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BACKGROUND PAPERS

WATER-ENERGY-FOOD (WEF) NEXUS INTERACTIONS AND AGRICULTURE RESEARCH FOR DEVELOPMENT - THE CASE FOR INTEGRATIVE MODELLING VIA PLACE-BASED OBSERVATORIES

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SUMMARY

The impact of Agriculture Research for Development (ARD) is key to justifying investments in technologies and management models with potential to address environmental challenges such as climate change and advance the cause of poverty reduction. Agriculture has become the key driver for four Planetary Boundaries (PB's) that are at a critical stage of risk at a time when two billion people who lack sufficient calories and nutrients co-exist with approximately two billion others who consume too many calories. This imbalance in food security is reflected in an imbalance in the bio-physical world; evident in trends such as the transformation of the Nitrogen and Water cycle. Circular economy arguments for adoption of retrofit, reuse, re-manufacture, reduce and replace are crucial in trying to restore balance between how much is being consumed and by whom. Trade-off analysis can reveal the costs of switching to alternative models of production and the incentives that are required for cooperation at transboundary, regional and local government levels to emerge. Crucial to such analysis are the use of "thresholds" for examination of bio-physical and institutional dimensions of resource use that operate at both planetary and administrative scales. Qualitative, descriptive studies of adoption pathways in the real world may be useful for generating hypotheses, but there has been insufficient attention to putting these hypotheses to a rigorous test. It is in this connection that place-based observatories can play an important role in supporting integrative modelling by downscaling global environmental models, developing nexus typologies of a developmental challenge and advancing data valorization and knowledge translation through pilot-testing of composite indices.

Key Words

WEF Nexus, planetary boundaries, typologies, trade-offs, Wastewater Reuse Effectiveness Index (WREI), place-based observatories, administrative scale, composite indices.

1. INTRODUCTION

The challenge of addressing poverty and environmental sustainability through improved Natural Resources Management (NRM) is an important priority for international agriculture (FAO, 2014). The CGIAR is mandated to develop global public goods such as high yielding varieties of seeds, improved livestock, irrigation and fishery management practices and models of agricultural value chains. The development of global public goods has been pursued based on two assumptions with respect to poverty reduction: (a) the technical options once developed will be adopted by resource poor farmers and (b) their successful adoption will activate pathways out of poverty for resource poor communities that could be reflected in trends such as diversification of income, reduction of crop productivity risk and stabilization of demand for farm labour all of which increasingly operate within a complex political economy of food production, distribution, retail and consumption (CGIAR, 2016, Tomich et.al, 2018). Given the fact that agriculture poses a major threat to planetary boundaries, it is pertinent to inquire to what extent the adoption of such public goods could have an ameliorating effect on freshwater use, biogeochemical flows, changes in biosphere integrity and climate change through support for reuse and recycle of wastewater in agriculture (Campbell et.al, 2017, UN-Water, 2018)[1].

The Water-Energy-Food (WEF) Nexus has the potential to enhance the societal relevance of global public goods research. This assertion is supported by our definition of the Nexus as an approach that supports integrative modelling[2] of trade-offs within socio-ecological systems with the objective of informing decisions relating to management of environmental resources, delivery of public services and associated risks and with the potential to impact upon water, energy and food security and planetary boundaries. From an analytical perspective this would presuppose that attention be paid to conceptual building blocks of the Nexus approach: trade-offs, synergies and critical mass of financing and technology (Kurian, 2017). The potential benefits of employing a Nexus approach include addressing rebound effects of developmental action through an explicit focus on incentives, financing models and integrative monitoring norms. The Nexus approach by distinguishing between global challenges such as climate change that operate at planetary scale and local and regional challenges of food, energy and water security that operate at administrative scale, enhances the prospects for “institutional” embedding of NRM research (Bernhofer et.al, 2016).

Institutional embedding would make it clear that while administrative and planetary scale challenges and the concomitant pressures they impose may be interconnected and interdependent, policy and management interventions need not necessarily succeed in ensuring “convergence and coherence” in development practice. The Nexus approach offers a framework to view policy and management interventions as outcomes of choices that operate at global, national and local scales, guided in turn by norms, agency and individual behavior with regards to allocation of financial and human resources and institutional capacity with the goal of balancing bio-physical risks with institutional ones that may subsequently be reflected in differing emphasis on advancing efficiency and equity considerations in infrastructure operation and maintenance (Kurian, 2017). Therefore, the novelty of the Nexus approach lies in its emphasis on coordination across sectors to remove siloes in decision making without presuming that integrated management much rather integrative analysis will improve the prospects for sustainable development (Kanter et. al, 2018).

[1] The relevant Sustainable Development Goals (SDG’s) relate to poverty (goal 2), water and sanitation (goal 6) and climate action (goal 13) (CGIAR, 2016).
[2] For a glossary of terms contained in this paper see Annexure 5

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To better understand the pathways for adoption of technical options global public goods research must fundamentally pivot away from a narrow focus on crop systems towards a broader engagement with food systems- food production, distribution, retail and consumption. Place-based observatories[3] that emphasize principles of dispersed data collection, analysis and sharing can potentially serve as a powerful mechanism in supporting such a pivot towards food systems. Place-based observatories can bring about the much-needed political engagement through their support for regional research calls/dialogues by which research questions are locally incubated and research projects are curated by a consortium of international and regional knowledge institutes with the objective of addressing pressing policy concerns such as food insecurity, climate change and water scarcity (Kurian et.al, 2016). A recent UNU-FLORES research project that adopted this approach was able to successfully advocate for inclusion of a sub-indicator on reuse to monitor Sustainable Development Goal (SDG) target 6.3 (UN-Water, 2018:58). This background paper will draw upon some of the lessons emerging from the experience of collaborating with UNHABITAT (co-custodian agency for SDG 6.3) to stimulate discussions on the following issues:

- The concept of planetary boundaries and its implications for global public goods research on natural resources management (NRM) for poverty reduction and environmental conservation.
- A framework for systematic analysis of WEF Nexus interactions based on the case of wastewater reuse in agriculture through a discussion of concepts of trade-offs, synergies and typology construction in agriculture research for development.

This background paper highlights a serious shortcoming of previous analyses that have confused between implementation of nexus research and the application of nexus principles in development practice (see Liu et.al, 2018). To clarify our position Section 2 will make an important distinction between planetary and administrative scale perspectives of water-energy-food interactions in discussing concepts of food systems, circular economy and institutional risk thresholds. Section 3 discusses how Nexus concepts of trade-offs, thresholds and typologies can guide the design of agriculture research for development. Section 4 employs the example of the Wastewater Reuse Effectiveness Index (WREI) to advocate for combining bio-physical and institutional and socio-economic data to enhance the relevance of agriculture research. Section 5 draws some key conclusions with implications for the design and implementation of CGIAR research that focusses on robust monitoring of research outcomes for environmental conservation and poverty reduction.

[3] For an overview of the Nexus Observatory online platform (phase 1 project) at the United Nations University please see: https://nexusobservatory.flores.unu.edu/

2. PLANETARY BOUNDARIES AND INTERACTIONS OF WATER, ENERGY AND FOOD

Notions of Planetary and Administrative Boundaries

"Post-World War II development theory proceeded based on a characterization of duality in developed and developing economies. The distinction between developed and developing economies was based on the extent of an informal sector (Brohman, 1996). The agriculture sector for instance was characterized by informal mechanisms that mediated access to credit, seeds, fertilizers, labour and technology. The "stages of growth" model viewed agricultural development along a continuum that extends from establishing basic infrastructure (for irrigation, electrification and other nexus-related resources, but also roads, land registration systems, etc.) towards a gradual infusion of private finance to support the growth of factor and product markets for food, seeds and fertilizers (Dorward et.al, 2005). It was argued that because of the successful transition towards market driven development the formal sector would expand to support improvements in agricultural productivity with potential to reduce poverty and hunger" (Kurian et.al, 2018a).

In 2009 Rockstrom et.al (2009) introduced the concept of Planetary Boundaries (PB's) to emphasize that human activities significantly impact earth system functioning. The PB's are intended to represent Earth system processes, which, if crossed, could generate unacceptable environmental change in agriculture potentially endangering human existence (Campbell et. al, 2017). Steffen et.al, (2015) recognized nine PB's that include land-system change, freshwater use, biogeochemical flows (nitrogen and phosphorous cycles), biosphere integrity, climate change, ocean acidification, stratospheric ozone depletion, atmospheric aerosol loading and introduction of novelties. Of the nine PB's, five are in the high risk or increasing risk zones with agriculture the major driver of four of them and a significant driver of the remaining one (Campbell et. al, 2017). The four PB's for which agriculture is a major driver are climate change, land-system change, biogeochemical flows and biosphere integrity. There is considerable debate as to whether the freshwater use PB has been exceeded. The arguments that have been made for the four PB's at high or increasing risk are as follows:

Land-system change

According to Foley et. al, (2005), croplands and pastures are one of the largest terrestrial biomes on the planet, occupying approximately 40% of the land surface. This makes agricultural production the planet's single most extensive form of land use. In the tropics expansion of agricultural land will come at the expense of rain forests, savanna and increase in emissions of methane and nitrous oxide with potential to reduce crop yields. Incidentally, between 1980 and 2000, more than 55% of new land for agriculture replaced pristine forests, while 28% came from degraded forests (Gibbs et.al, 2010).

Biogeochemical Flows

Human activities such increased use of fossil fuels, agriculture, low use efficiencies and growing industrial demand have transformed the global Nitrogen (N) cycle. According to Fixen and West (2002) the use of N fertilizer in agriculture increased by approximately 800% from 1960 to 2000 leading to soil and air pollution, biodiversity loss and pollution of coastal waters and watersheds. Agriculture's share of total anthropogenic nitrogen use has been estimated at 86.1% (Galloway et.al, 2008). Other studies have pointed out that low use efficiencies meant that only half of nitrogen applied to croplands is incorporated into plant biomass, while the remaining is lost through leaching (16%), soil erosion (15%) and gaseous emissions (14%) (Liu et.al, 2010 and Bordirsky et.al, 2012). Human activities such as mining rock phosphate to produce phosphate (P) fertilizers have also transformed the global P cycle. With increased global demand for food due to rising population numbers and changing diets, demand for P could increase by 50-100% by 2050 (Cordell and White, 2013). The accelerated P cycle is likely to increase eutrophication of freshwater and estuarine systems (Reddy et.al, 2018). Some options to balance P budgets include increased use of recycled P from manure, human excreta and food residues to reduce reliance on new, mined P. Another option to reduce P losses from farms to aquatic systems is to use better tillage practices[4], restoring wetlands and establishing and maintaining riparian buffers (Campbell et.al, 2017).

Biosphere Integrity

Human activities such as land clearing have reduced forest cover with adverse impacts on genetic and functional diversity. Several species of flora and fauna and animal and bird species have become extinct and with it the functional aspects of diversity (for example, pollination of seeds by certain species of birds) have been compromised. Further, climate change and habitat fragmentation through major infrastructure interventions such as development corridors have resulted in the spread of invasive species into natural habitats at unprecedented levels with alarming consequences for biodiversity and ecosystem functions.

Climate Change

Agricultural activities emit large amounts of non- CO2 greenhouse gases, while deforestation, to create more space for agriculture, releases significant amounts of CO2. The entire food chain and its related activities, from production of fertilizer to distribution of food commodities, also emit significant amounts of CO2. All combined, this makes agriculture as one of the most important anthropogenic activities contributing to climate change. Furthermore, it is known that climate change will itself influence the conditions for agriculture and will have significant impact for the entire agricultural system. It has been estimated that agricultural emissions at national levels will contribute approximately 35% of total emissions in developing countries and 12% in developed countries (Richards et.al, 2015). The figure rises to approximately 25% when the entire supply chain, fertilizer manufacture, agricultural production, processing, transport, retail, household food management and waste disposal is considered (Vermuelen et.al, 2012).

Food Systems and the Circular Economy

We saw in the previous discussion that agriculture was the key driver for four Planetary Boundaries (PB's) that were at a critical stage of risk. We could deduce from the arguments of "stages of growth" theorists that as economies grow infrastructure begins to play an important role in connecting populations to services in the form of irrigation, wastewater treatment or hydro-power. "This is where planetary scale analysis of climate change, biogeochemical flows, biosphere integrity and land-system change need not necessarily support decision making at administrative scale: plot, farm, local government or river basin authority. So, while results of planetary scale analysis may emphasize the finiteness of water, soil and waste resources and advocate for recharge of aquifers, restoration of soils, multiple uses of forest ecosystems, extended life-cycle management of infrastructure or tax rebates for adoption of renewable energy, administrative scale decisions need not necessarily emphasize policies, projects or programs that support circular economy pathways such as reuse, re-manufacture, replace, reduce and retrofit" (Kurian et.al, 2018b). On the contrary the political

[4] See Kurian 2010 for a case study on field trials of soil erosion technologies in Laos

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economy compulsions may drive decision makers to commit more resources towards exploitation of newer sources of water and energy without ensuring that established infrastructure is properly functioning. This may satisfy entrenched political interests but may exacerbate pressure on environmental resources (Kurian and McCarney, 2010).

“Given the divergence between planetary and administrative scale analysis, five contemporary trends within the agriculture sector necessitate particular attention to enable a transition from a narrow focus on crop systems towards food systems (*Annexure 1):* (a) De-coupling of GDP growth from labour force participation in agriculture in contrast to food systems (the entire spectrum of activities from food production to processing and retail) (Campbell et.al, 2017), (b) increasing diversion of water from agriculture towards urban water supply reflecting a growth in secondary towns at the peri-urban interface, (c) changes in diets away from staples towards processed food reflecting changes in composition of labour force and changes in income and non-farm employment, (d) Land sub-division with potential to affect the viability of farming operations especially in high-density tropics (Saith, 1992) and (e) the growing influence of transnational corporations for seeds, capital, pesticides, marketing and mechanization that has had the effect of exacerbating the separation of power from local politics and decision making structures (Kurian et.al, 2018a)”.

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3. BRIDGING PLANETARY AND ADMINISTRATIVE SCALE PERSPECTIVES OF NATURAL RESOURCES MANAGEMENT: HOW THE NEXUS APPROACH CAN HELP AND WHAT IT MEANS FOR CGIAR'S HUMAN RESOURCES SKILLS SET?

In the previous section we pointed out that while results of planetary scale analysis may emphasize the finiteness of water, soil and waste resources and advocate for recharge of aquifers, restoration of soils, multiple uses of forest ecosystems, extended life-cycle management of infrastructure or tax rebates for adoption of renewable energy, administrative scale decisions need not necessarily emphasize policies, projects or programs that support circular economy pathways such as reuse, re-manufacture, replace, reduce and retrofit. This is primarily because of the compulsions of decision makers to balance the need for production of food (cereals, pulses etc.) with the organizational compulsions of departments to construct infrastructure and manage the distribution of bio-physical and institutional risks within permissible thresholds. Interestingly, this balancing act need not necessarily advance the cause of poverty reduction if structural dimensions of poverty such as household power dynamics, changes in prices in factor and product markets, foreign exchange rates and land tenure remain unaddressed.

Campbell et.al (2017) allude to the following paradox: two billion people lack enough calories and nutrients, while at the same time approximately two billion people consume too many calories (Ng et.al, 2014, FAO, 2014). This imbalance in food security is also reflected in an imbalance in the bio-physical world; evident in trends such as the transformation of the Nitrogen and Water cycle. Circular economy arguments for adoption of retrofit, reuse, re-manufacture, reduce and replace are crucial in trying to restore balance between how much is being consumed and by whom. However, trade-off analysis will reveal the costs of switching to alternative models of production and the incentives that are required for cooperation at transboundary, regional and local government levels to emerge. Crucial to such analysis are the use of "thresholds" for bio-physical and institutional dimensions that operate at both planetary and administrative scales. This when combined with a better understanding of synergies involving skills, clarity of functions and critical mass of interests will help bridge the gaps between planetary and administrative scale analysis of WEF Nexus interactions (*Annexure 2)*.

The Political Economy of Water-Energy-Food (WEF) Interactions

Half a century of experience has demonstrated that there is a gap between economic development theory and practice of sustainable development (White, 2009). What we know is that State formation can be key in defining the overall direction and momentum of institutional change (Fukuyama, 2012). For example, constitutional rules can determine the extent to which land reforms are undertaken. On the other hand, collective choice rules that usually operate at lower jurisdictions of provinces and districts can determine whether roads and irrigation systems are built according to acceptable standards (Ostrom, 1990). Operational rules at the level of watersheds can determine the extent to which taxes and tariffs are collected to ensure routine maintenance of irrigation infrastructure. It must be emphasized in this context that the forces of history,

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power relations between organizations in a multi-level governance structure and inter-governmental financing norms play a role in legitimizing an institutional framework and provides the basis for the exercise of property rights, laws and policy (*Annexure 3*).

Trade-off Analysis: Resource Challenge versus Allocative Challenge

The rise of modern nation states is predicated upon the notion of welfare; governments as a result play an important role in providing services that are affordable to those who do not have the means. Governments also invest in public goods such as forests, rivers and pasture lands when private interests would not be interested in anything else than short term gain. The welfare state invests in infrastructure to gain legitimacy. Modern legislatures enact laws protecting public resources such as wetlands, forests and pastures not because of their private profit but because of their mandate to conserve the public goods and advance welfare through maximization of ecosystem services in the form of recharge of aquifers, sustenance of plant and animal diversity in protected reserves and recovery of soil nutrients. National executive branches of governments execute laws through policies. The judiciary exists to interpret laws and guide the implementation of policy. At the global scale governments coordinate their action to protect the global commons such as oceans and the atmosphere through global treaties and conventions. The Paris Climate agreement is one example of a policy enacted involving multilateral coordination through the UN. While not legally binding unlike national level legislation, the Paris agreement still emphasizes the collective will to undertake climate action.

The concept of a Nexus trade-off is crucial to understanding how available public resources- human resources and finances can be deployed to address issues of food, energy and water security. The Sustainable Development Goals (SDG's) are an expression of the need to achieve food, energy and water security at a planetary scale. The target for each of the SDG's reflect important norms such as for example, wastewater reuse and recycle- SDG 6.3. The Nexus trade-off is an expression of the fact that achieving food, energy and water security is less of a resource challenge but more of an allocative challenge (*Annexure 4)*. In other words, if the challenge of achieving food, water and energy security was as simple as deploying environmental resources and technology, then logically the challenge would have been addressed by now. But on the contrary advances in technology and rising prosperity while increasing the volume of available water, soil and waste resources has had limited success with ensuring a proportionate increase in access to crucial public services such as irrigation, power and waste treatment.

Operationalizing the Nexus approach in research can potentially enhance the impact of global public goods research on food security through a focus on food systems. The implications for CGIAR are that conventional research skills will need to be combined with skills of political negotiation and strategic communication with UN agencies and Member States. Very often this issue can be incorrectly framed as a social science versus a physical science issue. The Nexus approach however, by emphasizing integrative analysis highlights the need for scholars from different disciplines to work together based on an agreed conceptual framework. In the case of our collaboration with UNHABITAT conceptualization of key Nexus concepts of trade-offs, synergies and resource optimization provided clarity to the initial desk review, formal agreement and regional consultations. The following eight non-iterative steps that were considered crucial in the design and execution of policy-oriented research emerged from a conceptualization of the Nexus approach:

- Initial desk review: public documents
- Formal agreement (MoU/Cooperation Agreement)
- Regional Consultation bringing together researchers and decision makers

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- Translating of a policy concern into a researchable question
- Scientific validation (citations)
- Input into political process (negotiation)
- Communication (Press release, communique, proceedings, publications, reports)
- Political Endorsement by UN/Member States

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4. INTEGRATIVE MODELLING OF TRADE-OFFS: THE EXAMPLE OF THE WASTEWATER REUSE EFFECTIVENESS INDEX (WREI) FOR SDG 6.3

Three distinct circumstances defined the process by which research on wastewater monitoring via a composite index were framed at UNU-FLORES. First, as part of a regional workshop on SDG monitoring methodologies that was organized by the United Nations, practitioners and scientists debated the state of the art on indicators for target 6.3 of the SDG's (Meyer and Kurian, 2016)? Second, participants queried whether the objective of global monitoring is to benchmark country performance on reuse or to ultimately identify the incentives required that would make reuse possible and build capacity to enable institutional change. Third, during a field visit to a wastewater treatment plant in Hanoi, workshop participants from five countries identified a common policy concern. Our approach to the subsequent research was influenced by the common policy concern that was articulated as follows: which sewer system- combined versus simplified was better placed to facilitate wastewater reuse in the context of rapid urbanization? (Kurian et.al, 2016b).

"From the perspective of discussing WEF Nexus interactions, wastewater reuse assumes importance since it has been estimated that approximately 20 million[5] hectares of land are currently under cultivation worldwide using wastewater (Rijsberman, 2004). When wastewater is better managed, significant economic benefits can be derived in developing countries through reuse for productive purposes like agriculture, kitchen gardens and poultry rearing (Jimenez and Asano, 2008; Amerasinghe et al. 2013). Some of the direct benefits of wastewater collection and reuse could include double cropping and lower input costs for agriculture (Kurian et.al, 2013). There may also be important economy-wide trade-offs of encouraging freshwater swaps through use of treated domestic wastewater in agriculture. While these trade-offs could involve enhanced source sustainability of the urban water supply, lower energy pumping costs and improved food security arising from increased farm incomes (Kurian et.al, 2013), linearity of outcomes cannot be assumed (Miller-Robbie et,al, 2017). In contexts characterized by complex feedback loops between resource use, agricultural productivity and considerations of distributional equity, posing the relevant question can be a major challenge in devising a methodology for monitoring a global goal on wastewater reuse (Harriss and Lyon, 2014).

Wastewater Reuse and Associated Trade-offs

Reused wastewater has an economic value and the establishment of a reliable price is necessary to guarantee an efficient allocation. Determining the *Willingness-to-Use* (WTU) and the *Willingness-to-Pay* (WTP) for wastewater therefore highlights several potential trade-offs. Molinos-Senate *et al*. (2013) emphasize that to encourage the use of recycled water, its tariffs should be significantly smaller than those of drinking water. They claim that the principle of cost recovery should not be strictly applied on water reuse projects while drinking water is being subsidised, as low drinking water rates make reused water uncompetitive. Additionally, when setting the price of recycled water, the cost of producing positive externalities should be considered namely those related to the regeneration of ecosystem service functions such as aquifer recharge. Educational campaigns to increase public awareness about the advantages of

[5] This figure translates into approximately 1.5% of the global cultivated area. It is important to acknowledge that this land area is not distributed evenly and reaches a much higher share in some geographies

reused water and to promote communities' involvement in water management issues may reduce the reluctance to use reclaimed water and increase the WTP for it.

Towards a Typology of Wastewater Reuse

Waste water management needs to be taken up at an appropriate scale for addressing the issue comprehensively. Interlinkages between surface, subsurface and soils necessitates the need to examine hydrological / watershed / river basin scale issues to understand the interlinkages and incorporate all the externalities. For, waste water could have positive and negative externalities as it impacts groundwater, surface water and soils beyond the periphery of its origin. For instance, groundwater contamination in distant areas due to seepage of wastewater is observed in several cases (Reddy et. al., 2018). Often, waste water recharged groundwater in downstream locations is observed to be less harmful to agriculture. Similarly, pollution impacts due to discharge of wastewater in upstream locations is very common in most river basins. All these externalities can be included only when appropriate scale is identified or defined. Defining the physical boundaries according to hydrological (aquifer) boundaries helps in including all the externalities in the case of groundwater. Soil impacts due to run off externalities could be captured at the watershed scale. River basin scale not only considers the surface water impacts but also groundwater and soil related externalities. The extent of impact also depends on the quantity and quality of wastewater generated and discharged. Highly polluted and huge quantities could have widespread impacts in the downstream. But, river basin scale may create problems of attribution as there could be multiple sources of pollution for a river basin, especially big ones" (Kurian et.al, 2018a).

There is need for defining the scale based on the problem in all its complexity. For instance, there could be different forms of waste water collection, treatment and use. These include: i) mixed systems for municipal waste and storm water, ii) separation of storm water from municipal waste, iii) mixing of industrial effluents with municipal waste water or storm water; iv) direct use or discharge of waste water into water bodies, v) simple treatment of wastewater through stabilization, and v) high quality treatment and use or discharge. Waste water generation and treatment need not necessarily result in its reuse. Reuse would depend on several factors ranging from natural (climatic); economic; geographical; and social. Natural factors could include: water scarcity conditions existing in the region. It is more likely that waste water reuse is more likely in water scarce regions. For example, most of urban areas would face water scarcity in the context of climate change coupled with unsustainable water management practices. Geographical factors including size of the town, vicinity of agricultural surroundings or water based industrial density could also influence water use.

The conventional view is that larger towns are more likely to generate more waste water. But this view that waste water problems are limited to class megacities is being challenged given the higher rates of urbanization in smaller towns. The problems could be more severe (water scarcity) in the smaller towns requiring treatment and reuse options. In fact, direct reuse of waste water is more likely in smaller towns (often un-recorded), given lower levels of infrastructure coverage. Their vicinity to agricultural lands and water dependent industry prompts higher levels of wastewater reuse. Higher levels of poverty may push people to reuse wastewater, especially for irrigated agriculture. Higher social capital in these regions may help users to organize and demand reuse options. For instance, in one of the small towns in South India, farmers in peri-urban areas were successful in pressurizing municipal authorities to release wastewater for irrigating their crops in upland regions and during summer months (Kurian et. al, 2013). Therefore, based on reuse options five waste water typologies could be identified and characterized with potential applications in developing countries (*Table 1*).

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Table 1: Typologies of Trade-offs for Wastewater Use in Agriculture

Typology	Characteristics	Trade-offs
1. Water Endowed	Large quantities of waste water generation. Low demand for reuse. Preference for fresh water. Economically better off. High likelihood of groundwater and down-stream contamination.	Water Security ↑ Food Security ↓ Energy Security ↓
2. Water Stressed	Relatively less generation. Demand for reuse. Relatively poor. High likelihood of direct reuse. Improved livelihoods. Incidence of wastewater related morbidity.	Water Security ↓ Food Security ↑ Energy Security ↔
3. Agro-ecology	High Demand for reuse. High likelihood of direct reuse for agriculture and livestock. Improved livelihoods. Low quality and contaminated food and milk. High morbidity and health costs	Water Security ↓ Food Security ↑ Energy Security ↔
4. Large Cities (Class I & II)[6]	Large Quantities of waste water generation. Number of reuse options viz., industry, urban and peri-urban agriculture; livestock rearing and others. Improved livelihoods. High morbidity. High potential for waste water management.	Water Security ↓ Food Security ↑ Energy Security ↑
5. Smaller Towns (Class III & IV)	Less Generation of waste water; Severe micro environment problems. Limited reuse options like vegetable crops and livestock rearing. High morbidity. Low potential for waste water management.	Water Security ↓ Food Security ↓ Energy Security ↔

Note: Arrows Indicate ↑↓ ↔ increase, decrease and constant respectively.

Given the characteristics of the typology, the possible resource trade-offs could be visualized. Here resource trade-offs are defined as increasing ones' resource security (say water) at the cost of other resource security (energy / food). At the same time resource security could go down for one or more resources and without any improvement in security of another resource (Typology 5), as the waste water is not effectively managed[7]. Trade-offs for Water-Energy and Food can therefore be characterized as ranging between high, medium or low. A high trade-off can be characterized as a situation where one resource gains at the cost of two resources (Typology 1). Medium trade-off is where one resource gains at the cost of another resource while the other remains stable (Typologies 2 & 3). Low trade-off is where two resources gain at the cost of one (Typology 4). The optimum situation would be when further trade-offs between resources is marginal. The difference between optimum and high trade-offs is the allocative efficiency. Allocative efficiency is achieved in the optimum case, whereas in the high trade-off there is high potential for allocative efficiency. That is, the optimum trade-off scenario incorporates the institutional and governance context as well and the low trade-off is close to optimum. Optimum trade-off could be termed as '*parito-optimal*' viz., where gaining security of

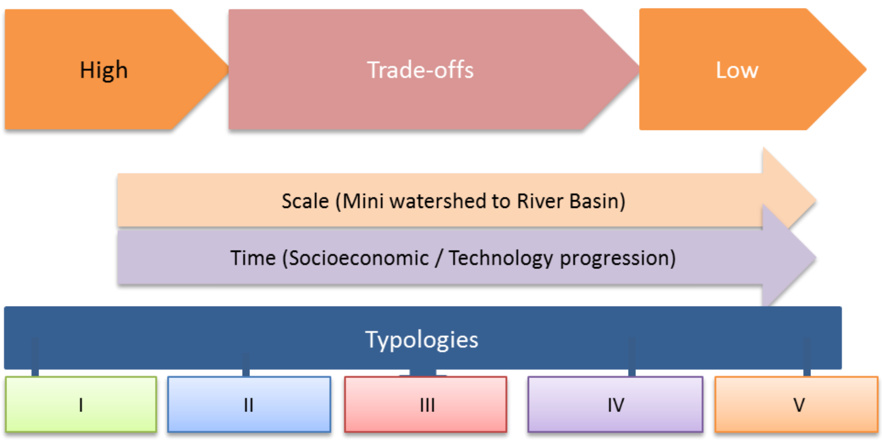
[6] Class I, II, III and IV cities and towns are identified based on population criteria and altered periodically based on Census data.
[7] This could be due to technology, financial or institutional constraints.

one resource is not possible without forgoing security of another resource, highlighting the inter-dependencies between environmental resources.

Figure 1 presents a stylized account of a typology of wastewater reuse situations that are characterized as ranging from between low to high trade-offs. Here trade-offs include institutional and governance aspects, which could underpin effective reuse of wastewater. It is portrayed that the potential resource linkages, incorporating externalities increases as one moves from micro (mini watersheds) to macro (river basins). In other words, one can hypothesize that as the scale increases the potential for optimum allocation through better allocative efficiency becomes possible under a low trade-off scenario. The time dimension reflects the socioeconomic progression and technology progression and adoption under a given institutional context. Thus, over time one moves from high trade-off scenario to low trade-off scenario. Theoretically, regions can be placed in different typologies given their present status to develop a characterization of trade-offs and create a basis for an improved understanding of institutional incentives required to support effective wastewater reuse. Existing research across regions dealing with nexus approach (waste water) could be placed in different typologies. While these projects may not reflect the true nexus perspective, their continuous refinement by initiating additional interventions in a case study mode could help identify Nexus principles in development practice. (Hazell, 2017).

Given the multiplicity of indicators and the inter linkages in the nexus context, incorporating all the indicators would cause practical problems for assessment and estimation. While the Nexus approach requires identifying the significant resource and feedback loops it can prove to be difficult and time consuming from a research perspective. Standard assessment or project evaluation tools such as life-cycle cost assessment find it difficult to incorporate all the linkages and externalities (Reddy et.al, 2015). Further, self-imposed boundary conditions are needed in life-cycle assessment to keep the assessment at a manageable level. This makes it is necessary to limit the scope of evaluations by identifying appropriate indicators. Boundary conditions could be specified based on theoretical consideration and typology of the problem and availability of quality information. This is where composite indices that combine both bio-physical and institutional and socio-economic data can be helpful in bridging the gap between science and development practice (OECD, 2008).

Figure 1: Stylized Characterization of Nexus Typologies.



5. IMPLICATIONS FOR INTERNATIONAL AGRICULTURE RESEARCH FOR DEVELOPMENT AGENDA

A Water-Energy-Food (WEF) Nexus framework can enhance the relevance of CGIAR research through the emphasis on integrative modelling of trade-offs involving environmental resources, services and associated bio-physical and institutional risks. Our analysis leads us to advocate for use of place-based observatories as a vehicle that can organize data and models to pursue integrative modelling, especially in contexts where the relationship between poverty and natural resources management are being challenged by structural changes in land ownership, income and employment. Place-based observatories by encouraging the use of composite indices, online learning portals, remote sensing and data visualization techniques in research could narrow the gap between planetary scale imperatives of promoting a circular economy model and the institutional incentives that are required to make such a transition possible (OECD, 2008). From a CGIAR perspective organizing models and data would support the use of typologies, scenario analysis and performance benchmarking tools in research with potential to advance robust monitoring of the impact of NRM research on poverty and environmental conservation (Kurian et. al, 2018b).

This background paper highlights several issues that are of significance for the agriculture for development research agenda. First, seen as contributing to development by enhancing resource-use effectiveness, the nexus requires rigorous analysis of feedbacks between developmental programs and outcomes in terms of poverty and environmental sustainability, going beyond descriptive characterization of laws and policies (Turral and Kurian, 2010). Second, analysis of feedback loops would benefit from institutional examination of social networks across a range of domains: a) organizations in a multi-level governance structure, b) individuals drawn from within and outside the public-sector, c) the private sector, and d) community organizations. Third, a truly integrative nexus analysis of environmental resources, services and risks would necessitate imaginative approaches to framing research questions, synthesis of cases, data management and pedagogical and didactic innovation for capacity building. Fourth, integrative analysis of trade-offs, potential for synergies and scope for optimization of resources (budgets, environmental and human resources) can go a long way in identifying incentives that support synergetic and coordinated decision making. Finally, a monitoring framework that draws upon the insights of integrative analysis can make trade-offs explicit and mitigate the rebound effects of developmental action.

A recent review of 245 papers/book chapters on the Nexus approach points out that the absence of institutional perspective can curtail the scope for synthesis and policy uptake (Albrecht et.al, 2018). Based on the discussion of key elements of institutional risk thresholds that was undertaken in this background paper we can highlight the following questions that CGIAR research employing a Nexus framework can address in the future (Kanter et.al, 2018):

1. What typologies of Nexus trade-offs can be identified based on a characterization of a circular economy with implications for reuse/recycle of environmental resources?
2. How can place-based observatories leverage the power of remote sensing, social network analysis, big data and in-situ data collection using GPS/mobile technology to model “thresholds to public action” in response to risks that have been identified through an engagement with bio-physical, institutional and socio-economic data?

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3. What open source software can be developed to support continuous improvement of visualization, data transformation, benchmarking and scenario analysis tools with potential to enhance integrative monitoring of socio-ecological systems?
4. What pedagogical and didactic innovations can be fostered to enable online learning to support construction of longitudinal case studies based on reuse of datasets and co-design of nexus principles in development practice?

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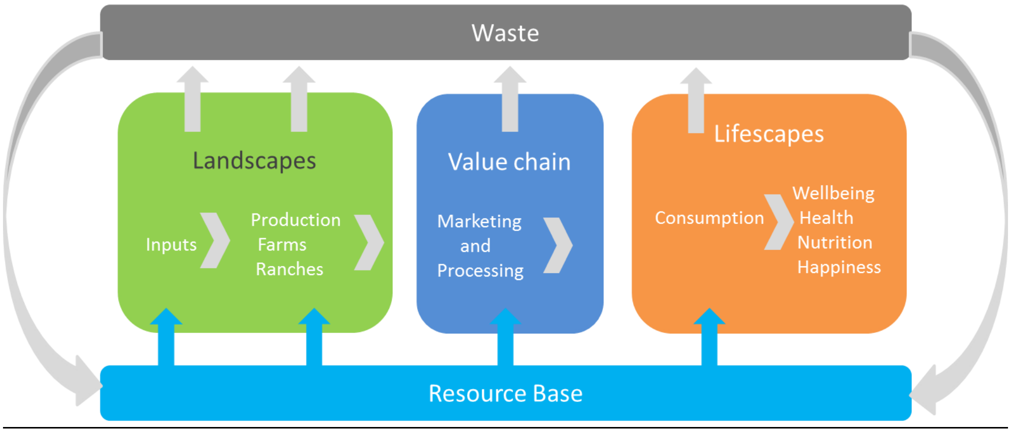
ANNEXES

Annexure 01: Flow perspective of food systems (adapted from Tomich et al. 2018)

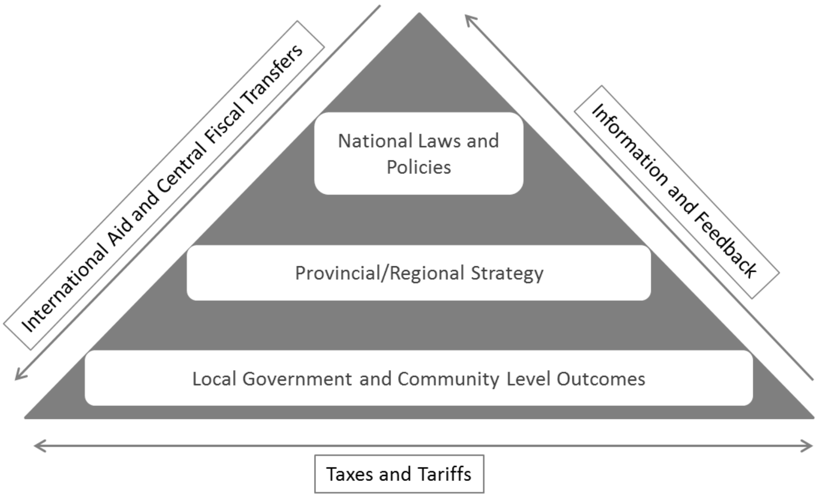


Annexure 02: Pathways Linking Agricultural Research for Development to Poverty Reduction

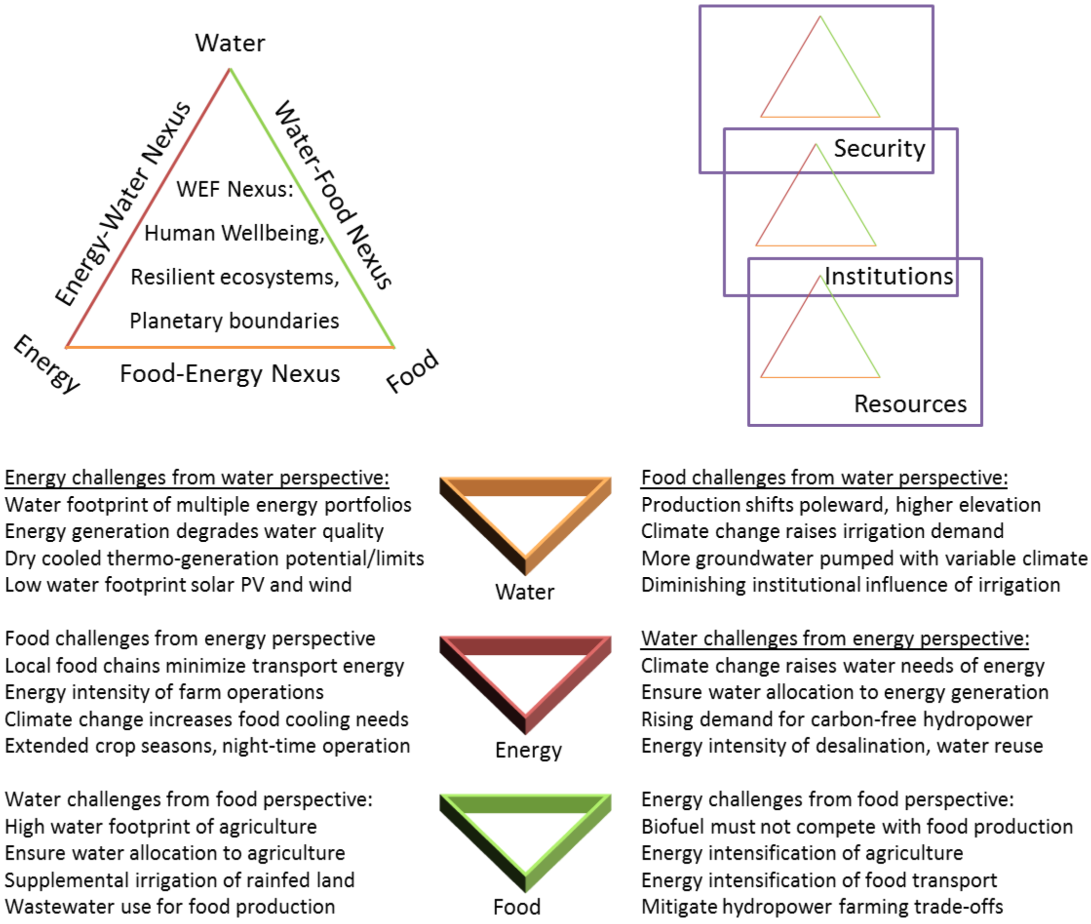
Impact Pathway	R&D Activity	Output	Uptake	Outcome	Impact at agro-ecological/national scale
Human nutrition	Farming system, breeding, input system, value chains, agricultural management practices	Cultivars and varieties, improved management practices for irrigation, livestock or fisheries	Adoption by households, awareness of policy makers and private sector	Diversification of income and farm and non-farm employment	Increased revenue for farmers
Innovations to increase productivity	Farming practices	Productivity enhancing farming models	Adoption by poor farming households	Reduced farm-level risk; incentives for investment	Reduced vulnerability of famers, stable demand for farm labour
Food Supply	Policy analysis, farming systems, breeding and agricultural management practices	Policy analysis covering value chains, market infrastructure, high yielding varieties and cultivars	Adoption by households, awareness of policy makers and private sector	Greater supply of food and lower food prices for consumers in both urban and rural areas	Increased income in real terms, especially for poor farming households
Education (agricultural skills)	Program, design and development, assessment	Organizational models	Awareness, participation of poor	Policy makers and civil society organizations made aware and capacity built	Higher labour productivity, organizational capacity, greater access to information

Source: *Tomich et.al, 2018*

Annexure 03: Individual and agency behaviour shaped by the role of public financing (adapted from Kurian et al. 2017)



Annexure 04: Interlinkages and challenge perspective at multiple levels in the water-energy-food nexus (adapted from Scott et al. 2015)



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Annexure 5: Glossary of Terms

Integrative modelling: Integration of bio-physical and institutional considerations in modelling exercises

Socio-ecological systems: Systems of analysis that incorporate a coherent framework for examination of social systems as embedded within bio-physical systems and processes and that also have the potential of being able to influence bio-physical systems.

Trade-offs: Outcomes of a process of political negotiation that is focussed on maintaining a balance between efficiency of bio-physical systems and equity and distributional concerns inherent in governance systems.

Synergies: Outcomes generated by a governance system tasked with managing complex, changing and differentiated socio-ecological systems. Synergies are a function of a critical mass of financing and technology, information sharing within social networks and institutional capacity to respond to a given environmental challenge based on an alignment of resources and interests within a multi-level governance structure.

Administrative Scale: The level at which decisions relating to financing of infrastructure and delivery of public services such as food storage and distribution, water supply or irrigation are made.

Planetary scale: Analysis of environmental resources at terrestrial scale- eg. oceans, atmosphere.

Food Systems: Framework of analysis of food security that considers not just production but consumption, processing, retail and storage

Crop Systems: Analysis that is limited to performance of crop systems under controlled soil or climate conditions

Place-based observatories: Mechanisms that enable the systematic organization of data and models to develop, validate and pilot-test approaches that address challenges of environmental management and food security based on tools (eg. composite indices) of integrative analysis.

Circular economy: A perspective that is focussed on optimizing use of environmental resources by advancing principles of reuse, recycle and remanufacture to address challenges such as climate change, water scarcity and food insecurity.

Bio-physical risk thresholds: It could range from anything from structure of soil particles being transported or the pressure with which water is transported. Sensors are normally used to measure these aspects- but the point being that decision makers need to be conscious of the need to monitor bio-physical thresholds to support system performance

Institutional risk thresholds: Conditions such as availability of subsidies, taxes and tariffs that define the viability of infrastructure for management of environmental resources and delivery of public services. For example, will governments subsidize maintenance of constructed infrastructure? will consumers pay for services? Depending on local context institutional risk may vary and thresholds will need to be defined to ascertain when the system will become susceptible to collapse.

Political economy: Systematic analysis that incorporates the compulsions of revenue generation and expenditure in decisions by public agencies relating to management of environmental resources and delivery of public services.

Integrative analysis: Integrated management focusses on the development side- managing for example, water, soil or waste in an integrated way. Integrative analysis refers to the analytical aspects involved in modelling behaviour of both bio-physical and institutional systems that are inherently non-linear, complex and differentiated.

REFERENCES

Albrecht T, Crootof A and C.A. Scott. 2018. The Water-Energy-Food Nexus: A systematic review of methods for nexus assessments, *Environmental Research Letters* forthcoming

Amerasinghe, P., R.M. Bhardwaj, C.A. Scott, K. Jella, F. Marshall. 2013. Urban wastewater and agricultural reuse challenges in India. *IWMI Research Report No. 147.* International Water Management Institute. Colombo, Sri Lanka. 36 p. doi: 10.5337/2013.200, www.iwmi.cgiar.org/Publications/IWMI_Research_Reports/PDF/PUB147/RR147.aspx

Bernhofer, C., Barfus, K., Pavlik, D., Borges, P., Söhl, D. (2016): Climate Change information for IWRM. Springer Environmental Sciences Edited Volume, D. Borchardt et al. (eds.), *Integrated Water Resources Management: Concept, Research and Implementation*, DOI 10.1007/978-3-319-25071-7_8, 171-197.

Bordirsky B, Popp A, Weindl M, Dietrich J, Rolinski S, Scheiffele L, Schmitz C, Campen-Lotze H. 2012. N20 Emissions from the Global Agricultural Nitrogen Cycle- Current State and Future Scenarios, *Biogeosciences* 9(10): 4169-4197

Brohman J. 1996. Popular development: rethinking the theory and practice of development, Blackwell publishers, Cambridge MA

Campbell B, Beare D, Bennett E, Hall-Spencer J, Ingram J, Jaramillo F, Ortiz R, Ramankutty N, Sayer J, Shindell D. 2017. Agricultural Production as a Major Driver of the Earth System Exceeding Planetary Boundaries, *Ecology and Society* 22 (4): 8

CGIAR. 2016. CGIAR Strategy and Results Framework 2016-2030, Consultative Group on International Agriculture Research

Cordell D. and S. White. 2013. Sustainable Phosphorous Measures: Strategies and Technologies for Achieving Phosphorous Security, *Agronomy* 3(1): 86-116

Endo, A., Burnett, K., Orencio, P., Kumazawa, T., Wada, C., Ishii, A., Tsurita, I., Taniguchi, M., 2015. Methods of the water-Energy-Food nexus. Water 7, 5806– 5830.

Fixen P. and F West. 2012. Nitrogen Fertilizers: Meeting Contemporary Challenges, AMBIO: A Journal of the Human Environment 31(2): 169-176

Foley J, De Fries R, Asner G, Barford C, Bonan G, Carpenter S, Chapin F, Coe M, Daily C, Gibbs H. 2005. Global Consequences of Land Use, *Science* 309 (5734): 57—574

Food and Agriculture Organization (FAO). 2014. The State of Food Insecurity in the World: Strengthening the Enabling Environment for Food Security and Nutrition, FAO, Rome, Italy

Fukuyama. F. 2012. The origins of political order: from pre-modern times to the French revolution, London: Profile Books.

Galloway J, Townsend A, Erisman W, Bekunda M, Cai Z, Freney J, Martinella A, Seitziner S and M. Sutton. 2008. Transformation of the Nitrogen Cycle: Recent Trends, Questions and Potential Solutions, *Science* 349(6243): aac4722

Gibbs H, Ruesch A, Heunke J, Steffan W, Richardson K, Cornell S. 2010. Tropical Forests were the Sources of New Land in the 1980's and 1990's. Proceedings of the National Academy of Sciences 107 (38): 16732-16737

Harriss, F., Lyon, F., 2014. Transdisciplinary environmental research: A review of approaches to knowledge co-production. Nexus network think piece series, Paper 002, November.

Hazell P. 2017. Global Trends in Urbanization, Agriculture and Smallholder Farming, in Pingali P. and Serraj R (Eds), Agri-Food Systems into 2050: Threats and Opportunities. World Scientific (forthcoming)

Kanter D, Musumba M, Wood S, Palm C, Antle C, Balvanera P, Dale V, Havlik P, Kline , Scholes R, Thornton P, Tittonell P, and Andelman S. 2016. Evaluating Agricultural Trade-offs in the Age of Sustainable Development, *Agricultural Systems*

Kurian M. Scott C, Alabaster G, V. Reddy, A. Nardocci, R. Boer. 2018a. Governing the Nexus of Water-Energy and Food- Resources, Risks and Unintended Consequences of Development, *Ambio (under review)*

Kurian M, Portney K, Rappold G, Hannibal B, Gebrechorkos S. 2018b. Governance of the Water-Energy-Food Nexus: A Social Network Analysis to Understanding Agency Behaviour, in Huelsmann S and R. Ardakanian (Eds) Managing Water, Soil and Waste Resources to Achieve Sustainable Development Goals, Springer, Switzerland.

Kurian M and R. Ardakanian. 2015. Governing the Nexus- Water, Soil and Waste Resources considering Global Change, Springer, Dordrecht.

Kurian M, L. Veiga, R. Boer and G. Alabaster. 2016a. Wastewater Reuse Effectiveness Index (WREI)- Monitoring Methodology for SDG Target 6.3, Dresden, UNU-FLORES

Kurian M. R. Ardakanian, L. Veiga and K. Meyer. 2016b. Resources, Services and Risks- How can Data Observatories bridge the Science-Policy Divide in Environmental Governance? Springer, Switzerland

Kurian M. 2010. Making sense of Human-environment Interaction- Policy Guidance under conditions of Imperfect Data, in Kurian M. and P. McCarney (Eds) *Peri-urban water and sanitation services- policy, planning and method,* Springer, Dordrecht

Kurian M. 2017. The Water-Energy-Food Nexus- trade-offs, thresholds and trans-disciplinary approaches to sustainable development, *Environmental Science and Policy,* Vol. 68, pp. 97-108.

Kurian M. V. Ratna Reddy, T. Dietz, D. Brdjanovic. 2013. Wastewater Reuse for Peri-urban Agriculture- A Viable Option for Adaptive Water Management? *Sustainability Science,* Vol. 8, No. 1, pp. 47-59, Springer, UNU- Tokyo.

Liu J, You L, Amini M, Obersteiner M, Herroro M, Zehnder A, Yang H. 2010. A High-Resolution Assessment on Global Nitrogen Flows in Cropland, *Proceedings of the National Academy of Sciences,* 107(17): 8035-8040

Liu J, V. Hull, C. Godfray, D. Tilman, P. Gleick, H. Hoff, C. Wostl, Z. Xu, M. Chung, J. Sun, S. Li. 2018. Nexus approaches to global sustainable development, *Nature Sustainability,* pp. 466- 476, September 14.

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Meyer K. and M. Kurian. 2016. Water-wastewater nexus in urbanizing Asia: building capacity for monitoring water quality risks, Proceedings, Regional consultation workshop, Hanoi, Vietnam, May 24-25.

Miller-Robbie L, A. Ramaswami and P. Amerasinghe. 2017. Wastewater treatment and reuse in urban agriculture: exploring the food, energy, water and health nexus in Hyderabad, India, *Environmental Research Letters, 075005.*

Molinos-Senate, M., Hernandez-Sancho, F., & Sala-Garrido, R. (2013). Tariffs and cost-monitoring water quality risks, technologies by modelling the total urban water cycle. *Urban Water Journal*, 9(1), 1-10.

Ng. M, Fleming T, Robinson M, Thomson B, Graetz N, Margono C, Mullany E, Biryukov S, Abbafati C, Abera S. 2014. Global, Regional and National Prevalence of Overweight and Obesity in Children and Adults during 1980-2013: A Systematic Analysis for the Global Burden of Disease Study 2013, *Lancet* 384 (9945): 766-781.

OECD (2008); Handbook of Constructing Composite Indicators-Methodology and User Guide, Organisation for Economic Cooperation and Development, Paris.

Ostrom E. 1990. Governing the commons: the evolution of institutions for collective action, University Press, Princeton, Cambridge

Reddy V, D. Cunha and M. Kurian. 2018. A Water-Energy-Food Nexus Perspective on the Challenge of Eutrophication, *Water, Vol. 10, pp. 101,* MDPI, Switzerland.

Reddy V, M. Kurian and R. Ardakanian. 2015. Life-cycle Cost Approach for Management of Environmental Resources- A Primer, Springer, Dordrecht.

Ricciardi V, Ramankutty N,Mehrabi Z, Jarvis L. 2018. How much of the World's Food do Smallholders Produce, *Global Food Security,* Vol. 17, pp. 64-72?

Rijsberman F (2004) Sanitation and access to clean water. In:Lomborg B (ed) Global crises, global solutions. Cambridge University Press, London.

Rockstrom J, W. Steffan, K. Noone, Persson A, Chapin F, Lambin E, Lenton T, Scheffer M, Folke C, Schellnhuber H, Nykvist B, de Wti C, 2009. A Safe Operating Space for Humanity, *Nature* 461 (7263): 472-475.

Saith A. 1992. The Rural Non-Farm Economy- Policy and Process, International Labour Organization, Geneva

Scott, C.A., Kurian, M., and Wescoat, J. L., Jr. 2015. "The Water-Energy-Food Nexus: Enhancing Adaptive Capacity to Complex Global Challenges," in M. Kurian and R. Ardakanian, eds., Governing the Nexus: Water, Soil and Waste Resources Considering Global Change. Cham, Switzerland: Springer International.

Steffan W, Richardson K, Rockstrom J, Cornell S, Fetzer I, Bennett E, Biggs R, Carpenter S, Vries W, de Wit C, Folke C. 2015. Planetary Boundaries: Guiding Human Development on a Changing Planet, *Science* 347 (6223): 12598855

Stevenson J. and P. Vlek. 2018. Assessing the Adoption and Diffusion of Natural Resource Management Practices: Synthesis of a New Set of Empirical Studies, *CGIAR Standing Panel on Impact Assessment Synthesis Report,* April

Tomich T, Lidder P, Coley M, Gollin D, Dick R, Webb P, and Carberry P. 2018. Food and Agricultural Innovation Pathways for Prosperity, *Agricultural Systems,* forthcoming

Turral. H and M. Kurian. 2010. Information's role in adaptive groundwater management. In Kurian M and McCarney P (Eds), Peri-urban water and sanitation services- policy, planning and method, Springer, Dordrecht

UN-Water. 2018. Sustainable Development Goal 6: Synthesis Report on Water and Sanitation, United Nations, New York.

Vermuelen S, Campbell B and Ingram J. 2012. Climate Change and Food Systems, *Annual Review of Environment and Resources* 37(1): 195-222

White H. 2009. Theory Based Impact Evaluations: Principles and Practice, *Working Paper No. 3,* International Initiative for Impact Evaluation, Global Development Network, New Delhi.

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