Understanding Water–Energy–Food Security Nexus to Design Technology and Policy Approaches for Enhanced Adaptation to Climate Change in India

Report of Researcher Exchange June 2017

November 2017

INDIA-UK
Water Centre
भारत-यूके
जल केन्द्र

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भारत-ब्रिटेन जल कें द्र एमओईएस-एनईसीआरसी(यूके) जल सुरक्षा अनुसंधान के पूरक प्राथमिकताओ के बीच सहयोग और सहयोग को बढ़ावा देने के लिए करना है

Front cover image: Sugarcane, Pixabay, (Vijayanarasimha)

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Executive Summary

This report provides an overview of the participation, activities and conclusions of a Researcher Exchange on “Understanding Water–Energy–Food (WEF) Security Nexus to Design Technology and Policy Approaches for Enhanced Adaptation to Climate Change in India”, undertaken by Dr. N. K.Tyagi (International Development Centre, India) and hosted by Prof. L. Mehta (Institute of Development Studies, University of Sussex, UK) during 8–29th June 2017 under the India UK Water Centre’s Researcher Exchange initiative. It includes a summary of activities and outputs, synthesis on developments in the nexus approach, WEF security concerns in India, and the required technology and policy changes for implementing nexus approach. The report is intended for the India-UK Water Centre (IUKWC) community, and stakeholders interested in WEF nexus research.

1. Activity Leads

Researcher:
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Lead Researcher
International Development Centre
Foundation, India

Host:
Prof. Lyla Mehta
Institute of Development Studies,
University of Sussex, UK

The Researcher Exchange was convened by the India-UK Water Centre (IUKWC) and led by the Activity Leads:

The Research Exchange was held at the Institute of Development Studies, UK, during 8–29th June, 2017, and included visits to research institutions including Cranfield University and University College London.

2. Researcher Exchange Aims

The IUKWC aims to facilitate development of cross-disciplinary partnerships, exchange knowledge and build capacity to deliver a portfolio of activities across five key cross-sectoral themes. This exchange aimed to focus on the water–energy–food security nexus and address the following three IUKWC themes:

- Developing hydro-climate services to support water security;
- Building cross-sectoral collaborations to understand the dynamic interactions across the water-energy-food nexus;
- Using new scientific knowledge to help stakeholders set objectives for freshwater management.

This IUKWC Researcher Exchange aimed to:

- Study the water–energy–food security nexus, relevant technology and policy issues for increased adaptation to climate change impacts on agriculture, in India.
- Explore opportunities for collaborative research on issues relating to the water–energy–food (WEF) nexus under climate change, and improvement in weather and water smart technology advisory services: a key concern of the IDC Foundation and the IUKWC.
- Increase awareness amongst the water professionals in India and the UK on India's current water issues and approaches in the food sector through workshops, scientific papers and seminars.

3. Activity Structure

The research exchange was mainly designed to initiate interactive discussions with identified experts on important aspects of the water–energy–food nexus. This was facilitated by seminars on the current status of research in natural resource management and food production in India. Additionally, a critical review of the research on some aspects of the WEF security nexus was undertaken to better understand the WEF concept.

3.1. Interactive discussions

Interactive discussions were held with several leading researchers at the University of Sussex, Cranfield Water Science Institute, and the University College of London (Annex A). The issues discussed included: integrated water resources management (IWRM) vs the nexus approach; science and technology foresight and policy for WEF nexus; governance of WEF nexus; models for technology assessment for development; impact of soil degradation on food production; eco-innovations and green economy and the circular economy and WEF nexus.

The water-energy-food nexus, a successor to integrated water resources management (IWRM) approach, is an emerging concept, which is being increasingly advocated to define and address the complex and interconnected nature of resources, which are basic to social, economic and environmental development of society (FAO, 2014). The plus points of the nexus approach are the concepts of trade-offs, synergies and thresholds, which provide flexibility in decision making. The nexus approach requires that in future GDP growth should come not from increased resource use, which introduces environmental pressure, but from increased efficiency with a low-carbon circular economy. The pathways, policy levers and capacity developing measures, required to strengthen the WEF security may include: creation of improved information systems on ecological resources management, strategies to strengthen land use efficiency etc., but in the ultimate analysis it is the political agenda that will play the crucial role in promotion of a WEF nexus approach. In spite of the several obvious advantages, there is a group of researchers, who feel that it has been promoted largely by the corporate sector to gain access to scarce natural resources. But the fact remains that the IWRM approach overlooked the importance of administrative boundaries and the role of political negotiations in governance of water, which the WEF nexus approach is able to address elegantly.

An extended account of these interactions is presented in Annex B.

Figure 1. (L).Dr N.K. Tyagi and Prof L. Mehta (IDS, Sussex); (R) Dr N. K. Tyagi and Prof Reimund (UCL, London)

Figure 2. Visit to Soil Conservation Lab, Cranfield University, Dr N.K Tyagi and Prof Jane Rickson.

3.2. Seminars

During the exchange the lead researcher delivered two seminars, one at IDS Sussex (see Box 1); and the second at the Water Science Institute (WSI), Cranfield (see Box 2). The slides of these two presentations are shared in Annexes C and D.

Box 1: Seminar Synopsis, IDS, University of Sussex

Implications of Government Policies on Climate Change Adaptation, Mitigation and Resilience in Agriculture in India.

The government of India has pursued polices which support the development of agrarian economy through promotion of green revolution technologies. The prevailing subsidy dominated policies on fertilizers, irrigation and energy were shaped by green revolution requirements, and are not unique to India. Such policies are often pursued if inter-sectoral income disparities between agricultural and non-agricultural sectors during the transition period are large. A first order assessment of the impacts of these development policies implemented over several decades, on intensification of climate change impacts, is made. Analysis is based on the hypothesis that productivity enhancement is a good means of reducing global warming, as it avoids deforestation, thereby reducing intensification of emissions and enhancing food security.

Box 2: Seminar Synopsis, WSI, Cranfield University

Transitioning from an Unsustainable Irrigated Agrarian to an Environmentally Safe and Food Secure India: Challenges and Opportunities in the Irrigation Sector.

India is often said to be a hydraulic civilization, where growing food in arid climates was linked to management of water resources. The practices of irrigation in India have evolved over the last two millennia; technological development and public policies have enabled India to become the second most irrigated country, feeding a population of more than 1.25 billion. A threefold increase in irrigated area and greater than fivefold increase in agricultural production is no doubt commendable, but it has come at a huge cost in terms of degradation of natural resources and reduction in ecosystem services, introducing an element of unsustainability. How to make the irrigated production system sustainably compliant to meet the promises enshrined in "Future we want–healthy people and healthy ecosystem" is the issue (UN, 2012). Fortunately, there are a number of technological, economic, regulatory and policy based options to increase the resilience of water resources. There is very strong empirical evidence to show that increasing land and water productivity through various agro-technological interventions and their mainstreaming in public development programmes can minimize the projected water demand and supply gaps.

Figure 3. Seminar at Cranfield University

3.3. Overview of WEF Nexus Research

As part of the learning process to increase the understanding of WEF security nexus, an intensive review of the literature was undertaken. The nexus approach has been succinctly summed up by Weitz et al. (2014) as "Nexus interactions are about how we use and manage resource systems, describing interdependencies (depending on each other), constraints (imposing conditions or a trade-off) and synergies (reinforcing or having shared benefits)".There are many similarities as well as significant differences between the IWRM and nexus approaches, with the latter placing increased emphasis on socio-ecological systems perspective in planning and decision-making (Davis, 2014). There are very many conceptualisations of nexus, which vary in their scope, objectives and understanding of the drivers. Different concepts, frameworks and methodologies have evolved to analyse the inter-linkages between water, energy, food and ecosystems (Bizikova et al., 2013; ADB, 2013; ICIMOD, 2012). The foci of different approaches are on promoting action though policies, promoting synergies and reducing trade-offs for transiting to a more sustainable future

To achieve the goals linked to WEF security as included in Earth Summit (UN, 2012), answers have to be found to issues such as: how to meet the development needs (food, water, energy) sustainably without degrading ecosystems; technologies which would help achieve the desired results; the mixes of policies, which would give solutions that are economically viable, socially acceptable and ecologically sound and harmonising the actions of different authorities in respect of sharing the common resources (Welsch et al., 2013). Answers to these questions are generated through application of nexus tools to case studies. A very detailed review of the nexus tools is included in Chang et al., 2016; Endo et al., 2015; amongst the nexus tools reviewed, Nexus Tool 2.0 (Mohtar and Daher, 2013), WEAP (SEI -Internet) and WFENI (El Gafy et al., 2017) look promising and can be used in our studies.

The responsible governance of natural resources is the necessary first step for action on the water–energy–food nexus (Bahaduri et al., 2015; Pahl-Wostl, 2017), as it balances the trade-offs between different sectors arising due to conflict of policies. Suitable economic, legal instruments, and administrative setups have to be put in place. The 'mantra' for the success of nexus is intensive involvement of all the stakeholders including scientists, decision makers, business and industry in identifying the research issues. There cannot be a fixed route for governance of WEF as the administrative structure and required policy instruments may vary with scale and the region. In India, land and water are state subjects, and are only on concurrent lists of the central government. Interstate disputes on sharing of river water often lead to conflicts. The fragmented decision-making process, data availability and transparency are major barriers for WEF implementation. (Azhoni et al., 2017). Of course, the government of India had appointed a high-level committee to look into some of the issues, whose recommendations are yet to be implemented.

The three metrics of nexus accounting—physical (resource intensity), monetary (price and cost dynamics) and distributive (implications of social allocations) are not fully understood and implemented (ESCAP, 2013). The actual case studies employing nexus approach at a scale have been very few, but the growing discourse is slowly resulting in warning of the social and ecological dangers of a compartmentalised management structure (Williams et al., 2014). Some of the important issues for further research should include the following.

1. Improved simulation models to predict the consequence of planned interventions and climate change impact.
2. The assessment implications of WEF nexus are not scale neutral, and therefore studies should be conducted to address issues at different scales—local, state, country and region.
3. Impact of existing WEF related policies have environmental costs in the form of externalities. These costs are generally not included in the assessment, but both individuals and the society as a whole end up paying for them.

4. The health of ecosystem plays an important role in ensuring the security of WEF, and the society derives a number of benefits from ecosystem, and therefore the natural environment should be an integral part of the nexus studies (Krchnak et al., 2011). Satellite data could help in rapid assessment of the value of ecosystem services. Techniques for using satellite data to provide inputs for estimating the variables like: water accounting, energy accounting, and nutrition accounting on different scales, should be developed.
5. In empirical studies, the credibility of the results depends upon the chosen methodology. A study should be undertaken to assess these methodologies and associated data needs.
6. Establishing national and regional data-hubs will enable social learning that can empower adaptive management.

In conclusion application of a nexus approach on a broad scale will require bridging the existing knowledge gaps through focussed research. The gaps lie in: i) the quantitative assessment of inter-dependencies in WEF requiring additional data and analysis; ii) current and projected challenges as influenced by demand and supply drivers including climate change; iii) response options and iv) appropriate governance framework.

Note: A detailed review in the form of a Status paper, analysing the global research on WEF nexus, a look at the current and projected WEF security concerns in India, assessment of the existing technologies and policies for facilitating the transition to sustainable development in respect of WEF security, and focus on agro-hydro-technologies to beat the increased temperature impacts of climate change on agricultural production system, is given in Annex E.

4. Activity Conclusions and Outputs

The Researcher Exchange afforded opportunities of interaction with leading researchers, visits to research facilities, delivering seminars, and networking with large groups in the conference. Based on the insight gained through these multifarious engagements, the relevant emerging key points and the recommendations from the activity are briefly outlined.

4.1. Key themes

The key points needing attention are briefly mentioned. A review on WEF security status, technologies, policies and refinement needs in India is presented in Annex E.

- The five transitions (population, urbanization, nutrition, climate change and agriculture), which are impacting India's WEF security, make it imperative that India choose a nexus approach to undertake some transformative changes in respect of technology generation and policy formulation.
- The nexus approach, which is essentially a mechanism for allocating scarce resources with minimum environmental stresses with clearly outlined synergies and trade-offs, would be helpful in generating technology and policy options.
- The application of a nexus approach would be useful in making quantitative assessment of WEF interdependencies. But additional efforts aimed at data generation and management, analysis and interpretation are required.
- India being a large country with widely varying agro-climatic conditions, natural resource base and projected climate change impacts, WEF nexus studies should first concentrate on more critical issues at state level. Groundwater–energy–food nexus in areas with sharply declining water table should be the priority.
- The circular economy which is restorative and regenerative by design, can rebuild natural capital and resilience. This concept has been successfully introduced in the UK. In the context of WEF security nexus, the treatment of domestic wastewater, sugar industry wastes and organic solid waste are some of the areas where the concept of circular

economy can be profitably practiced in India.

- The multi-task-holder platforms which are being evolved, would require people equipped with knowledge of science, technology, institution building and financial planning at different levels. Collaboration with judiciously chosen UK institutions and individuals equipped with requisite knowledge would be helpful in capacity building. The Institute of Built Environment Edinburgh, WSI Cranfield, Institute of Sustainable Resources-UCL London, Grantham Climate Research Centre-London School of Economics, and SPRU/IDS Sussex are some of the identified institutions.
- On the basis of the Lead Researcher's limited interaction with researchers in UK, the impression is there is limited understanding by UK researchers of the on-the-ground realities of Indian land and water management issues. UK researchers would benefit, if opportunity is given to them, to have pre-research project proposal exposure in India for extended periods of 1-2 months.

4.2. Conclusions and recommendations

The Researcher Exchange provided an excellent opportunity to understand the science of water–energy–food interdependence and its implications for developing a suite of technologies and policies for sustainable food production under climate change. WEF security and environmental protection are important concerns and major policy issues in India. The nexus approach, which is emerging as an instrument for developing research agenda, policy formulation and development planning at global level, should be looked upon as an opportunity for a Green New Deal (Bleischwitz et al., 2011). It appears that there are significant opportunities for India and UK to learn from each other through such exchanges. Some important opportunities for research, training and workshops etc. are identified.

4.2.1 Research

Groundwater–energy–food nexus

- Modelling for scenario building for inter-sectoral resource reallocation in the Upper and middle Indo- Gangetic Plain (Punjab, Haryana, Uttar Pradesh, Bihar);
- Sustainable agricultural development under climate risks in East India (Bihar, West Bengal, Odisha);
- Farmers' perceptions of WEF security under climate change;
- Analysis of development policies with WEF security perspectives.

4.2.2 Potential areas for training workshops

In India

1. Managing water-and energy on small farm agriculture;
2. Wastewater management in agriculture to promote circular economy approach;
3. Climate change and farmers' perspectives;
4. Water delivery management in large irrigation systems;
5. Reversing declining groundwater table trends.

In the UK

1. Methodology for involving stakeholders in identifying issues and approaches to address them;
2. Customization of nexus tools;
3. Methodology for foresight development;
4. Conflict resolutions in sharing of resources;

5. How to overcome barriers in implementation of WEF Nexus approach;
6. Levers for behaviour change;
7. WEF security as part of macro-economic development;
8. Governance and collaboration, especially involvement of private sector.

4.3. Next step

The IDC Foundation is running a small project under the theme “Farmers’ Friends” which aims to increase the awareness about the impacts of climate change on agriculture and educate farmers on practical steps which they can take to manage and mitigate impacts. Further information on this activity, which could be extended to larger areas if funds were available, may be obtained by contacting the IDC. A proposal for a workshop on “Climate change and farmers’ perspectives” will be developed and submitted to the IUKWC for consideration under its Workshop funding scheme. Depending upon the opportunities available, the Lead Researcher would share experiences in WEF nexus research through invited lectures, seminars and workshops.

4.4. Acknowlegements

I grateful to the two Coordinators at IITM Pune and at CEH Wallingford, for selecting my Exchange proposal. I am particularly thankful to Ms. Priya Joshi, the Stakeholder Manager at IUKWC Pune, who facilitated the visit very efficiently. The support provided by Ms. Anita Jobson and Dr. Carol Diffenthal is highly appreciated. The Activity host Professor Lyla Mehta and Ms. Alice Shaw, the Programme Manager, Natural Resources Politics Cluster, were excellent hosts, and they made my stay at IDS Sussex very enjoyable. I continue to be a part of a IUKWC Water Network, and look forward to more such interactions in coming years.

Annexes

Annex A: List of persons met and issues discussed

Date	Name & Designation of Researcher	Scientific issue discussed
9-06-2017	Dr. Shilpi Srivastava, Post-Doctoral Research Officer, IDS	General discussion on IDS programmes in politics of natural resources cluster, water regulations in India
12-06-2017	Prof. Ben Martin, University of Sussex D.r Saurabh Arora, University of Sussex	Technology foresight Approaches for innovations and technology development
15-6-2017	Professor Lyla Mehta Cluster Head, IDS Dr. Jeremy Allouche Research Fellow, IDS	Farmers' perception about climate change Governance issues
16-6-2017	Dr. Patrick Schvoder Research Fellow, IDS	Circular Economy
19-06-217	Professor Tim Flowers, University of Sussex Dr. Richard Tol, University of Sussex Seminar by me at IDS	Progress in Halophyte research Climate Policy Seminar topic: "Implications of Government Policies on Climate Change Adaptation, Mitigation and Resilience in Agriculture in India"
20-06-2017	Dr. Lars Otto Naess Research Fellow, IDS Professor Andey Stirling, University of Sussex	Political Economy Technology assessment, transformation of innovation process
21-06-2017	Dr. Tim Hess Associate Professor WSI, Cranfield Seminar by me at WSI Cranfield Dr. Guy Kirk Prof. WSI, Cranfield	Water footprints of fruits and vegetables, Virtual water import Seminar Topic: "Transitioning from an Unsustainable Irrigated Agriculture to an Environmentally Safe and Food Secure India: Challenges and opportunities in Irrigation Sector" Soil physics, CO2 emissions from soil &plants, lysimetric setup

22-06-2017	Dr. Ian Holman Professor Jane Rickson WSI, Cranfield Dr. Imail Haltas University of Cranfield Dr. Tobe Waine D.r Boris Snapir University of Cranfield Dr. Andrea Momblanch Researcher at WSI, Cranfield	Water Management Soil Conservation, Soil Conservation Lab Food Waste Processing Remote Sensing Current & future of agriculture in North India
23-06-2017	Prof. Raimund Bleischwitz, University College London	Innovations, Resources Economics, Macro-economic modelling for sustainable development
26-06-2017	Lídia Cabral Research Fellow, WSI Cranfield	Green revolution across India, Brazil and China
27–29-06-2017	Circular Economy Conference	Conference on sustainable life style at IDS/SPRU
30-06-2017	Dr. Lyla Mehta, IDS	Nexus briefs & future works

Annex B: Interactive Discussions on Important WEF Nexus Issues

N K Tyagi

A successor to the previously advocated integrated water resources management (IWRM) approach, the water–energy–food (WEF) security nexus is still an emerging concept. The need for WEF thinking emerged from the failure of the IWRM approach, which overlooked the importance of administrative boundaries from an implementation point of view and sector-bound decisions characterized poor participation mechanisms and the consequent cascading effects (Golam and Sharma, 2015; Howarth and Monasterolo, 2016). The IWRM approached integration of water management through: inter-sectoral competition for surface fresh water, integration of water management at farm, project and basin scales; conjunctive use of surface and ground water and; prioritization water for human consumption and environmental protection (Turral and Kurian, 1998), but overlooked the role of political negotiations in governance of water. In a nexus approach effective governance infers a set of rules, practices, and processes (formal and informal). It is through these processes that the decisions for the management of water resources and services are taken and implemented. The stakeholders also articulate their interest and decision-makers are held accountable through the same process. This is considered the most crucial element for the success of a nexus approach as it introduces the concepts of trade-offs, synergies and thresholds, which are useful for governance in a nexus approach (Bhaduri, 2013; Mohtar and Daher, 2014).

In order to obtain the perspectives of leading researchers and practitioners on some of the important dimensions and issues of the WEF nexus, the lead researcher held interactive discussions with several individuals at the University of Sussex, Cranfield Water Science Institute and the University College of London (see Annex A). The understanding gained on some of these issues is briefly discussed in this Annex.

B.1. IWRM vs WEF Nexus approach

The IWRM approach was an umbrella concept, encompassing multiple principles aimed at a holistic and coordinated management between different aspects of water management–which are not much different from the objectives of the nexus approach. The developments in IWRM, which gave rise to the modified concept of adaptive water management (AWM), involving a 'learning by doing' process and used feedback mechanisms to make incremental changes (Benson, 2015). Though both the nexus and IWRM have integration between water and policy sectors, the IWRM was overtly focussed on water and advocated river basin as the planning unit, but nexus calls for macro- or meso-scale norms and advocates 'policy coherence' across sectors (Hoff, 2011).

The nexus approach also reflects a leaning towards the corporate sector. Though the WEF nexus is being presented as a novelty, there is a group of researchers who believe that, as far as farmers are concerned, water, energy, and food have never been separated in the way it is now being presented by the experts (Allouche et al., 2014; Srivastava and Mehta, 2014). They consider the nexus concept as another buzzword—a global discourse pushed by development organisations—and reflects corporate underpinnings. The WEF nexus approach talks of innovative "public-private coalitions for water sector transformation", and still remains water centric, as water is the only real limit to food and energy security (Allouche et al., 2015). It is contended by this group, that the WEF nexus was still an immature concept and enough focus had not been placed on ecosystem services, which were so important for poor people. There were apprehensions that governance of the WEF nexus would be more difficult than IWRM, as the former had different governing regimes, and that it may be an attempt to grab lands in locations well-endowed with natural capital, but economically less developed.

The fact remains that apart from some case studies, planned implementation of a WEF nexus approach at any scale has not taken place, even in developed countries like the UK. It has been argued that nexus debates had masked the issues of inequality and access to resources, which was creating social tension and instability. The framing of nexus must address the issues of nature and social inequity in access to natural resources (Allouche et al., 2014).

There appears to be a distinct difference in the thinking of sociologist and water management engineering groups about the nexus, where the latter is more positively inclined towards the WEF nexus approach.

B.2. Science and technology foresight and policy for WEF nexus

Technology foresight is now considered a strategic resource that can serve multiple objectives including: providing an approach for making choices in relation to science and technology, and identifying priorities. It promotes flow of technology and information among people, enterprises and institutions. It also acts as a mechanism for integrating research opportunities with economic and social needs (Martin and Johnston, 1999). Technology foresight may play a beneficial role in identifying research pathways for combating climate change impacts. The issues of technology foresight in India have been debated (Sherawat et al., 2013). There several prospective technologies (GPS-, drone- and robot-based precision farming; development of genetically modified crops which could be transformative.

The interconnections of water–energy–food security and sustainability for the future are revealed to us by science, and it is the application of technology and innovations through which the sustainability objectives (increase in resource efficiency, poverty alleviation, green growth etc.) are achieved. The pathways, policy levers, and capacity developing measures required to strengthen the WEF security may include: creation of improved information systems on ecological resources management; strategies to strengthen land use efficiency; and incentives to small farmers to increase their ecological resilience. But in the ultimate analysis it is the political agenda that will play the crucial role in promotion of a WEF nexus approach. The recent withdrawal of the United States from the Paris Agreement shows how political decisions may derail the agenda drawn up by scientists and technologists.

B.3. Governance of the WEF nexus

Formal and informal rules, processes, and institutions which help in decision making and implementing them constitute governance. An integrated approach for WEF requires coordination, harmonization of public policies, and the alignment of strategies, regulations and incentives (Rasool, 2016). Since nexus involves inter-sectoral interactions, governance of the WEF nexus is much more complicated. The responsible governance of natural resources has been identified as an important step for the success of the WEF nexus as it helps in reducing the negative impacts of policies on individual sectors, saving resources, minimizing trade-offs and enhancing synergies (Bahudri, 2014). Wide consultation among the stakeholders and consensus-building ability helps in governance of the WEF nexus. The researchers in social science lay greater emphasis on interaction with farmers and other grassroots-level functionaries; and include their concerns in formulating guidelines (van Eeden et al., 2016). For example, the process of democratization in consensus building for decision making; sustainable solution may emerge, if opinion of all stakeholders is given due weightage in decision making (S. Arora, 2017 pers. comm.). But in practice, the national water needs are given priority over local community. In most countries the historically entrenched, vertically structured government departments and sector based policies act as barriers. As resources are becoming scarce and conflicts are increasing, the decision-making is becoming more and more political. The unequal power relationships, as is the case of India, decides how the nexus interdependencies are handled.

B.4. Models for technology assessment for development

Technology assessment (TA), which denotes processes that collect, interpret and evaluate information and perspectives about different technological options can play an important part in steering science, technology and innovation (STI) to achieve sustainable development goals. The essential components of new models of technology assessment include: participation of citizens, decision-makers and technical experts; use of information and communication technologies to gather information; network assessment and to address issues across disciplines flexibly. The knowledge and values fed into the models being from diverse sources, enables 'broadening out' of inputs; and do not produce a single recommendation around a best technology or policy, but come up with multiple solutions- 'broadening out' outputs. This brings accountability and democratic legitimacy in subsequent decision-making. The keys to the success of these technology assessment models are: greater focus on the problems as compared to specific technology; larger participation of stakeholders, which helps define the problem; plurality in assessment criteria; and diversity of social and technological approaches to address the problem. The usefulness of these models has been tested in several developing countries (Ely, 2011).

B.5. Impact of soil degradation on food production

Soil degradation (soil erosion by water, compaction, loss of organic matter, loss of soil biodiversity and soil contamination) which is impacting close to 12Mha of agricultural land annually, poses a grave risk to water and food security (Young et al., 2015). Though partial damage is masked by use of chemical fertilizers, multiple problems of soil degradation can only be addressed by comprehensive soil conservation practices. A number of researchers have used an ecosystem services framework to assess effects of degradation on capacity of soils to support a range of 'final goods'. This distinguishes between on-site and off-site costs, and market and non-market effects (Graves et al., 2015). Soil erosion not only leads to loss of soil productivity, but the sediments accompanying run-off pollute water and lower its ecological status. The Cranfield Water Science Institute, for example, has developed excellent research laboratory facilities to evaluate the effect of different conservation measures.

B.6. Eco-innovations and the green economy

Eco-innovation refers to any form of innovation that reduces the impacts on the environment, enhances resilience to environmental pressures, or achieves more efficient and responsible use of natural resources. A series of such connected changes that reduce use of natural resources and decrease the release of harmful substances would lead to a green economy. The nexus approach, which is emerging as an instrument for developing research agendas and development planning, should be looked upon as an opportunity for a New Green Deal (Bleischwitz et al., 2011). In future, GDP growth should come not from increased resource use, which introduces environmental pressure, but from increased efficiency through a low-carbon circular economy (R. Bleischwitz, 2017 pers.comm.).

B.7. The circular economy and the WEF nexus

"The circular economy is restorative and regenerative by design which can rebuild natural capital and resilience" (EMF 2015).

The IDS organized a conference on 'Sustainable Lifestyles, Livelihoods and the Circular Economy', 27–29 June 2017. In recent years Europe, including the UK, has moved towards a circular economy by developing technologies and policies to turn waste into a resource. The advance of the circular economy is essentially a move toward sustainable development and is based on: reduction in material and energy use in production process; substitution of hazardous material with recyclable material; and designing products for recycled material (eco-design).

As opposed to a linear economy (make, use and dispose), the circular economy extracts the maximum value from the resource, while the product is in use, and then recovers and regenerates products and materials at the end of each service life, thereby reducing the use of resources and replacing it service (labour) through use of the recycled material at multiple stages.

The concept of a circular economy has been successfully introduced in the WEF sector. A good example of using this principle includes wastewater treatment to recover phosphorus, energy production from methane, dried sludge to be used as fertilizer. Subsequently reclaimed wastewater can be substituted for freshwater (saved for high-value uses). This concept has been profitably implemented in India in the case of sugar industry waste. Similarly, wasted food in the UK is being processed for energy and fertilizer.

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Annex C: Implications of Government Policies in India on Climate Change Adaptation, Mitigation and Resilience in Agriculture.

See PowerPoint files (36 slides)

Annex D: Transitioning from an Unsustainable Irrigated Agriculture to an Environmentally Safe and Food Secure India: Challenges and opportunities in Irrigation Sector

See PowerPoint files (41 slides)

Annex E: Status Paper. Managing Water–Energy–Food Security Nexus under Changing Climate: Implementation Challenges and Opportunities in India

N K Tyagi

Abstract

Food security concerns, which are very intricately linked with water and energy, are being amplified by climate change; and it requires maintenance of optimal balance between synergies and trade-offs generated in the food production processes. The nexus approach is an emerging concept being advanced to unravel the intricacies of these interconnections. This status paper provides an overview of the global research on different dimensions of the water–energy–food (WEF) nexus. An analysis of the current and projected WEF security situations and the assessment of agro-hydro-technologies and development policies, through which the food security is to be achieved, are reviewed. A suite of technology and policy refinements required to meet the challenges arising due to multiple transitions, which impact the WEF security in India, are outlined.

E.1. Introduction

Food security, which is very intricately linked with water and energy security, has become a matter of global concern; and the issue is being debated at numerous platforms (UN, 2002; Beddington et al., 2012; UN, 2012). If we look into the matter a little deeper, these security issues are also linked to environmental security, and this thinking is reflected in the statement of the UN conference “The Future We Want” (UN, 2012). Two scenarios are emerging simultaneously: the demands for WEF are rapidly growing, while, because of human actions taken in the past as well present, the safe planetary boundaries of the resources, particularly of land, water, biodiversity and climate, have been violated (Rockstrorm et al., 2017). How to ensure the economic and social wellbeing of the people, particularly those who are at the lower ladder of development like in South Asia and Africa, without violating the planetary resource boundaries, is the issue.

India, like similarly placed other regions in the world, is facing major transitions, due to which established methods of managing food, water, and energy concerns have become untenable. These transitions include “urbanization transition” with growing middle income groups having increased purchasing power; “nutrition transition” leading to increased demands for animal and other high value products; “climate transition” increasing temperature, variability in water supply (due to increased variability in rainfall) and change in growing conditions for crops; “energy transition” with vastly increased consumption, and with changing composition of energy resources; and “agricultural transition” with increased mechanization requiring a shift from subsistence agriculture to commercial agriculture (Rogers and Daines, 2014; Tyagi, 2017a). The Indian situation in respect of these transitions is given in Table 1.

Not only are these transitions taking place simultaneously, but there are the additional factors of degradation of land and water resources, and continuing increase in pollution of surface and ground water resources, which are further complicating the situation. Naturally, the question then arises: what should be the alternate modes of development planning and implementation approach which would help us better address the water, energy and food security related issue, as enshrined in the sustainable goals (UN, 2012)? Despite so many scientific and political deliberations around the globe, the fact remains that in most countries, planning and management of one sector in WEF is handled independently of the other two sectors. This often results in conflicting strategies and avoidable competition for the same resources (WEFWI, 2011; Mohtar and Daher, 2012) creating situations of resource constraints for meeting requirements of different sectors (Pittock et al., 2013; Stirling, 2015; Sharmina et al., 2016).

Table 1. The five transitions impacting WEF security in India

Transition Item	Value in 2010	Value in 2050
Urban population with higher purchasing power	31%; per capita income INR 53,000	55%; per capita income INR 40,1839
Nutrition transition: higher demand for animal products/ high value products	2200 kcl; 8% from animal products	3000 kcl, 16–20% from animal product
Climate transition: increasing temperature, variable rainfall, greater crop-water demand	Impact observed - no estimates	2°C rise, increase in water demand by 10–15%
Energy transition: from fossil fuels to renewable energy resources	Per capita consumption 725 kWh (74 FS: 26 RS)	Per capita consumption 3000 kWh (50FS:50RS) (1935)
Agricultural transition: from small-scale subsistence farming to large-scale commercial operations.	85% farms ≤2 ha; Per capita income INR 40,772 (2011–12)	Farm size expected to increase due to urbanization, and shift to industry & service sectors

E.1.1. Objectives

This study, which is based on a review of existing literature, has four main objectives:

- Synthesize information on different aspects of WEF nexus, including conceptual frameworks, analytical tools and applications as a part of the learning process;
- Look into the current and projected WEF security concerns of India, in view of the increased demands for goods and services, declining health of the production system with the added stress of climate change impacts, and the commitments towards sustainable development goals;
- Assessment of the existing technologies and policies for facilitating the transition to sustainable development goals in respect of WEF;
- Refining focus on agro-hydro-technologies to beat the climate change heat on agricultural production systems.

E.1.2. Organization of paper

This working paper is organized in six sections. An overview of the nexus approach including its conceptual frameworks, nexus tools and similarities and departures from IWRM approach are presented in Section 2. Status of water, energy, and food security in India is covered in Section 3. Assessment of the existing technologies and policies is addressed in Section 4. Refinements and transformation in agro-hydro technologies and policies for adapting to climate change impacts are discussed in Section 5. The paper concludes with a set of technology and policy recommendations for implementation of nexus approach for WEF security in Section 6.

E.2. Overview of WEF nexus

The concept of WEF has its roots in the reports of the Water Resources Group, which were promoted by leading global corporate groups who considered water scarcity a cause for global economic slowdown as well as of the political instability (2030 WRG, 2009, 2012).The idea has been actively promoted by the World Economic Forum Water Initiative that advanced it in academic and political forums giving rise to numerous conferences, the most prominent amongst them being the Bonn Conference and United Nations Conference on Sustainable Development (UNCSD, 2002; WEFWI, 2011; Leese & Meisch, 2015). The history of the nexus approach is well traced by several authors (Bhave et al., 2016; Benson et al., 2015; Sharmina et al., 2016). The nexus approach, which aims at improving the system's performance rather than individual sectors, helps in understanding this interconnectedness, interdependencies, synergies and trade-offs to reconcile competing demands from different sectors and arriving at better solutions (Hoff, 2011; WEFWI, 2011). It is an attempt to put forth a new perspective on non-sustainable development and use of natural resources. The WEF nexus approach is essentially about balancing different resource-user goals and interests—while maintaining the integrity of ecosystems. The WEF nexus is talked about more when resources are scarce and demand exceed supply. The interconnections of the water–energy–food system (Table 2), are now well recognized and is advocated to harness the synergies and minimize the trade-offs embedded in the WEF system (Hoff, 2011; FAO, UN, 2013).

Table 2. Nexus between, water, energy and food system (WEF) (Adapted from Bizikova et al., 2013)

Sector	Food	Water	Energy
Food	Limiting factor for nutrition, overall socioeconomic growth and human development.	Increased pressure on water resources to produce food and other agro inputs (seeds, fertilisers, agro chemicals etc).	Increased consumption in irrigation, and other post production processes.
Water	Limiting factor for food production agro-inputs and food supply chain.	Reduction in per capita water availavbility Limiting factor for human development	Limiting factor for power generation from hydro, thermal, nuclear, and bio energy.
Energy	Limiting factor for food production; agro- inputs and food supply chain.	Limiting factor for groundwater and surface water access; utilization; treatment; and transportation.	Limiting factor for human development and economic growth.

"Nexus interactions are about how we use and manage resource systems, describing interdependencies (depending on each other), constraints (imposing conditions or a trade-off) and synergies (reinforcing or having shared benefits)" (Weitz et al., 2014).

The societal demand from WEF sectors are rather contrasting. The expectation from the water sector is of keeping a balance in demands for food, energy and ecosystems to maintain sustainable abstraction. At the same time, it also requires that the water resources should accommodate the impacts of rising population and climate change, which have their own impacts on catchment hydrology. On the other hand, the energy sector is supposed to maintain an adequate supply at affordable prices and contribute to adaptation and mitigation of climate change.

The main purpose of nexus thinking is on the security of water, energy and food in combination together. The adoption of WEF nexus in development planning requires better understanding of the nature of the relationships among the three sectors, consequences of changes in other sectors, and implications for policy development. The nexus-oriented approach, which is linked with concept of a green economy, is needed to address unsustainable patterns of growth and it advocates: investing to maintain ecosystem services; creating more with less; and improving access and inclusiveness (Hoff, 2011). The nexus approach makes the sectors visible and transparent, and better addresses the externalities that link sectors together (Alouche et al., 2015). But these authors emphasize that to create the alternative sustainable development pathways taking care of other social issues the nexus approach must consider the interaction of ecological, social and technological systems across scales, and recognize the importance of local contexts and the political nature of decision making, without losing sight of the role of science and technology, and technological choices. Obviously, a tall order to accommodate all in one implementable programme.

E.2.1. Nexus and integrated water resources management (IWRM)

The WEF nexus approach is the successor of the well-established Integrated water resources management (IWRM) approach, which was an umbrella concept encompassing multiple principles aimed at a holistic and coordinated management between different aspects of water management, which is not much different from the objectives of a nexus approach. Benson et al. (2015) trace the developments in IWRM, which gave rise to the modified concept of adaptive water management (AWM), emphasizing a 'learning by doing' process and using feedback mechanisms to make incremental changes. Though both the nexus and IWRM approaches have integration between water and policy sectors, the IWRM was overtly focussed on water and advocated river basin as the planning unit, but the nexus approach calls for macro- or meso-scale norms and advocates 'policy coherence' across sectors (Hoff, 2011).

The nexus approach also reflects a leaning towards the corporate sector. Though WEF nexus is being presented as something of a novelty, a group of researchers believe that insofar as farmers are concerned water, energy, and food have never been separated the way it is now being presented by experts (Allouche et al., 2014; Srivastava and Lyla, 2014).They also suggest that to promote nexus thinking on sustainable basis, it must explore the interaction of ecological, social and technological systems across scales; make use of scientific knowledge and technological choices; be rooted in local knowledge and value diverse opinion; and recognize that decision making is highly political in nature. There is also an apprehension, that it may be an attempt to grab lands in locations well-endowed with natural capital, but economically less developed.

Table 3. Key features of the water–energy–food nexus and IWRM (Source: Benson, et al., 2011).

Item	Nexus	IWRM
Integration	Integrating water, energy and food policy objectives	Integrating water with other policy objectives
Optimal governance	Integrated policy solutions; Multi-tiered institutions	'Good governance' principles
Scale	Multiple scales	River-basin scale
Participation	Public-private partnerships multi-stakeholder platforms for increasing stakeholder collaboration	Stakeholder involvement in decision-making Multiple actors, including women
Resource use	Economically rational decision making; Cost recovery	Efficient allocations, Cost recovery, Equitable access
Sustainable development	Securitisation of resources	Demand management

E.2.2. Nexus conceptualizations

There are very many conceptualisations of the nexus, which vary in their scope, objectives and understanding of drivers. Different concepts, frameworks and methodologies have been evolved to analyse the inter-linkages between water, energy, food and ecosystems (Bizikova et al., 2013; ADB, 2013; ICIMOD, 2012). The policy focus of different approaches (Table 4) is on promoting action though policies promoting synergies, reducing trade-offs for transiting to a more sustainable future.

Table 4. Identified Areas for Interventions in Promoting WEF (Adapted from IISD, 2013)

Policy	Objective
Engaging stakeholders to build awareness and capacities about the interconnected nature of the elements of the WEF nexus	Community-level empowerment and implementation to local actors (World Economic Forum, 2011)
Improving policy development, coordination and harmonization	To account for trade-offs and build on the increased interconnectedness of water energy and food (World Economic Forum, 2011).
Governance, and integrated and multi-stakeholder resource planning	To promote cross-sectoral and cross-departmental approaches to planning and working with stakeholders at different levels to improve public sector-led governance, planning and information flows (World Economic Forum, 2011; Hoff, 2011; FAO, 2014)
Influencing policies on trade, investment in environment and climate by focusing on improving ecosystem management	
• Market-led resource pricing	• To account for local impacts (social and environmental costs of resource exploitation) and global impacts (contribution to climate change) (World Economic Forum, 2011; FAO, 2014)
• Investments in “smart” environmentally and socially sound infrastructure	• Specific attention to climate-related infrastructure development in irrigation, hydropower generation and flood management (Hoff, 2011; World Economic Forum, 2011; ICIMOD, 2012).
• Promoting more effective waste management	• Circular economy by reducing waste and using it in more diverse ways in production (Hoff, 2011).
• Stimulating development through economic incentives	• To provide incentives to local stakeholders to manage ecosystems (FAO, 2014)

E.2.3. Tools for nexus assessment

To achieve the goals linked to water, energy, and food security as included in the Earth Summit (UN, 2012), it is important to obtain answers to the following questions (Welsch et al., 2013):

- How to meet development needs (food, water, energy) in a sustainable manner without compromising the availability of natural resources (ecosystems)?
- Which individual technologies and their combination can help us achieve the desired results?
- What are the mixes of policies which would give solutions that are economically viable, socially acceptable and ecologically green?
- Will the proposed interventions help us in turning down the heat and meeting the targeted goal of keeping global temperature increases below 1.5°C?
- How can the actions of different authorities be harmonised in respect of sharing common resources?

Answers to these questions are generated through application of nexus tools to case studies. A very detailed review of the nexus tools is included in Chang et al. (2016) and Endo et al. (2015). The important WEF nexus tools are briefly presented below.

Metabolism (MuSIASEM): The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) integrates quantitative information generated by distinct types of conventional models based on different dimensions and scales of analysis (Giampietro et al., 2013). The MuSIASEM is a multi-concept based model including the flow-fund model, borrowed from bio-economics, and three conceptual tools–multi-scale accounting, multi-purpose grammar and the impredicative loop analysis (A concept borrowed from theoretical ecology, wherein unlike conventional deterministic models, MuSIASEM accommodates the chicken-egg predicament typically encountered in the description of complex systems). The model uses technical, economic, social, demographic, climate, and ecological variables in the analysis of the metabolic pattern of modern societies for natural resource accounting (FAO, 2013). The model is capable of addressing the integration of resource assessment at local or national level with respect to population dynamics, greenhouse gases and land use changes; and can be used for diagnostic purposes or to develop scenarios. This tool has been applied to several case studies including one in Punjab (India) (Giampietro et al., 2013).

The WEF Nexus Tool 2.0: This tool offers a common platform for evaluating scenarios and identifying sustainable resource allocation strategies. The model develops scenarios to quantify inter-linkages between WEF considering the effects of population growth, changing economies and policies, climate change and other stresses (Mohtar and Daher, 2013).The required inputs are: Food portfolio (identifying local food production levels versus imports, and technologies in agricultural production); Water portfolio (identifying different sources of water and amounts needed of each); Energy portfolio (identifying sources of energy for water, and energy for agricultural production). The outputs from the model for each scenario are: water requirements; local energy requirements; local carbon emissions; land requirements and financial requirements; imported energy and carbon emissions.

WEAP-LEAP tool: This toolkit combines an energy system (Long-range Energy Alternatives Planning System-LEAP) with hydrology (WEAP-water evaluation and planning) model produced by the Stockholm Environment Institute (SEI) (http://sei-us.org/software). The WEAP itself is an integration model. It integrates water supplies generated through watershed-scale hydrologic processes with a water management model driven by water demands and environmental requirements and is governed by the natural watershed and physical network of reservoirs, canals, and diversions. Thus, optimal resource allocations are found by the analyst exploring a technically consistent solution space. The LEAP-WEAP is a flexible toolkit which can be shaped around data availability. It being a simulation tool, the applicability is limited to studying explicitly user defined scenarios. The model is being used on a number of river basins worldwide.

CLEWS approach: The Climate, Energy, Water and Land-use Systems (CLEWS) model is based on an integrated analytical assessment approach, which explicitly values various interdependencies and interactions between CLEWS, primarily from an energy sector perspective, which tracks resources and technologies required for achieving certain development goals. It has been applied in several case studies, the important one's being in Mauritius to assess the energy, water and land-use system in the context of improved local energy generation (bioethanol from sugarcane) under different future climate change scenarios (Welsch et al., 2013)

Water–food–energy nexus index (WFENI): This is a novel technique to analyse the WEF nexus in the form of a water–food–energy nexus index (WFENI) developed by El Gafy et al. (2017). It simulates interdependency between water, energy and food production. The approach may be useful to suggest optimal cropping patterns which minimize water and energy consumption and maximizes their productivity. The economic value of water and energy could be added to the list of indices to make it broader based.

Amongst the nexus tools reviewed Nexus Tool 2.0, WEAP and WFENI look promising and could be used in our future studies because of their limited data requirements and simplicity.

E.2.4. Governance and institutions

The responsible governance of natural resources is the necessary first step for action on the water–energy–food nexus (Bahaduri et al., 2015; Pahl-Wostl, 2017), as it balances the trade-offs between different sectors arising due to interaction of policies. The 'mantra' for the success of nexus is the intensive involvement of all the stakeholders including scientists, decision makers, business and industry in identifying the research issues. The efficient governance would require putting in place a system which would make such broad involvement possible. The design of transformative changes for sustainable governance of the nexus in WEF would require an increasing role of science (Pahl-Wostl, 2017). There cannot be a fixed route for governance of WEF as the administrative structure and required policy instruments will vary with scale and region. In India, land and water are state subjects, and only on the concurrent lists of the federal government. Interstate disputes on sharing of river water often leads to conflicts. The decision-making process is fragmented and there are often issues with data availability and transparency (Azhoni et al., 2017). Many of the problems arise because water allocation issues are not decided at the time of creation of new states by dividing the existing large states. The existing water and energy pricing policies also lead to poor governance. Obviously, the solution lies in reforming the water allocation and distribution laws and restructuring the water sector administration. The government of India recently commissioned a study to look into the structural issues of water resources management (IPRS, 2016).

E.2.5. Summary

There have been concerted efforts in the last decade to understand the intricacies of the WEF nexus, which have led to a number of conceptual frameworks and models. In spite of considerable deliberations, the world over, there is little clarity on issues such as: what constitutes a successful nexus approach? How can it be achieved, monitored and evaluated, as different stakeholders, who compete for resources have conflicting views? The three metrics of nexus accounting—physical (resource intensity), monetary (price and cost dynamics), and distributive (implications of social allocations) are not fully understood, nor implemented (ESCAP, 2013). The actual case studies employing a nexus approach at a large scale have been very few. But the growing discourse is slowly resulting in warnings of the social and ecological dangers of compartmentalised management system (Williams et al., 2014). Some of the important issues for further research should include the following:

- Improved simulation models to predict the consequence of planned interventions and climate change impact;
- The assessment implications of WEF nexus are not scale neutral, and therefore studies should be conducted to address issues at different scales—local, state, country, and region;
- Impact of existing WEF related policies have environmental costs in the form of externalities. These costs are generally not included in the assessment, but both individuals and society as a whole is paying for them;
- The health of ecosystems plays an important role in ensuring the security of WEF, and society derives a number of benefits from ecosystems, and therefore nature should form part of the nexus studies (Krchnak et al., 2011). Satellite data could help in rapid assessment of the value of ecosystem services. Techniques for using satellite data to provide inputs for estimating variables like water accounting, energy accounting, and nutrition accounting on different scales, should be developed;
- In empirical studies, the credibility of the results depends upon the chosen methodology. A study should be undertaken to assess these methodologies and their associated data needs;
- Establishing national and regional data-hubs will enable social learning that can empower adaptive management.

The target year for achieving the targets outlined in the UN's sustainable development goals is 2030. It would require concerted efforts to accelerate the implementation of a WEF nexus approach. The three main guidelines laid down by the International Conference on Sustainability in the Water–Energy–Food Nexus (Bhaduria, 2014) for acceleration in adoption of a nexus approach are: responsive governance of the natural resources to minimize the negative impacts of technologies and polices, minimised trade-offs and enhanced synergies; extensive involvement of stakeholders; and increased financial, institutional, technical and intellectual resources for nexus research and applications.

Finally, water resources management is highly political in nature, and the climate induced scarcity will make it still more political. The most effective way to motivate policy makers to integrate climate smart water resources management into development plans will need generating based on research, strong empirical evidence, and establishing effective communication channels with policy makers.

E.3. Status of water, energy, and food security in India

India, being a large country, has wide spatial variations in the natural resources endowments. Climate change is going to make considerable changes in WEF security. Because of its size different regions will experience differentiated effects. The four climate sensitive zones in India are the Himalayan region, the Northeast region, the Western Ghats and the coastal areas. There are a number of projections regarding varying effects on crops and animal stock in different zones. The Government of India has established an Indian Network for Climate Change Assessment (INCCA) to study the impact of climate change and advise the government. The INCCA Report of 2010 (INCCA, 2010a), has developed projections on the effect of climate in different regions through field studies and simulations (Table 5). According to these projections rice, which is a major food crop of the country, would suffer yield loss of 4–20% under irrigated conditions and 35–50% under rainfed conditions as early as 2030. These projections are much more alarming than the earlier projections and tally with Cline's (2007) estimates of 30–40% yield losses. The only difference is that what was expected to happen in 2080 may happen in 2030.

Table 5. Impact of climate change in different sectors and regions of India by 2030 (INCCA, 2010b).

Sector	Himalayan Region	North East	Western Ghats	Coastal Region
Crops	Apples: Overall negative impact	Irrigated rice: -10%–+5% Rain-fed rice: (-)35% to (+)5% Maize: Reduce up to 40%	Yield reduction: Rice: 4%, Maize: 50% Yield increase: Coconut: 30%	Yield reduction: Irrigated rice:10–20% Rain-fed maize:35% Irrigated maize:15–50% Coconut: up to 40% (West coast) Yield increase: Coconut10–30% (in parts of the east coast)
Fishery	-	-	-	Positive impact
Livestock		Negative impact on production	Negative impact on production	Negative impact on production
Water	Increase in supply	Decrease in supply	Variable supply	General reduction
Biodiversity (in terms of Net Primary Production (NPP))	NPP increase by 57%	NPP increase by 23%	NPP increase by 20%	NPP increase by 31%

The next question is how to minimize the adverse outcomes and build on positive ones. Naturally the adaptive capacity of different regions, against the climate change impacts, varies and so do their perceptions on WEF security. Let us look at how India is placed on issues of WEF security.

E.3.1. Water security

India supports more than 18% of world population with only 4% of global fresh water and has an external dependency ratio in annual renewable supply of 33.4% (ADB, 2013). The per capita availability of water is declining and will reach the critical level of 1000m^3/capita by 2050. The constructed surface water storage capacity is only 224km^3 as compared to 830km^3 in China, which has a population of comparable size (FAO Aquastat, 2015). The generous allocation of water to agriculture and the rapid growth in demand for this scarce resource from other sectors of the economy is adversely impacting the water budgets and the environment in river basins. The production systems in the most productive basins like the Indus and Upper Gangetic Plain are currently under hydro-stress due to overexploitation (Tyagi, 2017). The Indus, Cauvery and Krishna River Basins have reached the state of physical scarcity (Amarsinghe et al., 2004). The projected 2030 and 2050 water demands by different sectors show greater increase in demand from the industrial and energy sectors (Table 6). The projected deficits vary between 380 billion cubic metres (BCM) and 755BCM (ADB, 2014; 2030 WRG, 2009). The degree of surface water diversion (SWD) from the river systems as well as the level groundwater abstraction ratios (GWAR) have already crossed desirable limits.

Table 6. Sustainability indices of water resource development in India (Tyagi, 2016).

Item	Level of development of water resources (BCM)		
	2000	2010	2050
Surface water	360 (690)*	404	647
Groundwater	210 (396)*	260	396
Degree of stress			
SWD	0.522 (High)	0.586 (High)	0.938 (Extremely high)
GWAR	0.530 (Normal)	0.657 (High)	1.0 (Extremely high)

*Values in parenthesis are utilizable potentials of surface and ground waters

There is a high level of dependency (65%) on groundwater for irrigation, which has led to over exploitation of groundwater (Table 7). In the agriculturally important states of Punjab and Haryana the level of groundwater development is between 133–172%, which is beyond safe limits (≤70-90%) (Suhag, 2015). Indications are that the water demands of 2030 and beyond would not be met with the current and contemplated water resources development plans in the business as usual mode.

Whilst considering the future of water security, in view of the increased demands due to increasing population, changing lifestyle, additional stress due to climate and the prevailing depletion and degradation of water resources, we have to answer the following questions:

1. How much water do we need to produce food for meeting the requirements in the future, e.g. 2050?
2. Based on today's crop yields, how much production can be sustainably achieved at projected water availability values in 2050?
3. If there is a gap between the demand for water, at today's water productivity values, to produce food required in 2050 and the projected water requirement for this purpose, how is it going to be met?
4. To what extent can gains in efficiency and water productivity enable higher levels of crop yield?

Table 7. Level of Groundwater development in some Indian states in 2011 (CGWB, 2015)

State	Level of groundwater development (%)
Andhra Pradesh	37
Assam	14
Bihar	44
Delhi	137
Gujarat	67
Haryana	133
Karnataka	64
Madhya Pradesh	53
Maharashtra	57
Odisha	28
Punjab	172
Rajasthan	137
Telangana	55
Tamil Nadu	77
Uttar Pradesh	74
West Bengal	40

The serious water security threat to India arises from three directions: groundwater overexploitation, river flow depletion and water pollution

E.3.2. Food security

There are various projections of increase in demand for food commodities. According to one scenario (Kumar, 2015), at 7% growth rate in GDP the demand for food grains will grow only by about 50%, but the rise in demand for fruits, vegetables, and animal products will be more spectacular, the range being 100–300% (Figure 1) (ICAR, 2015).

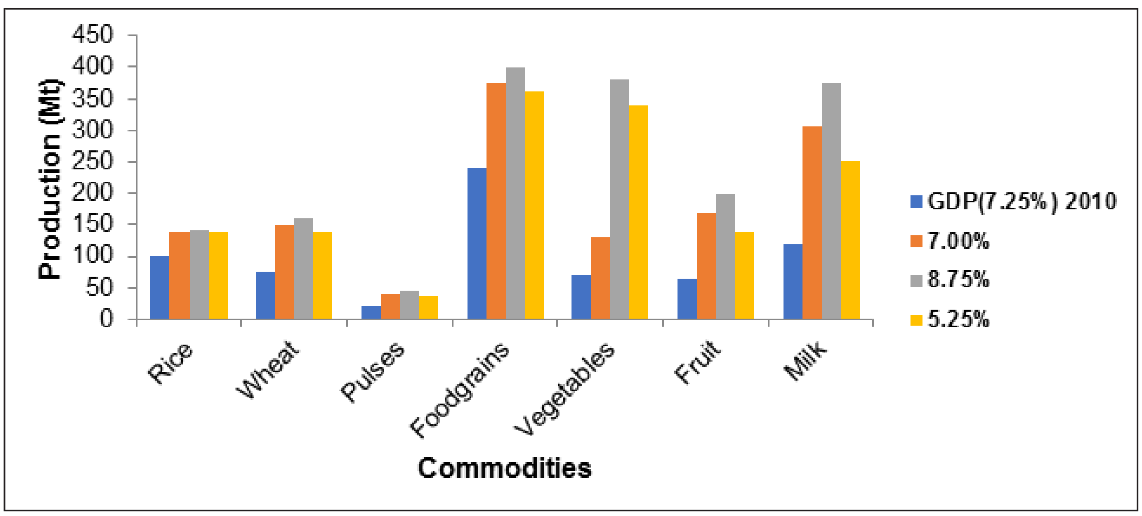

Figure 1a. Demand for various food commodities (FD) in 2010 and projections for 2050 at 7%, 8.75 % and 5.25 % growth in GDP (Personal communication from P. Kumar,, 2015).

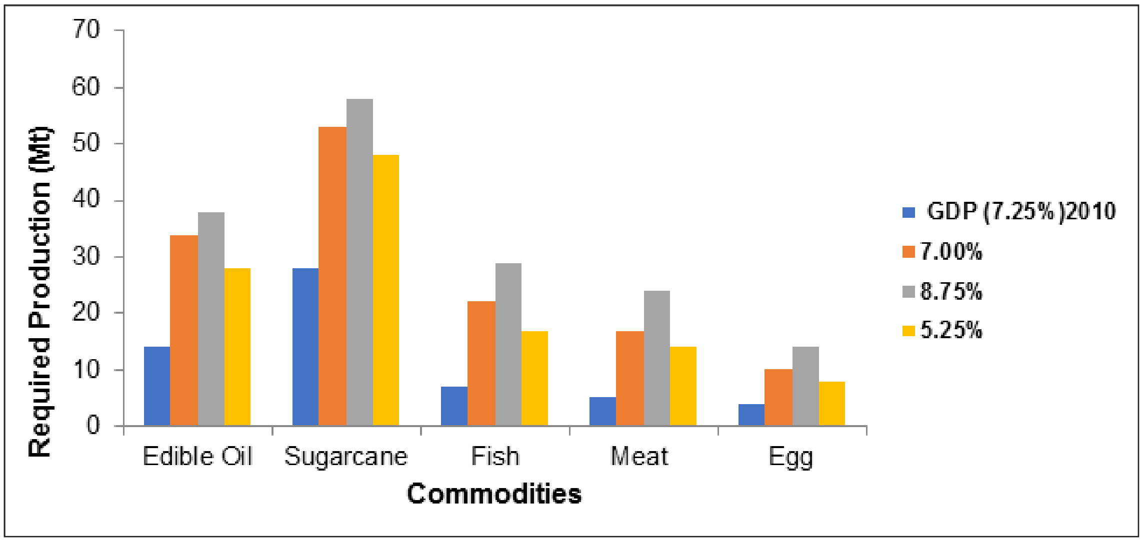

Figure 1b. Demand for various food commodities (FD) in 2010 and projections for 2050 at 7%, 8.75 % and 5.25 % growth in GDP (Personal communication from P. Kumar, 2015).

Food security includes access to healthy food and nutrition which in turn is dependent on a healthy and sustainable food system. A major concern of food security in India would be nutrient imbalance, quality of food, and stability of supply (affected by climate change). The values of some of the food security indicators show that India has a long way to go to achieve security in a true sense (Table 8). According to the recent report on Global Hunger Index (GHI) by von Grebmer et al. (2016) India ranked at 97th amongst 118 developing countries. With 15.2% of its citizens undernourished and 38.7% of children under five years stunted, India has a 'serious' hunger problem. If hunger level declines at the current rate, then India will still have 'moderate' hunger scores in the year 2030, short of the UN goal to end hunger by that year. Opportunities of livelihood, which would determine the access (notwithstanding the food security bill), will have impact on the security situation.

Table 8. India's food security indicators (Reddy, 2016)

Security indicator	Value
Food import as % of total export (2011–13)	5
Food inadequacy (2014–16) (%)	24
Variability in food supply (2009–11), kcal/capita/day	49
Average protein supply, (2009–11) g/capita/day	59
Prevalence of undernourishment (2014–15) (%)	15
Underweight children of less than five years of age (2012–14) (%)	40
Prevalence of anaemia among pregnant women (2009–11) (%)	54
Population with access to sanitation facilities (2013–14) (%)	39
Average value of food production at constant prices of 2004–06 (2013–14), $ per capita	186

E.3.3. Energy security

Energy consumption has grown at the cumulative aggregate growth rate of 5% during 2001–11, and the existing estimates show that to maintain an economic growth rate of 8%, primary energy supply would have to increase by 5% for the next 20 years (TERI, 2015). As India's energy supply is highly import dependent, to the extent of 40% at present, and to the extent of 74% in 2030 (Reference Energy Scenario: energy trajectory with current demand and supply trends), any increase in international prices will have an adverse impact. Climate change will lead to increase in food and water related energy demands. Higher temperatures and prolonged droughts will be frequent, as the number of consecutive dry days for a 10-year return period will increase from 139 to 142 by 2050 (CRIDA, 2014). Consequently, there will be increased demand for irrigation. The total energy demand will grow from 717 million tonnes of oil equivalent (Mtoe) in 2011 to 1,950 Mtoe in 2031. The energy demand in the agriculture sector is projected to increase from 21 Mtoe in 2011 to 74 Mtoe in 2030, in the reference energy scenario (Table 9) (TERI, 2015). The situation will be further worsened by high subsidies on energy which encourages wasteful water use, leading to depletion of water tables and higher energy consumption.

Table 9. Status of energy security indicators in India (TERI, 2015)

Security indicator	2011	2031		
		RES*	ESM**	ESA***
Import dependence (%):				
Oil	76	91	84	77
Coal	23	66	40	22
Natural Gas	21	60	41	63
Total energy import dependence for fossil fuels (%)	40	74	54	44
Share of fossil fuels in the primary energy supply energy mix (%)	69	83	79	74
Net energy intensity (ktoe/INR)	0.012	0.0082	0.0069	0.0060
Average consumption of energy per capita (ktoe/capita)	435	1137	956	840
Access to electricity	67	100	100	100
Access to modern cooking energy fuels	29	5	20	25

*RES (Reference Energy Scenario): Energy trajectory with current demands and supply trends).

**ESM (Moderate Energy Security Scenario Energy trajectory that would ensure energy security in the future with efficiency improvements both on the supply and demand sides).

***ESA (Ambitious Energy Security Scenario: Energy trajectory that entails faster implementation of efficiency measures, rapid penetration of new technologies, and increased electrification of the economy.

E.3.4. WEF security summary

Although India has been able to increase its food production by more than seven-fold since 1950, it has been achieved at the cost of degradation of natural resources; the rate of progress cannot be sustained in the long run. It is apparent from the review of WEF security that India is scarce in water–energy resources, and will have to consider alternate approaches to achieve the essential securities. The WEF nexus approach, if applied, may be helpful in the following ways:

- Identification of options to manage groundwater irrigation, to meet food security and to achieve energy security;
- Assistance in scenario building with an integrated vision for socio-economic development and costing;
- Preventing intra- and inter-state disputes such as in Punjab–Haryana in the Indus Basin, Karnataka–Tamil Nadu in the Cauvery Basin; Maharashtra–Andhra Pradesh in the Krishna Basin.

E.4. Assessment of the existing technologies and policies

The guiding principles for building resilience in food production systems are based on limiting use of natural resources, adaptive allocation, transparent markets, and maintenance of environmental flows (Box 1). Minimizing economic and environmental trade-offs often remains an issue in observance of these principles.

Box 1: Broad Adaptation Options for Sustainability of Agricultural Water Use

- Altering crop varieties/species to suit altered thermal regimes and resistance to other biotic and abiotic stresses;
- Altering irrigation and drainage practices and methods to respond to changed atmospheric and root zone environment;
- Practicing conservation farming (tillage, residue management, land shaping) to harvest and conserve water;
- Diversification and reallocation of water and land resources;
- Improvement in weather forecasting, enhanced use of weather advisories and insurance of climate risks through risk transfer mechanism to minimize production risks of the farmers;
- Transparent water markets;
- Policies to incentivize optimal mix of options.

E.4.1. Agro-hydro technologies

There are a number of technological, economic, regulatory and policy-based options which may be used to increase the resilience of water resources (2030 WRG, 2009). The objective criterion for selection is that the technologies should lead to improvement in soil health, reduce GHG emissions, and help maintain ecosystem services. Collectively, these can be termed as climate smart agricultural technologies (Agarwal, 2008). The important water smart technologies include improved irrigation techniques (irrigation scheduling, laser levelling, micro-irrigation, system of rice intensification, alternate wetting and drying (AWD), deficit irrigation etc.). There being a very close nexus between water, energy and food production systems, adoption of different technologies gives rise to differential GHG emissions for example, and one can decide the technology combination for adoption to meet the target reduction in emissions and financial implications.

Development and adoption of the appropriate agro-technologies, those would minimize trade-offs and increase synergy between food and nutrient security, water and energy sectors, is a challenge. But there is very strong empirical evidence to show that increasing land and water productivity through various agro-technological interventions and their mainstreaming in public development policies is the key to minimizing the projected water demand and supply gaps (Schipper, 2009; 2030 WRG, 2009; Chakraborty et al., 2012; Iglesias and Garrote, 2015).

Some of these technologies such as laser levelling, micro-irrigation and reduced tillage have been out scaled in sizeable areas. Laser levelling, which has been extensively promoted in the Indo-Gangetic Plain, was found to save water to the extent of 20–30 %, increase yields by 15–20 % and the reduction in energy used in pumping was a bonus (Jat et al., 2006).Similarly micro-irrigation which has so far been extended over 4Mha, proved to be a ‘triple wins’ intervention as it was estimated to have increased production by 3.483 Mt, reduced water use by 0.73Mham, and effected GHG reduction of 5.555 CO_2e, Mt (Table 10) at average efficiency of 30 % (Joshi et al., 2015).

Table 10. Water saving, production increase, food grain increase, and emission reduction from due to existing 3.87Mha area under micro irrigation (Tyagi et al., 2014)

Parameters	Increase in application efficiency of micro-irrigation efficiency over surface irrigation		
	20%	30%	40%
Saving in water (Mha-m)	0.488	0.733	1.47
Increase in production (Mt)	2.522	3.483	4.644
Increase in food grain availability(kg/capita/yr)	2.08	3.13	4.16
Reduction in GHG emission (CO2e, Mt)	3.704	5.555	7.605

Introduction of zero-till drill has made a revolutionary change in seed bed preparation and seeding of crops by reducing the cost and time required for sowing. A special feature of this technology, which is hugely significant for climate change adaptation, is its energy saving. The water productivity of zero tillage systems in rice wheat could be increased by 15–37%, while the net global warming potential is lowered by 26–31% as compared to conventional tillage systems (Pathak et al., 2011). An increase of 28% in water productivity in wheat has been reported from Bihar (Upadhyaya and Sikka, 2016). It is apparent that higher water productivity (lower water foot print) is associated with lower warming potential and adaptation led mitigation.

Higher productivity translates into increased food security, more income and greater buffer against climate induced fluctuations-Adaption

E.4.2. Policies and institutions for promotion of adaptation and mitigation in India

The policies in India have to date focused on development and it was a sheer coincidence that the world started talking of climate change, calling for modification in the model of development, at the initial stage of India's development. Yet the need for policies and legal frameworks, and its enforcement to protect the health of the agricultural production system, is necessary. The main pillars of agriculture development efforts in India have been the increased supply of high yielding crop seeds, expansion of irrigation through surface and ground water development, watershed management programmes, and the progressively increasing introduction of chemical fertilizers.

E.4.2.1. Broad National policies

The main instruments of national and international policies applicable to India concerning climate change are the National Climate Policy (NCP), National Communications on Climate Change (NCCC), UN Framework Convention on climate Change (UNFCCC), and National Action Plans (NAP) which deal exclusively with laws, regulations, and strategies on how countries deal with the issues of climate nationally and internationally. The second National Communication to UNFCC provides a report card on environmental health in different sectors, including agriculture, and gives indications on how India proposes to align national policies to achieve the global target of restricting the temperature rise to 2°C by the end of this century. Since all country's NCCC's follow common guidelines and format from UNFCCC, the documents look alike in nature with variation being only in the country specific information contained therein. It is the NAPs that elaborate on country specific policies and action plans.

BOX 2: Some Common Features of Climate Policy in India

Unlike global climate policy, where agriculture is not in focus, India has laid emphasis on climate change adaptation in agriculture. In the absence of legislation there may not be direct mention of policy, and adaptation strategies are sometimes called action plans. These are currently the most common policy instrument for adaptation (Satpathy et al., 2011).

Climate policy documents make a special mention of attending to concerns of farming communities and rural poor as one of the guiding principles of climate policy.

Subsidy has been used as a mechanism for promoting adaptation in development programmes.

Policy statements are quite elaborate, but mechanisms to put them into practice are sometimes missing, and this is particularly true of funding the adaptation and mitigation programmes.

E.4.2.2. Agriculture sector policies in India

"Indian agricultural policy focussed on modernization of agriculture sector through subsidies. Though greenhouse gases were not specifically targeted in this effort but modernization had a modest effect on total GHG emissions." (Climate Policy Initiative, 2013)

Agriculture is the critical component of India's development story. In the beginning the emphasis was on increasing production by harnessing the green revolution technologies, but after 2000 the policy has shifted to sustainable development and the National Policy on Agriculture came into force (GOI (MOA), 2000). The salient points of this policy are, targeted efficient use of resources through technological adoptions; conservation of soil, water, and biodiversity; and fixing a 4% annual growth target for agriculture. The current programmes that support agricultural development to increase adaptive capacity to climate change are: The Mahatma Gandhi National Rural Employment Guarantee scheme; national seed policy; Rastriaya Krishi Vikas Yojana (RKVY); Mission on Micro irrigation; AIBP etc., which support agriculture in achieving the production targets in a sustained manner and generate employment in rural areas.

The prevailing policies on fertilizers, irrigation, and energy were shaped by green revolution and are not unique to South Asia, or India, in particular. The pressure for agricultural subsidy is common during transformation from agricultural to industrial economy. As correctly explained by Hayami and Godo (2004), this happens due to inter-sectoral income disparities between agricultural and non-agricultural sectors during the transition. The maximum contribution to adaptation, mitigation, and resilience in agriculture sector has been achieved by irrigation (Joshi and Tyagi, 2017). But the water policies have weakness on sustainability; the government should rise to the occasion to plug the policy loop holes and strengthen water governance. Amongst the technology policies evaluated, the micro-irrigation policy appears to have paid rich dividends. It fared well in terms of all the performance measuring parameters including: mitigation, adaptation, resilience, and sustainability.

E.5. Refining focus on agro-hydro technologies and policies to beat the climate change heat on agricultural production systems

There is considerable scope for productivity enhancement even with the currently available technologies, and for current levels of climate change impacts. Most of these technologies (micro-irrigation, no till, integrated nutrient management) are no-regret adaptations. Technology development alone will not be sufficient, as there are economic, social and cultural barriers to adaptations. It would, therefore, be important to assess the effectiveness of adaptation options under different operating policy regimes, geographical differentiations and risk transfer programmes.

E.5.1. Land productivity improvement

Land productivity, which at present hovers around 20, 000 kcal/ha/day, will have to increase to more than 30,000 kcal/ha/day to supply the targeted nutrients in the human diet. This 50% increase in land productivity will require significant improvements in production technologies. The seed route is the cheapest option to increase productivity and it has been very successful in the past. But productivity enhancement alone will not remain the best criterion in future. Probably it will have to be calories/protein (or other nutrients in which the population is deficient in a region) per unit water/energy/carbon. The target value for required enhancement will have to be fixed on the basis of some composite index with differing weights according to geography/economy/ natural capital so as to maximize synergy and minimize trade-off. It would require appreciation for the WEF nexus approaches. Further, effectiveness of the current technologies will go down with increased warming. To beat the heat arising due to climate change, genetic improvement in crops for heat and drought tolerance would be major candidates for future research. Projection made on the basis of meta-data analysis on yield improvement and the consequent reduction in land requirement for food production show that no-till, precision agriculture and technologies related with nitrogen-use efficiency improvement will play a major role (Spielman, 2013). Further research to evolve heat and drought tolerant crop varies, to take care of the impact of global warming will have to be speeded up (Table 11). Similarly, research on nutrient fortification of crops will require added emphasis.

Table 11. Impact of alternative technologies on global yield and harvested area in 2050 (% change from base line) (Adapted from Spielman, 2013)

Technology	Maize		Rice		Wheat	
	CY	CHA	CY	CHA	CY	CHA
No till	15.8	-8.2	NA		16.4	-7.4
Precision agriculture	3.7	-2.2	8.5	-3.2	9.7	-4.8
Nitrogen use efficiency	11.3	-6.3	20.2	-6.8	6.2	-3.8
Heat tolerance	16.2	-8.4	3.0	-1.4	9.3	-4.6
Drought tolerance	11	-0.6	0.2	-0.1	14.0	-0.7

CY - Change in crop yield (%); CHA - Change in harvested area (%)

E.5.2. Cost effective but low carbon technology

Some other adaptations like adjustment in crop areas, reallocation of water or introduction of tolerant cultivars have been found to be useful (Howden et al., 2010; Iglesias and Garrote, 2015), but may generate conflict between productivity (income) and environmental sustainability goals, as being observed in northwest India's rice-wheat system and groundwater decline (Ambast et al., 2006). No single technology can reduce the water demand–supply gap, and therefore adaptation to climate change requires adoptions of multiple technologies. The optimal technology mix varies with location and socioeconomic situation of the adaptors. Decision making prioritization tools, like cost curve, payback period curve, and quantitative modelling, which now have become available could be used in deciding the portfolio of technology actions (2030 WRG, 2009; Ahmed & Suphachalasai, 2014). The farm, irrigation projects or basin level improvements would have to be achieved through a combination of technologies in the form of precision agriculture which may be based on real-time data on weather, soil and water quality, crop maturity and equipment etc. Agriculture is gradually becoming commercialized, and therefore increasing productivity alone will not remain the targeted objective, but will be replaced by profitability. Generally, only the adaptations of greater economic value for the farmers would be adopted. The use of decision support tools like cost curve, pay back curve, and models like IMPACT will be needed to charter policy pathways (Rosegrant et al., 2012; 2030 WRG, 2009).

E.5.3. Involvement of industry

Agricultural research in India is largely production centric. But in the food sector as a whole, post food production processes consume about 20% water and 80% energy, before it reaches the table. To achieve breakthroughs in these technologies, collaboration with industry and institutions outside national agricultural research system (NARS) would be necessary.

E.6. Suggestions for changes in agriculture and allied sector policies

E.6.1. Reduction in consumptive use

It may be added that efficiency improving policies would be helpful, but real sustainability in water resources will come only by reducing net consumptive use (Ambast et al. 2006). This would require policies which help in modification and transformation in cropping patterns across the region.

E.6.2. Electricity linked groundwater depletion reduction measures

Groundwater is largely a common pool resource, but in but in actual practice, the common ownership is impacted adversely by the size of ownership of land. The possible options are: regulation of tube wells, state ownership of tube wells, and community based management. Each option has its merits and demerits. The issue of energy management in the context of groundwater has been given due attention in the report by CEEW (2012). Based on these recommendations, ideas presented in other reports (Shah, 2009), and looking at the prevailing macro-policy environment the following policy reforms look promising.

Box 3: Some promising electricity policy reform options

- Separate agriculture electricity feeders from rural domestic feeders.
- Introduce targeted credit for pump investment and collective groundwater irrigation facilities for small and marginal farmers. Replace inefficient agricultural pumps with BEE certified efficient pumps which save at least 30% energy.
- Notify agriculture pump sets as “an appliance” under section 14 of the Energy Conservation Act.
- Use remote sensing and IT-enabled monitoring of pumping volumes and power consumption through pre-installed electronic chips in the pump sets.
- Expand micro-irrigation (sprinklers and drip).
- Rationalize power tariffs to make power utilities financially viable.

E.6.3. Organics as substitute of inorganic chemicals

In South Asian countries, unlike developed countries, the environmental degradation due to soil erosion, industrial effluents, and deforestation is far more serious than from fertilizers, which are being used at much below the recommended levels. Organics will not be able to substitute chemicals, but as argued by Desai (1991), organics have a definite complementary role and should be promoted for that role and not as an alternative to chemicals.

E.6.4. Input pricing

The price polices and input subsidies appear attractive because a single policy lever can serve multiple objectives of correcting market failure and helping development. But the problem is that after sometime, it becomes counter-productive and breeds inefficiency. This is what is happening in the case of electricity and irrigation water pricing in India as the exit routes are closed and phasing out policies are absent. These programmes are becoming a budgetary millstone and need fresh look.

E.6.5. Concluding remarks

In conclusion application of a nexus approach on a scale will require bridging the existing knowledge gaps through focussed research. The gaps lie in: i) the quantitative assessment of inter-dependencies in WEF requiring additional data and analysis; ii) current and projected challenges as influenced by demand and supply drivers including climate change; iii) response options; and vi) appropriate governance framework.

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