UNIVERSITY OF TECHNOLOGY SYDNEY

Faculty of Engineering and Information Technology

# A NEXUS APPROACH TO ENERGY, WATER, AND FOOD SECURITY POLICY MAKING IN INDIA

By

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**A dissertation submitted in the fulfilment of the requirement for the degree Doctor of Philosophy**

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# CERTIFICATE OF ORIGINAL AUTHORSHIP

I, Garima Vats, declare that this thesis, is submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Information, Systems, and Modelling under the Faculty of Engineering and Information Technology at the University of Technology Sydney. This thesis is wholly my own work unless otherwise reference or acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis. This document has not been submitted for qualifications at any other academic institution. This research is supported by the Australian Government Research Training Program.

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*Dedicated to my parents*

## Acknowledgement

While I was engaged in exploring the concept of 'nexus' (the central idea of my thesis), I saw a striking similarity in the last few years of my life to this concept. This thesis examines the interlinkages or 'nexus' between energy, water, and food and associated policy trade-offs across different domains. My life in past few years seemed no different, what with the interlinkages in all its facets, and the trade-offs they demanded.

While I was the exploring the concept of energy, water, food nexus from different domains or perspectives, I simultaneously discovered some aspects of my own personality, barely known to me earlier. While examining the policy trade-offs, I recognized the ones real life offers us – either to comfortably survive in your "business-as-usual" or to push your own boundaries and step out of your comfort zone. No words can describe my experience of last few years, however, I can certainly articulate some words to thank those without whom I could not have initiated and completed this journey.

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# List of Abbreviations

| | |
|---|---|
| AAY | Antyodaya Anna Yojana |
| AEZ | Agro-ecological zoning |
| AoA | Agreement on Agriculture |
| APDRP | Accelerated Power Development and Reforms Programme |
| ASP | Activated Sludge Process |
| BAT | Best Available Technologies |
| BAU | Business-as-Usual |
| BCM | Billion Cubic Metres |
| BPL | Below-poverty-line |
| BRICS | Brazil, the Russian Federation, India, China, and South Africa |
| BTS | Base Transceiver Station |
| CACP | Commission for Agricultural Costs and Prices |
| CAGR | Compounded Annual Growth Rate |
| CBM | Coal Bed Methane |
| CCS | Carbon Capture and Storage |
| CEA | Central Electricity Authority |
| CES | Constant elasticity of substitution |
| CET | Constant Elasticity of Transformation |
| CGDS | Capital Goods |
| CGE | Computable General Equilibrium |
| CHP | Combined Heat and Power |
| Comtax | Commodity Tax |
| CPCB | Central Pollution Control Board |
| CROPWAT | Crop water requirements |
| CSP | Concentrated Solar Power |
| DEA | Data Envelopment Analysis |
| EEFP | Energy Efficiency Financing Platform |
| EEIO | Environmentally Extended Input-Output |
| ES | Energy Security |
| EWF | Energy-water-food |
| FAO | Food and Agriculture Organization |
| FAOSTAT | Food and Agriculture Organisation Statistics |
| FBEP | Gross factor-based subsidies |
| FBR | Fast Breeder Reactor |
| FCV | Fuel cell Vehicle |
| FDI | Foreign Direct Investment |
| FEEED | Energy Efficient Economic Development |
| FS | Food Security |
| FTRV | Gross Factor Employment Tax Revenue |
| GDP | Gross Domestic Product |
| GHG | Green House Gas |
| GoI | Government of India |
| GST | Goods and Services Tax |

| | |
|---|---|
| GTAP | Global Trade Analysis Project |
| IAD | Institutional Analysis and Development |
| ICDS | Integrated Child Development Services |
| IESS | Indian Energy Security Scenarios |
| IGCC | Integrated Gasification Combined Cycle |
| IIUSE | Intermediate Use |
| ILO | Indian Labour Organisation |
| IMPACT | International Model for Policy Analysis of Agricultural Commodities and Trade |
| INM | Integrated Nutrient Management |
| INR | Indian Rupees |
| IO | Input-Output |
| ISA | International Solar Alliance |
| ISEP | Net Intermediate Input Subsidies |
| IWMP | Integrated Watershed Management Program |
| IWRM | Integrated water resources management |
| JNNSM | Jawaharlal Nehru National Solar Mission |
| JNNURM | Jawaharlal Nehru National Urban Renewal Mission |
| Kgoe | Kilogram of oil equivalent |
| LEAP | Long Range Energy Alternatives Planning system |
| LED | Light Emitting Diode |
| LPG | Liquefied Petroleum Gas |
| LUSET | Land use evaluation tool |
| LWR | Light Water Reactor |
| MARKAL | Market and Allocation |
| MBR | Membrane bio-reactors |
| MFAREV | Export Tax Equivalent of Multi-Fibres Agreement (MFA) Quota Premia |
| MLD | Million litres per Day |
| MMT | Million Metric Tonnes |
| MNRE | Ministry of Renewable Energy |
| MNREGA | Mahatma Gandhi National Rural Employment Guarantee Act |
| MoP | Ministry of Power |
| MOSPI | Ministry of Statistics and Programme Implementation |
| MoWR | Ministry of Water Resources |
| MRIO | Multi-Regional Input-Output |
| MSP | Minimum Support Prices |
| MSW | Municipal Solid Waste |
| MTEE | Market Transformation for Energy Efficiency |
| MuSIASEM | Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism |
| MW | Mega Watts |
| NAPCC | National Action Plan on Climate Change |
| NAS | National Account Statistics |
| NCAER | National Council of Applied Economic Research |
| NDC | Nationally Determined Contribution |
| NEP | National Environment Policy |
| NHM | National Health Mission |

| | |
|---|---|
| NICRA | National Initiative on Climate Resilient Agriculture |
| NITI | National Institution for Transforming India |
| NMEEE | National Mission for Enhanced Energy Efficiency |
| NMSA | National Mission on Sustainable Agriculture |
| NPK | Nitrogen-Phosphorus-Potassium |
| NSGM | National Smart Grid Mission |
| NSM | National Solar Mission |
| NSSO | National Sample Survey Organisation |
| NTPC | National Thermal Power Corporation |
| NURM | National Urban Renewal Mission |
| NWM | National Water Mission |
| NWQSM | National Water Quality Sub-Mission |
| PAT | Perform, Achieve and Trade |
| PDS | Public Distribution System |
| PFA | Power for All |
| PFCE | Private Final Consumption Expenditure |
| PFI | Population Foundation of India |
| PHWR | Pressurised Heavy Water Reactor |
| PKVY | Paramparagat Krishi Vikas Yojana |
| PLF | Plant Load Factor |
| PNG | Piped Natural Gas |
| PPP | Public-Private Partnership |
| PV | Photovoltaic |
| PWHR | Pressurized Heavy Water Reactor |
| R-APDRP | Restructured Accelerated Power Development and Reforms Programme |
| RBI | Reserve Bank of India |
| RGNDWM | Rajiv Gandhi National Drinking Water Mission |
| RPOs | Renewable Purchase Obligations |
| SAM | Social Accounting Matrix |
| SBR | Submerged Bed Reactor |
| SC | Super Critical |
| SDG | Sustainable Development Goals |
| SEEP | Super-Efficient Equipment Programme |
| SHM | Soil Health Management |
| SMAF | Sub-Mission on Agroforestry |
| SPM | Suspended Particulate Matter |
| SWI | Shannon Weiner Index |
| T&D | Transmission and Distribution losses |
| TARIFREV | Tariff Revenue |
| TFRV, ADV | Ordinary import duty, ad valorem |
| TPDS | Targeted Public Distribution System |
| UASB | Upflow Anaerobic Sludge Blanket Reactor |
| UDAY | Ujwal Discom Assurance Yojana |
| UIDSSMT | Urban Infrastructure Development Scheme for Small and Medium Towns |
| UJALA | Unnat Jyoti by Affordable LED for All |
| UNCED | United Nations Conference on Environment and Development |

| | |
|---|---|
| UNDP | United Nations Development Programme |
| UNESCAP | United Nations Economic and Social Commission for Asia and the Pacific |
| UNFCCC | United Nations Framework Convention on Climate Change |
| UNICEF | United Nations International Children's Emergency Fund |
| UNU | United Nations University |
| USC | Ultra-Super Critical |
| USD | United States Dollar |
| VDGM | Domestic purchases, by government, at market prices |
| VDPM | Domestic purchases, by households, at market prices |
| VST | Margin exports |
| VXMD | Non-Margin Exports, At Market Prices |
| WEAP | Water Evaluation and Planning, |
| WEF | World Economic Forum |
| WEO | World Energy Outlook |
| WRI | World Resources Institute |
| WS | Water Security |
| WSP | Waste Stabilisation Ponds |
| WtE | Waste-to-Energy |
| WTO | World Trade Organization |
| XTRV | Ordinary Export Tax |

# Abstract

Prompted by the rising concerns about the security of Energy-Water-Food (EWF) – innate human needs – and premised upon the contention about the siloedness, and hence inadequacy, of current policy approaches to redress EWF security – this research examines the efficacy of EWF nexus-informed policy-approach for redressing EWF security in the context of India – a country whose future prosperity is critically dependent on the provision of adequate quantities of EWF, at affordable prices and by sustainable means. To achieve this objective this research has developed an EWF-extended Input-Output framework (model), supported by flexible production functions to accommodate price-induced input substitution possibilities. This framework is employed in this research to examine the impacts – in terms of selected attributes for EWF security, economic, social and environmental outcomes, over the period 2015-2047 – of (five) alternative policy pathways (scenarios). These scenarios include: Business-as-Usual (BAU), Energy Security (ES), Water Security (WS), Food Security (FS), and EWF-Nexus-oriented (Nexus). Each scenario represents specific policy emphasis (e.g., ES scenario, on improving energy security; WS - water security, FS - food security, and Nexus - joint EWF security). Accordingly, each scenario is supported by a range of emphasis-relevant technologies and strategic measures to achieve its policy objective. The analysis in this research presents a rather insightful array of indications about EWF security, economic, social and environmental outcomes – over the short, medium, and long-term. For example, the ES scenario, while producing best energy security and economic outcomes in the long-term, is likely produce considerably worsened water security throughout the study period; and yield worst environmental outcomes in the short and medium-term. The FS scenario – while producing consistently superior food security outcomes, also produces the best water security outcomes in the short-term, and worst energy security outcomes in all time periods. The WS scenario, while producing considerably improved water security in the long-term, is likely to produce worst economic outcomes throughout the study period. Overall, the Nexus scenario produces the best joint EWF security outcomes, and considerably superior economic, social and environmental outcomes. These insights – especially cross-sectoral (e.g., energy, water, food), cross-domain (security, economic, social, environmental), and temporal (short, medium and long-term) trade-offs – should provide the Indian policy-makers a robust platform for engendering policy debate and making appropriate policy choices for redressing the EWF security challenge, and for other pressing challenges underscored by multiplicity of interdependencies. Therein resides the significance of this research – it is argued.