The synergy of Water User Associations in the Water-Energy-Food Nexus: The role of multi-level governance and equity in the Allocation

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Abstract

Water-Energy-Food (WEF) Nexus is an integration paradigm to achieve Sustainable Development. The water governance of Andhra Pradesh is construed as a socio-technical regime in this study. The regime of Water User Associations (WUAs) with a regime rationality of enhancing financial recovery of the system and ensuring equitable water supply for farmers is envisioned through the transition research framework. The synergy that WUAs held in the WEF nexus can better be analyzed by combining the Institutional Analysis and Development Framework (IAD) and Transitions Heuristic Framework. The results suggest that the role of finance plays a major role in the transitions to accelerate. For effective management of the WEF nexus, the coordination among actors, coherence among institutions and policy spheres in multi-system transitions is the key.

Keywords: Water-Energy-Food Nexus, Water User Associations, Multi-level Perspective, Equity.

1. Introduction

Water, Energy, and Food are essential for human sustenance, economic growth, livelihoods, and environmental sustainability (Lebel & Lebel, 2018). It mainly stemmed from the three interrelated Sustainable Development Goals (SDGs) namely- goal 2 (food), goal 6 (water), and goal 7 (energy) (Mahjabin et al., 2020). The Water-Energy-Food (WEF) nexus is the set of interconnections and interdependencies existing among them in production and consumption (Jeswani et al., 2015). Hence, it entails trade-offs and synergies (Biggs et al., 2015). Add to this, the complexity exerted by population growth, rapid urbanisation, rising income levels, and changing lifestyles (Dargin et al., 2019). The rise and popularity of the 'WEF nexus' in research, policy, and business circles are attributed to the '2011 Bonn Conference of the nexus, Germany' (Hoff, H., 2011). It is unsurprising given that 'nexus' means different things to different people (Sušnik, 2018) leading to varied perspectives (Proctor et al., 2020) and critiques (Cairns & Krzywoszynska, 2016). Mitigating the trade-offs and tapping the synergies requires an integrated approach (Weitz et al., 2017). The effective management of the WEF nexus would seek integration from technological, institutional, and policy spheres (Al-Saidi & Elagib, 2017). To this end, this paper uncovers the potential of Water User Associations (WUAs) in the effective management of the WEF nexus from an institutional perspective. WUAs in this study are conceptualised as a regime in the transition framework (Miörner et al., 2022). The abstraction of groundwater for irrigation across the world is granted, provided the lack/limitations of irrigation infrastructure such as dams, tanks, canals, etc. But, the presence of infrastructure with improper functioning of the WUAs has an impact on the sustainable management of the WEF nexus (Bhaduri et al., 2015; Mekonnen et al., 2015; Shenhav & Domullodzhanov, 2017). The link is clear in the sense that farmers resort to groundwater sources in the case of improper functioning of WUAs. But the abstraction of groundwater is deeply linked to the energy policies and property regimes existing. Hence the WUAs make the case for the WEF nexus to act upon from the institutional aspects. Furthermore, groundwater abstraction has environmental impacts too (Mukherji, 2022). Therefore, this study portrays the functioning of WUAs in Andhra Pradesh from an MLP lens and suggests that policy coordination among the actors in the WEF nexus is the key to capitalise on the synergies existing in the WEF nexus particularly arising out of WUAs. Following this introduction, section 2 covers the background against which the study is undertaken, section 3 dwells on the Material and Methods, section 4 deals with the results and discussion of the study, section 5 points to the limitations and further research, and finally, section 6 concludes the study.

2. The background against which the study is undertaken.

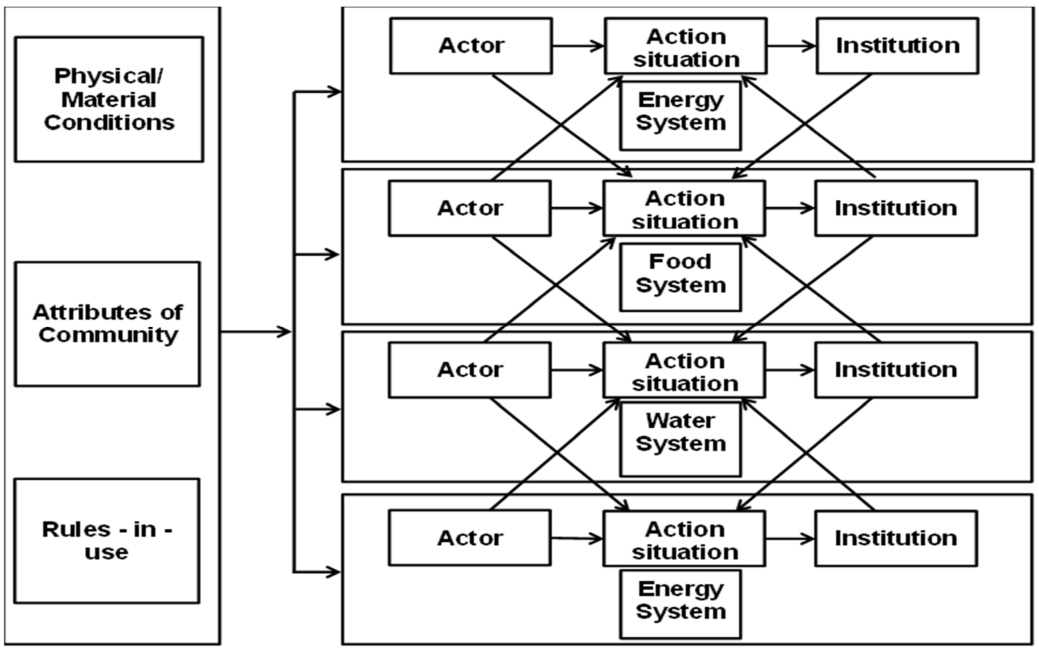
The focus of this paper is on tandem with the expanding scope of the field of sustainability transitions. Sustainability transitions initially included analysis of electricity and transport sectors. However, eventually, it embraced other domains such as water, food, health, housing, and manufacturing (van den Bergh et al., 2021). In this vein, this paper attempts to analyze the WEF nexus. The concept of the WEF nexus did not percolate to developing countries to a great extent (Gain et al., 2015). Along with this, the WEF nexus has evolved as another integration paradigm in the realm of environmental resources. The other paradigms are

Integrated Natural Resources Management (INRM) and Integrated Water Resources Management (IWRM) and Integrated Solid Waste Management (ISWM). The key difference between IWRM and the WEF nexus is the former is water-centric, while the latter integrates the three sectors (Benson et al., 2015). Moreover, one complements the other rather than competes (Roidt & Avellán, 2019). Since the IWRM is governed at a river basin scale, WUAs can be conceptualised as the decentralized form of governance within the scope of IWRM (Richards, 2019; Richards & Syallow, 2018). However, India did not implement IWRM (Pandit & Biswas, 2019). Against this backdrop, The Government of Andhra Pradesh (GoAP) has initiated the process of reforms in irrigation management by enacting the act namely- the Andhra Pradesh Farmers' Management of Irrigation Systems Act, 1997. This was possible mainly due to fact that water is a state subject in the Indian Constitution. It can be modeled by 'Innovative power' of (Avelino & Rotmans, 2009)'s approach to power. It is the first of its kind in India, hence called the 'Andhra Model' of irrigation. Succinctly put, the background for the Irrigation Management Transfer Programme in Andhra Pradesh is to bring allocative efficiency and equity into the system since they have bearing on the financial sustainability of the irrigation systems, which in turn affect the Physical sustainability of the system (Narayanamoorthy & Deshpande, 2005). The huge revenue gap (i.e., between the revenue assessed and revenue realized) in the irrigation sector inter-alia; the rising input costs of providing irrigation services, low recovery ratio (the percentage of revenue recovered through water fees i.e., Gross Receipts to cover Operation & Maintenance expenses), inequity in the allocation had together become the drivers of the reform process. If WUAs are concerned within the WEF nexus, the equity in the allocation of water has impacts on the energy and environment. Many barriers exist to the good governance of the WEF nexus. Some generic barriers include limited data availability, limited institutional capacity, insufficient funding, limited integration of other sectors, issues related to implementation, maintenance, and operations and lack of policy coherence and coordination, and difficulty to implement effective multi-level governance. The majority of the barriers are similar to the classical barriers to implementing IWRM (UNEP, 2016). In general, multi-level governance is key to effective management of the WEF nexus (Pahl-Wostl et al., 2020) though multi-level integration is challenging (Pahl-Wostl, 2019). In this vein, this paper applies an MLP framework combined with the IAD framework specific to WUAs to account for the sustainability transition processes.

3. Material and Methods

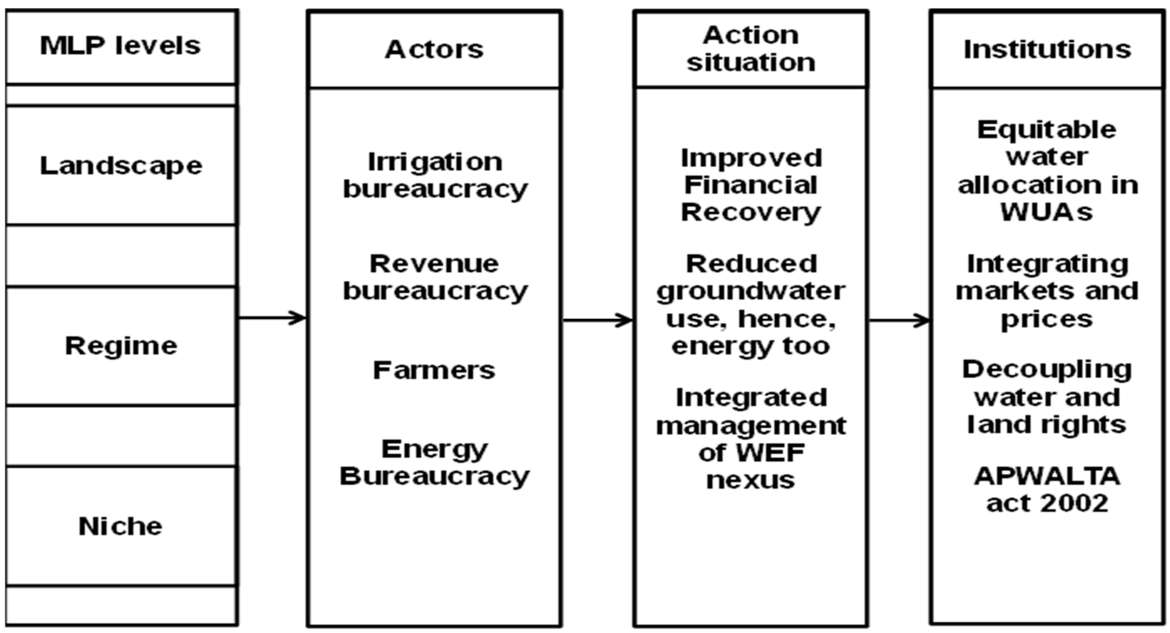
This study adopted the insights from a tailored Institutional Analysis and Development (IAD) framework for holistic management of the WEF nexus (Märker et al., 2018), though the base of it was developed by Elinor Ostrom in the 1980s (Ostrom, 2008). This framework is used to analyze the collective choice in WUAs (Dhakal et al., 2018). See **Figure 1**.

Figure 1. Institutional Analysis and Development (IAD) framework for the WEF nexus.



The interdependence among transactions for pursuing WEF securities by actors in the different action situations generates a need for coordination in changing or sustaining institutions, policy goals, and policy instruments that guide actions leading to sustainable outcomes (Srigiri & Dombrowsky, 2021). The actors comprise all the uses, users, and the bureaucracy who deal with the available resources and have a stake in the sustainable management of the WEF system. An institution is a set of formal or informal rules, regulations, and organizations that work with a common objective. The existing system (Physical/material conditions, attributes of community, and rules-in-use) determines together with the (actors, action situations, and Institutions) in one sector, say food, energy, or water along with the (actors, action situations, and Institutions) of the other two sectors the IAD framework. The movement from 'silos' to integrated management of the resources is realized, provided the bidirectional interactions are embraced in the decision-making (Märker et al., 2018). Furthermore, we combined the IAD framework with the Multi-Level Perspective (MLP) in analyzing the governance of WUAs. The MLP framework consists of three nested levels that are key to the explanation of transitions, namely- niche, regime, and landscape (Raven et al., 2012). MLP argues that transitions come about through dynamic processes within and between three analytical levels: 1) niches, which are protected spaces and the locus for radical innovations; 2) socio-technical regimes, which represent the institutional structuring of existing systems leading to path dependence and incremental change; and 3) exogenous socio-technical landscape developments (Köhler et al., 2019). See **Figure 2**.

Figure 2 MLP framework integrated with the IAD framework.



Water Governance is characterized by a complex and long-term process comprising multiple actors at different scales and levels. This process entails changes in technology, culture, policies, politics, power and economics where a wide range of vested interests are involved to promote particular solutions, policy instruments or packages (Nastar & Ramasar, 2012). The complexity can be addressed through the analysis of Landscape, Regime, and Niche levels in the water governance in general and of WUAs in particular (Geels, 2011). This study contributes to the literature on sustainability transition frameworks in two important ways. One is the use of MLP with the IAD framework to analyze the processes that aim at sustainability transitions. To achieve the same, hitherto, MLP was often integrated with other than the IAD framework such as Social Practices Approach (SPA), Technological Innovation

Systems (TIS) Approach, Transition Management (TM), and Strategic Niche Management (SNM) (Truffer et al., 2022). Second, this paper also strives for holistic treatment of the sustainability transition by moving beyond the processes i.e., outcome oriented. In this vein, the Wilcoxon signed-rank test is used to assess the improvement of financial recovery through the water fees received from the farmers in Andhra Pradesh. Furthermore, the data we used for analysis is the secondary one. Along with this, the quantitative analysis used in this study is a simple correlation. The Pearson correlation analysis is conducted between the Gross Irrigated Area from Groundwater and the electricity consumption for agriculture from 1985-86 through 2013-14 because both the variables are measured on a ratio scale. Electricity consumption for agriculture can be used as a proxy for energy usage in agriculture (Barik et al., 2017). The proxy used in this study for groundwater withdrawal in agriculture is the Gross Irrigated Area (GIA) from the wells.

4. Results and Discussion

The MLP framework along with the aspects covered in the IAD framework such as rules in use, attributes of the community, and material conditions of the system portrays the factors that determine the functionality of the WUAs.

4.1 MLP description of the case

The use of MLP is the key to understanding the formation and functioning of WUAs because WUAs globally rise to the forefront with the contributions from several constituencies such as academic, political, and donor agencies (Vishwa Ballabh, 2008). Finance has not been a priority focus of transition studies. This is surprising provided its role in supporting experimentation, innovation, scaling, diffusion, and system transformation. The role of finance should receive more attention in transition research because the sums required to meet SDGs or climate goals are very large (Turnheim et al., 2020).

The transitions require a huge amount of financial support as a transaction cost (Barbier, 2011). The external funding assistance came timely with the support of $ 141 million (approximately 512 crore INR at the prevailing exchange rate of 1 US $ = 36.31 INR) as a loan under the Andhra Pradesh Economic Restructuring Project (APERP) from World Bank (a landscape actor) in 1997-98 and is essentially designed to support the WUAs (Raymond Peter, 2001). The loan amount was nearly half of the Working Expenses spent for the same year on the irrigation sector in the state. Moreover, they are increasing every year. On top of this, external aid is granted in the manner that it is linked to the presence of a set of principles in the host country. The five principles for the 'Bank villages' i.e., villages in which water users' associations are created by the World Bank are a). The provision of adequate and reliable water supply b). The water users' associations are formed on a 'hydraulic' basis, rather than an administrative basis c). Enabling the water users' associations' rights to collect water fees d). The pricing of water should be 'Volumetric' e). No interference from the local government (Wang et al., 2010). These principles serve to create pressures or opportunities in the Regime (Kungl & Geels, 2018). The transaction costs in the irrigation reforms of Andhra Pradesh mainly stem from the election of WUA presidents in the state.

In recent years, the theoretical conceptualization of the socio-technical regime has undergone an institutional turn (Fuenfschilling & Truffer, 2016). Scholars have increasingly drawn on concepts from institutional theory to describe the norms and rules that stabilize a socio-technical system (Geels, 2004). Coming to the case, the Andhra Pradesh government has also capitalized on the benefit from the Government of India for the implementation of the reform. Under the restructured Command Area Development and Water Management Programme (CADWM), more emphasis is being given to the participatory approach in India. Under this Programme, the payment of central assistance to states is linked with the formation of WUAs (Arun et al., 2012). The period (1997-98) marked by reforms has remarkably taken approximately 40 crore INR from the scheme (NITI AAYOG (GoI), 2015). See **Table 1**.

Table 1. year-wise loan taken by Andhra Pradesh from the CADWM program in INR lakhs.

Year	Amount in INR Lakhs
1974-75	46.28
1975-76	95.93
1976-77	173.78
1977-78	227.24

1978-79	378.12
1979-80	136.26
1980-81	166.44
1981-82	351.77
1982-83	550.79
1983-84	459.36
1984-85	366.58
1985-86	631.99
1986-87	494.78
1987-88	135.68
1988-89	204.98
1989-90	160.18
1990-91	50.19
1991-92	100.02
1992-93	134.84
1993-94	119.84
1994-95	182.91
1995-96	190.81
1996-97	99.40
1997-98	3839.57

The data is taken from (NITI AAYOG (GoI), 2015) and the data from the period 1998-99 through 2013-14 are zero. It is evident from the data that the political will is so strong for implementing the reforms as stressed by Raymond Peter (Raymond Peter, 2001), the then, Secretary of Irrigation in GoAP. Regarding the Implementation process i.e. a technical system in MLP jargon (Bilali, 2019), GoAP has followed the 'Big Bang' approach i.e. creating a mass number of WUAs at a time. Although done by duly incorporating the implications from earlier pilot-based studies conducted in 1995-96, more than 10000 WUAs were formed within one year post the reforms were initiated. The 'area of operation' under the 10790 WUAs is 4800000 Ha. But, the area irrigated at the highest from canals and tanks stood at 3258510 Ha and the lowest stood at 1906220 Ha (Swain & Das, 2008). The state believed that the sudden handover of operation and management responsibilities to farmers is unwieldy because the expenses were to the tune of thousands of crores. So, the big bang approach is implemented gradually with the plow back scheme of water rates that were received by the farmers in the sector. Before handing it over fully to the farmers, the government sought to plow back 100 percent of water fees into the system in the first year, 66 percent in the second year, 33 percent in the third year, and finally to the farmers. The effective functioning of physical systems in the irrigation system depends upon financial sustainability because of the large requirements of funds for operation and maintenance activities such as repairs, and desilting mud. The inequity in allocation among the tail-end farmers (i.e. location disadvantage) and the design properties of the system (i.e. seepage) in the head-end farmers, pricing of irrigation water has an impact on the recovery ratio in the irrigation system of the state (Jairath, 2001). The farmer's income also plays a prominent role in the financial sustainability of WUAs because it shows their ability to pay the water fees and contribute to the well-functioning of the irrigation systems (Narayanamoorthy, 2018).

We now turn to describe the interactions in a multi system transition (Rosenbloom, 2020) . In other words, the interplay of institutions is particularly important because they have aligned with the established rules in case of the intersection of sectors (Wirth et al., 2013). Since our analysis of WUAs span three sources namely- water, energy, and food/agriculture, we aimed to study the interplay of institutions. The pricing of water in Andhra Pradesh is not 'Volumetric' but rather based on 'Acreage'. The proposition of 'Volumetric' pricing of water further intensifies the transaction costs of the reforms because of the rise in administration costs and the implementation costs associated with it.

The interactions considered in this paper are grounded in the factors that seek integration from various regimes for the effective management of the WEF nexus. The energy link to agriculture we discuss here is solely the electricity consumption for agriculture and does not include the diesel consumption for farm mechanization and fertilizer consumption. The electricity consumption is due to pumping the groundwater for irrigation purposes. The production of electricity, in turn, requires water in the various stages of energy generation with the emissions as a byproduct contributing to climate change. Climate change further impacts agriculture in the form of floods and droughts (Shah, 2009). Therefore, we provide a case for the benefits of the efficient management of surface water over environmental sustainability with reduced dependence on groundwater and energy. As far as surface water allocation for the irrigation purpose is considered, i.e. tanks and canals; the decentralized mechanism of allocation is generally suggested in the policy circles and development initiatives (MacDonald, 2019).

The level of groundwater abstraction for agriculture can be better understood through the gross area irrigated from wells. The link between surface water and the groundwater is so complex in the sense that the seepage from canal water contributes to the recharge of the nearby aquifer to some extent (Narayanamoorthy, 2018) inter-alia, the return coefficient of the crop irrigated (Kumar et al., 2011) and generally, it hovers around 25 percent at the distributary level in the irrigation system (Mekonnen et al., 2015) which is abstracted by the usage of electricity. Groundwater is the major source of irrigation in Andhra Pradesh with 49 percent of the net irrigated area in the state being from wells (Amarasinghe et al., 2008). Despite the huge initial costs associated with groundwater extraction (i.e., for digging the well or bore well, the electricity charges for pumping the water) and the environmental impacts such as saltwater intrusion, it became the alternative and more reliable supply source of water.

Table 2. Year-wise and Source-wise GIA in Andhra Pradesh in 1000 Ha

Year	Area Irrigated from Canals in ‘000’ Ha	Area Irrigated from Tanks in ‘000’ Ha	Area Irrigated from Wells in ‘000’ Ha	Total Gross Area Irrigated in ‘000’ Ha
1980-81	2129	977	1125	4342
1981-82	2190	1201	1160	4678
1982-83	2252	955	1197	4518
1983-84	2441	1266	1212	5058
1984-85	2326	856	1149	4470
1985-86	2200	846	1161	4337
1986-87	2244	825	1165	4360
1987-88	2099	742	1322	4298
1988-89	2458	1263	1540	5440
1989-90	2469	1149	1647	5454
1990-91	2311	1107	1760	5370
1991-92	2212	1035	1929	5378
1992-93	2202	788	1904	5085
1993-94	2220	701	1912	5020
1994-95	2184	769	2016	5185
1995-96	2056	839	2203	5304
1996-97	2199	969	2391	5782
1997-98	2048	614	2306	5158
1998-99	2286	928	2644	6092
1999-00	2208	719	2596	5746
2000-01	2202	798	2693	5916
2001-02	2089	634	2618	5548
2002-03	1452.01	454.21	2478.59	4536.2
2003-04	1513.43	537.6	2572.75	4780.69
2004-05	1730.41	514.91	2563.32	4986.71
2005-06	2231.15	761.79	2796.08	5996.46

2006-07	2298.45	695.81	2891.63	6069.57
2007-08	2249.69	668.87	3174.28	6284.78
2008-09	2375.44	726.21	3417.03	6740.57
2009-10	1864.61	370.55	3342.53	5763.95
2010-11	2503.03	755.48	3672.13	7152.86
2011-12	2215.6	601.29	3755.78	6784.51
2012-13	1683.41	558.66	3841.43	6268.31
2013-14	1900	661	3958	7260

In Andhra Pradesh, the average percentage of GIA from canals to the total GIA during the period 1980-81 to 1986-87 is 49% which has declined to 38% during 1987-88 to 2012-13. Similarly, in the case of tanks, it decreased from 21.7% to 13.7% during the same period. Despite the increase in GIA much of it has come from groundwater. The contribution of GIA from wells to the total GIA, on average, has increased from 25.7% during 1980-81 to 1986-87 to 44.7% from 1987-88 to 2012-13. The data contained in **Table 2** is collected from the Indiastat database.

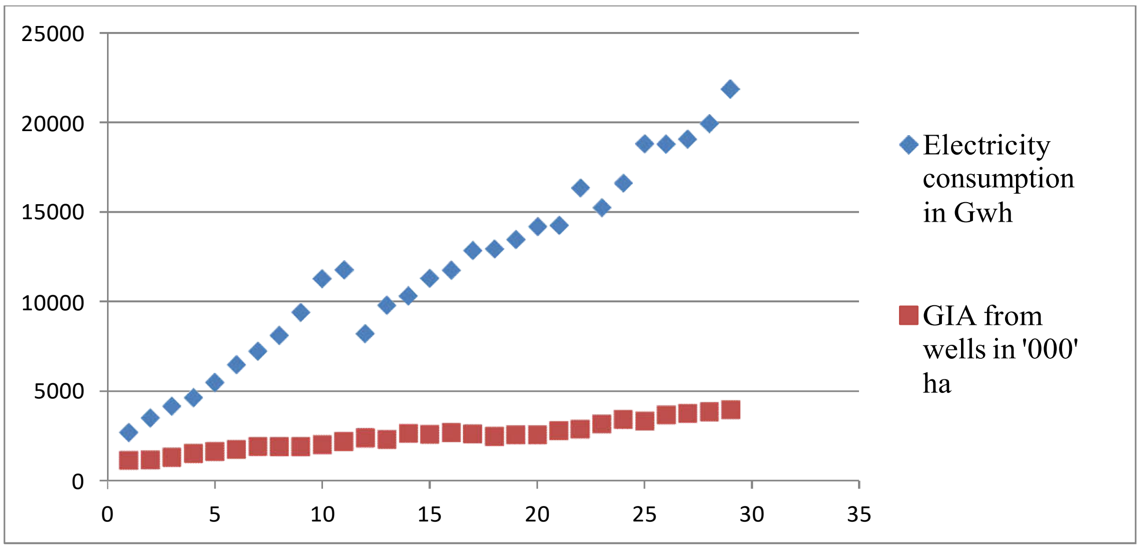
The energy use of such groundwater abstraction is evident in **Table 3**. The electricity consumption for agriculture data is collected from the EPWRF time-series database, whereas the data on GIA from wells and surface water (sum of area irrigated from canals and tanks) is collected from the Indiastat database.

Table 3. Year-wise Electricity consumed for Agricultural purposes and GIA from wells in Andhra Pradesh.

Year	Electricity consumption in Gwh	GIA from wells in '000' ha
1985-86	2697.52	1161
1986-87	3501.25	1165
1987-88	4155.63	1322
1988-89	4629.58	1540
1989-90	5477.01	1647
1990-91	6459.68	1760
1991-92	7218.94	1929
1992-93	8094.58	1904
1993-94	9366.8	1912
1994-95	11269.75	2016
1995-96	11757.42	2203
1996-97	8210.44	2391
1997-98	9798.78	2306
1998-99	10307.21	2644
1999-00	11285.1	2596
2000-01	11748	2693
2001-02	12828.92	2618
2002-03	12912.1	2479
2003-04	13448.19	2573
2004-05	14160.72	2563
2005-06	14226.2	2796
2006-07	16327.92	2892
2007-08	15241.05	3174
2008-09	16604.57	3417
2009-10	18825.02	3343
2010-11	18798.57	3672
2011-12	19076.05	3756
2012-13	19935.79	3841
2013-14	21857.35	3958

Using the data contained in **Table 3**, we conducted the Karl Pearson simple correlation coefficient between the electricity consumption in agriculture and GIA from wells because both are on a ratio scale. It is found to be 0.96. It depicts the strength of the linear association between the GIA from wells and the electricity consumed. The two variables vary together in a positive direction. The co-movement of the two variables is shown in **Figure 3**.

Figure 3. Scatterplot between GIA from wells and the electricity consumed for Agriculture.



The high correlation of 0.96 signifies interdependence and is not to be concluded as synergy along the lines of (Fader et al., 2018; Putra et al., 2020) while the latter studies used the correlation between the indicators of the WEF sectors to classify them as either synergies or tradeoffs.

The next interaction which deserves attention is the subsidy regime. The subsidy regime is an incentive structure of regulatory rule in the regime (Bilali & Probst, 2017). The use of groundwater for irrigation is made possible with low or no tariffs for electricity and surprisingly for water itself (Shah et al., 2018). Moreover, in Andhra Pradesh, the electricity is supplied free for seven hours a day (Kondepati, 2011). The result of such subsidies leads to the competitive digging of bore wells and more water usage than necessary. However, the direct transfer of the electricity subsidy to farmers for reducing electricity consumption can be viewed as a Pareto improvement for all the stakeholders involved namely- farmers, power utility companies, government, and most important environment. This is due to the marginal loss of gross value of output due to a reduction in electricity consumption is far less than the increase in subsidy for that amount of electricity consumed (Amarasinghe, 2014) and along with the renewable integration to the groundwater abstraction points out to be the place where the policy coordination in the WEF system arises.

Another interaction stems from fragmented sources of a resource. The public trust doctrine is embodied for surface water but not for groundwater (Ananda & Aheeyar, 2020). Many colonial acts have not yet been superseded and the basic structure of common law rights linking water rights and land rights has not yet been comprehensively reworked, however, the changes are under the way (Cullet, 2018).

The recognition of the competitive digging of the bore wells by the government made it enact the regulatory (Command and control approach) legislation namely- Andhra Pradesh Water, Land, and Trees Act in 2002. The APWALTA act aims to put bans on the digging of new bore wells (Prakash et al., 2015). The APWALTA act is one of the approaches to tackle the groundwater problem. There are other approaches too, for instance, law 10-95 in Morocco's water policy to address the issue of groundwater overexploitation. In Morocco, water deeper than 40 meters below the soil surface is restricted from pumping (Meir et al., 2021)**.** The competitive digging of the bore wells is intensified due to policies such as free power supply and the subsidies for the agro wells and a lack of demand management policies (Villamayor-Tomas et al., 2015).

The niche-level description provides us an opportunity to dwell upon breakthroughs of a sustainable transition and delve into outcomes as well. In the MLP, transitions are crucially dependent upon activities within niches (Smith et al., 2010). Coming to the outcome, the major backdrop against which WUAs were initiated in Andhra Pradesh was to bring financial sustainability into the system. The recovery ratio which is equal to the percentage of gross receipts to the working expenses is an indicator of the financial performance of the irrigation projects in developing countries (Reddy, 2009). Accordingly, we took the data from (CWC, 2015) for major and medium irrigation projects only because the major chunk of both the plan and non-plan expenditure of the government on irrigation goes into it. See **Table 4**.

Table 4. Financial aspects of Major and Medium Irrigation projects in Andhra Pradesh

Year	Working Expenses in Rs crore	Gross Receipts in Rs crore	Percentage Recovery
1979-80	26.10	1.98	7.6
1980-81	29.88	2.09	7
1981-82	33.94	2.24	6.6
1982-83	35.76	2.39	6.7
1983-84	40.32	4.91	12.2
1984-85	42.27	9.21	21.8
1985-86	38.88	14.35	36.9
1986-87	30	3.42	11.4
1987-88	134.64	5.44	4.03
1988-89	490.98	5.44	1.1
1989-90	315.54	35.21	11.15
1990-91	360.32	48.78	13.54
1991-92	392.1	13.82	3.52
1992-93	430.41	65.72	15.27
1993-94	504.42	76.79	15.22
1994-95	613.78	103.8	16.91
1995-96	711.82	94.61	13.29
1996-97	820.1	64.77	7.90
1997-98	944.39	6.33	0.67
1998-99	1111.91	5.11	0.46
1999-00	1053.18	4.05	0.38
2000-01	1295.39	11.43	0.88
2001-02	1342.13	10.27	0.77
2002-03	1574.47	8.47	0.54
2003-04	1726.56	15.52	0.90
2004-05	1772.31	56.27	3.17
2005-06	2470.94	47.82	1.94
2006-07	3026.51	68.81	2.27
2007-08	4541.49	42.03	0.93
2008-09	3797.6	38.33	1.01
2009-10	5116.54	81.88	1.60
2010-11	6092.56	65.32	1.07
2011-12	6349.33	72.27	1.14
2012-13	8394.21	193.25	2.30
2013-14	8370.12	206.82	2.47

While the data on recovery ratio from the period 1979-80 to 1989-90 are excerpted from (GoI, 1992) and the EPWRF time-series database. To analyze the improvement in the financial recovery from the irrigation systems from the pre and post reforms a Wilcoxon signed-rank test is used on the recovery ratio variable. The results are shown below.

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Test for difference between post-WUAs and pre-WUAs
Wilcoxon Signed-Rank Test
Null hypothesis: the median difference is zero.

Difference     rank      signed rank.

  -0.38          1            -1
  -0.74          2            -2
   1.17          3             3
   1.81          4             4
   3.02          5             5
   4.35          6             6
  -4.52          7            -7
   5.36          8             8
   6.82          9             9
   9.04         10            10
 -10.45         11           -11
  42.38         12            12
  52.85         13            13
  63.37         14            14
  68.06         15            15
  89.45         16            16
 112.21         17            17

n = 17
W+ = 132, W- = 21
(Zero differences: 0, non-zero ties: 0)
Expected value = 76.5
Variance = 446.25
z = 2.6036
P (Z > 2.6036) = 0.00461257
Two-tailed p-value = 0.00922515
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The results suggest that the test performed allows rejection of the null hypothesis of the median difference is zero i.e., the recovery ratio in the post-WUAs implementation period performs relatively better than in the pre-WUAs period. This indicates the increased ability of farmers to pay their water fees. As mentioned earlier, the financial sustainability of the system further contributes to its physical system as well. Initially, we tried to assess the difference in recovery ratio using a dummy variable, but the data does not follow a normal distribution. Then we tried to do the same with a paired t-test, albeit the differences between pre- and post-reform groups do not follow a normal distribution. To overcome such probability distribution-related problems, we resorted to a non-parametric test known as the Wilcoxon Signed-Rank test. It is an alternative to the paired t-test.

At the niche level, the two major actors that play crucial roles are the Revenue Department and the Irrigation Department. The volume of water withdrawal for irrigation and the timing of the release of water is determined at the niche level. The Inequity in the water allocation between the tail-end and head-end farmers is one of the reasons for the low recovery ratio in the irrigation sector and for the abstraction of groundwater for irrigation purposes. Hence, the equity in the water allocation in the WUAs helps to reduce the reliability of groundwater and thereby on the electricity too. The increased demand for water and energy exerts pressure on the ecosystem structure and function. It is where the WUAs have wider impacts on the WEF nexus including the environment.

5. Limitations and scope for further research

The present study used MLP to analyse the WUAs but can be extended to the WEF nexus by encompassing the broad range of institutions from the three resources of the system. The use of MLP to analyze WEF nexus is deemed to be necessary for two reasons. *First*, all the resources in the WEF system are tradable (Bazilian et al., 2011), hence the global contexts are inevitable in the analysis. *Second*, the WEF nexus is gaining importance as yet another movement of integrative thinking of resources agenda globally after IWRM, which has attained partial success (Ngene et al., 2021). We did not emphasis on fertilizer consumption too despite its bearing on the environment. If susceptible to overuse and under improper monitoring of the water resources may cause eutrophication (Reddy et al., 2018).

6. Conclusion

The synergies suggested in the WEF nexus so far by the literature span across the three sectors constituting the WEF nexus. For instance, water conservation technologies such as drip and sprinkler systems; recycling of and nutrient recovery from wastewater arise from the water sector, use of renewable energy technologies such as solar irrigation pumps, Agrivoltaics emerge from the energy sector, and likewise the anaerobic digestion of food waste from the food sector. This study analyzed the synergy arising out of WUAs from an institutional perspective and hints at one of the opportunities for the sustainable management of the WEF nexus. It has been shown that the financial recovery in the major and medium irrigation sector of Andhra Pradesh has witnessed an improvement in the post-WUAs period, though absolutely. This reflects the farmers' ability to pay for their water fees has significantly increased in the post-WUAs period. However, being content with it would not result in the sustainability of the WEF nexus system due to consideration of a parallel increase in the gross irrigated area from wells. Furthermore, the state shall strive to increase the area operated under WUAs to bridge the potential gap currently existing. Hence, it is important for revitalizing and invigorating the WUAs. To tackle this wicked problem, the integration of renewable energy would contribute to the sustainability of the WEF nexus along with the maneuver of the APWALTA act designed to manage the groundwater problem. To achieve the integration of renewable energy into the irrigation, the Government of India came up with a program called 'Kisan Urja Suraksha evam Utthaan Mahaabhiyan' (KUSUM) scheme which will support the installation of (i) stand-alone off-grid solar pumps to replace existing diesel pumps; (ii) decentralized ground or stilt-mounted, grid-connected solar power plants (~0.5–2.0 MW) by an individual or group farmers, WUAs, cooperatives or *panchayats* (Local Self Governments) based on expressions of interest issued by distribution companies (DISCOMs) and available sub-station surplus capacity; and (iii) "solarizing" existing grid-connected pumps by outfitting them with solar panels, and allowing owners to sell excess electricity back to DISCOMs. The applied multi-level perspective framework to the analysis of the WUAs in Andhra Pradesh suggests the importance of policy coordination for the effective governance of the WEF nexus and the sustainable management of the WEF resources. The policy coherence among the fragmented sources of a single resource along with the policy coordination among all the resources in the WEF system namely- water, energy, and food are essential for decision-making to mitigate the trade-offs and tapping the synergies. For a sustainable transition to be successful, integration would emerge from all three levels in MLP. Succinctly put, niche level coordination, regime-sub regime, regime-regime, and landscape integration are key for a sustainable transition process to be effective as well. Thus, this paper suggests that integrated governance and institutions combined with renewable energy technologies would feed sustainability into the WEF nexus management.

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