energy sectors are focused along with water demand assessment and vice versa with two other resources. Data regarding resource composition, divergent water demand and availability, power generation trend and potentiality, energy consumption pattern are assessed along with considering rainfall, sea level rise, natural disaster impacts, and agricultural land and environmental issues regarding water, energy and food sectors to determine drivers that instigate WEF nexus. The WEF nexus scenario is then constructed from the interaction of drivers creating synergy within three interfaces of food-water, water-energy and energy-food and impacts of these nexuses are also evaluated. Interconnected scenarios from three interfaces are combined to manifest a water-energy-food nexus conceptual framework for Bangladesh presented through comprehensive illustration. Several existing and potential responses to WEF nexus scenarios are determined along with government projects to counter nexus complexity. Concerned secondary data were collected from survey reports, environmental impact analysis reports, international statistical reports, master plans, journal papers etc.

SDG indicators datasets are used to evaluate quantitative interdependencies among SDG-2: zero hunger, SDG-6: clean water & sanitation & SDG-7: affordable & renewable energy. Pearson Correlation Coefficient is calculated by dividing the covariance of two variables by the product of their standard deviations and Significance Level was evaluated by comparing p-value calculating through regression analysis. Statistical Significance Levels of Pearson Correlation Coefficients are attributed as; not significant when $p > 0.05$; * for $p < 0.05$; ** for $p < 0.01$ and *** for $p < 0.001$ i.e. highly significant. Synergy or trade-off among SDG-

2, SDG-6 & SDG-7 is measured by following Advanced Sustainability Analysis (ASA) developed under European Framework Programmes FP6 & FP7. The Advanced Sustainability Analysis (ASA) is a mathematical information system that can analyze indicator data for the different point of view decomposing factors affecting changes that offers decision makers a tool for policy development for dimensions of sustainable development (Luukkanen, J., 2004). Primarily indicator datasets for SDG-2, SDG-6, and SDG-7 are normalized to the base or previous year and then calculating relative changes between two normalized indicator data by their ratio. If the resultant is greater than 1, then the quotient is inverted to keep the index between -1 to +1.

3.2 National policy assessment

Existing national plans, policies and strategies of Bangladesh regarding water, energy, and food resources are analyzed for their prospect to incorporate WEF nexus perspective. Legal documents regarding water resources are scrutinized to investigate their coherence of food and energy-related issues. Similarly, energy and food-related legal documents are investigated to acknowledge their integration of dealing with issues relating other two resources. National policy documents such as seventh five-year plan, perspective plan, delta plan, national water, food, agriculture, energy policies are investigated to evaluate the integration level of WEF nexus through investigating their coherence of interdependency issues regarding water, energy and food resources.

3.3 Key Informant Interview

A key informant interview with questionnaire survey is accomplished to explore expert view on the country‟s readiness level, domestic & international efforts along with coordination body necessary to integrate the WEF nexus approach in SDG implementation. Total 43 respondents including 18 from the agriculture sector, 13 from water sector, 4 from the energy sector and others are from government planning and statistical agencies and international research organizations participate in interviews providing opinions through a questionnaire consisting WEF nexus and SDG related issues. Expert opinion on country‟s readiness level to integrate WEF nexus approach in the implementation plan of SDG-2, SDG-6, and SDG-7 is collected from food, water, energy and planning sectors. They also provide a view on kind of domestic and international efforts necessary to adopt WEF nexus approach in the process of SDG implementation and attributed importance of the efforts by strong, moderate, low or no consents. Lastly, stakeholders argue on whether the existing institution or developing new agency is required to coordinate SDG implementation by integrating WEF nexus. Information collected through interviews is processed through Microsoft Excel to provide comprehensive graphical presentation of stakeholder"s opinion on incorporating WEF nexus for SDGs planning.

CHAPTER 4

ASSESSMENT OF WATER, ENERGY AND FOOD RESOURCES POLICIES OF BANGLADESH

The obligation of Plans and policies of the Government of Bangladesh to address the dynamic synergies between the sustainable development goals to implement SDGs is quoted in the preamble of Data Gap Analysis of Sustainable Development Goals (SDGs) (GED, 2017). The National Sustainable Development Strategy (GED, 2013) of Bangladesh identifies Agriculture, Industry, Energy, Transport and Human Resource Development as five priority development sectors. The five-year plan for the period 2016-2020 is found thematically fully aligned with food, water, and energy issues of SDGs except for adequately expressing concern over their nexus approach. The Perspective Plan of Bangladesh (2010-2021) (GED, 2012), though draws tenuous attention to electricity management for agriculture, emphasizes greatly to integrate water resources management for achieving self-sufficiency in food production. The perspective plan reveals its skeptical view on the attainment of hydropower contribution to the national grid for its dependency on co-operation from neighboring countries. Except planning to economize natural gas consumption to power production by utilizing the released gas as fertilizer, there is scant indication of synergy between power and agriculture in the plan.

4.1 Review of National Water, Energy, Food and Agriculture Policy Regarding WEF Nexus

The National Water Policy (NWPo) (MoWR, 1999) acknowledges the synergy between water and agriculture adequately focusing on irrigation water use efficiency through water recycling, crop diversification, conjunctive water use and rotational irrigation along with ensuring safeguarding environment from pollution and identified alternating food and water scarcity during wet & dry seasons as one of the most critical & immense challenges against progress towards fulfilling the national goal of food security. It calls for designated flood risk zone & appropriate measures to safeguard agriculture from flood damaging while the allocation of irrigation water is prioritized after domestic and municipal uses, non-consumptive uses and sustenance of the river regime in drought. It also concerns over lowering of groundwater table from excessive irrigation water extraction and pollution of swallow aquifers from seepage of agrochemicals and facilitates preserving natural depressions, rainwater harvesting, conservation, balancing wastages etc as solutions. The NWPo, 1999 emphasizes on sustaining of ecosystem balance for development of hydropower systems.

The National Food Policy (MoFDM, 2006) envisions establishing dependable and sustained food security recognizing the interconnection between food and water while not pointing to the synergy between energy and food. It emphasizes on efficient water resource usage for irrigation & production of livestock, fish and other non-crop items including fruits for agricultural development & extension and calls for improved irrigation management programmes including improved infrastructure, participatory approach, water conservation, improved technology, uninterrupted electricity etc to increase yield and production of food-grains and other crops. It also highlights the development and extension of more location-specific flood/drought tolerant varieties and supplementary irrigation during drought for disaster mitigation for agriculture. On a lighter note, the policy points on rural electrification and irrigation power supply issues regarding food security.

The National Energy Policy (MoPEMR, 2004) underlines environmentally sound energy development programmes incorporating renewable energy to enable rural development. Apart from hydropower, any detailed mentioning of the linkage between energy with water and food is absent in the document. The National Agriculture Policy (MoA, 1999) encompasses the development of food security through increased production of all crops underlining SDG agenda of ending hunger. The NAP emphasizes on achieving irrigation water management efficiency in the light of National Water Policy and Water Resources Development Plan with little enlightening on power supply issues.

4.2 Review of Bangladesh Delta Plan regarding WEF Nexus

Bangladesh Delta Plan (BDP 2100) demonstrates the highest integration of water energy food nexus perspective forming its strategies and policies to respond to resource complexity challenges in sustainable development. BDP 2100 argues that constant dependency on groundwater based mechanized irrigation without an attempt to augment the supply of surface water in the dry season is not sustainable and presents a major risk to food security.

Issuing imminent agricultural water shortage due to climate and upstream abstraction, water saving technologies, cultivation of high-value low water demanding crops in the dry season and sound zoning policies for agriculture are constituted by BDP 2100 as partly mitigating initiatives. In order to preserve water quality to ensure environmental sustainability, BDP 2100 recommends the use of composted natural fertilizer to run agricultural production in a very eco-friendly way.

BDP 2100 acknowledges irrigation power demand as the foremost synergy between energy-food indicating challenges as droughts present severe impact on energy demand as pumping load rises with falling water tables. BDP 2100 provides an opportunity to be explored by private sectors to implement solar irrigation facility for dry season agriculture. Exploration of biomass resources for gas-based electricity generation is promoted to flourish renewable energy sector. Bio-energy production from agricultural crops and residues reducing carbon and N_2O emission is addressed as a mitigation measure in the agriculture sector. In order to reduce post-harvest energy consumption, improved rice parboiling system initiative by the government is cited to reduce the carbon emission and ensure energy efficiency.

Water-energy nexus is well acknowledged in Bangladesh Delta Plan 2100 incorporating resource complexity and intelligent response contributing pathway to sustainable development. For hydropower generation, along with proposing barrages on major rivers, BDP 2100 promotes the development of micro and mini-hydropower in hilly regions regarding the environmental friendly point of view. It also proposes harnessing of tidal current and tidal waves for generating electricity in the coastal and offshore islands. Climate change induced synergy between water and energy like floods and cyclones causing power supply failures and infrastructure damages are implied to affect sustained development of the Bangladesh Delta and flood-proofing of critical energy infrastructures has been suggested in the BDP 2100 Investment Plan.

4.3 Integration Level of WEF Nexus in Plans and Policies of Bangladesh

The integration level of WEF nexus in the policy context of Bangladesh has been summarized in table 4.1. Different level of integration starting from very low to very high is attributed to national policy documents against their incorporation of WEF nexus issues and response options. Very high level of integration is attributed in the case of sufficiently incorporating issues and responses regarding water and food nexus; water and energy nexus; food and energy nexus situations and subsequently high, moderate, low and very low level of integration is attributed with the decrease in focusing on the interrelations among water, energy and food resources and an overall integration level is accredited to integration of water energy food nexus.

Table 4.1 Policy Coherence with WEF nexus for Bangladesh

Plan & Policy	Water & Food Nexus	Water & Energy Nexus	Food & Energy Nexus	Water-Energy-Food Nexus
7th 5 Year Plan, 2015	High	Very Low	Very Low	Very Low
Perspective Plan, 2012	Moderate	Low	Very Low	Very Low
National Water Policy,1999	High	Low	Very Low	Very Low
National Food Policy, 2006	High	Very Low	Very Low	Very Low
National Energy Policy, 2004	Very Low	Low	Low	Very Low
National Agriculture Policy, 1999	High	Very Low	Very Low	Very Low
Bangladesh Delta Plan, 2017	Very High	Very High	Very High	High

It is evident from table 4.1 that synergy of energy with water and food resources lacks sufficient incorporation in national policy documents whereas food water nexus is well coordinated in majority cases. Water & food nexus is integrated insufficient extent in most cases in the form of groundwater irrigation, water disaster management and environmental water quality issues with substantial response options. In an unsubstantial extent, the nexus between water & energy and food & energy are integrated mostly in the form of hydropower generation and irrigation power supply issues. Table 4.1 also illustrates the nexus approach along with its three interfaces is well incorporated in latest delta plan of

Bangladesh as the BDP 2100 is described as a testimony of integrating development dimensions in a balanced and coherent manner by Voluntary National Review (VNR), 2017. Currently under process perspective plan for 2021-2030 and SDG Action Plan need to incorporate nexus aspects of water, energy, and food to ensure sustainable development. Proper integration of the WEF nexus perspective to the country policy and action plans is must succeed in the implementation of sustainable development.

CHAPTER 5

ASSESSMENT OF LEADING CONCEPTUAL FRAMEWORKS FOR WEF NEXUS

The water-energy-food nexus has been conceptualized in diverse framework models distinct in their challenges, scopes, goals, responses consenting on the issue of sustainable resource and ecosystem management. WEF nexus frameworks of the regional and international arena are assessed in order to evaluate their representation of the issue to further develop such framework in a national level that will eventually assist in integrating WEF nexus approach in country‟s policymaking. The assessment determines the key features of WEF nexus and recommendations for nexus management by different WEF nexus frameworks in this study.

5.1 Bonn 2011 WEF Nexus Framework

Investing to sustain ecosystem services, creating more with less and accelerating access, integrating the poorest are central guiding principles of Bonn 2011 nexus framework that accounts for water, energy and food security by an understanding of the interdependence of water, energy and climate policy and determining trade-offs and synergies that meet demand without compromising sustainability. Global trends of accelerating development, urbanization, globalization, climate change, scarcity of land, water, and other resources, degradation of the resource base are accounted to challenge water, energy and food security causing the requirement of nexus approach. Several opportunities are identified to arise from WEF nexus approach including increased productivity of resources, waste utilization as a resource in multi-user systems, stimulating development through economic incentives; governance, institutions and policy coherence; benefiting from productive ecosystems systems, integrated poverty alleviation and green growth, capacity building and raising awareness to improve water, energy and food security (Hoff, 2011).

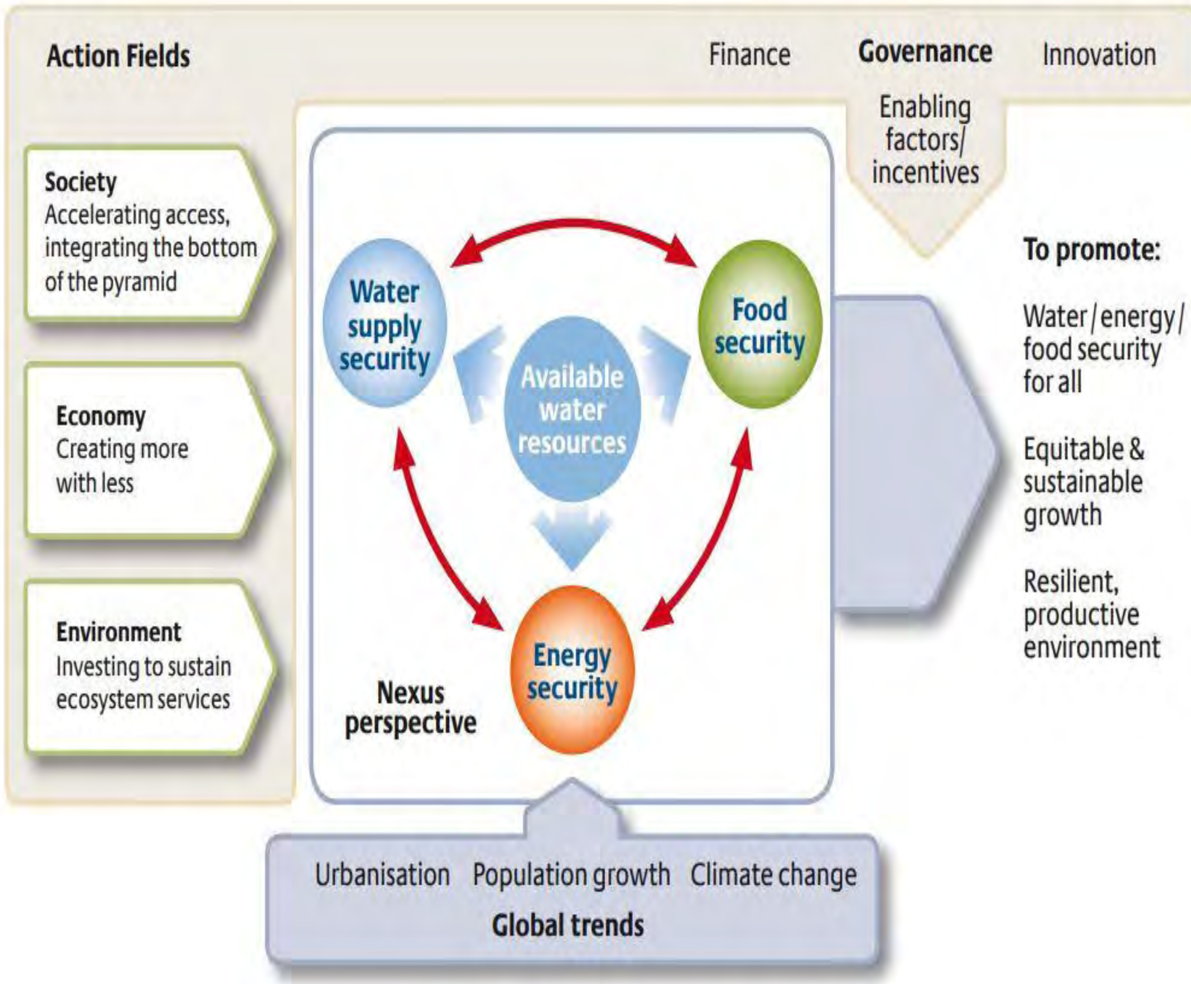

Figure 5.1 Bonn 2011 water, energy and food security nexus framework (Hoff, 2011)

The water, energy and food security nexus framework presented at the Bonn 2011 Nexus Conference as illustrated in figure 5.1 centers around water availability referring water as stable and control variable of change for its non-substitution in biomass production, with biomass being a central resource for energy and food security in the green economy (Hoff, 2011). Interactions across the nexus for four intersections including water for energy, energy for water, water for food and energy for food were determined through global secondary data assessing and a case study that was followed by evaluating potentials for resource use efficiency in conjunctive uses. In an effort to elaborate WEF security nexus, Bonn 2011 nexus framework exemplified nexus scenarios from upstream to downstream of food production chain, showing that at upstream of the chain, increasing irrigation may increase land productivity but in turn results in energy intensity and suggesting rain-fed agriculture as a response reducing demand for water and energy inputs whereas at downstream, reducing wastage, increasing efficiency, changes in lifestyles and consumption patterns can reduce pressure on water, energy and land. Considering the fact of water, energy and food production sectors are contributors along with vulnerable to climate change, Bonn 2011 nexus approach includes climate change within WEF nexus framework suggesting climate policies to undertake integrated perspective across the nexus to avoid maladaptation and negative externalities (Hoff, 2011). The Bonn 2011 nexus framework highlighted the importance of implementing policies leading to additional benefits to outweigh transaction costs associated with stronger integration across sectors (ESCWA, 2015). The framework, being guided by central principles arising from natural resource management challenges, tends to determine interdependence of water, energy and food resources and determining trade-offs and synergies, eventually explores potentials for improving resource use efficiency and benefit sharing across nexus perspective without compromising sustainability.

5.2 European Development Report (EDR) nexus framework

The European Development Report (2012) entitled “Confronting Scarcity: Managing Water, Energy and Land for Inclusive and Sustainable Growth”, implying on growing population, rising income levels and global environmental change, urges for radically transformed approaches to managing water, energy and land (WEL) in order to support inclusive and sustainable growth in the poorest developing countries. The water-energy-land nexus of EDR aims to focus on the complexity of water, energy, and land characterized by three key features including; i) greater competition among users for a limited pool of resources; ii) greater interdependency between the production and consumption drivers worldwide, and iii) possibilities of the absolute scarcity of ecosystem functions. It accounts for several current and expected trends in water-energy-land nexus including consumption of agricultural water, land and food grains for biofuels, freshwater demand for the energy sector, future pressure in agricultural water for near doubling food production, threats posed to agriculture by salination. The nexus concept evaluates how solutions to natural resource constrain in one area place additional strains on another as illustrated in figure 5.2 like how expanding the provision of biofuels can contribute to pressures on both land and water (ERD, 2012).

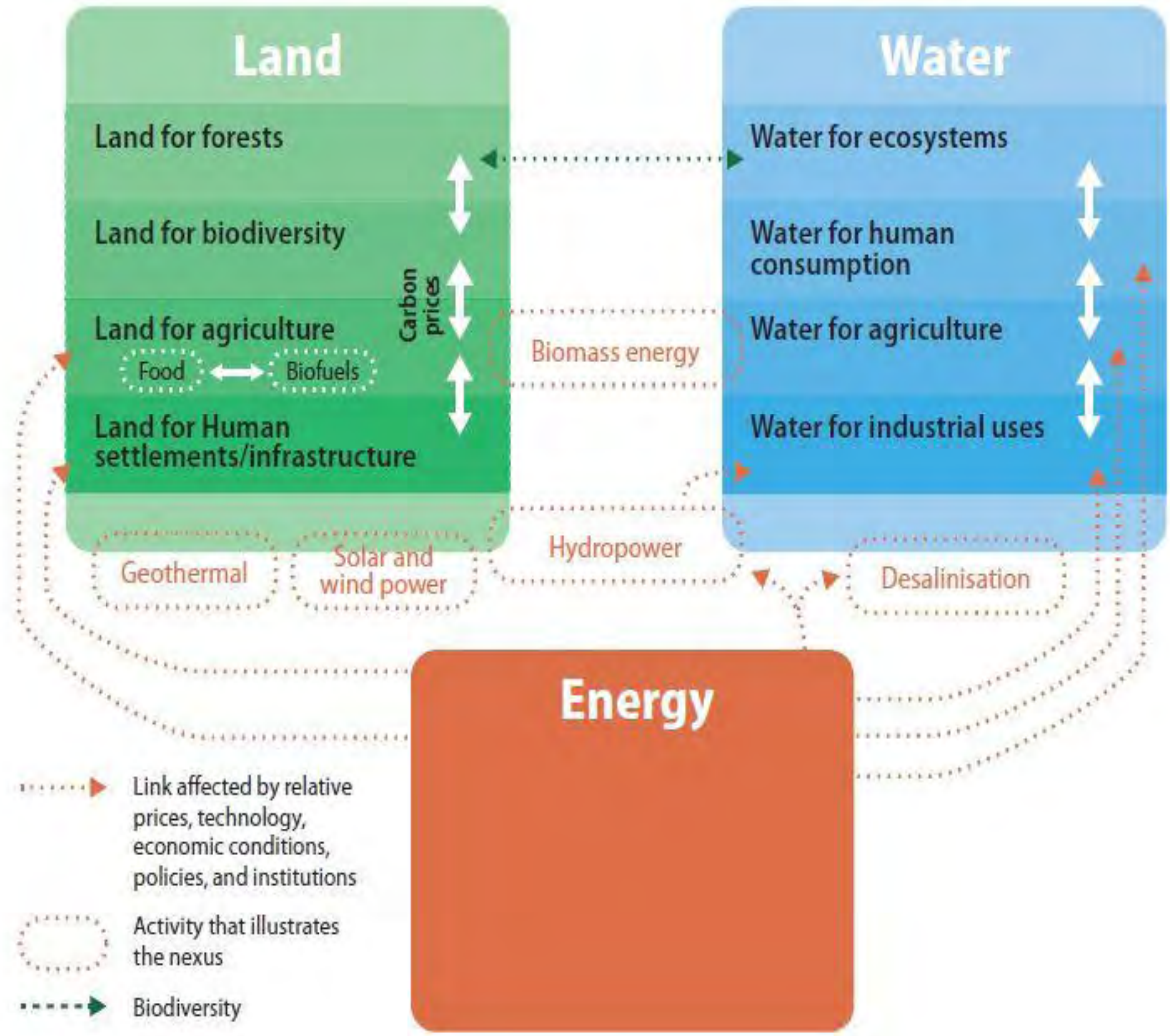

Figure 5.2 European Development Report water-energy-land nexus Framework (ERD, 2012)

Three types of actors are suggested to play a vital role in managing the WEL nexus challenge: the public sector setting the regulatory and legal framework, the private sector making its business models more inclusive and sustainable and investing in sustainable outcomes, the European Union (EU) supporting poorer countries as a major trade and investment partner, major donor and through contributions to global governance promoting better policy coherence for development (ERD, 2012).

Coordinated action in five areas is cited for facilitating transformative approach of WEL nexus including globally reducing environmental footprint of consumption, promoting innovation for increasing agricultural productivity and renewable energy, reforming institutions for an integrated management approach, issuing inclusive land policy ensuring equitable access to land and water and lastly, comprehensive and appropriate pricing of natural resources and services safeguarding the welfare of the poorest (ERD, 2012). Focusing on negative environmental costs of "business as usual" approach in water, energy and land management, transformative approaches addressing water-energy-land nexus formulated by EDR can ensure inclusive and sustainable growth.

5.3 Water–energy–food security nexus framework by IISD

The International Institute for Sustainable Development (IISD) developed a geospatially explicit framework showing the nested nature of the securities and the linked nature of the elements that affect WEF security embedded in a process aiming to inform investment, decision making and associated risk management to ensure optimization of water, energy, and food security. The IISD defined its WEF nexus framework in five series of circular diagrams as illustrated in figure 5.3. Bizikova et al. (2013) defined the WEF nexus through three primary central circles each one around illustrative of each resources forming independent security clusters. The second layer depicts access to water, energy, and food to watershed communities through purchasing, bartering and self-production. Beyond this layer, external elements affecting WEF security independently such as distribution systems, production, and treatment, conversion etc are identified. Fourth concentric ring combining of natural and built systems comprises of ecosystem services and infrastructures those can provide resources and influence access and stable supply of water, energy, and food. Finally, the fifth ring including governance and management systems, policies, markets, agreements represents the human and institutional elements of water, energy and food securities.

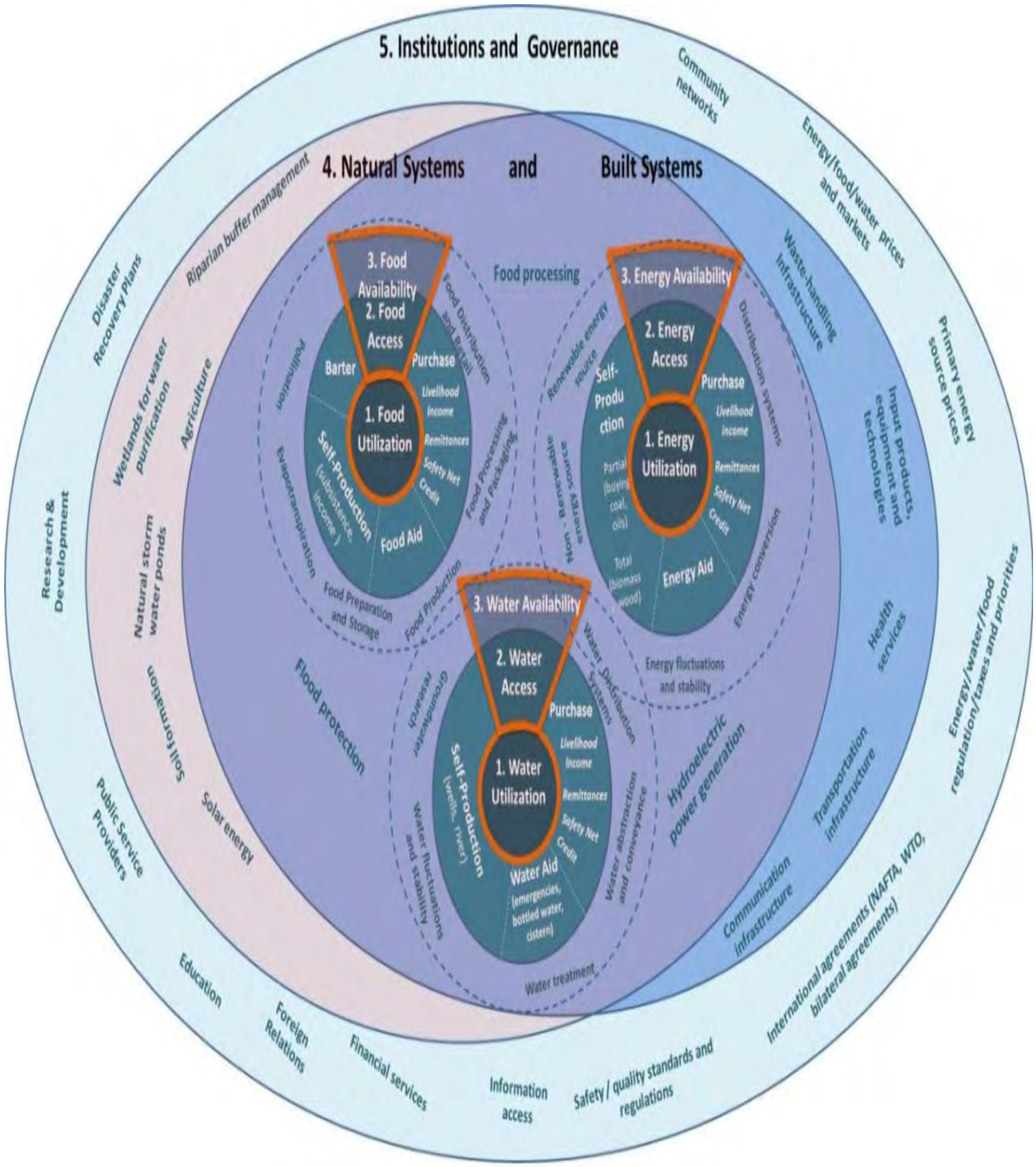

Figure 5.3 Water–energy–food security nexus framework by IISD (Bizikova et al., 2013)

To integrate the IISD WEF security nexus framework within practical participatory planning process, Bizikova et al. (2013) suggested four main stages of approach including assessing the water-energy–food security system understanding past, current and future trends, envisioning future landscape scenarios by identify critical uncertainties, investing in a water–energy–food-secure future and transforming the system through communication, implementation, monitoring, adaptation and improvements. The IISD WEF security nexus framework is adaptable to similar contexts of water, energy and food resources globally along with its suggested integration process in the planning process to ensure sustainable ecosystem management.

5.4 FAO approach to WEF nexus

The FAO water-energy-food nexus approach presents a framework adopting sustainable development debate, explicitly addressing complex interactions and feedback between human and natural systems to provide decision makers opportunity to better understand and manage interactions between water, energy and food resources. The WEF nexus approach of FAO, 2014, as illustrated in figure 5.4, identified global drivers including demographic change, urbanization, industrialization, climate change, cultural and societal beliefs and behaviors etc to develop nexus interaction among resource base consisting both biophysical and socioeconomic resources on which development goals are dependent pertaining to water, energy and food resources.

FAO presents working areas of WEF nexus based on conditions of capacity to evaluate nexus interactions and developing and prioritizing response options. Three working areas as dynamic and complementary components of an overall approach to managing and using our natural resources sustainably include evidence through data and analysis, scenario development and response options (FAO, 2014).

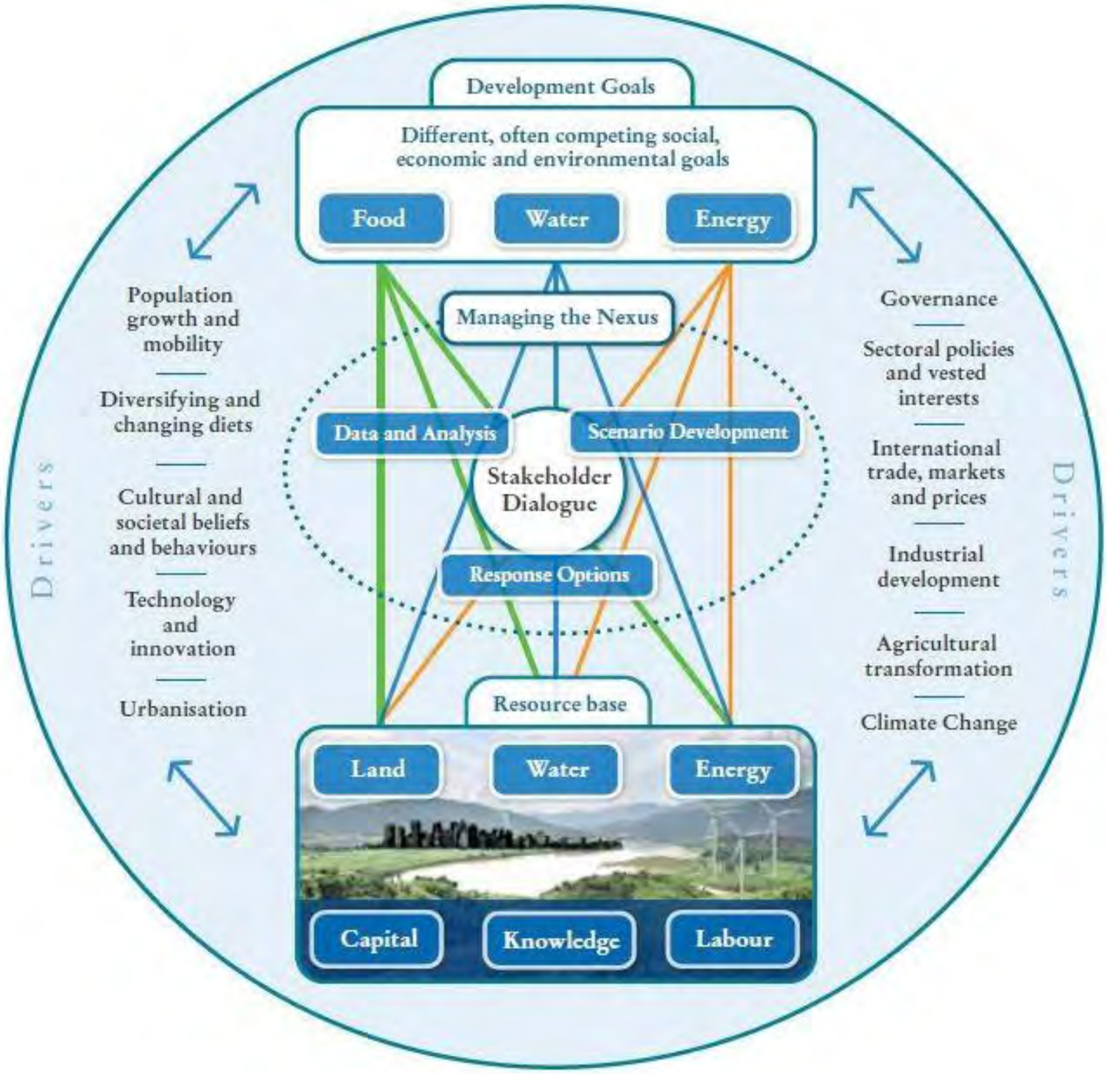

Figure 5.4 FAO Approach to the Water-Energy-Food Nexus (FAO, 2014)

In order to assess and analyze nexus interactions, accurate, pertinent and timely data is needed to provide an overview of the current state of natural resources and their uses and an outlook on key nexus issues, making explicit the current baseline scenario as well as possible future scenarios, trends, and goals. Evidence exerted from data are utilized to develop scenarios through quantitative tools or qualitative approaches such as participatory and forward-looking scenario approach (FAO, 2012). Response options are developed on the basis of other working areas on data, evidence-based analysis, scenario development and stakeholder dialogues that include the planning and implementation of new policies, regulations and incentives, capacity development training, technical interventions and the process of evaluating and revising already existing policies and strategies. The stakeholder dialogue among a broad range of sectors and interest can complement and reaffirm different working areas contributing to informed decision-making in regard to water, energy, and food (FAO, 2014). The nexus approach as presented by FAO is convenient to formulate WEF nexus in country level by illustrating water, energy, and food interaction scenario within national border assessing data of resource base and perceiving response options through stakeholder dialogue.

5.5 WEF Nexus Framework by ICIMOD

International Centre for Integrated Mountain Development (ICIMOD) has developed a regional water energy food nexus framework for South Asia focusing on Hindu Kush Himalayan (HKH) sub-region centering on ecosystems goods and services as illustrated in figure 5.5. The framework focuses on the importance of regional integration between upstream and downstream regions of South Asia to improve resource use efficiency and productivity revealing a high degree of dependency of downstream communities on upstream ecosystem services for dry-season water for irrigation and hydropower, drinking water, and soil fertility and nutrients. It emphasizes on coordinated management of Hindu Kush Himalayan (HKH) ecosystems with neighboring countries following the role of HKH ecosystem services in sustaining food, water, and energy security downstream. Rasul, 2014 identified key characteristics of WEF nexus in South Asia are water and energy-intensive food production, high economic and environmental dependency on upstream resources and black carbon from burning of biomass fuel casing acceleration of melting of snow, ice, and glaciers in the Himalayas while upstream-downstream linkages of HKH ecosystem and regional transboundary river basins are an integral part of it. Two prolonged approaches including firstly enhancing cross-sectoral coherence and secondly improving management of the Himalayan ecosystem are suggested to address the nexus challenge sustainably followed by some recommendations of harmonizing policies through integrating interdependencies of water, energy, food sectors, reducing inter-sectoral externalities, introduction of regulations and incentives for efficient resource use, strengthen coordination among upstream and downstream countries on ecosystem issues etc. Considering HKH ecosystem impacts on downstream countries, WEF nexus framework of ICIMOD provides unique features of resource interdependency, management approach and policy recommendations in regional scale helpful in developing such frameworks for any part of South Asia.

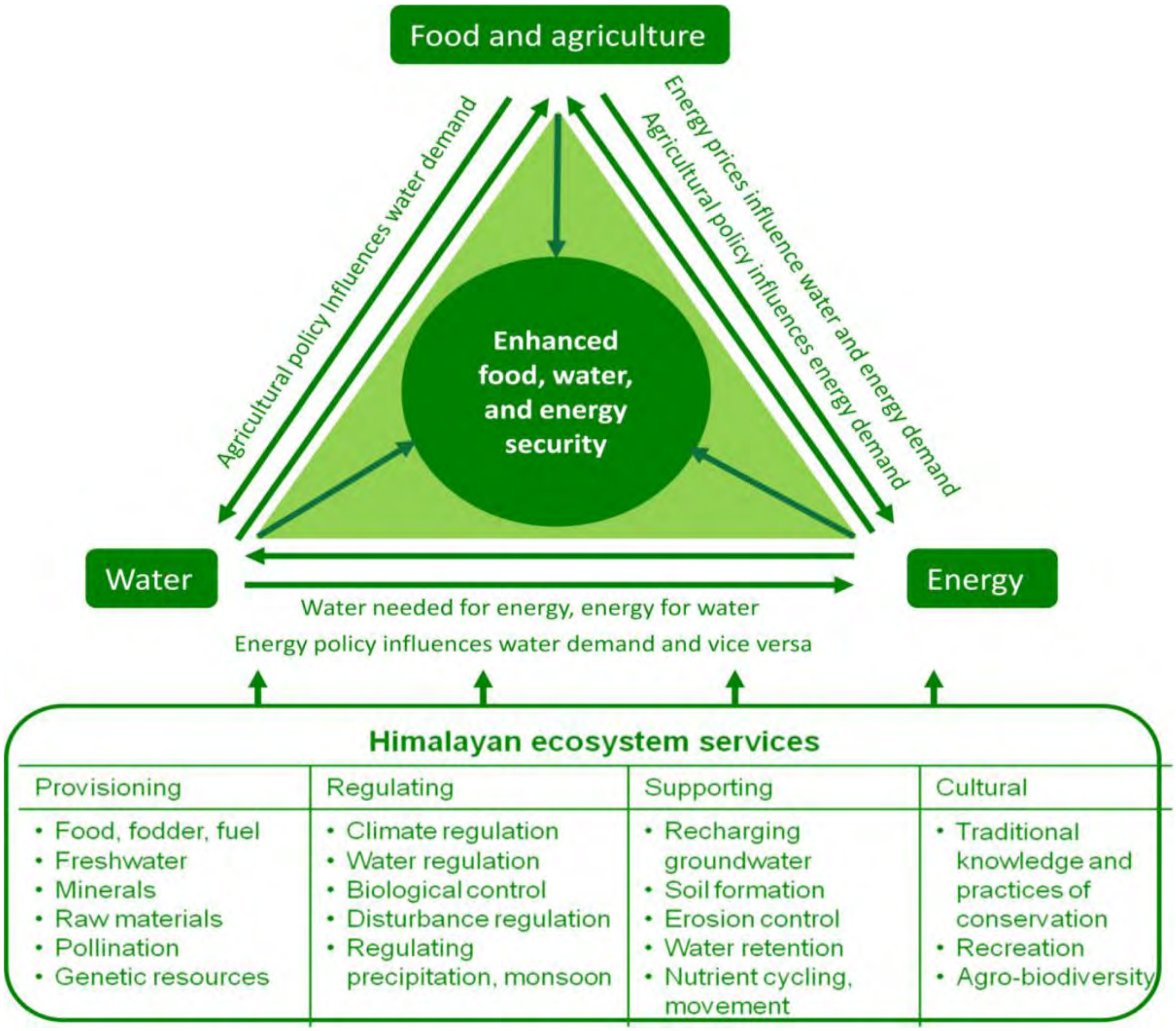

Figure 5.5 WEF Nexus Framework by ICIMOD (Rasul, 2014)

WEF nexus frameworks primarily embodied interdependencies among water, energy and food resources assessing regional and global trends focusing on distinctive cases like nexus across upstream to downstream of food production chain as done by Bonn 2011 framework or upstream and downstream nexus within mountain ecosystem as framed by ICIMOD framework ultimately aiming for sustainable natural resource and ecosystem management. FAO approach provides a theory of erecting a WEF nexus framework with its working areas comprising of evidence, scenario development and discovering response options through stakeholder dialogue. Policy integration, improving resource use efficiency, promoting innovation, reforming institutions for cross-sectoral coherence are commonly suggested by most frameworks to address the WEF nexus approach in the planning and management process. Key features and recommendations for WEF nexus management derived from the above assessment are illustrated in Table 5.1.

Table 5.1 Assessment of leading WEF nexus frameworks

WEF Nexus Framework	Key Features	Recommendations
Bonn 2011 WEF nexus framework	It accounts for global trends of urbanization, population growth & climate change to erect nexus relationship centering around water availability to ensure green economy	Waste utilization, economic incentives, governance, institutions and policy coherence, capacity building, awareness raising
European Development Report 2012 nexus framework	It determined three key features including greater competition, greater dependency & absolute scarcity of ecosystem services to develop nexus among resources & suggested three vital actors in managing the nexus are public sector, private sector & European Union	Reducing consumption, promoting innovation, reforming institutions, inclusive land policy, appropriate pricing of natural resources
IISD 2013 WEF security nexus framework	It developed a geospatially explicit framework centered on ecosystem management by identifying access, availability, utilization & external factors of water, energy & food sectors for informing investment, decision making and associated risk management of nexus	Participatory planning process
FAO 2014 water-energy-food nexus framework	It provides a theory of erecting a WEF nexus framework with its working areas comprising of evidence, scenario development and discovering response options through stakeholder dialogue	Planning and implementation of new policies, regulations, and incentives, capacity development training, technical interventions

ICIMOD 2014 WEF nexus framework	It is a system-wide, rather than sectoral approach illustrating Himalayan ecosystem goods & services developing connected nexus triangle of water, energy & food resources	Cross-sectoral coherence, improving ecosystem management, the introduction of regulations & incentives, coordination among upstream and downstream countries

CHAPTER 6

DEVELOPMENT OF WATER ENERGY FOOD NEXUS FRAMEWORK FOR BANGLADESH

Assessment of water, energy, and food resources policies of Bangladesh showed lacking integration of water, energy and food nexus in national plans and policies. Addressing WEF nexus in the country‟s planning process will be benefited from provisioning of a framework depicting important nexus relations between water, energy and food sectors with subsequent impacts and relevant responses. A conceptual framework of Water Energy Food nexus for Bangladesh has been manifested by evaluating three bilateral interfaces of food-water, water-energy, and energy-food through assessment of their interconnected scenarios, demands and issues. The framework has been developed by following working areas of determining driving forces, erecting nexus scenarios along with subsequent impacts as of leading conceptual WEF nexus frameworks.

6.1 Food-Water Nexus

Bangladesh is a low-lying riverine country formed as a deltaic plain at the confluence of the Ganges-Brahmaputra-Meghna (GBM) basin constituting about 80% of fertile alluvial land. Because of its favorable natural environment for crop production and food demand for ever-increasing population, agriculture has been of the utmost focused sector for the stability of the country. The total cultivable area of Bangladesh is about 8.55 million hector covering about 60% of the total land of the country and 46% of the economically active population has been active in agriculture as of 2009 (FAO, 2012). The food sector is completely water dependent in case of irrigation that is the vital precondition for agricultural production. Total water withdrawal in 2008 was 35.87 km3 of which 31.50 km3 (88 percent) was for agriculture as shown in figure 6.1 (FAO, 2012), that defines the dependency of food production on water alone against other sectors. The major source of irrigation water is groundwater in Bangladesh as shown in figure 6.2 because of two reasons. Firstly, despite being abundant with surface water in monsoon season, flat deltaic topography and instability of major rivers make gravity irrigation by surface water difficult. Secondly, surface water irrigation in the dry season is difficult due to unavailability of water in tributaries, lakes, and rivers (FAO, 2012). This is resulting in depletion of groundwater level for high exploitation against less recharging and increasing pressure on electricity for groundwater extraction systems. The net irrigation water demand was 28.05 km3 in 2008 that constitutes the major portion of agricultural water demand and water demand for irrigation varies throughout the year as shown in figure 6.3 (Barua et al. 2016). From mid-dry season to beginning of pre-monsoon (December to March), irrigation water requirement is higher than other times creating major electricity demand for groundwater extraction leading to massive load shedding.

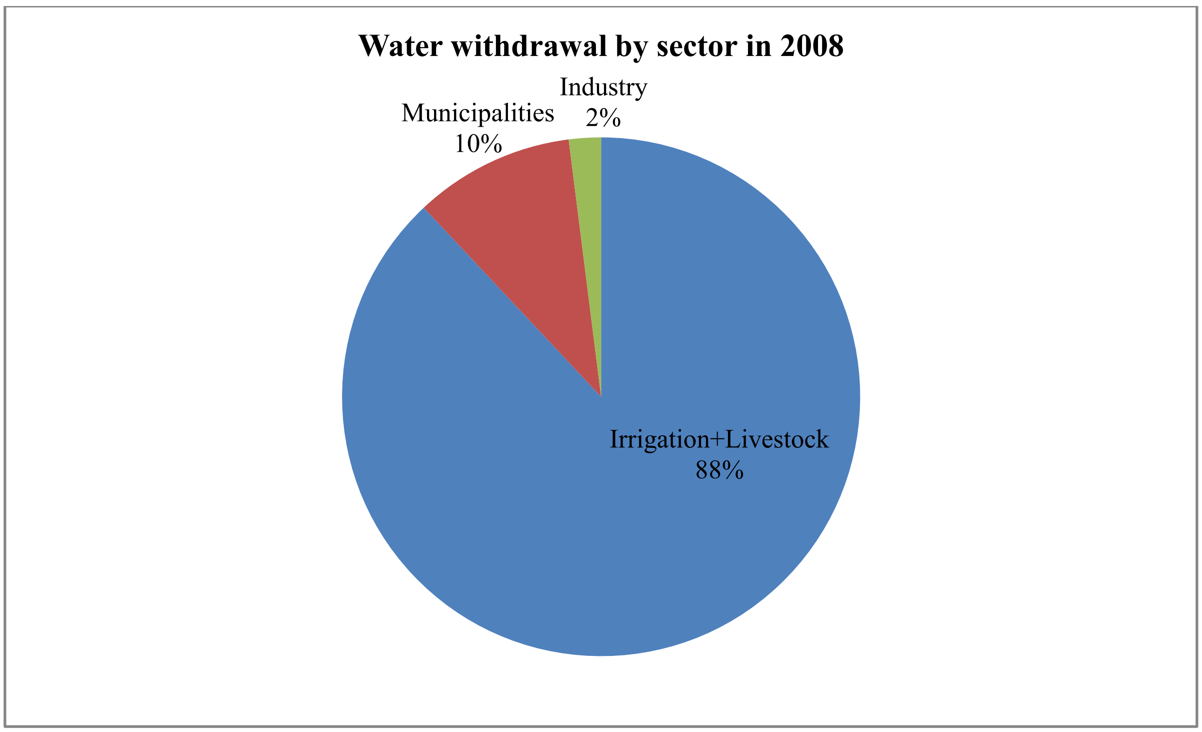

Figure 6.1 Composition of total water withdrawal in Bangladesh (FAO, 2012)

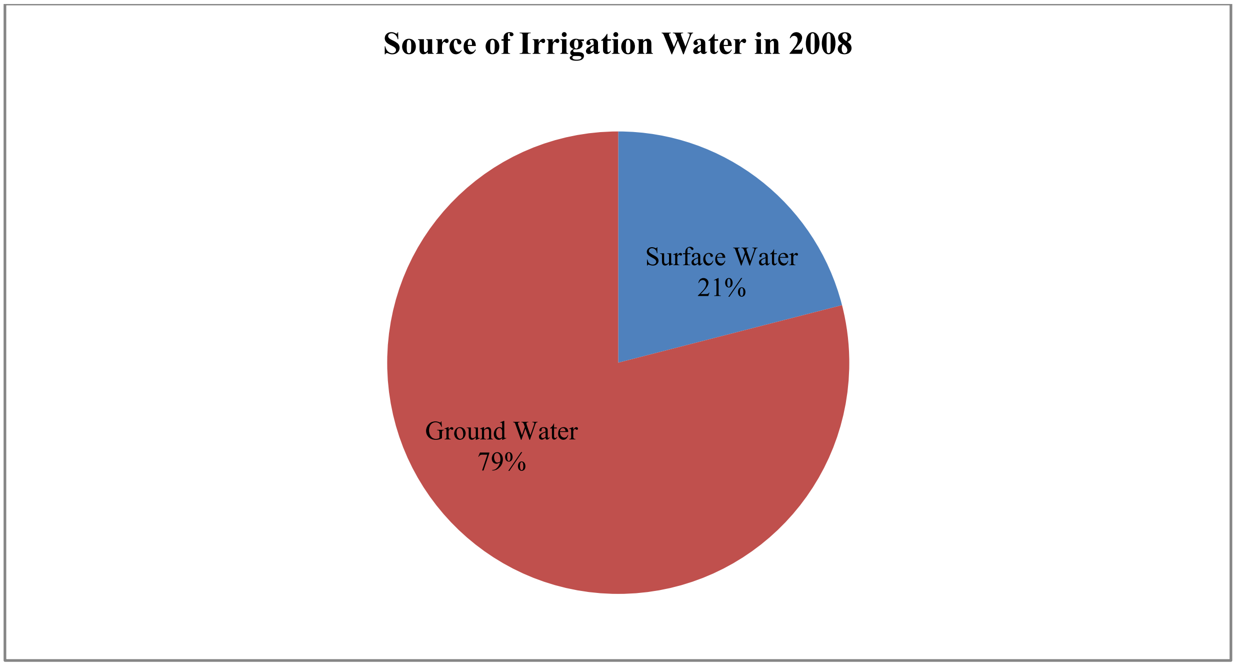

Figure 6.2 Source of irrigation water in Bangladesh (FAO, 2012)

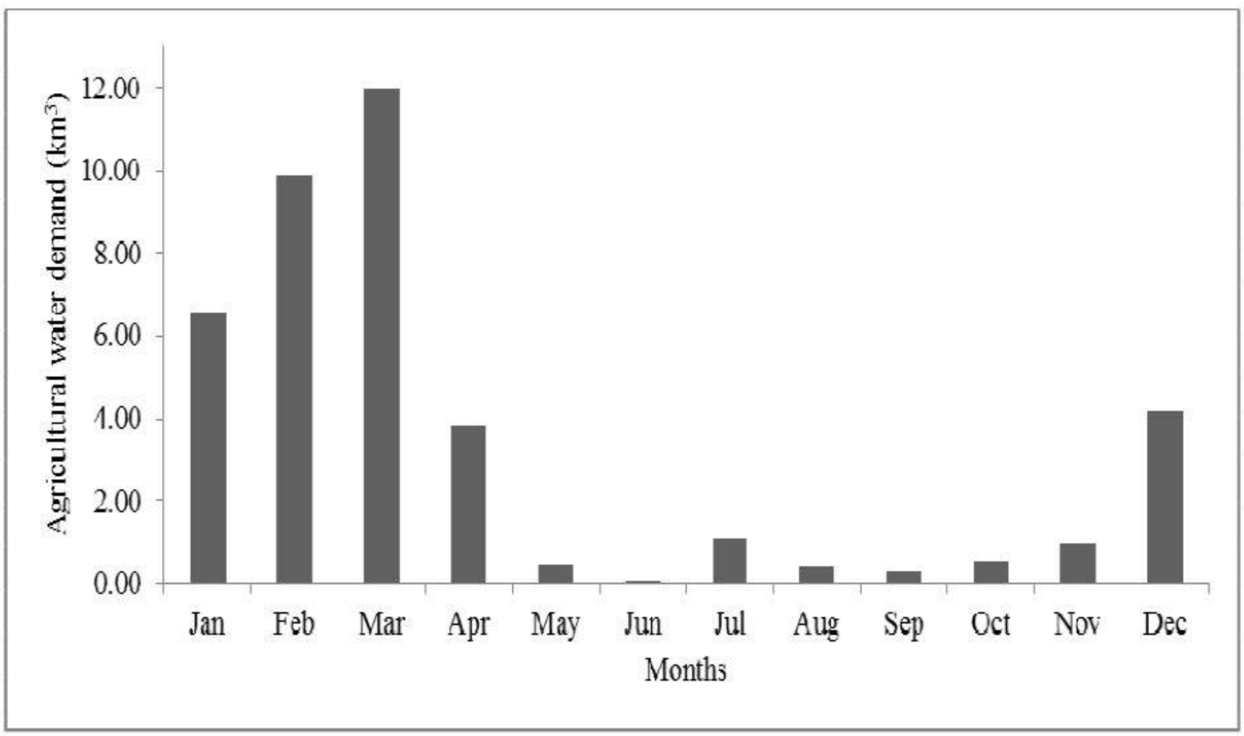

Figure 6.3 Monthly irrigation water demands in Bangladesh (Barua et al. 2016)

On the contrary of water being essential to agriculture, food production of Bangladesh is heavily hindered by water-induced disasters like floods. Each year from May to September, about 25% of the country is flooded in varying degrees when more than 60% of the cereals are produced. The production potential is not attained for recurrent flooding that restricts farmer"s option to grow traditional low yield rice variety that can thrive in deep water. On the other hand, cultivation of high yield rice variety constituting about 36% of total rice production is limited due to the scarcity of irrigation water during March-April (AHMED and ROY, 2007).

Besides agriculture, other food production sectors such as fisheries are also water intensive. Total annual water demand for fisheries in Bangladesh is 5.2 km2 where open water capture fisheries water demand is 3.1 km2 and closed water culture fisheries water demand is 2.1 km2 (CSIRO et al. 2014). A hydrological region wise annual water demand for fisheries as estimated by CSIRO is shown in table 6.1.

Table 6.1 Annual water demand for fisheries by hydrological regions in million cubic meters (CSIRO et al. 2014)

Hydrological Regions	Open Water Capture Fisheries Water Demand mcm	Closed Water Culture Fisheries Water Demand mcm	Total Fisheries Water Demand mcm
NW	1133	667	1800
SW	855	547	1402
NC	533	286	819
NE	80	115	195
SE	180	251	431
SC	251	249	500
EH	39	7	46
Total	3070	2123	5194

Intensive cropping is done in Bangladesh to produce food for 150 million people living in 147,000 km2 leading to extensive fertilization of cultivable lands. Chemical fertilizers subsidized by the government are extensively used to grow crops and vegetables that negatively effect water quality and subsequently fisheries. According to Uddin et al. 2011, besides geological features, application of Nitrogen fertilizer has a positive effect on Arsenic concentration in groundwater where the presence of Arsenic in drinking water is of great threat to public health. Organic fertilization can be promoted by the government to sustain ecological endurance and ensure positivity in the public health sector.

From evaluating corresponding data, a Food-Water nexus framework for Bangladesh has been developed by erecting nexus scenarios between food and water sector prompted by driving forces and their subsequent impacts. Driving forces such as population, food & agricultural water demand, topography, weather have forged to create the food and water nexus scenarios that impacted power demand, food security, and environment as shown in table 6.2. The Food-Water Nexus framework for Bangladesh has been illustrated in figure 6.4.

Table 6.2 Food-Water Nexus framework for Bangladesh

Driving forces	Food-Water nexus scenario	Impacts
Food demand, Agricultural water demand, Topography	The dependency of food production on irrigation water resulting in groundwater depletion	Pressurizing electricity demand
Topography, Weather	Food production jeopardized due to water prone natural disasters of flood & drought	Threatening food security
Population, Food demand	Water quality degradation by chemical fertilization affecting fishery	Environmental degradation

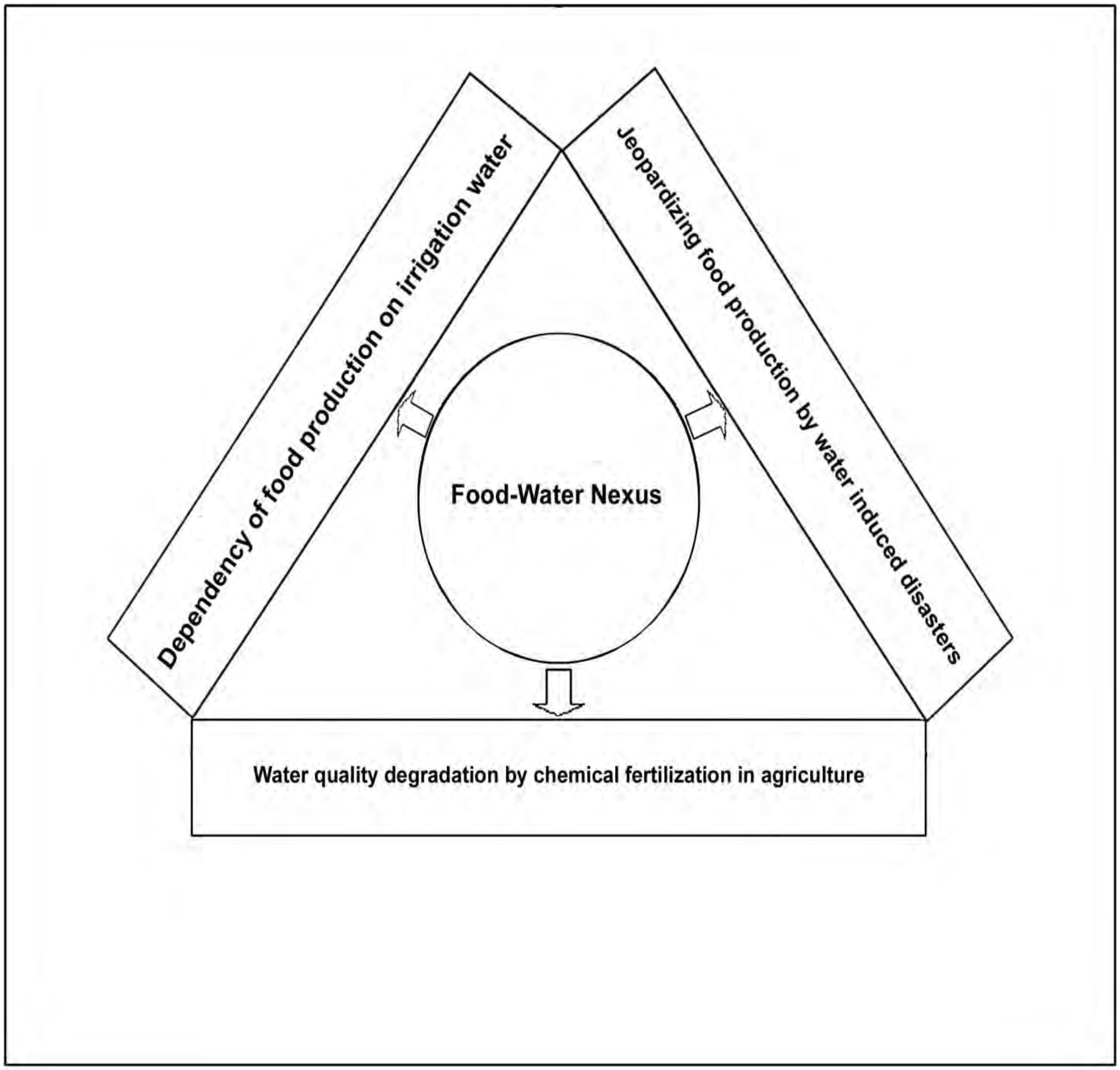

Figure 6.4 Food-Water Nexus framework for Bangladesh

6.2 Water-Energy Nexus

Water and energy are extremely interconnected influencing the security of these two resources that draws significance in exploring their nexus. Water management operations including its ground extraction, treatment, and supply system are fully run by electricity. On the other hand, water plays important roles in the production of electricity at the power plants.

Thermal power plants render the biggest electricity share of total production in Bangladesh. They constitute a major fraction of water demand in the power sector mostly due to cooling functions and air emission control of the plant drawing cool water from surface water sources and discharging hot water in rivers. An average of 95 liters of water has been estimated to be required to produce 1kWh of electricity (Heiner, 2010). Water is extensively used in energy resource extraction, refining, processing, transportation and other operations (Gain et al. 2015).

Water is an integral part of hydroelectric power generation for utilizing the hydro-kinetic energy to convert into electricity. Hydropower generation is limited in Bangladesh because of its plain terrains except for some hilly regions in the northeast and southeast parts of the country. Major considerations of energy source for power generation are natural gas, furnace oil, diesel, hydropower, and coal as shown in figure 6.4 among which hydropower constitutes only 3% as suggested by Bangladesh Power Development Board (BPDB) in 2012. The graph explicitly reveals the deficit of renewable energy sources in the national power production composition. Karnafuly Hydro Power Station, Kaptai is the only hydropower project operated in the country with a capacity of 230 MW. Gradual decrease of water level in Kaptai Lake has caused falling of power generation from the Hydro Power Station leading to cutting down the share of total electricity production of the country as shown in figure 6.5. The downgrading trend of hydroelectricity generation over years hinders energy security of Bangladesh by reducing renewable energy contribution to the national grid.

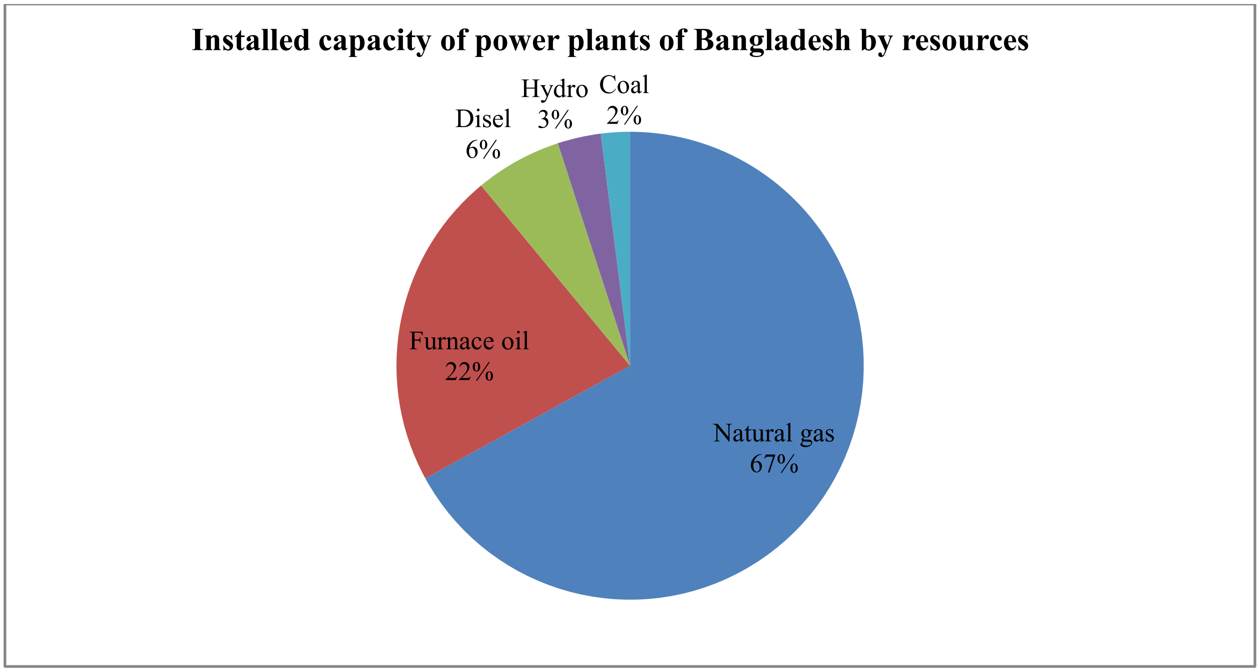

Figure 6.5 Installed capacities of power plants of Bangladesh by resources

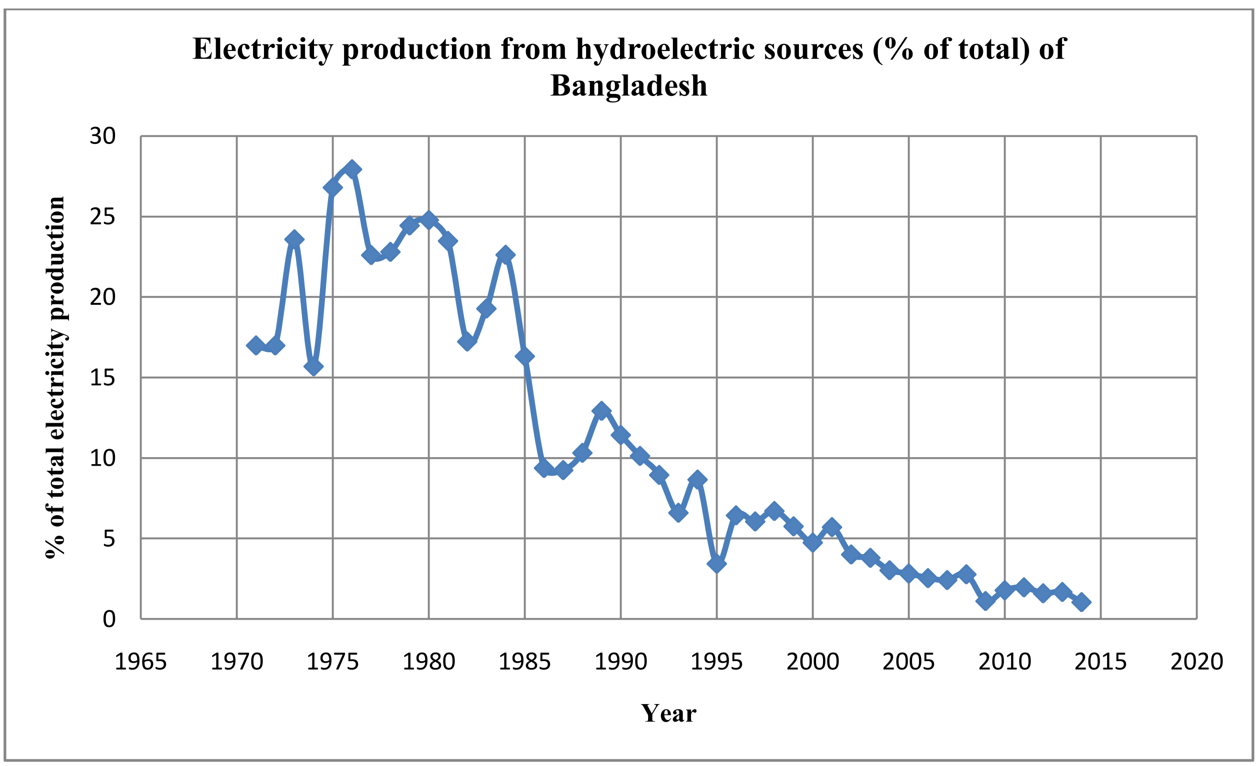

Figure 6.6 Electricity productions from hydroelectric sources (% of total) of Bangladesh (IEA, 2014)

Micro-hydropower projects utilizing small-scale tidal stream power plants provide an alternative solution to flourish in the renewable energy sector of Bangladesh. Electricity generation in small-scale plants is renewable and inexpensive similar to large hydropower plants. BPDB has identified Sangu (140MW) and Matamuhuri River (75MW) for further hydropower generation (Islam et al. 2013). A study by Bangladesh Water Development Board (BWDB) and Power Development Board (BPDB) reveals the potential of small hydro sites in power generation as shown in table 6.3. As it shows, more than 1 MW of electricity can be attained from these sites that can contribute to the renewable energy share of the electricity grid.

Table 6.3 Potential small hydro sites identified by BWDB & BPDB (Islam et al. 2013)

District	River/Chara/Stream	Potential of Electrical Energy in kW
Chittagong	Foy"s Lake	4
	Choto Kumira	15
	Hinguli Chara	12
	Sealock	81
	Nikhari Chara	26
	Budiachara	10
Chittagong Hill Tracts	Lungu Chara	10
Sylhet	Madhab Chara	78
	Ranga panu gung	616
	Bhugai-Kongsa	48
Jamalpur	Marisi	35
Dinajpur	Dahuk	24
Rangpur	Buri Khora Chiki	32
	Fulkumar	48

Power sector of Bangladesh is vulnerable to water induced natural disasters as an implication of climate change. Extreme rainfall has a widespread negative impact on power supply systems. Dhaka experienced 341 mm rainfall on 14 August 2004 and 333 mm rainfall on 27 July 2009 in 24 hours causing power outage in the capital by hampering the electricity supplies (Habib, 2011). Severe cyclones like SIDR in 2007, Aila and Bijli in 2009 caused major destruction in power transmission and distribution system by damaging electricity poles and downing power lines (Shahid, 2012). Floods are most regular water induced natural phenomenon that hampers the power sector greatly as shown in table 6.4. Sea level rise (SLR) creates tremendous concern in the freshwater availability and salinity in coastal Bangladesh with an indication of SLR increasing by 1 meter by 2100 (World Bank, 2000; Frihy, 2003). Freshwater becoming scarce create havoc for power plants in coastal Bangladesh which requires thousands of gallons of fresh water for daily operation (Shahid, 2012). Salinity threats the power production system as exemplified by Goalpara barge-mounted power plant, the main source of electricity for Khulna city, which has lead to corrosion and leakage and stopping several times for different duration for using saline river water.

Table 6.4 Impacts on power sector by recent flood events (Shahid, 2012)

Flood Events	Impact on Power Sector
1988	Eighteen electric power sub-stations flooded and about 2000 km 11-KV power lines de-energize.
1998	Prolong floods severely affected power supply system of Dhaka leading to power lines being de-energized in different parts of Bangladesh which affected over a million people.
2004	Power supply shut down in some parts of Dhaka city for few days and southeastern Sub-districts were out of power for more than a week.

2007	Electricity poles washed away by the flooded rivers in northwest and northeast Bangladesh causing disruption of electric supply in many parts of the country.

From evaluating corresponding data, a Water-Energy nexus framework for Bangladesh has been developed by erecting nexus scenarios between water and energy sector prompted by driving forces and their subsequent impacts. Driving forces such as electricity demand, topography, weather, climate change have forged to create the water and energy nexus scenarios that impacted water quality, renewable energy sector, power supply as shown in table 6.5. The Water-Energy Nexus framework for Bangladesh has been illustrated in figure 6.7.

Table 6.5 Water-Energy Nexus framework for Bangladesh

Driving forces	Water-Energy nexus scenario	Impacts
Electricity demand	Dependency of thermal power production on water supply for cooling and air emission purposes	Discharged water quality threatens the surrounding environment
Electricity demand, Topography	Limited opportunity of hydropower generation despite chances of flourishing micro-hydro power generation	Contributing renewable energy generation
Topography, Weather, Climate change	Damaging of power generation & supply system by water induced natural disasters	Jeopardizing constant power supply

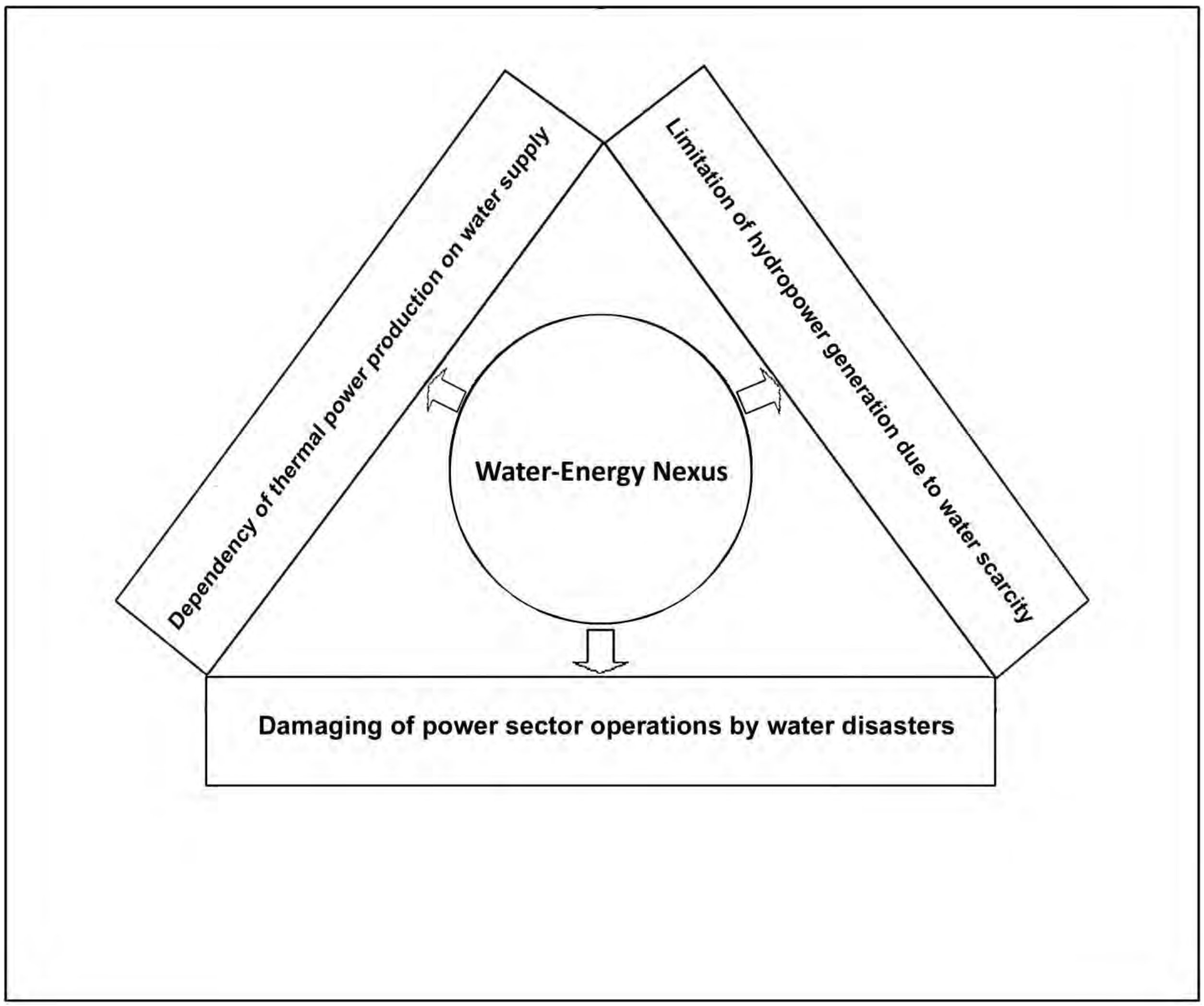

Figure 6.7 Water-Energy Nexus framework for Bangladesh

6.3 Energy-Food Nexus

Food and energy are extremely interconnected influencing the security of these two resources that draws significance in exploring their nexus. The agricultural sector of Bangladesh is immensely dependent on the power supply for irrigation purposes and on fuel energy for post-harvest activities. About 5% of the total primary energy consumption is constituted by food production industry and 3% of the total power consumption is used for only irrigation purpose in Bangladesh (SREDA, 2015) as shown in figure 6.1. During the pre-monsoon rice grown period, irrigation rate is forecasted to increase from 8.5 mm/day in the base year to 8.9 mm/day in 2050 and 9.3 mm/day in 2100. This will lead to pumping out of more water in less time causing declination of groundwater level. Eventually, more energy requirement to sustain cropping yield will cause an increase in peak power demand resulting in more load shedding during the pre-monsoon summer season in Bangladesh (Shahid, 2011). According to Ministry of Power, Energy, and Mineral Resources, for operating 11,014,412 water pumps across the country during irrigation season, around 15.56 lakh tonnes of diesel and 2000 MW of electricity is required. Besides about 100,000 traditional rice mills, around 500 semi-automatic mills and 50 automatic mills are run by electricity for rice dehusking (Farouk and Zaman, 2002; Jaim and Hossain, 2012). For transportation and plowing, 3000 diesel intensive tractors were being used in 2006 as suggested by IRRI, 2015.

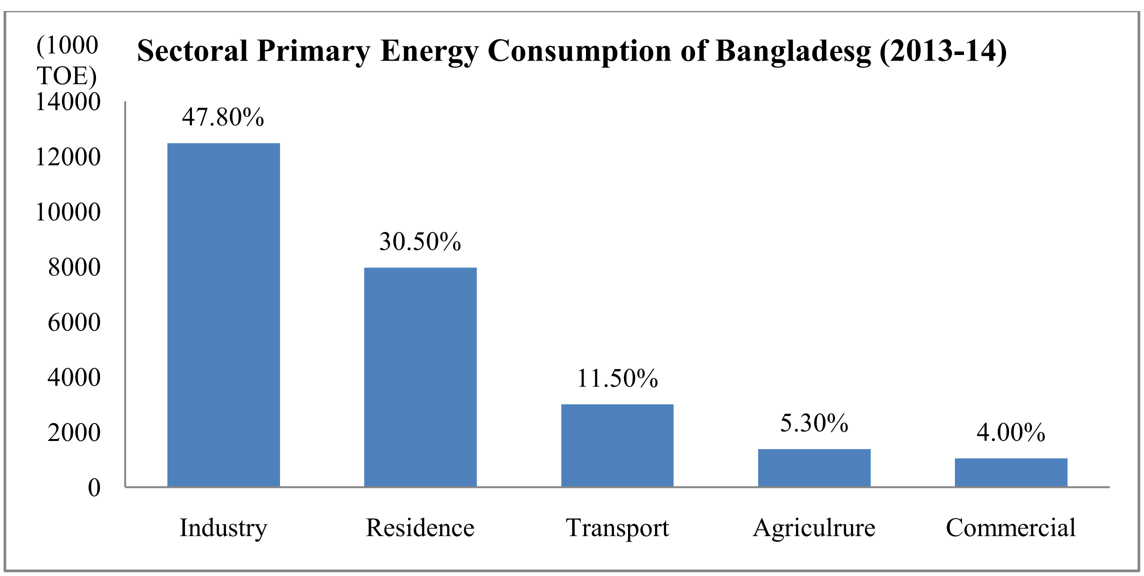

Figure 6.8 Sectoral Primary Energy Consumption of Bangladesh (SREDA, 2015)

Limited fossil fuel resources and fluctuating oil prices in the international market are straining crop production hindering food security of Bangladesh. An alternative solution of solar irrigation is being preferred by the government to reduce pressure on grid power or diesel fuel in a pro-environmental initiative. Bangladesh government has planned to replace 18,700 diesel pumps with solar irrigation pumps with an average capacity of kWp each of which 300 have already been installed (Islam et al. 2017). Despite being a preferable solution to the power shortage problem in the agricultural sector, solar irrigation can lead to groundwater depletion if over extraction occurs due to lower electricity expenses.

In order to deliver stable and high-quality electricity, Power System Master Plan of Bangladesh has set its focus on fuel diversification. It has set the target composition of the power supply as of 2030 including 50% for coals, 25% for natural gas and 25% for other sources such as oil, nuclear power and renewable energy (MoPEMR, 2011). Sources of renewable energy include solar energy, wind energy, biomass, biogas, micro-hydro and etc. Residues from food production are a great source of biomass energy that plays a vital role in rural energy security. Agricultural remains such as rice husk, rice straw, jute stick, sugarcane remains produce about 46% of conventional biomass energy. A small amount of biomass energy is also acquired from plants like wheat, potato, oilseeds, spices etc (Tayab et al. 2015). About 50% of the farm residues are recovered annually for energy purposes as shown in table 6.6. About 90% of total biomass energy from crops is attained from rice cultivation residues alone.

Table 6.6 Agricultural residues produced and recovered for energy purpose in Bangladesh (Mondal et al. 2010)

Crop Residues	Residue Generation (kton)	Residue Recovery (kton)
Rice straw	66258	23190
Wheat straw	2637	923
Sugarcane tops	2051	718
Jute stalks	2376	832
Vegetable residue	735	257
Rice husk	12548	12548

Rice bran	3244	3244
Sugarcane bagasse	1983	1983

The most popular sector for consumption of energy produced from biomass is cooking in rural areas whereas it is found to be used in the heating process in some industries also. Biomass energy source when used in power generation emits a low amount of CO_2 compared to other sources leading to being an eco-friendly alternative. Biomass consumption scenario shown in figure 6.7 depicts that while the major portion of biomass energy comes from crop residues, most of this energy is consumed by the domestic sector. Recent researches reveal that the total amount of recoverable biomass resource in Bangladesh is 126 MT per year and total energy that can be achieved from this amount is about 1282 PJ (Tayab et al. 2015). While biomass energy can contribute to securing energy security in rural areas, it can create further pressure on food production if overemphasized.

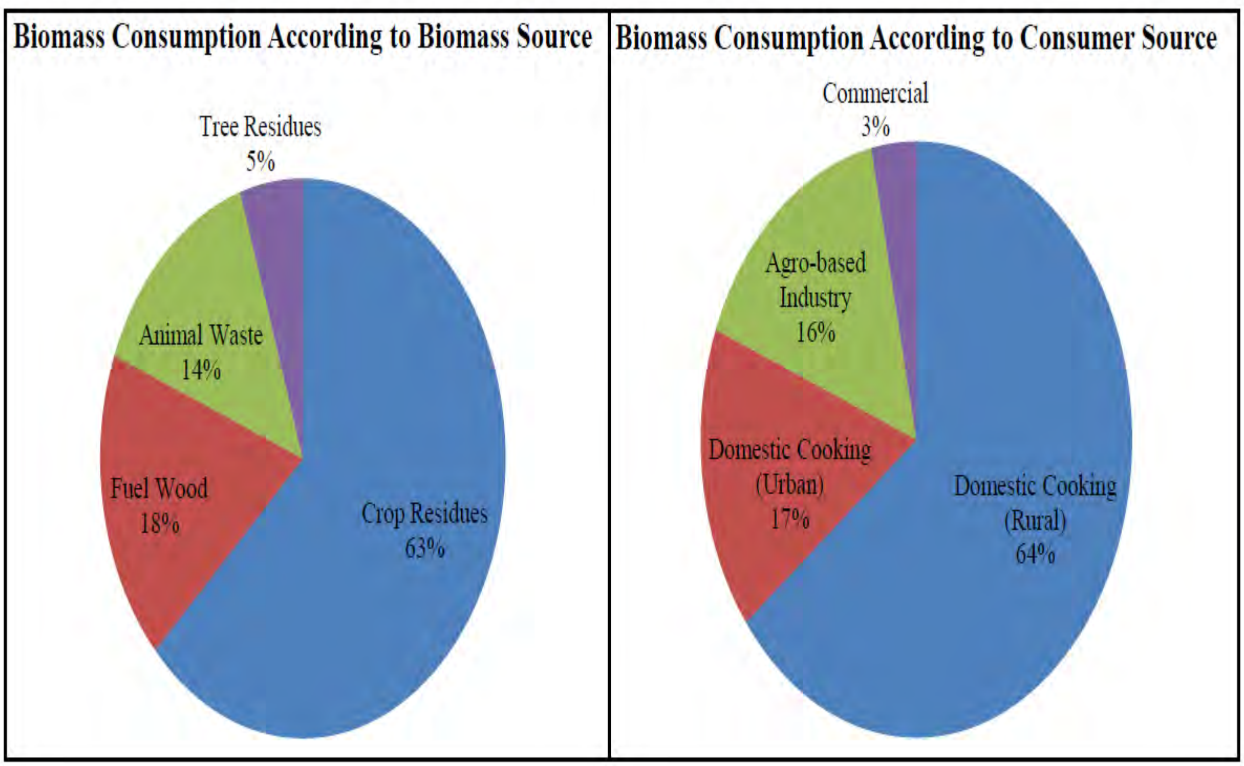

Figure 6.9 Biomass consumption scenarios (Hossain et al. 2007)

Managing non-cultivable land to set up power plants and preventing subsequent damages to agriculture and fishery have been a challenge to Bangladesh in making way to food and energy security concurrently. Non-cultivable land is difficult to acquire in the context of densely living population and barren land being cultivated to attain increasing food demand. Toxic smoke and ash accompanied by thermal effluents diffused in water produced from coal power plants exert a negative impact on crop yield and availability of fish. Land acquisition for Banshkhali coal power plant led to huge controversy on the issue of negative impacts on agriculture and fishery of that area. The coal-based Rampal power plant project plans cover 34,955 hectares of land near Sundarbans of which 75.4% (26,344 hectares) is Net Cultivable Area (NCA) and a huge amount of crops are to be damaged as depicted in table 6.7 (CEGIS, 2013). In an effort to avoid land allotment difficulties, Bangladesh is opting for planning transboundary solution of jointly operated power plants in India according to Bangladesh Power Development Board.

Table 6.7 Estimated crop production and damage in Rampal power plant project area (CEGIS, 2013)

Study location	Crop name	Crop area (ha)	Damage free		Damaged		Total production	Production lost (ton)
			Area (ha)	Yield (ton/ha)	Area (ha)	Yield (ton/ha)		
Project area	T Aman (local)	706	459	2.45	212	0.65	1285	467
Study area	B. Aus	2871	2440	2.1	431	1.02	5564	465
	T Aman (local)	24058	19246	2.45	4812	0.75	50762	8180
	Boro (HYV)	1344	1210	3.8	134	1.25	4764	343
	Total Paddy	28273	22896	-	5377	-	61091	8988
	G. Total Paddy	28979	23355	-	5588	-	62353	9455
	Rabi (Pulses)	632		0.8	-	-	506	-
	W. Melon	3345		29	-	-	97005	-
	Jute	922	-	2	-	-	1844	-
	Vegetables (S)	1581	-	12	-	-	18972	-

	Vegetables (W)	1581	-	14	-	-	22134	-
	Non-paddy	8061	-	-	-	-	140461	-

From evaluating corresponding data, an Energy-Food nexus framework for Bangladesh has been developed by erecting nexus scenarios between energy and food sector prompted by driving forces and their subsequent impacts. Driving forces such as food, energy & agricultural water demand, land & fuel scarcity, population have forged to create the energy and food nexus scenarios that impacted power demand, renewable energy sources, and conflicts as shown in table 6.8. The Energy-Food Nexus framework for Bangladesh has been illustrated in figure 6.10.

Table 6.8 Energy-Food Nexus framework for Bangladesh

Driving forces	Energy-Food nexus scenario	Impacts
Agricultural water demand, Food demand	Dependency of food production on power supply & fuel for irrigation & post-harvest activities	Increasing power demand during irrigation season resulting load shedding
Energy demand, Fuel scarcity	Food production residues used for biomass energy generation	Facilitating fuel diversification & renewable energy
Population, Land scarcity, energy demand	Exploitation of cultivable lands to set up power plants accompanied by damaging of agriculture & fishery by power generation effluents	Arousal of land & environmental conflict

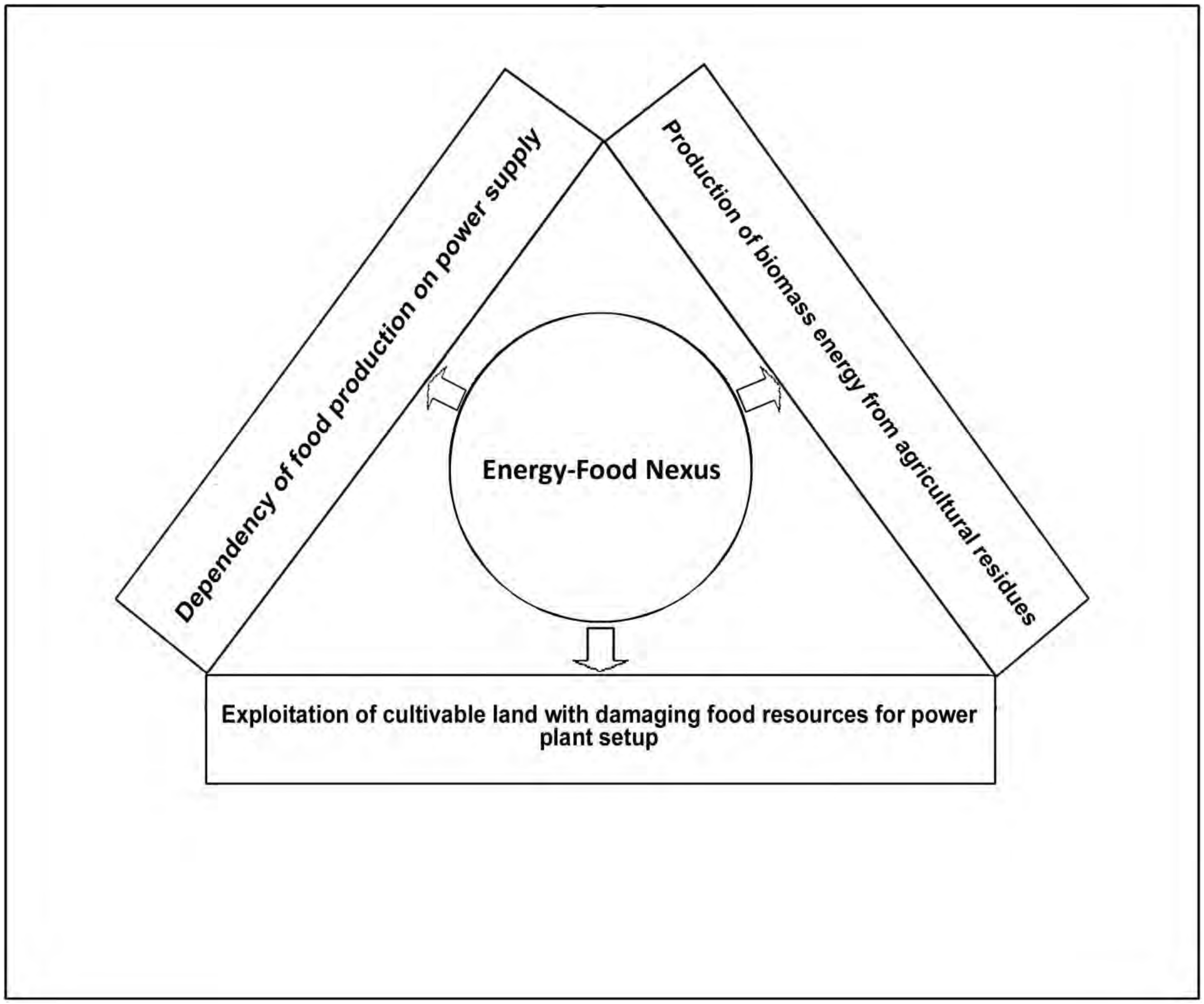

Figure 6.10 Energy-Food Nexus framework for Bangladesh

6.4 Water-Energy-Food Nexus

Nexus among water, energy and food resources in Bangladesh has been manifested through assessing their sectoral demands and issues. In one hand, food production is water intensive due to irrigation requirements that draw vast power demand. Power production is also dependent on water supply for both thermal and hydro plants whereas water management systems are run by electricity. Water-induced disasters bring devastation to both food and power production while fertilization in agriculture and criticality in land acquisition for setting up of power plants along with their discharged effluents in rivers causes damage to water quality, agriculture and fisheries of particular locations. Solar irrigation, crop diversification, biomass electricity, micro-hydro power generation, organic fertilization are some of the solutions to the criticality of WEF nexus being practiced in Bangladesh. The WEF nexus for Bangladesh has been conceptualized in the following figure 6.8.

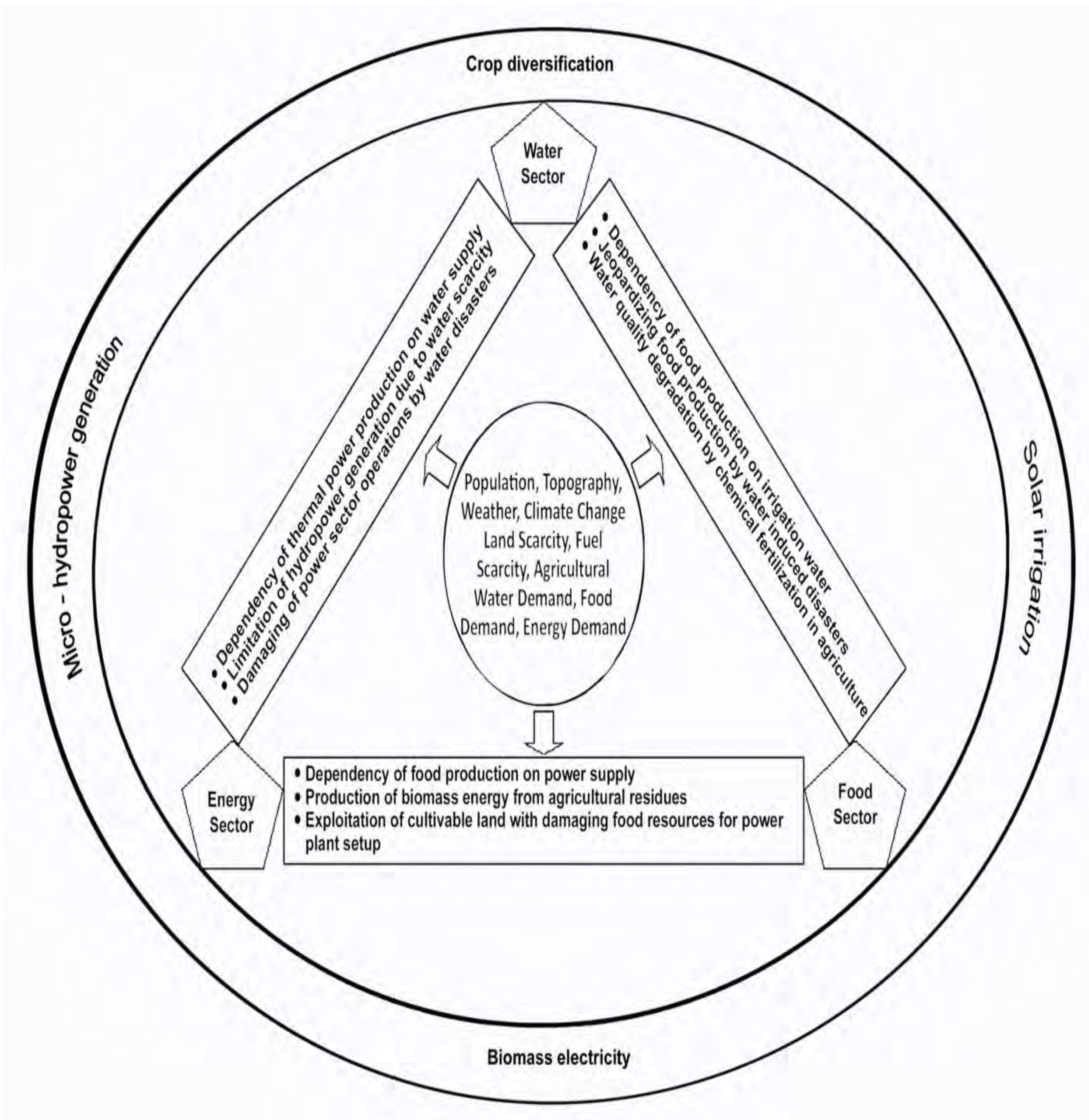

Figure 6.11 Water-Energy-Food Nexus framework for Bangladesh

CHAPTER 7

THE WATER ENERGY FOOD NEXUS AND SDGs REGARDING BANGLADESH

Bangladesh"s remarkable achievement in Millennium Development Goals (MDGs) led to the ambition of championing Sustainable Development Goals (SDGs) of the United Nations (UN). Water-Energy-Food nexus framework for Bangladesh features several targets & their subsequence regarding SDG-2: zero hunger, SDG-6: clean water & sanitation & SDG-7: affordable & renewable energy. Targets of SDG-2 including ensuring food production sustainability maintaining ecosystem & protecting from flood & drought and consequences of doubling agricultural production are subjected within food-water & food-energy nexus in the framework. Targets of SDG-6 including maintaining water quality and sustainable water withdrawal from all sectors are subjected within food-water, food-energy & water-energy nexus. Targets of SDG-6 including renewable energy have been subjected within water-energy & food-energy nexus. Addressing the synergy between water, energy and food supply and incorporating the WEF nexus in policy making is key to achieve SDGs. Facilitation of WEF nexus in the planning process of SDG implementation requires exploration of WEF nexus perspective in the agenda & experts opinion on country"s readiness level, required efforts and coordination authority for implementing SDG.

7.1 Water-energy-food nexus perspective in Sustainable Development Goals

UN General Assembly has issued 2030 agenda: Sustainable Development Goals (SDGs) including 17 global goals with 169 targets replacing Millennium Development Goals (MDGs) that ended in 2015. SDGs are considered to be integrated by synergy leading to the fact that aiming to achieve individual goals will be in vain if synergy among them is not considered. Among proposed goals, Goal 2, Goal 6 and Goal 7 focus on the security of three basic elements of food, water, and energy respectively. SDG-2: zero hunger, SDG-6: clean water & sanitation & SDG-7: affordable & renewable energy are interconnected and their nature of interdependency is critical in overall SDG implementation. The water energy food nexus thinking is well reflected in SDG- 2, SDG-6 and SDG-7 as illustrated in figure 7.1 making it essential to be integrated into policy-making process of Bangladesh for accomplishing overall success in SDG fulfillment. Achieving the SDGs regarding food, energy & water will require an integrated perspective across the plans of resource management exploring synergies, trade-offs, and conflicts among relevant sectors as presented through WEF nexus.

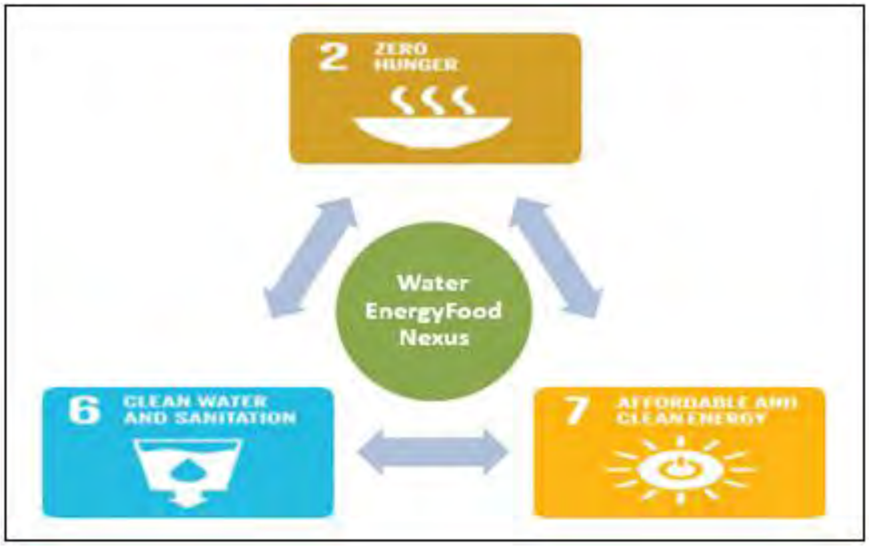

Figure 7.1 Water-energy-food nexus in SDG

7.2 Synergy and trade-off evaluation among SDG-2, SDG-6 and SDG-7

Evaluation of quantitative interdependencies among SDG-2: zero hunger, SDG-6: clean water & sanitation & SDG-7: affordable & renewable energy can contribute in the integration of WEF nexus scenarios in national policymaking, the establishment of cross-sectoral cooperation among government agencies and reflection of synergetic responses in action plans and programmes. Sets of indicators with available authentic well-defined datasets have been used as in table 7.1 to assess the correlation between targets of SDG-2, SDG-6, and SDG-7. The Pair-wise Pearson Correlation Coefficient & Statistical Significance Level of SDG targets calculated using indicator data as shown in table 7.1 is illustrated in table 7.2. It is to state that, Pearson Correlation Coefficient was calculated by dividing the covariance of two variables by product of their standard deviations and Significance Level was evaluated by comparing p-value calculating through regression analysis. Statistical Significance Levels of Pearson Correlation Coefficients were attributed as; not significant when $p > 0.05$; * for $p < 0.05$; ** for $p < 0.01$ and *** for $p < 0.001$ i.e. highly significant.

Table 7.1 SDG indicator values for different targets (United Nations Statistics Division, 2015; World Bank Data)

Year	SDG_T2.1 (Free from undernourished)	SDG_T6.1 a (Improved sanitary facility)	SDG_T6.1 b (Basic drinking water services)	SDG_6.2b (Open defecation)	SDG_7.2 a (Access to electricity)	SDG_7.2 b (Renewable energy use)
2000	79.2	45	94.65	18.36	32.00	59.01
2001	81.3	47	94.84	17.07	35.00	55.79
2002	81.8	48	95.03	15.76	37.31	54.32
2003	82.5	49	95.23	14.46	39.61	52.64
2004	82.9	50	95.42	13.18	40.60	52.12
2005	83.4	51	95.60	11.91	44.23	50.78
2006	83.7	52	95.79	10.66	50.53	48.90
2007	83.7	53	95.97	9.42	46.50	47.48
2008	83.6	54	96.15	8.19	51.25	45.58
2009	83.4	55	96.33	6.98	53.63	43.69
2010	83.1	56	96.50	5.79	55.26	41.05
2011	83.1	57	96.67	4.61	59.60	39.44
2012	83.2	58	96.84	3.45	60.88	38.61
2013	83.6	59	97.01	2.31	61.50	38.76
2014	84	60	97.17	1.19	62.40	37.63
2015	84.9	61	97.33	0.11	68.20	34.75

Values of indicators for SDG-2, SDG-6 & SDG-7 as shown in table 7.1 tabulated from the year 2000 to 2015 have been assessed to evaluate synergy and trade-off among them.

Table 7.2 Pair-wise Pearson Coefficient & Significance Level of SDG targets

	SDG_T2.1 (Free from undernourished)	SDG_T6.1a (Improved sanitary facility)	SDG_T6.1b (Basic drinking water services)	SDG_6.2b (Open defecation)	SDG_7.2 a (Access to electricity)	SDG_7.2 b (Renewable energy use)
SDG_T2.1 (Free from undernourished)	1	0.80***	0.79***	-0.79***	0.79***	-0.77***
SDG_T6.1a (Improved sanitary facility)	0.80***	1	1.00***	-1.00***	0.99***	-0.99***
SDG_T6.1b (Basic drinking water services)	0.79***	1.00***	1	-1.00***	0.99***	-0.99***
SDG_6.2b (Open defecation)	-0.79***	-1.00***	-1.00***	1	-0.99***	0.99***
SDG_7.2 a (Access to electricity)	0.79***	0.99***	0.99***	-0.99***	1	-0.99***
SDG_7.2 b (Renewable energy use)	-0.77***	-0.99***	-0.99***	0.99***	-0.99***	1

(Not significant when $p > 0.05$; * for $p < 0.05$; ** for $p < 0.01$ and *** for $p < 0.001$ i.e. highly significant)

It is found from table 7.2 that, the majority of the correlation coefficients are positive implying that increase or decrease in one target achievement will consecutively affect positively or negatively in the achievement of the other. Most of the values are found higher and all of them are highly significant resulting in the fact of high linear linkage among different SDG targets.

Interaction among different actors leading to an impact greater or less than the sum of individual effects is called synergy (if the result is positive) or trade-off (if the result is negative) (Mainali et al., 2018). Advanced Sustainability Analysis (ASA) developed by

European Framework Programmes can provide synergy and trade-off of SDGs specifying potential causality between SDG targets. The Advanced Sustainability Analysis (ASA) is a mathematical information system that can analyze indicator data for the different point of view decomposing factors affecting changes that offers decision makers a tool for policy development for dimensions of sustainable development (Luukkanen, J., 2004). In this study, synergy or trade-off is measured by primarily normalizing indicator datasets for SDG-2, SDG-6 and SDG-7 to the base or previous year and then calculating relative changes between two normalized indicator data by their ratio. If the resultant of the ratio is greater than 1, then the quotient has been inverted to keep the index between -1 to +1. Synergy and trade-off analysis have been done for relative changes of corresponding indicator data for each year difference. Bars above axis line represent synergy and bars below axis line represent a trade-off.

Synergy and trade-off between SDG-2 and SDG-6

Synergy and trade-off between SDG-2: zero hunger and SDG-6: clean water & sanitation has been measured against their indicators T-2.1: population free from undernourishment and T-6.1: population with improved sanitary facility. Relative change between the two indicators is shown in figure 7.2.

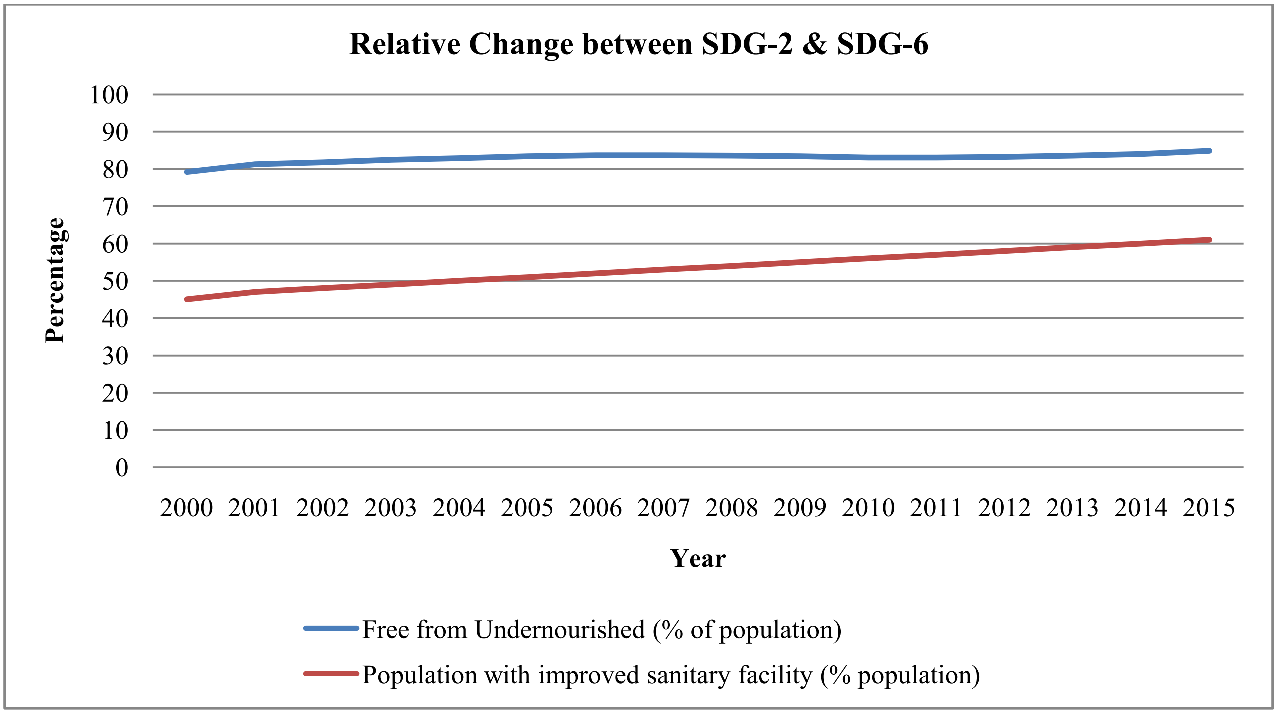

Figure 7.2 Relative Change between SDG-2 & SDG-6 (Population free from undernourishment and with improved sanitary facility)

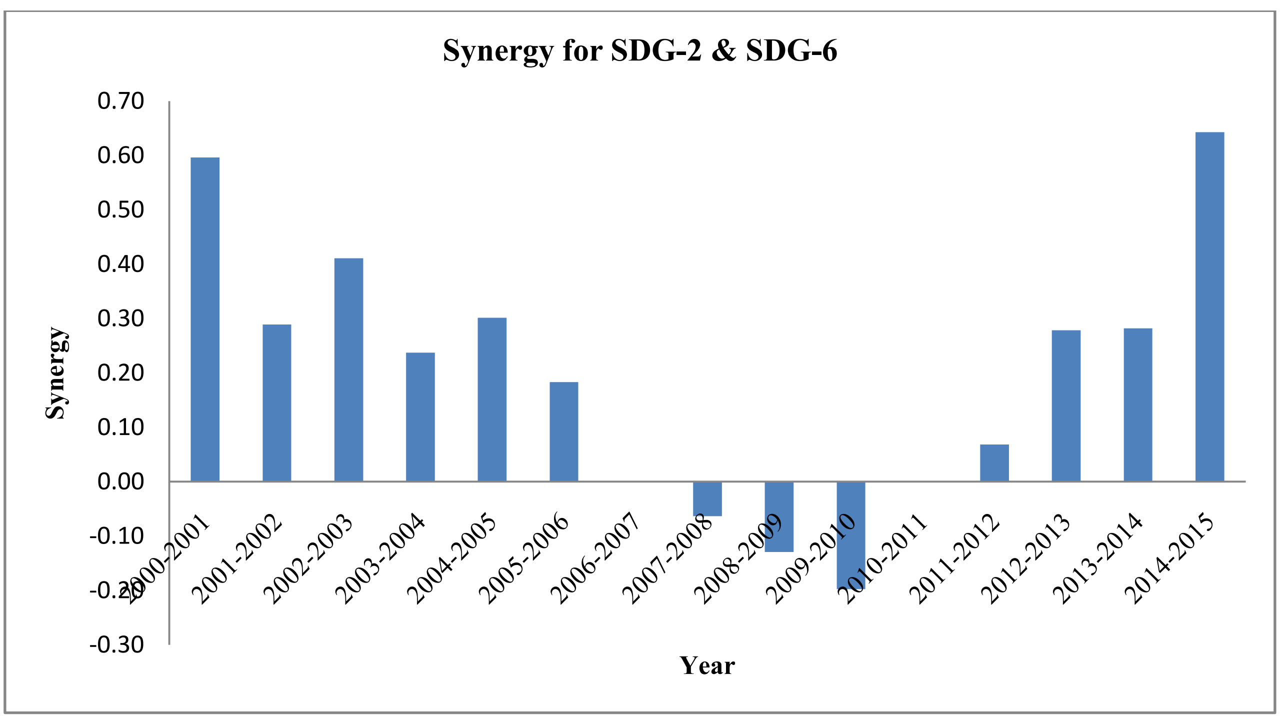

Figure 7.3 Synergy for SDG-2 and SDG-6 (Population free from undernourishment and with improved sanitary facility)

Synergy and trade-off analysis results shown graphically in figure 7.3 reveal that there exists mostly positive synergy except for small trade-off situation in between 2006 to 2011 between T-2.1: population free from undernourishment and T-6.1: population with improved sanitary facility. Though from 2000 to 2006, their synergy is irregular, from 2011 onwards, gradual positive synergy was found resulting possibly from the constant and stable economic growth of Bangladesh supported by Government projects. As achieving both, undernourishment and improved sanitary status, is driven by the same factors such as economic growth, infrastructural development, government concerns etc, positive synergy is most general in this case. The trade-off in between 2008 to 2011 has presumably resulted from a small drop in freeing the country from undernourishment though providing sanitary facilities were in constant increase. Aiming to maximize potential synergy between SDG-2 and SDG-6, hence it is evident that any increment in efforts to achieve one"s targets will result in strengthening the other.

Synergy and trade-off between SDG-6 and SDG-7

Synergy and trade-off between SDG-6: clean water & sanitation and SDG-7: affordable & renewable energy has been measured against their indicators T-7.2: population with access to electricity and T-6.1: population using at least basic drinking water services. Relative change between the two indicators is shown in figure 7.4.

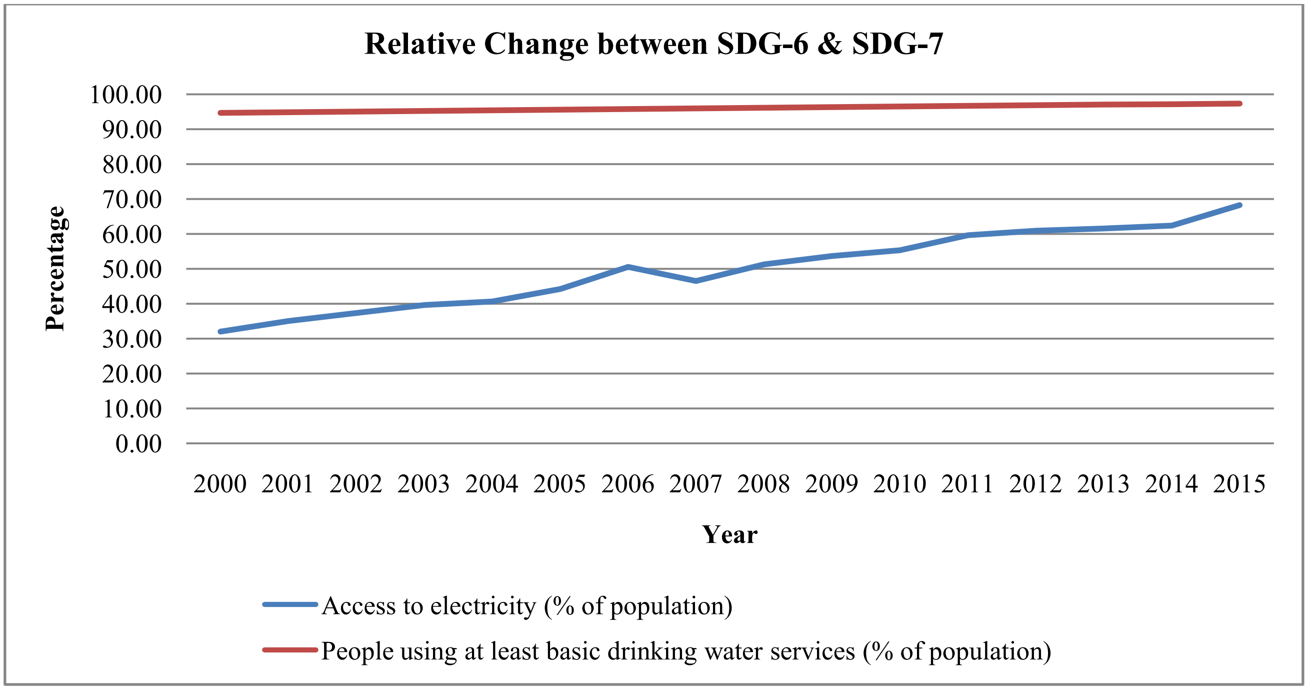

Figure 7.4 Relative Change between SDG-6 & SDG-7 (Population with access to electricity and using at least basic drinking water services)

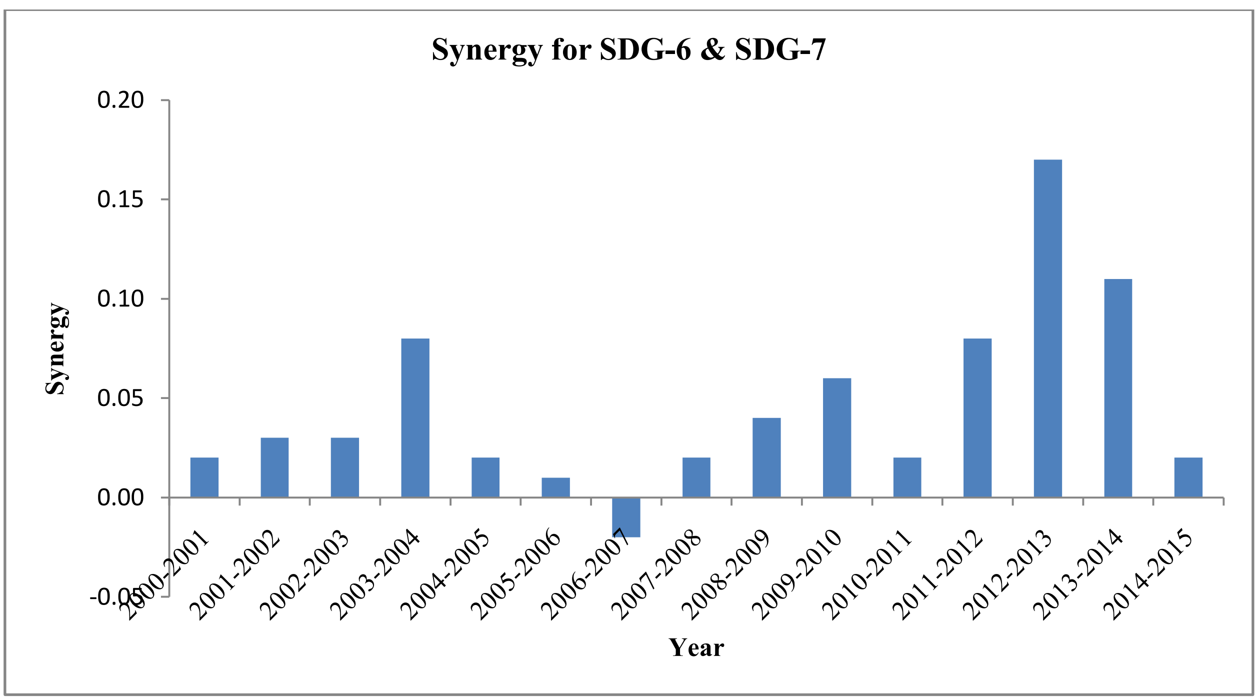

Figure 7.5 Synergy for SDG-6 and SDG-7 (Population with access to electricity and using at least basic drinking water services)

Synergy and trade-off analysis results shown graphically in figure 7.5 reveal that there exists mostly positive synergy except for small trade-off situation in between 2006 to 2007 between T-7.2: population with access to electricity and T-6.1: population using at least basic drinking water services. Abruption in electrification from 2006 to 2007 against constant increase in strengthening drinking water services has resulted in a trade-off for that period. From 2007 and onwards, there has been a gradual positive synergy between two targets resulting possibly from the constant and stable economic growth of Bangladesh supported by Government projects. It is also to state that electrification, in general, enables provision of drinking water services. Aiming to maximize potential synergy between SDG-6 and SDG-7, hence it is evident that any increment in efforts to achieve one‟s targets will result in strengthening the other.

Synergy and trade-off between SDG-2 and SDG-7

Synergy and trade-off between SDG-2: zero hunger and SDG-7: affordable & renewable energy has been measured against their indicators T-2.1: population free from undernourishment and T-7.2: population with access to electricity. Relative change between the two indicators is shown in figure 7.6.

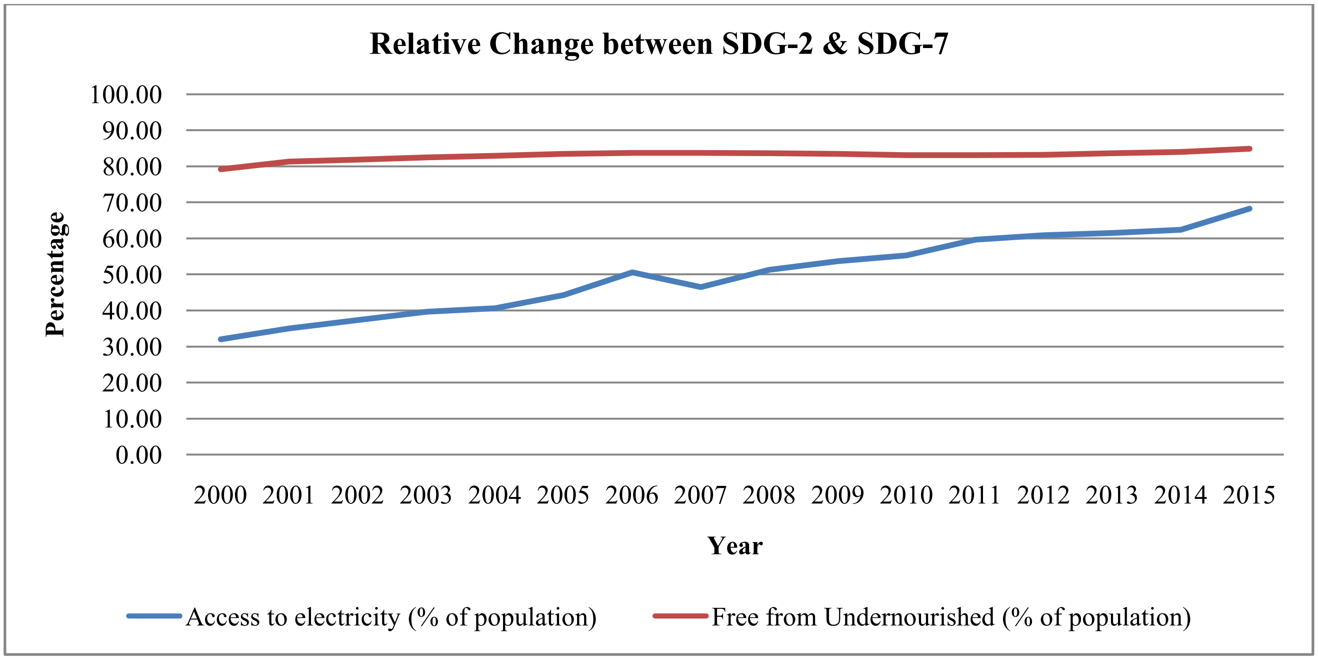

Figure 7.6 Relative Change between SDG-2 & SDG-7 (Population free from undernourishment and with access to electricity)

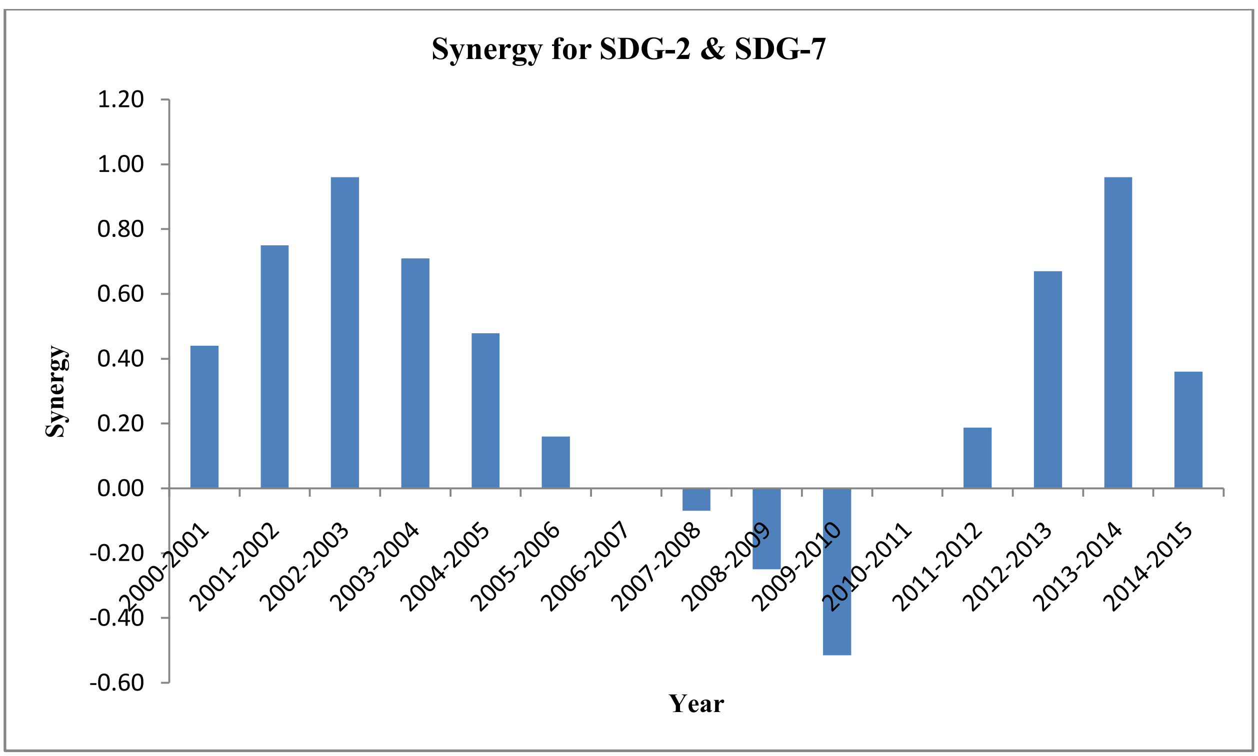

Figure 7.7 Synergy for SDG-2 and SDG-7 (Population free from undernourishment and with access to electricity)

Synergy and trade-off analysis results shown graphically in figure 7.7 reveal that there exists mostly positive synergy different over time except for small trade-off situation in between 2006 to 2011 between T-2.1: population free from undernourishment and T-7.2: population with access to electricity. Though from 2000 to 2006, their synergy is irregular, from 2012 onwards, gradual positive synergy was found resulting possibly from the constant and stable economic growth of Bangladesh supported by Government projects. As achieving both, undernourishment and access to electricity, is driven by the same factors such as economic growth, infrastructural development, government concerns etc, positive synergy is most general in this case. The trade-off in between 2006 to 2011 has presumably resulted from a small drop in progress towards freeing the country from undernourishment coupled with abruption in electrification from 2006 to 2007. Aiming to maximize potential synergy between SDG-2 and SDG-7, hence it is evident that any increment in efforts to achieve one‟s targets will result in strengthening the other.

The analysis has shown strong synergy differing over time among SDG-2, SDG-6, and SDG-7 evaluated by assessment of their target datasets. SDG-2, SDG-6, and SDG-7 showed higher synergy during periods of simultaneous positive increment of target data resulted from economic growth, infrastructural development, government concerns etc. Lacking indicator data has constrained efforts to the evaluation of synergy and trade-off in a broader sense.

7.3 Integration of SDG-2, SDG-6 & SDG-7 in Bangladesh Government Policy

The government of Bangladesh has highlighted existing policies/strategies/regulations to be instrumental for implementation of SDG targets. In a study by Center for Policy Dialogue (CPD), it is found that around 80% SDG targets reflect national priorities including SDG-2, SDG-6 and SDG-7 are better integrated into the existing national prioritization process. During formulation of 7th five year plan (7FYP), SDGs were emphasized while setting up priority areas resulting goals 2, 6 & 7 aligning around 82% of the 7FYP as illustrated in table 7.3.

Table 7.3 SDG-2, SDG-6 & SDG-7 as integrated in 7FYP (GED, 2016)

SDG-2: Zero Hunger	7FYP Target: Poverty and Hunger
End hunger, achieve food security and improved nutrition and promote sustainable agriculture	• Consolidation of Food Transfer Programmes as suggested by National Social Security Programme • Reduce proportion of stunting from 36.1% to 25% & proportion of underweight from 32.6% to 20% among under-five children
SDG-6: Clean Water and Sanitation	7FYP Target: Water and Sanitation
Ensure availability and sustainable management of water and sanitation for all	• Safe drinking water to be made available for all rural and urban population • Proportion of urban population with access to sanitary latrines to be increased to 100 % and 90% for rural population
SDG-7: Renewable Energy	7FYP Target: Renewable Energy
Ensure access to affordable, reliable, sustainable and modern energy for all	• Generation of electricity to be increased to 23,000MW • Electricity coverage to be increased to 96% & efficiency by 10%

National policies of food, water, and energy resources have been scrutinized to assess their integration level with concerned SDGs as illustrated in following tables 7.4, 7.5 & 7.6.

Table 7.4 SDG-2 as integrated in National Food Policy

SDG-2: Zero Hunger	National Food Policy, 2006
Target-1: By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round	Objective-2: Increased purchasing power and access to food of the people Strategy-2.1: Transitory shock management Strategy-2.2: Effective implementation of targeted food programmes to improve food security Strategy-2.3: Employment-generating income growth
Target-2: By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons	Objective-3: Adequate nutrition for all individuals, specially for women and children Strategy-3.1: Long-term national plan for ensuring balanced food in building a healthy nation Strategy-3.2: Supply of sufficient nutritious food for vulnerable group Strategy-3.3: Balanced diet containing adequate micronutrients
Target-3: By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm	Objective-1: Adequate and stable supply of safe and nutritious food Strategy-1.1: Efficient and sustainable increase in food production
	Objective-2: Increased purchasing power and access to food of the people Strategy-2.3.1: Support to women and the disabled in income generating activities Strategy-2.3.5: Education, skill and human resources development Strategy-2.3.6: Adoption of macro policy for broad-based labor-intensive growth

employment	
Target-4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality	Objective-1: Adequate and stable supply of safe and nutritious food Strategy-1.1: Efficient and sustainable increase in food production Strategy-1.1.1: Agricultural development and extension services Strategy-1.1.2: Efficient use of water resources Strategy-1.1.3: Availability of agricultural inputs and their efficient use Strategy-1.1.4: Agriculture diversification and improved agricultural technology
Target-5: Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries	Objective-1: Adequate and stable supply of safe and nutritious food Strategy-1.1.4: Agriculture diversification and improved agricultural technology Objective-2: Increased purchasing power and access to food of the people Strategy-2.3.2: Investment in employment enhancing technology

Table 7.5 SDG-6 as integrated in National Water Policy

SDG-6: Clean Water and Sanitation	National Water Policy, 1999
Target-1: By 2030, achieve universal and equitable access to safe and affordable drinking water for all	4.6 Water Supply and Sanitation: a. Facilitate availability of safe and affordable drinking water supplies through various means, including rainwater harvesting and conservation
Target-2: By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations	4.6 Water Supply and Sanitation: c. Mandate relevant public water and sewerage institutions to provide necessary drainage and sanitation in the interest of public health d. Empower, and hold responsible, municipalities and urban water and sewerage institutions to regulate the use of water for preventing wastage and pollution by human action. e. Mandate local governments to create awareness among the people in checking water pollution and wastage.
Target-3: By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally	4.7 Water and Agriculture: a. Encourage and promote continued development of minor irrigation, where feasible, without affecting drinking water supplies e. Strengthen the regulatory system for agricultural chemicals that pollute ground and surface water, and develop control mechanism for reducing non-point pollution from agro chemicals f. Strengthen appropriate monitoring organizations for tracking groundwater recharge, surface and groundwater use, and changes in surface and groundwater quality

	4.8 Water and Industry: a. Zoning regulations will be established for location of new industries in consideration of fresh and safe water availability and effluent discharge possibilities b. Effluent disposal will be monitored by relevant Government agencies to prevent water pollution c. Standards of effluent disposal into common watercourses will be set by WARPO in consultation with DOE d. Industrial polluters will be required under law to pay for the cleanup of water- body polluted by them
Target-4: By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	4.7 Water and Agriculture: c. Improve efficiency of resource utilization through conjunctive use of all forms of surface water and groundwater for irrigation and urban water supply d. Strengthen crop diversification programmes for efficient water utilization
Target-5: By 2030, implement integrated water resources management at all levels, including through trans boundary co-operation as appropriate	4.1 River Basin Management: a. Work with co-riparian countries to establish a system for exchange of information and data, joint assessment of all the international rivers flowing through their territories for better understanding of the overall basins' potentials, harnessing, development and sharing the water resources of the international rivers to mitigate floods and augment flows of water during the dry season, making concerted efforts for management of the catchment areas & prevention of chemical and biological pollution of the rivers flowing through these countries

	f. Seek international and regional cooperation for education, training, and research in water management 4.2 Planning and Management of Water Resources: j. Undertake comprehensive development and management of the main rivers through a system of barrages and other structural and non-structural measures k. Develop water resources of the major rivers for multipurpose use, including irrigation, fisheries, navigation, forestry, and aquatic wildlife l. De-silt watercourses to maintain navigation channels and proper drainage m. Delineate water-stress areas based on land characteristics and water availability from all sources for managing dry season demand n. Take steps to protect the water quality and ensure efficiency of its use o. Develop early warning and flood-proofing systems to manage natural disasters like flood and drought p. Designate flood risk zones and take appropriate measures to provide desired levels of protection for life, property, vital infrastructure, agriculture and wetlands q. Undertake survey and investigation of the problem of riverbank erosion and develop and implement master plans for river training and erosion control works for preservation of scarce land and prevention of landlessness and pauperization r. Plan and implement schemes for reclamation of land from the sea and rivers

Target-6: By 2020, protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	4.12 Water for the Environment: a. Give full consideration to environmental protection, restoration and enhancement measures consistent with the National Environmental Management Action Plan (NEMAP) and the National Water Management Plan (NWMP) b. Adhere to a formal environmental impact assessment (EIA) process, as set out in EIA guidelines and manuals for water sector projects, in each water resources development project or rehabilitation programme of size and scope specified by the Government from time to time c. Ensure adequate upland flow in water channels to preserve the coastal estuary eco-system threatened by intrusion of salinity from the sea d. Protect against degradation and resuscitate natural water-bodies such as lakes, ponds, beels, khals, tanks, etc. affected by man-made interventions or other causes e. Completely stop the filling of publicly owned water bodies and depressions in urban areas for preservation of the natural aquifers and environment f. Take necessary steps to remove all existing unauthorized encroachments on rivers and watercourses & to check further encroachments that cause obstructions to water flows and create environmental hazards g. Stop unplanned construction on riverbanks and indiscriminate clearance of vegetation on newly accreted land h. Encourage massive afforestation and tree coverage

	specifically in areas with declining water table i. Enforce the "polluter pay" principle in the development of regulatory guidelines for all regulatory actions designed to protect public health and the environment j. Provide education and information to the industrial and farming communities on self administered pollution control mechanisms and their individual and collective responsibilities for maintaining clean water sources

Table 7.6 SDG-7 as integrated in National Energy Policy

SDG-7: Renewable Energy	National Energy Policy, 2005
Target-1: By 2030, ensure universal access to affordable, reliable and modern energy services	Objective-9: To bring entire country under electrification by the year 2020 Objective-10: To ensure reliable supply of energy to the people at reasonable and affordable price
Target-2: By 2030, increase substantially the share of renewable energy in the global energy mix	Objective-6: To ensure environmentally sound sustainable energy development programmes, with due importance to renewable energy, causing minimum damage to environment
Target-3: By 2030, double the global rate of improvement in energy efficiency	Objective-5: To ensure rational use of total energy sources

As shown in table 7.4, National Food Policy is severely parallel to SDG-2 that is zero hunger with its strategies supportive to SDG targets that are again reflected through objectives of the policy. Clauses and sub-clauses of National Water Policy are tremendously approving to SDG-6 that is Clean Water and Sanitation, shown in table 7.5. As shown in table 7.6, targets of SDG-7 of renewable and affordable energy are also integrated in National Energy Policy. Overall, national and sectoral policies of Bangladesh integrate targets of SDG-2, SDG-6 & SDG-7 to a substantial extent. Integrating the Water Energy Food nexus in national planning process & programmes is further advanced approach in implementation of overall SDG that requires domestic efforts including institutional coordination, cross sectoral discussion, financial allocation, awareness raising and international efforts like planning support, knowledge & technology sharing, financial support etc.

There lie several challenges in terms of policy integration and governance to resolve issues arising from water-energy-food nexus in SDG implementation. Primarily, integration of the WEF nexus perspective in national plans and policies lacks in majority cases. Though water, energy and food policies reflect SDG targets of particular sectors, nexus issues require severe focus to attain except Bangladesh Delta Plan demonstrating highest integration of nexus perspective forming its strategies and policies addressing nexus inducing issues. Data availability for indicators to assess performance against SDG targets is a daunting challenge regarding the fact of only 29% data is readily and 45% data is partially available whereas 26% is not at all available according to data gap analysis by government of Bangladesh. Several other challenges such as financial and non-financial resource mobilization, ensuring stakeholders‟ engagements, enabling technological innovation and capacity development support from domestic and international means, as identified by Voluntary National Review, 2017, are crucial in resolving nexus oriented issues along with SDG implementation. There lies several ways forward for addressing these challenges and integrating nexus approach in practice;

- Integration of WEF nexus scenarios in national policy making and reflection of synergetic responses in action plans and programmes
- Increasing cross-sectoral cooperation along government agencies by facilitating technical organizations within planning process of SDG implementation
- Knowledge sharing, technology transfer regarding SDG target evaluation by assessing designated indicators and capacity building training programmes

along with formulation of Technical Assistance (TA) project with Ministry of Planning to adopt nexus approach

- Enhancing indicator data availability for SDG performance assessment and rendering necessary arrangements in this regard by Bangladesh Bureau of Statistics (BBS)
- Adequate financial allocation and awareness raising among government and stakeholders about importance of WEF nexus perspective in succeeding SDG goals

Currently under process perspective plan for 2021-2030 and SDG Action Plan need to incorporate nexus aspects of water, energy and food to construct a roadmap for SDG attainment. The government of Bangladesh in its Voluntary National Review, 2017 states that it plans to participate in all major initiatives in the international arena regarding SDGs implementation for acquiring knowledge from other country"s experience which definitely paves way for non-government stakeholder"s effort to convince planning agencies to integrate WEF nexus approach in SDG implementation.

7.4 Stakeholders perception assessment on WEF Nexus in SDG implementation

Major responsibilities regarding SDG implementation lies on Prime Minister"s Office, Planning Commission, Bangladesh Bureau of Statistics, concerned ministries, agencies along with relevant institutions, NGOs, Development partners and civil society. Their opinion and involvement in integrating WEF nexus in SDG implementation process possess great importance. A key informant interview with questionnaire survey was accomplished to explore expert view on country"s readiness level, domestic & international efforts along with coordination body necessary to integrate WEF nexus approach in SDG implementation. Data acquired from interviews from food, water, energy and planning sectors was processed by sectors to evaluate sectoral difference of opinion in SDG implementation.

7.4.1 Country's readiness level to integrate WEF Nexus in SDG implementation

Expert opinion on country‟s readiness level to integrate WEF nexus approach in implementation plan of SDG-2, SDG-6 and SDG-7 is illustrated as followed derived from key informant interview.

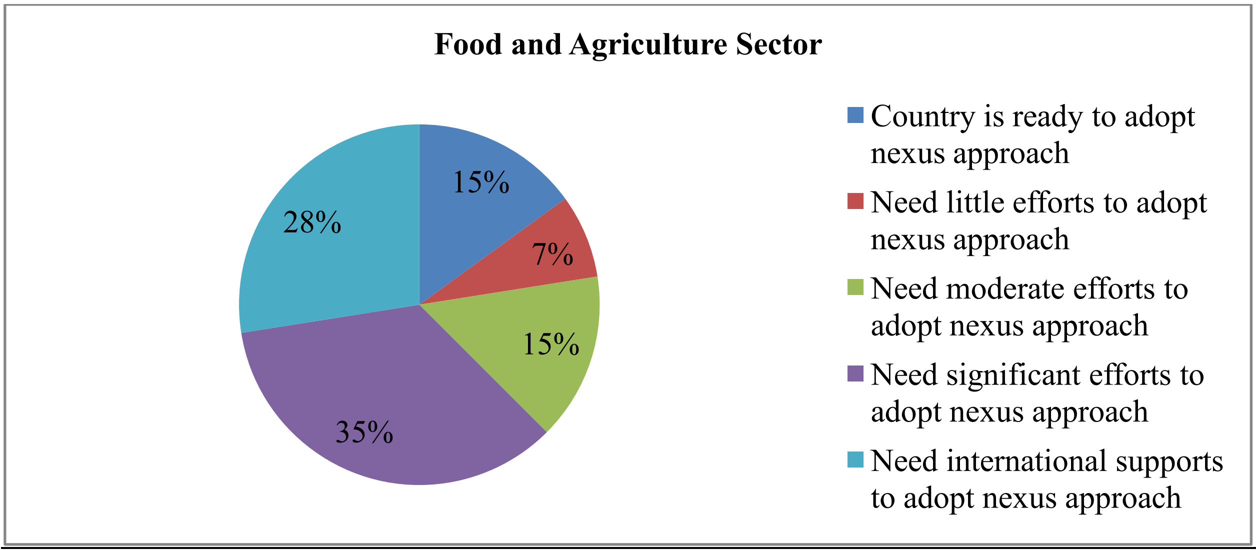

Figure 7.8 Food & agricultural sector‟s expert opinion on country‟s readiness level to integrate nexus approach in implementation plan of SDG-2, SDG-6 and SDG-7

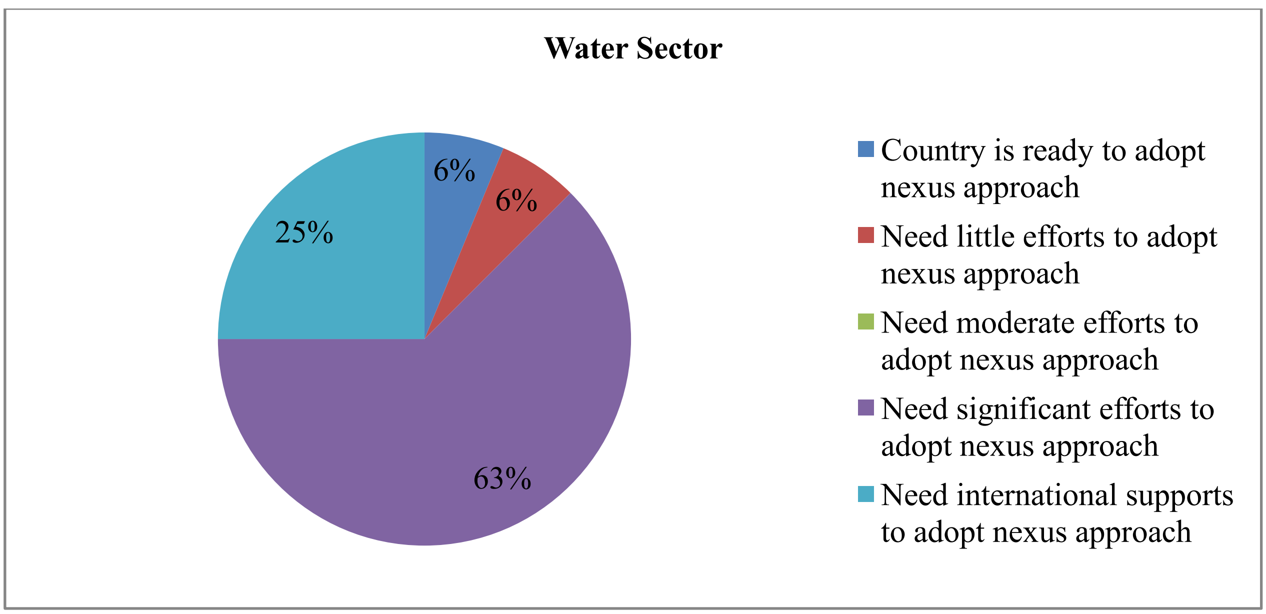

Figure 7.9 Water sector‟s expert opinion on country‟s readiness level to integrate nexus approach in implementation plan of SDG-2, SDG-6 and SDG-7

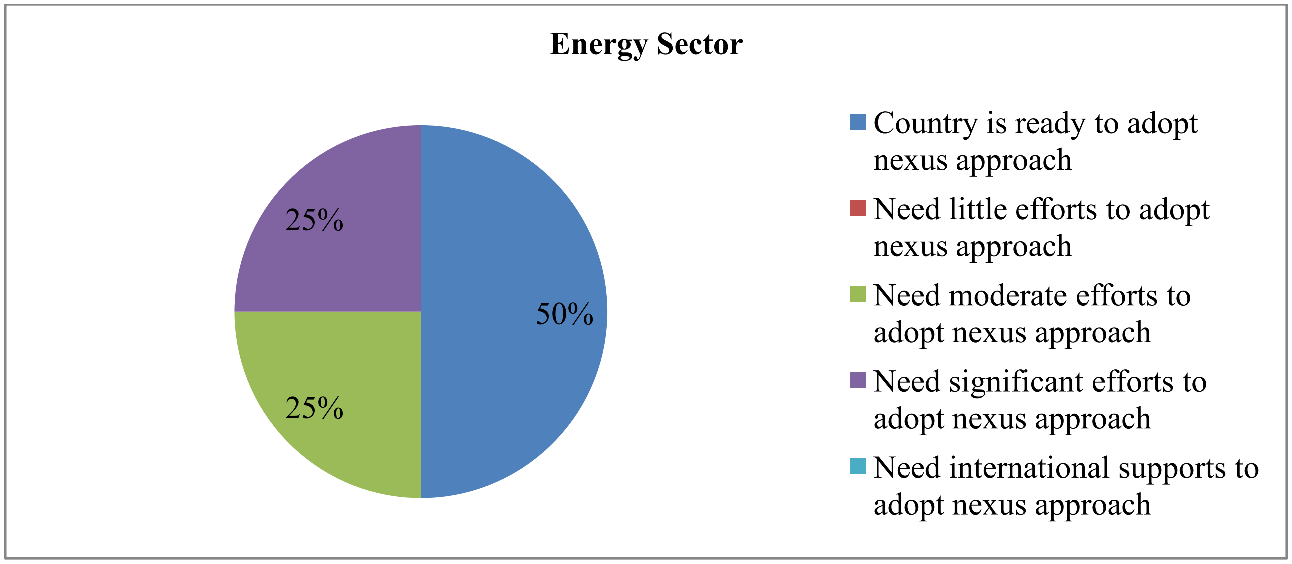

Figure 7.10 Energy sector‟s expert opinion on country‟s readiness level to integrate nexus approach in implementation plan of SDG-2, SDG-6 and SDG-7

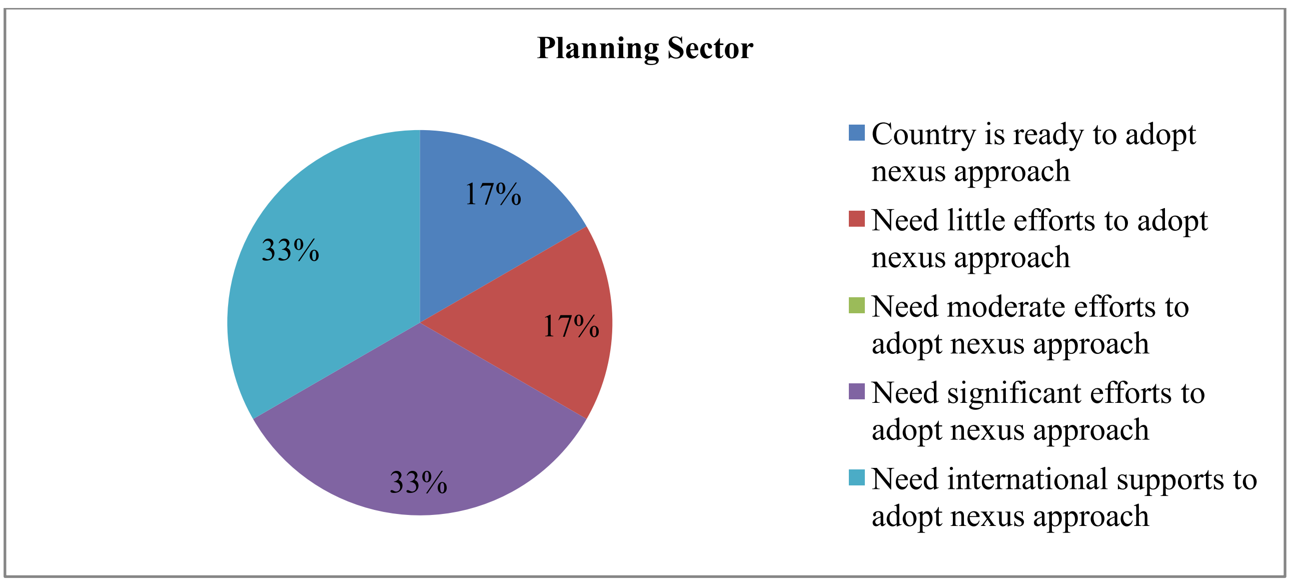

Figure 7.11 Planning sector‟s expert opinion on country‟s readiness level to integrate nexus approach in implementation plan of SDG-2, SDG-6 and SDG-7

Majority of all stakeholders in food, water and planning agencies, as showed in figure 7.8, 7.9 & 7.11, argued that significant efforts are needed to adopt nexus approach whereas requirement of international supports to adopt nexus approach are consented by second most majorities from these sectors. Majority stakeholders from energy sector, as illustrated in figure 7.10, claimed that country is ready to adopt nexus approach whereas remaining from the sector equally consented that significant effort and international support is necessary to integrate nexus approach in implementation plan of SDG-2, SDG-6 and SDG-7.

7.4.2 Domestic efforts necessary to adopt WEF nexus in SDG implementation

Expert view on kind of domestic efforts necessary to adopt WEF nexus approach in the process of SDG implementation is illustrated as followed derived from key informant interview.

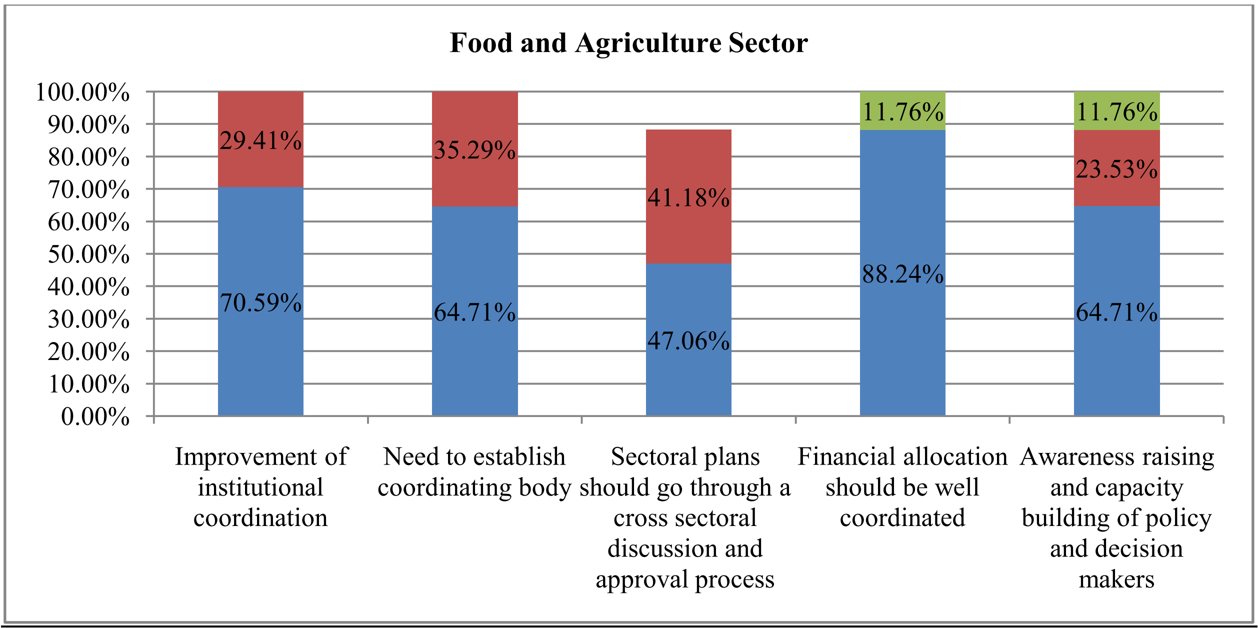

Figure 7.12 Domestic efforts necessary to adopt nexus approach according to food and agricultural sector

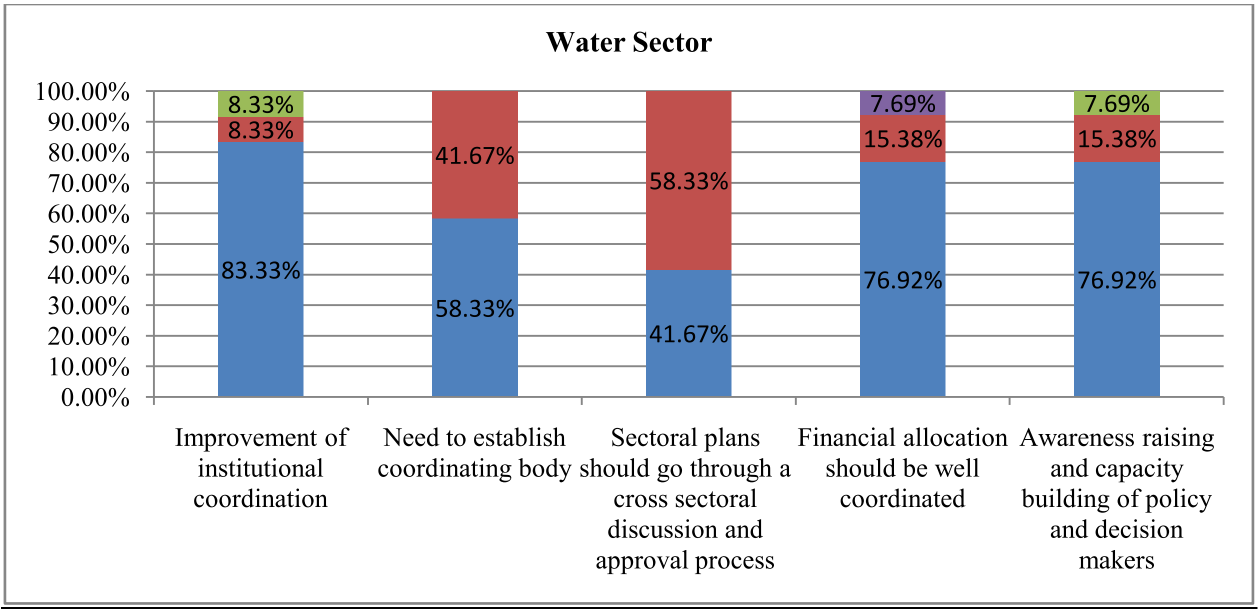

Figure 7.13 Domestic efforts necessary to adopt nexus approach according to water sector

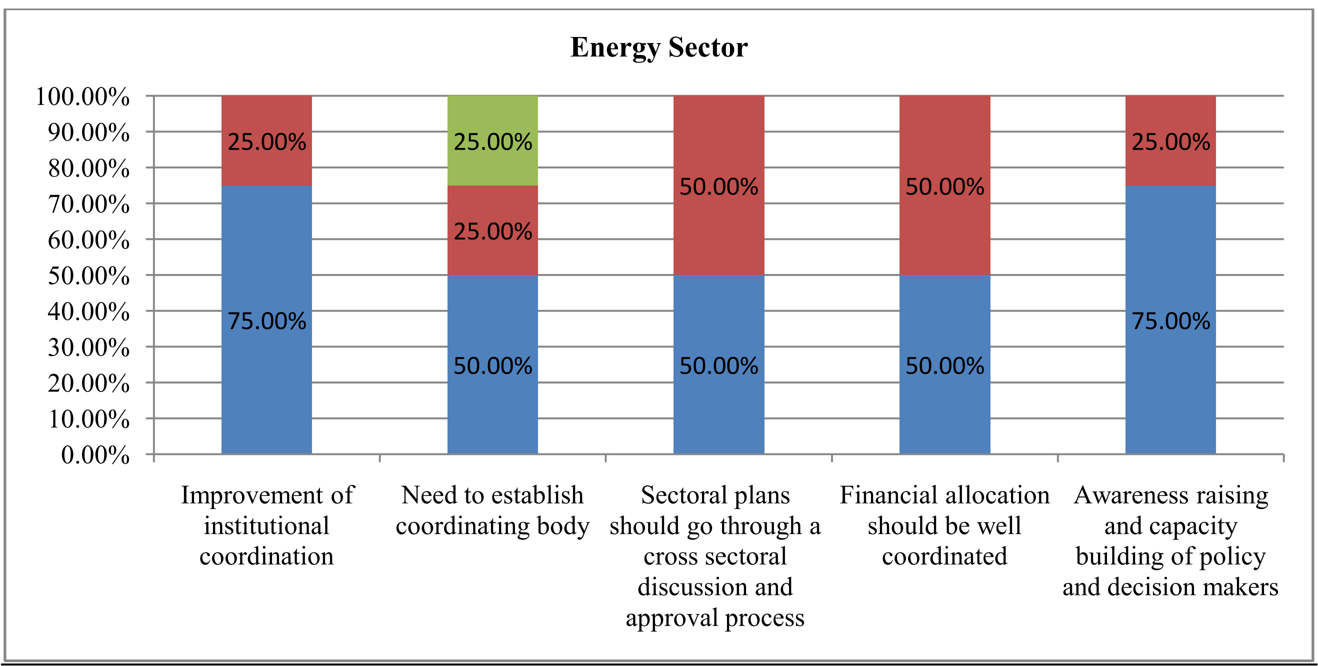

Figure 7.14 Domestic efforts necessary to adopt nexus approach according to energy sector

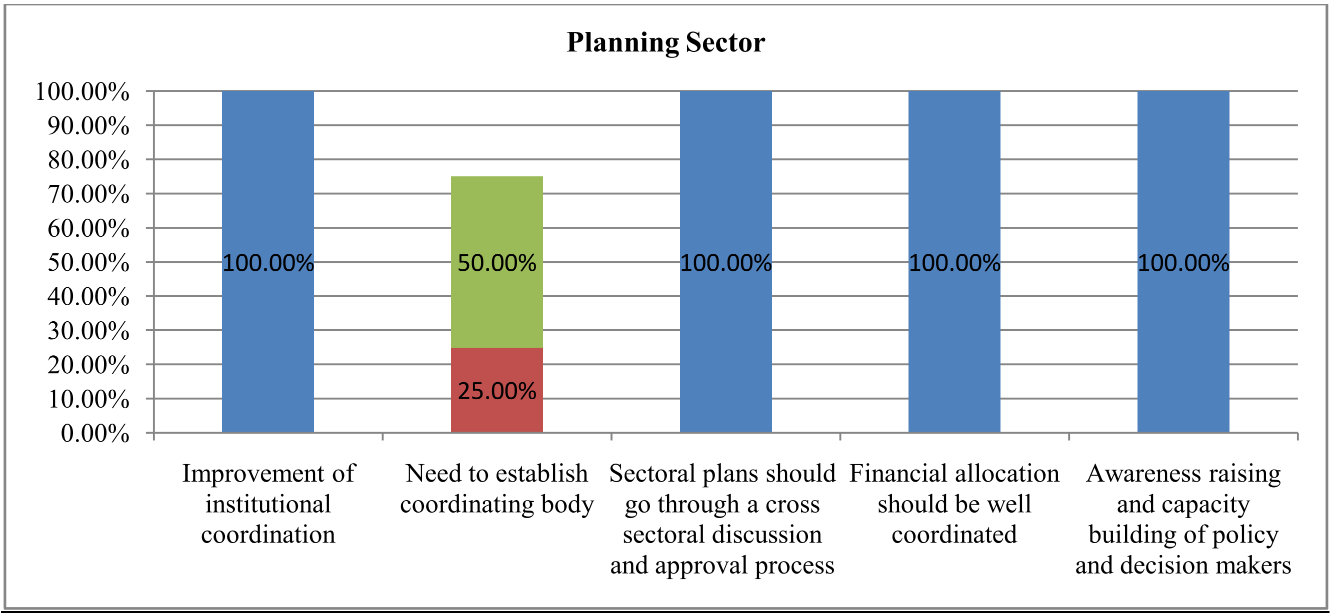

Figure 7.15 Domestic efforts necessary to adopt nexus approach according to planning sector

In the food and agriculture sector, as showed in figure 7.12, 71% strongly and another 29% moderately argued that improvement of institutional coordination is necessary to adopt nexus approach in the process of translating global goals to the country actions. In the water sector, as showed in figure 7.13, 83% strongly agreed on this issue. 75% stakeholders in the energy sector strongly and 25% moderately agrees on this issue as illustrated in figure 7.14. From the planning sector all strongly agreed on this issue as showed in figure 7.15.

In the food and agriculture sector, 65% strongly and another 35% moderately argued establishing coordinating body is necessary to adopt nexus approach in the process of translating global goals to the country actions. In the water sector, 58% strongly and 42% moderately agreed on this issue. 50% stakeholders in the energy sector strongly, others equally moderately and lowly agree on this issue. From the planning sector only 25% moderately agrees against 50% arguing that there is no need to establish coordinating body.

In the food and agriculture sector, 47% strongly and another 41% moderately argued sectoral plans should go through a cross sectoral discussion and approval process. In the water sector, 42% strongly and 58% moderately agreed on this issue. 50% stakeholders in the energy sector strongly, others equally moderately and lowly agree on this issue. From the planning sector all strongly agreed on this issue.

In the food and agriculture sector, 88% strongly and only 12% moderately argued that financial allocation should be well coordinated. In the water sector, 77% strongly and 15% moderately agreed on this issue. 50% stakeholders in the energy sector strongly, others equally moderately and lowly agree on this issue. From the planning sector all strongly agreed on this issue.

In the food and agriculture sector, 65% strongly and only 23% moderately argued that awareness raising and capacity building of policy and decision makers is necessary to adopt nexus approach in the process of translating global goals to the country actions . In the water sector, 77% strongly and 15% moderately agreed on this issue. 75% stakeholders in the energy sector strongly and other 25% moderately agree on this issue. From the planning sector all strongly agreed on this issue.

7.4.3 International efforts necessary to adopt WEF nexus in SDG implementation

Expert view on kind of international efforts necessary to adopt nexus approach in the process of SDG implementation is illustrated as followed derived from key informant interview.

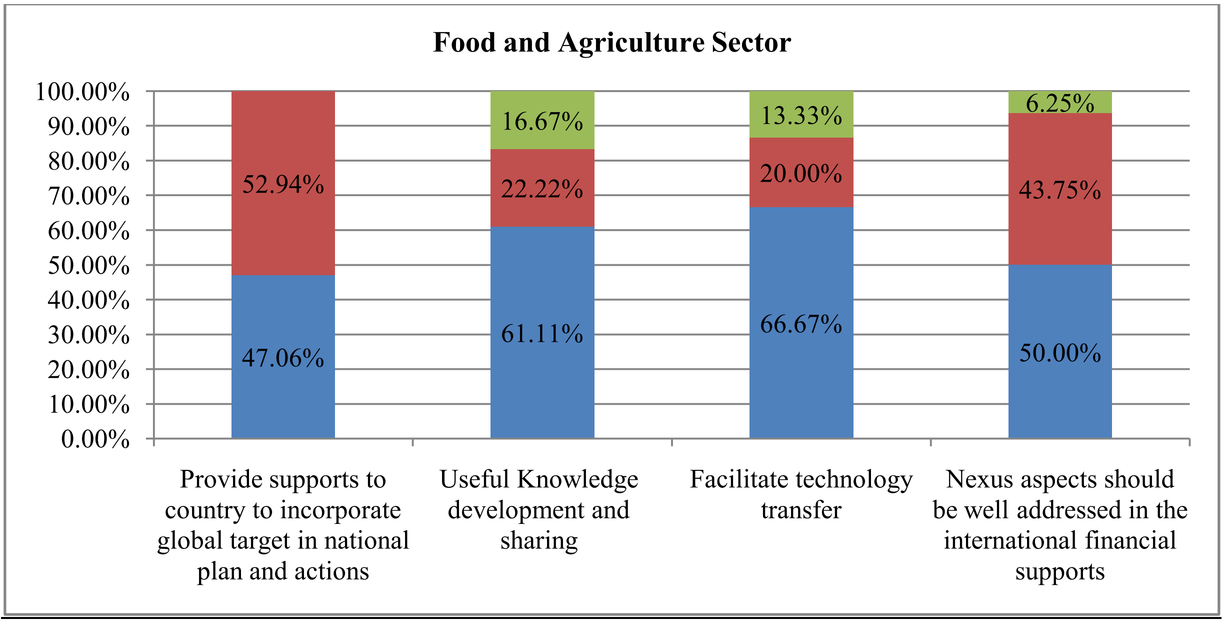

Figure 7.16 International efforts necessary to adopt nexus approach according to food and agricultural sector

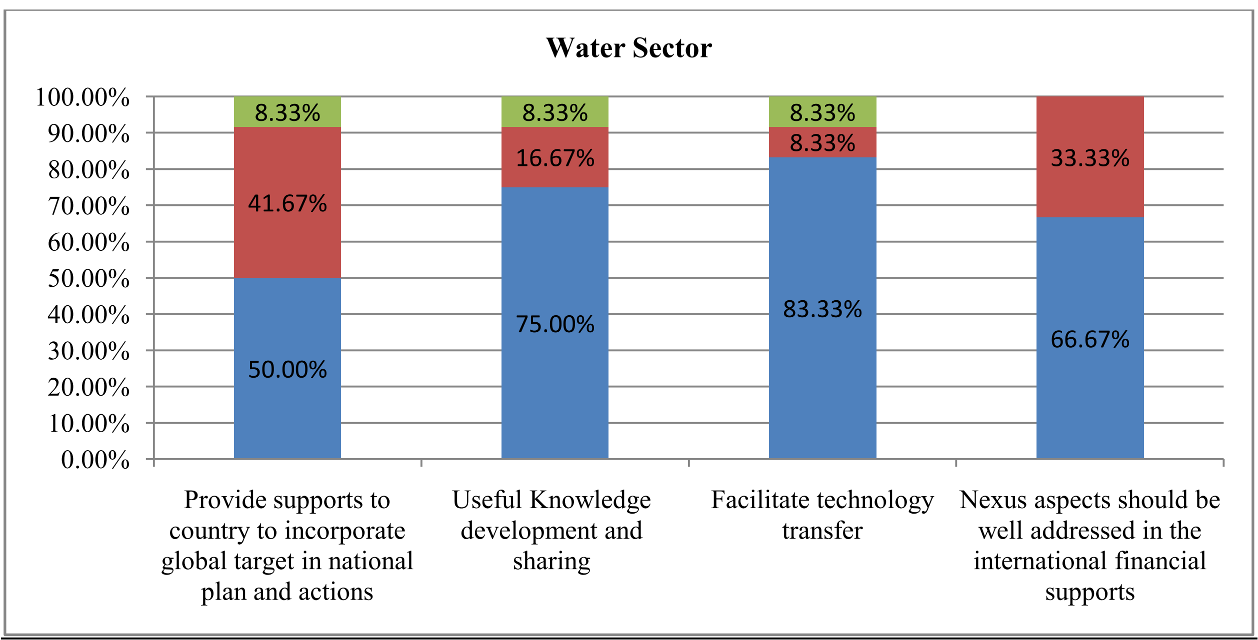

Figure 7.17 International efforts necessary to adopt nexus approach according to water sector

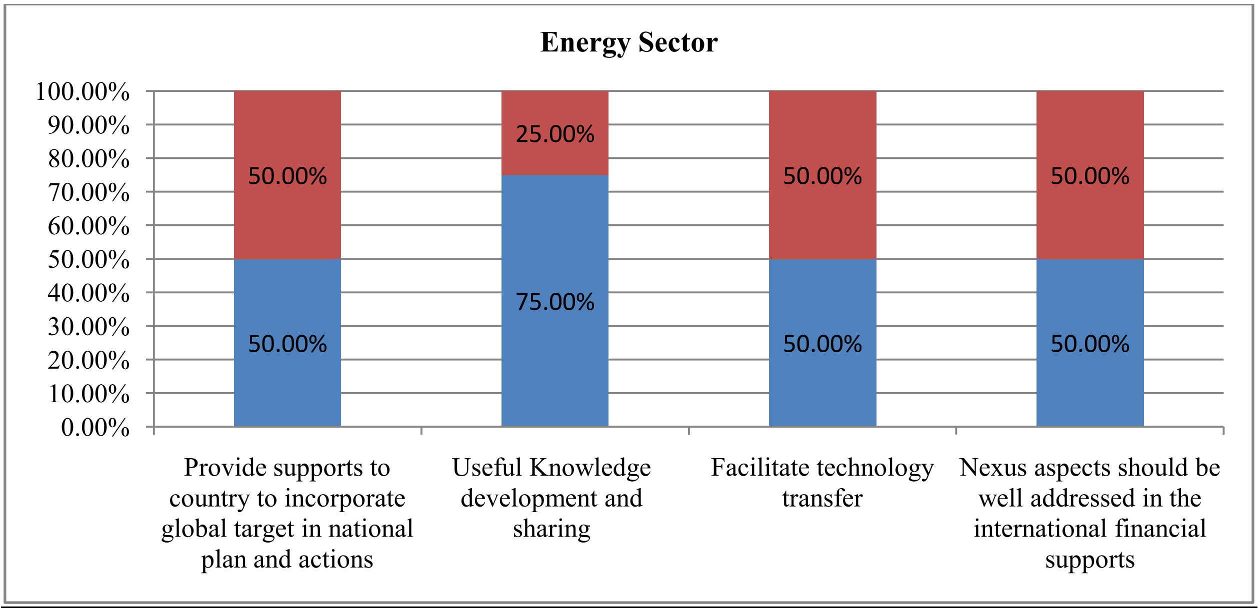

Figure 7.18 International efforts necessary to adopt nexus approach according to energy sector

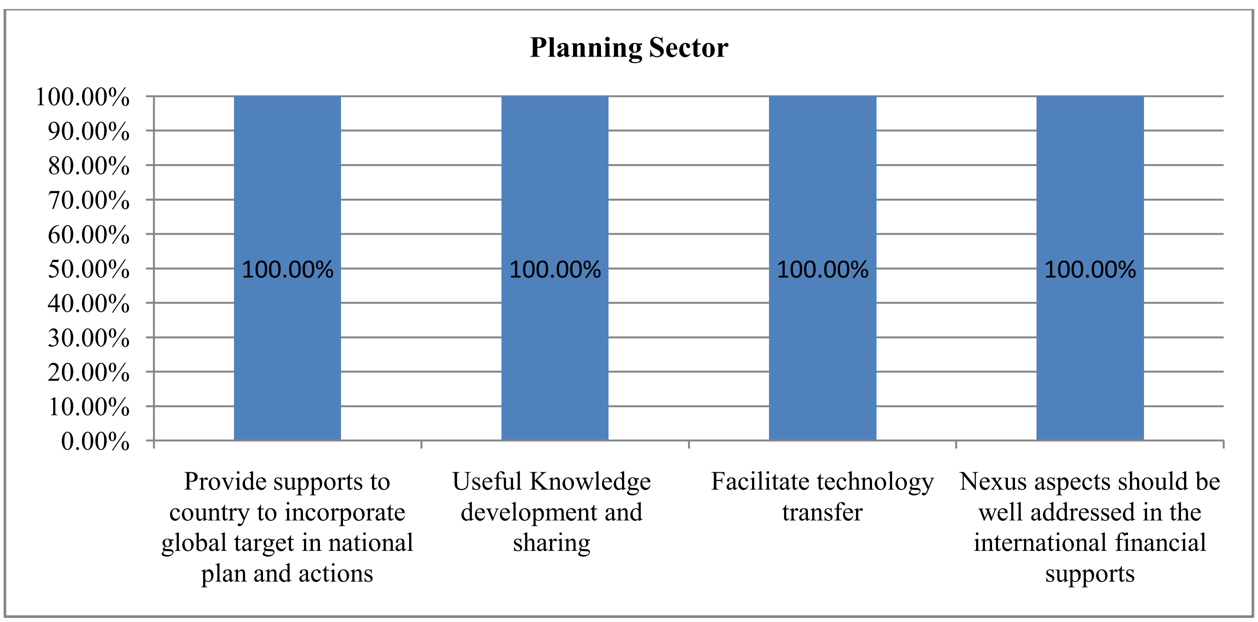

Figure 7.19 International efforts necessary to adopt nexus approach according to planning sector

In the food and agriculture sector, as showed in figure 7.16, 47% strongly and only 53% moderately argued that providing supports to country to incorporate global target in national plan and actions is necessary to adopt nexus approach in the process of translating global goals to the country actions . In the water sector, as showed in figure 7.17, 50% strongly and 42% moderately agreed on this issue. 50% stakeholders in the energy sector strongly and other 50% moderately agree on this issue as illustrated in figure 7.18. From the planning sector all strongly agreed on this issue as depicted in figure 7.19.

In the food and agriculture sector, 61% strongly and only 22% moderately argued that useful Knowledge development and sharing is necessary to adopt nexus approach in the process of translating global goals to the country actions whereas 17% lowly agrees . In the water sector, 75% strongly and 17% moderately agreed on this issue. 75% stakeholders in the energy sector strongly and other 25% moderately agree on this issue. From the planning sector all strongly agreed on this issue.

In the food and agriculture sector, 67% strongly and only 20% moderately argued that facilitating technology transfer is necessary to adopt nexus approach in the process of translating global goals to the country actions whereas 13% lowly agrees . In the water sector, 83% strongly agreed on this issue. 50% stakeholders in the energy sector strongly and other 50% moderately agree on this issue. From the planning sector all strongly agreed on this issue.

In the food and agriculture sector, 50% strongly and only 44% moderately argued that nexus aspects should be well addressed in the international financial supports whereas 6% lowly agrees. In the water sector, 67% strongly and 33% moderately agreed on this issue. 50% stakeholders in the energy sector strongly and other 50% moderately agree on this issue. From the planning sector all strongly agreed on this issue.

7.4.4 Expert view on coordinating body for SDGs planning

Expert view on coordinating body for SDGs planning is illustrated as followed derived from key informant interview.

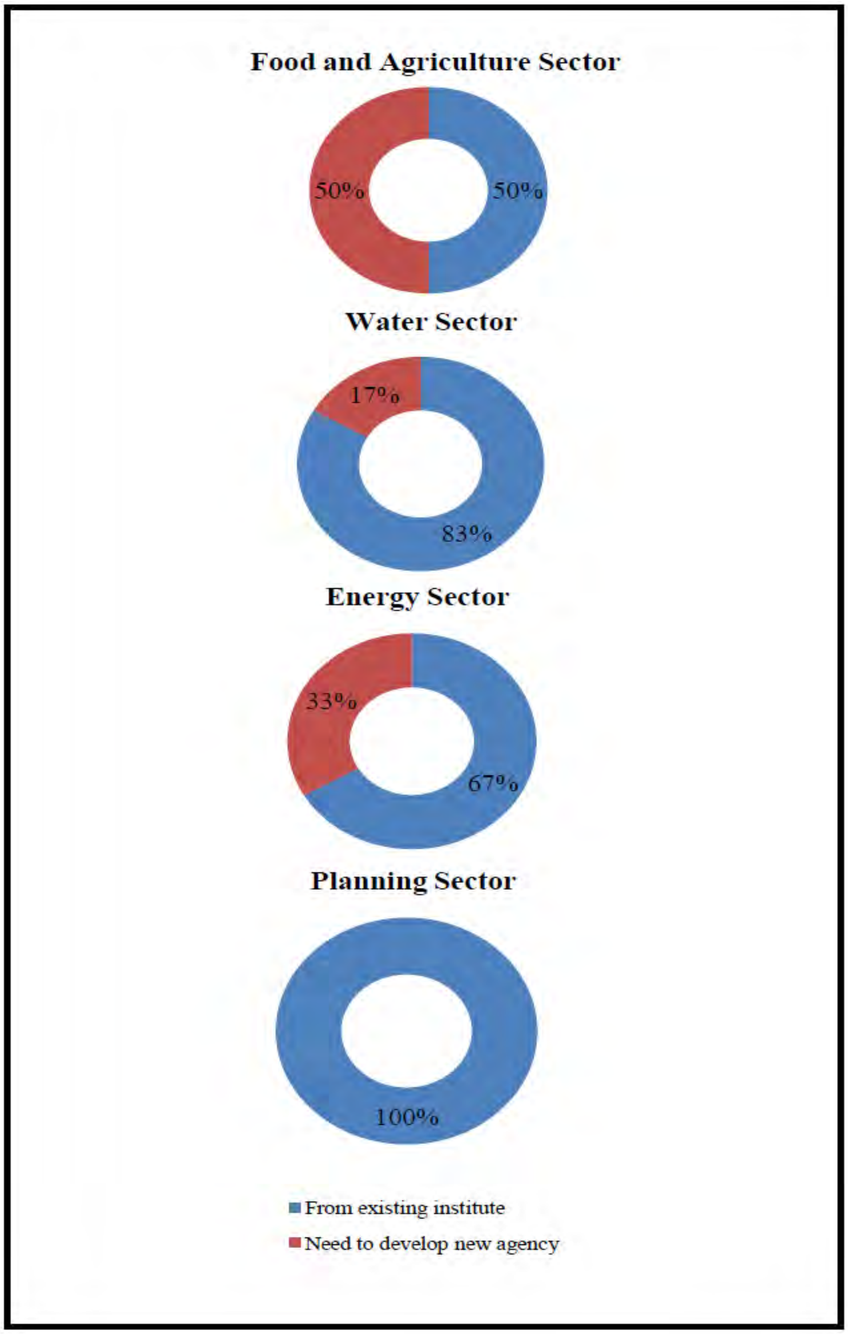

Figure 7.20 Expert views of different sectors on coordinating body for SDGs planning

Majority stakeholders from food, water & energy sectors, as showed in figure 7.20, argued that existing institutions are sufficient to coordinate SDG planning whereas a substantial remaining suggested incorporating sectoral technical agencies in the SDG coordinating process. All stakeholders from planning agencies claimed that existing institutions are sufficient and there is no need to develop new agencies to coordinate SDG planning.

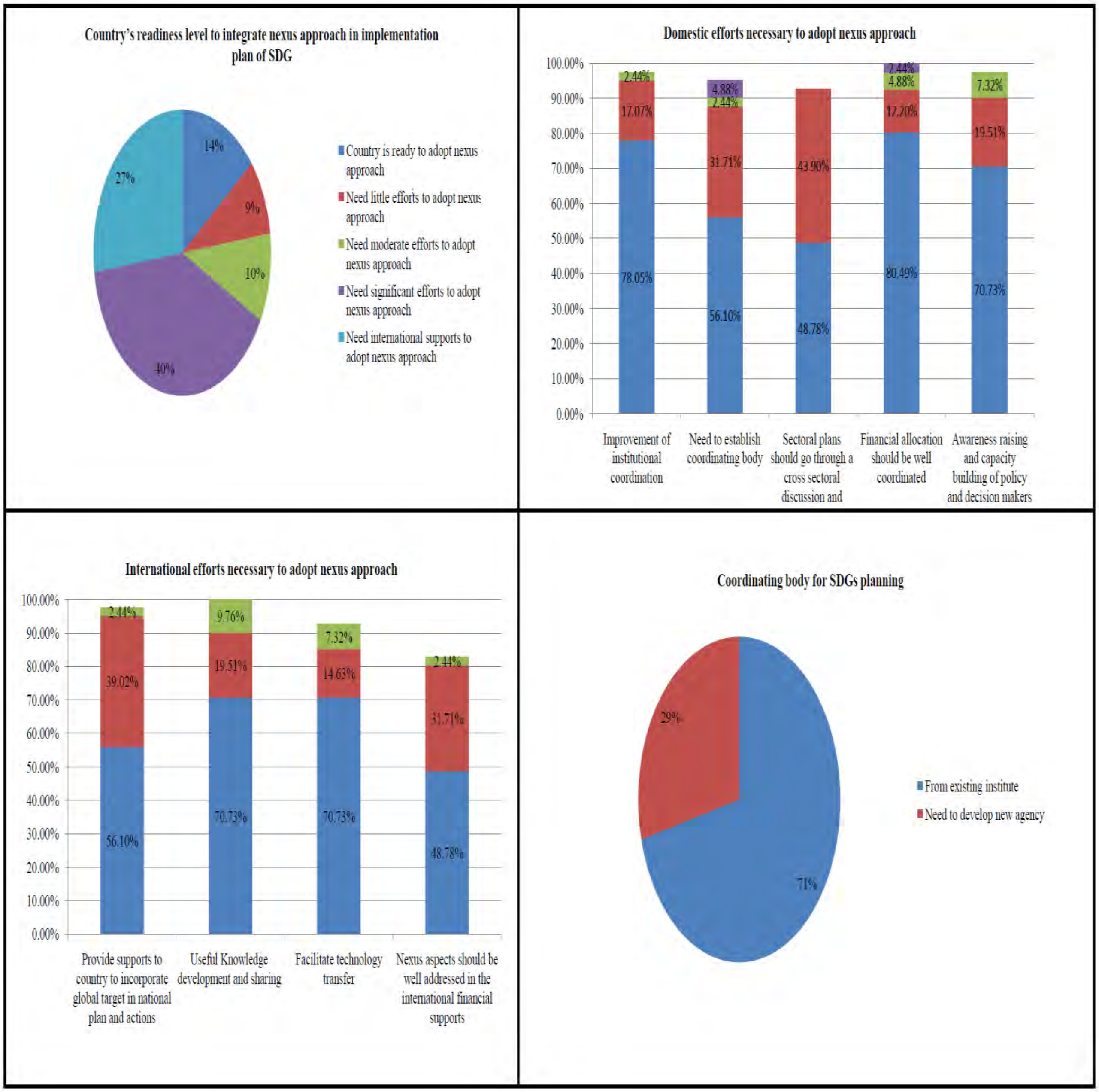

Figure 7.21 Stakeholders views on incorporating WEF nexus for SDGs planning

Perception survey analysis as shown in figure 7.21 reveals the consensus among various sectors that helping to address interlinkage of water, energy and food security for making balance between economic, social and environmental pillars in policy making is the strongest key factor for country planning. Stakeholders argue that, for food, water and energy goals, country is ready to implement global targets, but need adjust with national mid-term policies while significant effort is needed to adopt nexus approach. Divergent sectarian experts have strongly consented on efforts to improve institutional and financial coordination along with international technology transfer and capacity building training programmes to be initiated to adopt nexus approach in the process of translating global goals to the country actions. Planning stakeholders proposed formulation of Technical Assistance (TA) project with Ministry of Planning as coordinating role would be useful to the implementation of SDGs. Empowering of General Economic Division (GED) along with creating new SDG wing and units in ministries would accelerate SDG implementation, as suggested by planning officials. A twelve member cell in the Prime Minister"s office chaired by Principal Secretary is responsible for SDG monitoring followed by of Ministry of Planning as the coordinating body and Bangladesh Bureau of Statistics (BBS) being responsible for SDG related field data management. Apart from few technical and research field stakeholders recommending technical organizations to be incorporated in the coordinating process, majority of the experts consented on the existing coordinating institution to be sufficient.

CHAPTER 8

CONCLUSION AND RECOMMENDATION

8.1 Conclusion

The water-energy-food nexus perspective is an effective policy and management instrument to facilitate conservation of ecosystem in achieving sustainable development goals involving the interconnecting issues of natural resources into the planning and implementation strategy. This study aims to conceptually develop the WEF nexus framework regarding Bangladesh in the context of leading WEF nexus frameworks assessment and analyze national planning documentations to search the prospect to integrate the nexus approach in policymaking. The water-energy-food nexus framework developed in this study explicates several scenarios and their implications as followed;

- The water-energy-food nexus framework developed in this study illustrates how intensely three vital natural resources are interdependent and how unplanned exploitation of them can lead to serious consequences in Bangladesh

- Several synergetic responses such as solar irrigation, crop diversification, biomass electricity, micro-hydro power generation, organic fertilization are found to be solutions to the criticality of WEF nexus being practiced in Bangladesh

- National policy assessment in this study shows that nexus between water and energy along with food and energy resources lacks sufficient incorporation in national policy documents whereas nexus between water and food is well coordinated in majority cases

- Evaluation of quantitative interdependency in this study among SDG-2 (zero hunger), SDG-6 (clean water & sanitation) and SDG-7 (affordable & renewable energy) showed higher synergy during periods of simultaneous positive increment of target data showing integrated nexus within them leading to the importance of WEF nexus in SDG implementation

The aspiration of Bangladesh to achieve success in SDG cannot be attained without integrating the nexus approach to its policy formulation. Despite national plans and policies of Bangladesh tremendously focus on implementation measures to accomplish sustainability in water, energy, and food security, their lacking in incorporating the WEF nexus would result in impeding SDG championship. It is evident from this study that, the institutionalization of the synergy between water and agriculture is issued in major plans and policies whereas interconnection between water and energy, food and energy is not addressed to required extent whilst the WEF nexus aspect is absent.

8.2 Recommendation

Considering the challenges put forward by interdependency of water, energy and food resources and insufficiency in addressing the synergies within national plans, policies, and strategies as enclosed by this study, several recommendations can be made for incorporating water-energy-food nexus approach in country planning and SDG implementation as followed;

- Addressing the inter-linkages of water, energy and food security through integration of WEF nexus for making a balance between economic, social and environmental pillars in policy making is critical for SDG implementation
- Domestic efforts such as improved and well-coordinated institutional and financial allocation along with awareness raising and capacity building of policy and decision makers are strongly recommended to adopt nexus approach in the planning process
- International efforts such as knowledge sharing and technology transfer along with the formulation of Technical Assistance (TA) project with Ministry of Planning are strongly recommended to adopt nexus approach in the planning process
- Increasing involvement of technical agencies within the coordinating process of SDG implementation along with Ministry of Planning is suggested to be key for integrating WEF nexus perspective in country actions
- Enhancing indicator data availability regarding water, energy and food resources for monitoring and evaluation (M&E) of SDG is important in incorporating WEF nexus approach in the implementation process

Given growing criticality in resource management in water, energy and food sector, foremost ratiocination derived is to harnessing the WEF nexus in policymaking is of utmost importance for achieving a championship in SDG implementation.

REFERENCE

AHMED, A., M., M., M., Roy, Kingshuk, 2007, Utilization and Conservation of Water Resources in Bangladesh, Journal of Developments in Sustainable Agriculture, Volume 2 (2007) Issue 1 Pages 35-44, Online ISSN: 1880-3024, Print ISSN: 1880-3016

Bhaduri, A., Ringler, C., Dombrowski, I., Mohtar, R., Scheumann, W., 2015, Sustainability in the water–energy–food nexus, Water International, 40:5-6, 723-732, DOI: 10.1080/02508060.2015.1096110

Bakker K, 2012, Water security: research challenges and opportunities. Science 337:914–915, doi: 10.1126/science.1226337

Barua, S., Mullick, M., R., A., Barua, A., 2016, Renewable Water Resources and an Overall Water Demand Availability Analysis for Bangladesh, Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development (ICCESD 2016), 12~14 February 2016, KUET, Khulna, Bangladesh (ISBN: 978-984-34-0265-3)

Bazilian, M., Rogner, H., Howells, M., Hermann, S., Arent, D., Gielen, D., Steduto, P., Mueller, A., Komor, P., Tol, S., Yumkella, K., 2011, Considering the energy, water and food nexus: towards an integrated modelling approach, Energy Policy 39 (12) 7896–7906

Benson D, Gain AK, Rouillard JJ, 2015, Water governance in a comparative perspective: from IWRM to a „nexus" approach? Water Altern 8:756–773

Bizikova, L., Roy, D., Swanson, D., Venema, H. D., & McCandless, M., 2013, The Water-Energy-Food Security Nexus: Towards a Practical Planning and Decision-Support Framework for Landscape Investment and Risk Management, IISD Report, Winnipeg, Canada: International Institute for Sustainable Development (IISD)

Bizikova, L., Roy, D., Swanson, D., Venema, H., D., McCandless, M., 2014, Water-Energy-Food Nexus and Agricultural Investment: A Sustainable Development Guidebook, Winnipeg, Canada: International Institute for Sustainable Development (IISD)

CEGIS, 2013, Final Report on Environmental Impact Analysis of 2x (500-660) MW Coal Based Thermal Power Plant to be Constructed at the Location of Khulna, Center for

Environmental and Geographic Information Services, Ministry of Water Resources, Government of the People"s Republic of Bangladesh

CSIRO, WARPO, BWDB, IWM, BIDS, CEGIS, 2014, Bangladesh Integrated Water Resources Assessment: Final Report, Australia, Water for a Healthy Country Flagship Report Series ISSN: 1835-095X

ERD, 2012, Confronting Scarcity: Managing Water, Energy and Land for Inclusive and Sustainable Growth, European Report on Development, Overseas Development Institute (ODI), European Centre for Development Policy Management (ECDPM), German Development Institute/Deutsches Institut für Entwicklungspolitik (GDI/DIE), ISBN 978-92-79-23161-2, doi:10.2841/40899

ESCWA, 2015, Conceptual Frameworks for Understanding the Water, Energy and Food Security Nexus, Working Paper, Economic and Social Commission for Western Asia, E/ESCWA/SDPD/2015/WP._20 February 2015

FAO, 2012, Irrigation in Southern and Eastern Asia in figures, AQUASTAT Survey – 2011, Food and Agriculture Organization, Rome, ISBN 978-92-5-107282-0

FAO, 2012, Mutually acceptable mechanism on integrated use of water resources in Central Asia, Application of the scenario approach, Ankara: Food and Agriculture Organization of the United Nations

FAO, 2014, The Water-Energy-Food Nexus; A new approach in support of food security and sustainable agriculture, Rome, Food and Agriculture Organization of the United Nations

FAO, 2014, The Water-Energy-Food Nexus at FAO, Concept Note, Rome: Food and Agriculture Organization of the United Nations

Farouk, S., and M. Zaman , 2002, Improved of skill and work environment of landless wage earners engaged in rice processing system of Bangladesh, A project report submitted to the Research and Extension in Farm Machinery Issues (REFPI), Department of Farm Power and Machinery, Bangladesh Agriculture University, Mymensingh

Frihy OE, 2003, The Nile Delta-Alexandria Coast: Vulnerability to Sea-Level Rise; Consequences and Adaptation, Mitigation and Adaptation Strategies for Global Change 8, pp.115–138

Gain, A.K., Giupponi, C., Benson, D., 2015, The water–energy–food (WEF) security nexus: the policy perspective of Bangladesh, Water International, DOI: 10.1080/02508060.2015.1087616

GED, 2012, Perspective Plan of Bangladesh (2010-2021), General Economics Division, Planning Commission, Government of the People‟s Republic of Bangladesh

GED, 2013, National Sustainable Development Strategy (2010 – 2013), Planning Commission, Government of the People‟s Republic of Bangladesh

GED, 2016, Development Planning in Bangladesh: 7th Five Year Plan and SDG Implementation, Shamsul Alam, General Economics Division, Planning Commission, Government of the People‟s Republic of Bangladesh

GED, 2017, Data Gap Analysis of Sustainable Development Goals (SDGs): Bangladesh Perspective, General Economics Division, Planning Commission, Government of the People‟s Republic of Bangladesh

Giupponi, C., Gain, A. K., 2016, Integrated spatial assessment of the water, energy and food dimensions of the Sustainable Development Goals, Reg Environ Change, DOI 10.1007/s10113-016-0998-z

Habib A, 2011, Climate Change: Bangladesh Perspective, Workshop on Asian Climate Change And Variability: Trends and Policy, 20-22 JULY 2011, Divecha Centre for Climate Change, IISc., Bangalore, India

Heiner M, 2010, Power generation and water reuse – urgent, equal global priorities, Power Engineering International, Volume-17, Issue-11

Hellegers, P.J., Zilberman, D., Steduto, P., McCornick, P., 2008, Interactions among water, energy, food and environment: Evolving perspectives and policy issues, Water Policy 10 (Suppl. 1) 1–10

Hermann, S., Welsch, M., Segerstrom, R., Howells, M., Young, C., Alfstad, T., Rogner, H., Steduto, P., 2012, Climate, land, energy and water (CLEW) Interlinkages in Burkina Faso: an analysis of agricultural intensification and bioenergy production, Nat. Resour. Forum 36, 245–262

Hibbard, K., T. Wilson, K. Averyt, R. Harriss, R. Newmark, S. Rose, E. Shevliakova, and V. Tidwell, 2014, "Energy, Water, and Land Use," Ch.10 in Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, pp. 257-281

Hoff, H., 2011, Understanding the Nexus, Background Paper for the Bonn2011 Conference: The Water, Energy and Food Security Nexus, Stockholm, Sweden: Stockholm Environment Institute (SEI)

Hossain, A. K. and O. Badr, 2007, Prospects of renewable energy utilization for electricity generation in Bangladesh, Renewable and Sustainable Energy Reviews, 2007. 11(2007): p. 33

Hussey, K., Pittock, J., 2012, The energy–water nexus: managing the links between energy and water for a sustainable future, Ecol. Soc. 17 (1) 31

IRRI, 2015, World Rice Statistics Online Query Facility: Bangladesh, International Rice Research Institute, Los Banos

Islam, M. S., Gupta, S. D., Masum, M. S., Raju, N. I., Karim, S. A., 2013, Potentiality of Small-Scale Hydro Power Plant Using the Kinetic Energy of Flowing Water of Gumoti & Surma River of Bangladesh: An Energy Odyssey, International Journal of Renewable Energy Research, Vol.3, No.1

Islam, M. R., Sarker, P. C., Ghosh, S. K., 2017, Prospect and advancement of solar irrigation in Bangladesh: A review, Renewable and Sustainable Energy Reviews, Volume 77, Pages 406-422

Jaim, M., and M. Hossain, 2012, Rice milling processes, consumers‟ preferences and cooking practices in Bangladesh: Implications for nutritional value, in Adoption and

Diffusion of Modern Rice Varieties in Bangladesh and Eastern India, edited by M. Hossain, W. Jaim, T. Paris, and B. Hardy, pp. 77–92, IRRI/CIAT/BRAC/IFPRI, Los Banos

Kumar, A., Gurung, T., R., 2015, SAARC Outlook on Water-Energy-Food Nexus in SAARC Region, SAARC Agriculture Centre (SAC), Dhaka, Bangladesh, ISBN: 978-984-34-0623-1

Kumar, K.S., Karunagoda, K., Haque, E., Venkatachelam, L., Bahal, G, 2012, Addressing long-term challenges to food security and rural livelihoods in South Asia, Working Paper 75, Chennai, Indi, Madras School of Economics

Luukkanen, J., 2004, ASA TOOL FOR SUSTAINABILITY ANALYSIS, Finland Futures Research Center, Turku School of Economics and Business Administration

Mainali, B., Luukanen, J., Silveira, S., Kaivo-oja, J., 2018, Evaluating Synergies and Trade-Offs among Sustainable Development Goals (SDG): Explorative Analysis of Development Paths in South Asia and Sub-Saharan Africa, Sustainability, 2018, 10, 815; doi: 10.3390/su10030815

MoA, 1999, National Agriculture Policy 1999, Ministry of Agriculture, Government of the People‟s Republic of Bangladesh

MoFDM, 2006, National Food Policy 2006, Dhaka: Ministry of Food and Disaster Management, Government of the People‟s Republic of Bangladesh

Mondal, M. A. H. and M. Denich, 2010, Assessment of renewable energy resources potential for electricity generation in Bangladesh, Renewable and Sustainable Energy Reviews, 2010. 14(2010): p. 13

MoPEMR, 2004, National energy policy, 2004, Dhaka: Ministry of Power, Energy and Mineral Resources, Government of the People‟s Republic of Bangladesh

MoPEMR, 2011, Power System Master Plan 2010, Dhaka, Power Division, Ministry of Power, Energy and Mineral Resources, Government of the People‟s Republic of Bangladesh

MoWR, 1999, National water policy, Dhaka, Ministry of Water Resources, Government of the People"s Republic of Bangladesh

Parry, M., 2012, Food and energy security: Exploring the challenges of attaining secure and sustainable supplies of food and energy, Food and Energy Security, 1(1), 1–2. doi:10.1002/fes3.1

Rasul, G., 2014, Food, Water, and Energy Security in South Asia: A Nexus Perspective from the Hindu Kush Himalayan Region, Environmental Science and Policy 39, pp. 35–48

Scott, C., Pierce, S., Pasqualetti, M., Jones, A., Montz, B., Hoover, J., 2011, Policy and institutional dimensions of the waterenergy nexus, Energy Policy 39 (10) 6622–6630

Shahid S, 2011, Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. Climatic Change 105 (304): 433-453

Shahid, S., 2012, Vulnerability of the power sector of Bangladesh to climate change and extreme weather events, Regional Environmental Change, 12(3): 595-606

Sharma, S., Bazaz, A., 2012, Integrated assessment of water- energy nexus in the context of climate change, In: Presented at India Water Week 2012 – Water, Energy and Food Security: Call for Solutions, New Delhi, 10–14 April 2012

SOER, 2010, State of the Environment, Cross-sectoral assessment of the agriculture, energy, forestry and transport sectors, EEA

SREDA, 2015, Energy Efficiency and Conservation Master Plan up to 2030, Sustainable and Renewable Energy Development Authority, March 2015

Tayab, A. F., Nusrat, T., 2015, Biomass- The Perfect Alternative for Energy Situation in Bangladesh, International Conference on Mechanical Engineering and Renewable Energy 2015 (ICMERE2015) 26- 29November 2015, Chittagong, Bangladesh, ICMERE2015-PI-021

Uddin, M., S., Kurosawa, K., 2011, Effect of chemical nitrogen fertilizer application on the release of arsenic from sediment to groundwater in Bangladesh, Urban Environmental

Pollution 2010, Procedia Environmental Sciences 4 (2011) 294–302, doi:10.1016/j.proenv.2011.03.034

Walker B. et al., 2009, Looming global-scale failures and missing institutions, Science, 325, Issue 5946, pp. 1345-1346 DOI: 10.1126/science.1175325

WEF, 2011, Water Security: The Water-Food-Energy-Climate Nexus, The World Economic Forum Water Initiative, Island Press, Washington, DC 20009, ISBN-13: 978-1-59726-735-9

World Bank, 2000, Bangladesh: Climate Change & Sustainable Development. Report No. 21104 BD, Dhaka

APPENDIX A

QUESTIONNAIRE FOR STAKEHOKDERS

1. Country's readiness level to integrate WEF Nexus in SDG implementation

Question 1: Please provide your opinion on country‟s readiness level to implement SDG-2, SDG-6 and SDG-7

Readiness level	Your opinion (Yes/No)
Food	
Country is ready to implement globally adopted target, since it is in line with national targets	
Country is ready to implement global targets, but need adjust with national mid-long-term policies	
Country is not ready to achieve global target, but willing to achieve it if international supports are available.	
Country will not follow global target	
Water	
Country is ready to implement globally adopted target, since it is in line with national targets	
Country is ready to implement global targets, but need adjust with national mid-long-term policies	
Country is not ready to achieve global target, but willing to achieve it if international supports are available.	
Country will not follow global target	
Energy	
Country is ready to implement globally adopted target, since it is in line with national targets	
Country is ready to implement global targets, but need adjust with national mid-long-term policies	
Country is not ready to achieve global target, but willing to achieve it if international supports are available.	
Country will not follow global target	

2. Domestic efforts necessary to adopt WEF nexus in SDG implementation

Question 2: Please provide your opinion on domestic efforts necessary to adopt WEF nexus in SDG implementation

Domestic efforts	Strong	Moderate	Low	No
Improvement of institutional coordination				
Need to establish coordinating body				
Sectoral plans should go through a cross sectoral discussion and approval process				
Financial allocation should be well coordinated				
Awareness raising and capacity building of policy and decision makers				
Others:				

3. International efforts necessary to adopt WEF nexus in SDG implementation

Question 3: Please provide your opinion on international efforts necessary to adopt WEF nexus in SDG implementation

International efforts	Strong	Moderate	Low	No
Provide supports to country to incorporate global target in national plan and actions				
Useful Knowledge development and sharing				
Facilitate technology transfer				
Nexus aspects should be well addressed in the international financial supports				
Others:				

4. Expert view on coordinating body for SDGs planning

Question 4: Please provide your opinion on required coordination body for SDG planning

		Yes/No	Name of the Institute
1	From existing institute		
2	Need to develop new agency		