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Water-Energy-Agriculture Nexus for Sustainable Development: The Case of Iloilo Province, Philippines

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Abstract

Water, energy and agriculture (WEA) nexus perspective, an integrated approach that realizes the interlinkages between three resources, calls for the paradigm shift in resource management and security. As its concept aligns with the targets prescribed in the United Nation's Sustainable Development Goals (SDGs), the identification of nexus among the resources could contribute in achieving the global initiative. Considering that the notions on nexus in resource management has frequently been discussed on conceptual or global level, this study aims to provide regional level study on WEA nexus for improving the localization of SDGs through the identification of important intersectoral indicators using the social network analysis. The Iloilo province of the Philippines was selected as the research site since this agriculture-based region faces challenges on resource security due to the climate change, rapid population growth, urbanization and lack of institutional capacity. Based on the social

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network analysis and centrality analysis, the study presents a graphical presentation of regional nexus network and provides synergy or trade-off relationship among the influential indicators within the network. The result of the analysis emphasizes the need for improved partnership among the nexus indicators stakeholders of resources, private and public sectors, and regional and municipal government, to apply nexus perspective in policy decisions on regional level. This paper also provides insights to the policy makers' for future policy development and localization of SDGs.

Key Words: Water-Energy-Agriculture Nexus, Sustainable Development Goals, Social Network Analysis

Ⅰ. Introduction

The Iloilo province, located in the southeastern part of the Panay Island in the region of Western Visayas, Philippines, is characterized as the major food basket and rice granary of the country(Province of Iloilo 2019). While the region's economy relies heavily on the agricultural production, it is exposed to the climatic challenges such as dry spell, droughts, El Nino, extreme heat wave, and tropical cyclones, which would impact its total food production and resource management(PAGASA 2016). The population of the region is expected to grow from about 1,936,423 in 2015 to 2,603,766 by 2022 (PSA 2019), and the projection on the urbanization of its major city, the Iloilo City, would grow from about 466,456 as of 2019 to 621,134 in 2035(Mapa 2019; World Population Review 2019). Vulnerable to rapid population growth, urbanization, and severe impacts of climate changes and natural calamities, this agriculture-dependent province faces serious problems in meeting demands for water, energy, and agricultural resources(Regional Development Council VI 2011; Chumbler 2019; Yap 2013; Bernejo 2017). However, fragmented policy implication, lack of cross-sectoral partnership among stakeholders, and uncertainty in the identification of important inter-resource indicators would further exacerbate the challenges the region currently faces, thus, an integrated resource management seems crucial(Fernandez et al. 2013).

This situation calls for the adoption of water, energy, and agricultural(WEA) nexus perspective, a systems approach that realizes the connections among the resources and that incorporates integrated resource management(Bazillian 2011; Hoff 2011). While the lack of evidence for the benefit of nexus approach may hamper the willingness for its application(Galaitsi et al. 2018), understanding the resource nexus in the site of interest may promote cooperation, coordination, and policy coherence(Liu et al. 2018). There were few attempts to advance understanding of the interdependencies among resources on regional level(Zhuang 2018; Dale & Bilec 2014; Khan et al. 2017). However, many of them failed to address all of the water, energy, and agriculture sectors or remained merely in conceptualization of the connections among resources.

The objective of this study is to analyze the resource nexus of the Iloilo province, an agriculture-based region in the Philippines, through the network analysis and provide insights for the localization of Sustainable Development Goals(SDGs). The identified relationships among the regional data-based indicators may act as the empirical and statistical evidences for the application of WEA nexus in achieving

SDGs. Furthermore, the application of the SDG 17(Partnerships) targets for WEA sectors and their stakeholders may derive plausible policy implications for better management and allocation of resources on regional level. Based on the objectives of the study, this study aims to answer following research question: Which indicators among WEA nexus sectors indicate synergy and/or trade-off relationship?

This study is structured as follows. In the following section, introduction of the study area's challenges on the resource management is described in detail. In section three, the literature on the concept of the nexus, the methodologies applied for analyzing the nexus, and the application of the network analysis for the identification of the resource nexus were reviewed thoroughly. The methodology adopted in this study and description of data is presented in the section four. The results of the analysis are provided in section five with graphical presentation of the Iloilo Province's WEA nexus network with synergy and trade-off relationship among the indicators. Then, the study concludes with plausible policy implications for the study region.

Ⅱ. Challenges of WEA Resource Management in Iloilo Province

In this section, the paper analyzes the Iloilo province's water, energy, and agricultural resources and their management based on the perceived challenges and the interrelatedness of them. Iloilo province's water sources consist of surface water and ground water. Four bodies of water(the Iloilo, Batiano, and Jaro Rivers and Dungon Creek) and over 174 rivers and creeks that traverse across the region and among them, Jalaur river basin serve as the major source of agricultural irrigation(Iloilo Socioeconomic Profile 2010). Underground water supply(11 deep wells) and surface water(Maasin Dam) provide tapped water and potable water for domestic usage (Iloilo Provincial Profile 2017). Potable water to the consumers in Iloilo is provided by the government-owned Metro Iloilo Water District(MIWD). MIWD, however, is struggling to meet the growing water needs in the province and thus seeks to increase partnership with private companies such as Metro Pacific Water(MPW) (MPW 2018). Furthermore, on-going Jalaur River Multi-purpose Dam project The Jalaur River Multipurpose Project Phase II (JRMP II), funded by a $260-million loan from South Korea, involves the construction of three dams(109-meter Jalaur high dam, 38.5-meter Afterbay dam and 10-meter Alibutan catch dam), a 6.6-megawatt hydro-power plant and an 81-kilometer high-line canal at Jalaur River(Ocampo 2018). The dam is expected to provide affordable and accessible electricity, expand irrigable land area, and generate greater amount of potable water for domestic use(Scheidel 2015).

Although the proportion of household with access to safe water increased significantly from 40% in 2011 to over 88% in 2016, Vogel and other researchers(2013) describe that the climate change has exacerbated the region’s vulnerability to water, causing too much water(i.e., flooding), too little water(i.e., droughts), and degraded water(i.e., low water quality). Iloilo province is categorized as a dry spell affected region. Dry spell is defined as 3-consecutive months of below normal rainfall condition(21~60% reduction from average rainfall(PAGASA 2016), which incur water crisis of its towns and cities annually. The annual average rainfall reaches a little over two meters mainly because of the frequent and sometimes severe typhoons(PPDO 2011). Severe weather conditions, low level of agricultural water supply, poor governance and infrastructure on water not only affect the region’s water resources but also impact overall agricultural production.

The Iloilo province mainly rely on the diesel and coal-fire power plants for the energy generation. The Iloilo city, densely populated urban area, is powered by 167.4 megatwatt(MW) coal-fired power plant operated by Panay Energy Development Corporation(PEDC) and 72MW diesel power plant operated by Panay Power Corporation. Northern Iloilo is energized by 270MW coal-fired power plant operated by Palm Concepcion Power Corporation(PCPC) (PEDC 2014; Yap, 2016). In response to the global transition to renewable energy sources, the energy companies in the Iloilo province are undertaking various renewable energy projects, including: 5.67 MW solar farm by Cosmo Solar Energy, inc.; 35MW thermal biomass power plant by Green Power Panay Philippines, inc.; 5.1MW hydro power plant by Century Peak Energy Corporation; 213MW and 500MW wind power projects by Energy Development Corporation(Reyes 2018). Major power distributors of the region’s residential, commercial, and industrial markets are Panay Electricity Company(PECO) that serves Iloilo City, Iloilo 1 Electric Cooperative(Ileco 1) in Southern Iloilo, Iloilo 2 Electricity cooperative in Northern Iloilo(Ileco 2).

The province's agriculture is also related with energy production. Bagasse, dry pulpy fibrous remnants of the sugar cane, are used in the biomass power plants to produce electricity(15 MW). Biomass energy and renewable energy are regarded as the alternatives to enhance the cost efficiency and lower electricity fees, since the Ilocans(people of Iloilo) have been paying the highest electricity rates among the urbanized regions in the Philippines(Php 12.0917/kwh) due to the monopoly and over-billing of the major power provider(Dela Cruz 2018).

Agriculture is the most important sector among three resources in Iloilo province. With total land area of 4,663.42 km^2, over 73.93% of the Iloilo province's alienable and disposable land areas are subject to agriculture and crop production(PPDO 2017). Since the province ranks fifth in the rice production, sugar cane, and poultry and livestock industry on nationwide, its economy depends heavily on efficient allocation and effective management of agricultural resources(PPDO 2017). However, the region faces serious challenges on their agricultural production annually due to climate change. Provincial Agriculture Office(PAO) reported that in 2019, total of 13,630 farmers from 27 towns in Iloilo province have suffered crop damage caused by three months of dry spell, and 11,093 Ha of rice farms partially or totally were damaged, causing total loss of Php 401 million in value(Momblan 2019). Furthermore, conventional farming focused on the increasing food production is exacerbating the region's environment and accelerating the soil degradation.

To combat further threats on its environment, the government and private sectors in the Western Visayas region(Region VI) introduced organic agriculture in Iloilo. However, farmers in Iloilo province are reluctant to convert since conventional farming is easier and more productive agricultural method than organic farming(Berondo 2011). Conversion into organic farming have potentials to diminish overall energy used for agriculture since it has less reliance on energy intensive fertilizers, chemicals, and concentrated feed than that of non-organic farming(Ziesemer 2007). Faced with serious of challenges on its agriculture sector, effective agricultural planning that could provide sustainable irrigation system and water supply during dry spell and reduction of overall energy used for agriculture seems crucial to increase the value of the province's agricultural production and strengthen the capability of farmers.

As it can be concluded from the regional introduction of the Iloilo province, water, energy, and agricultural sectors are highly interrelated to one another. Although it is evident that the increase in demand for one resource limits another, current policy and studies in the region treats all three sectors independently. There were few attempts to incorporate nexus concept in the region's agriculture sector. For instance, Iloilo province recently built Solar Powered Irrigation System(SPIS) to better facilitate irrigation and enhance crop production with renewable energy source. Equipped with 10 horsepower(hp) submersible pump and topped with 56 solar panels, it was expected that the system could pump 800 to 1,000 gallons of water per minute and irrigate 100 hectares of land area(Philippines News Agency 2017). After the installation in 2019, however, the system's performance was less than expected since persistent El Nino phenomenon dried up the creeks and made SPIS useless and farmers lack technological knowledge to operate the system(Bacongco 2019). As it can be inferred from this incident, developing policy that incorporates WEA nexus requires better understanding on the important nexus indicators and synergies and trade-offs among the resources of the study region.

Considering that the half of the rice production in the province is irrigated, while others are rainfed, significant amount of energy is required to run irrigation facilities. The remnants of agricultural production are used to create bio-fuels, so conflicts between agricultural crops and energy crops are expected to rise. To promote water, energy, and agricultural(WEA) security of the region and to draft feasible agricultural policies, it is important to consider the interrelatedness(nexus) of the resources.

Ⅲ. Literature Review

1. Water-Energy-Agriculture Nexus

Climate change, global population growth, rapid urbanization, and rising demand for energy consumption are expected to draw significant challenges on sustainable resource management, especially on the security of water, energy, and food sectors(FAO 2011; Biba 2015; Lawford et al. 2013). While past studies and policies have analyzed and regulated water, energy, food resources individually, recent growth in the awareness of interdependencies and interlinkages among them calls for the holistic approach for better allocation and management of resources for the future(Rasul 2016; White et al. 2017). This systems thinking of resources is termed as water, energy, food(WEF) “nexus” perspective. “Nexus” means “to connect“ the individual factors under the overarching concept, therefore WEF nexus realizes the fact that access to one resource may constrain access to another, and examines the relationship that encompass synergies and trade-offs among three resources(Beck and Walker 2013; De Laurentiis et al. 2016). WEF nexus received more attention since 2011, when former Secretary-General of the United Nations, Ban-Ki Moon, noted in his speech that the “crucial interplay among water, food and energy is one of the most formidable challenges we face,” and when deeper academic discussions on nexus was convened in Bonn2011 Conference: Water Energy and Food Security Nexus(UN 2011; Allouche et al. 2015).

Among three resources, food sector has been addressed interchangeably with agricultural sector without any specific differentiations(Sanders and Masri 2016; Shenhav et al 2017; Latorre et al 2016). While food sector mostly focus on the food security indicators such as food availability, food access, food utilization, and stability of food prices and supply(Flammini et al 2014), agricultural indicators such as land availability, area of arable lands, number of farmers per crops, amount of energy crop production and others have been neglected in traditional nexus studies. For analyzing the resource nexus of the agriculture-based region such as Iloilo, Philippines, utilizing agriculture data that includes food data could be more appropriate for describing overall picture of the study region(Oh 2020). Thus, this study shall analyze the water-energy-agriculture

(WEA) nexus in the site of interest.

Then, why does the relationship of WEA resources matter? As Gleick and Christian-smith(2011) identifies, insufficient water and energy for agriculture diminish the crop productivity. This is because agriculture-based regions rely not only on rainfed cultivation but also utilize irrigation system to raise crops. In global level, agriculture takes over 70% of the world's fresh water withdrawals(FAO 2011). Energy is used to pump water to irrigated crops and as Famiglietti (2014) describes, energy for pumping water from ground water sources are increasing due to the decrease in surface water sources. On the other hand, agriculture may sometimes degrade water quality by using pesticides, herbicides, fertilizers and other chemicals necessary for crop production(Twomey et al. 2010). Tensions between agricultural sector and energy sector rise as the increase in cultivation of energy crops for biofuel production could conflict with the availability of land for food crops(Popp et al. 2014). As WEA resources are highly interrelated, identification of the areas that could increase positive synergies and diminish trade-offs among them is important to catalyze regional development(Nhamo et al. 2018).

Early studies on nexus analysis focused on the conceptualization and typology of the nexus according to geographical scales and types of the study region to better understand and systematically analyze the connections between water, energy, and food resources(Bazillian 2011; Hoff 2011; FAO 2014; Altamirano et al. 2018). Since then, various nexus frameworks and models, in collaboration with the concept of sustainable development, began to incorporate other resources and phenomena, namely: Global climate, land, energy, water strategies(CLEWS) that reflects the impact of climate change on integrated resource management(Howells et al. 2013); water-energy-food Nexus Tool 2.0(Daher & Mohtar 2015); Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism framework that characterizes energy, food and water flows within the environment(Giampietro et al. 2014); water-food- energy-ecosystem (De Strasser et al. 2016), and WEFO(Water- Energy-Food Optimization) model(Zhang et al. 2018).

Frameworks and models for integrated resource management varies significantly due to the complexity in the selection of indicators, difference in the scale of the research site, and lack of robust database and scientific methods(Endo et al. 2015; Chang et al. 2016; Kurian 2017). Furthermore, major barriers to the adaptation of WEA nexus approach for policy makers and decision makers were inflexible government structure, sector-based policy mechanisms, incompliance to the paradigm shift, lack of communication between the sectors, and lack of willingness to cooperate among stakeholders(Bizikoa et al. 2013; Lele et al. 2013; Conway et al. 2015; Scott 2017, Weitz et al. 2017). As Scott(2017) implies, the effectiveness of nexus approach is determined by capacity and cooperation of governing institution and synergies and trade-offs in WEA nexus is determined by local-level decision-making process. Thus, it is necessary to create a simplified local-level WEF nexus framework that identifies synergies and trade-offs among physical indicators of given resources. As Kurian(2017) elaborated, WEA nexus approach is an “expression of trade-offs, synergies, and resource optimization potential…of the relationship between environmental resources, public service delivery, and institutional and environmental risks". Network analysis, a methodology that identifies the network structure of the various indicators, will be able to provide insights to nexus analysis.

Water, energy, agriculture nexus coincide with the targets of the SDGs proposed by the United Nations. SDGs provides blueprints to achieve better and sustainable future for all(UN 2015). Among 17 goals, SDG 2(zero hunger), SDG 6(clean water and sanitation), and SDG 7(affordable and clean energy) are aligned with the notions of WEA nexus. Prior to the emergence of nexus perspective, however, the sustainability in the SDGs generally focused on the distributional justice of resources(Leese & Meisch 2015). Since the nexus perspective began to address the security of resources, SDGs by then began to consider synergy and trade-off among its targets. As Salam et al.(2017) noted, integration of water, energy and food under the nexus framework with the purpose of increasing resource efficiency is viewed as an integral approach to achieve SDGs. On the other hand, Biggs et al.(2015) explains that there is a general belief that improved resource security does not necessarily extend the accessibility to the resources. For instance, increasing food security does not necessarily diminish the frequency of undernourishment as stated in SDG 2. While there is some disputes between the concept of security under nexus perspective and resource management under SDGs, it is generally accepted that the SDGs provide the basis for the development of the resource nexus(Gallagher et al. 2016).

SDG 17, which emphasizes the global partnership and cooperation between governments, the private sector, and civil society for achieving the sustainable development goals(UN 2019), may also contribute for further implementation of the nexus perspective. When SDG 17 is scaled down into the local level, the enhancement of partnership among the stakeholders for sustainable development involve cross-sector collaboration among private and public sectors, business sector, and even small-holder agriculture(Florini & Pauli 2017). The nexus perspective coincides with the implications of SDG 17 and it may provide insights for the localization of SDGs. The Global Taskforce of Local and Regional Government(2019) emphasized the importance of awareness raising, advocacy, implementation, monitoring, and establishment of future goals for the localization of SDGs. The study on the inter-sectoral nexus indicators that directly impacts the stakeholders will not only the improve the awareness of local-level SDG implementation but also provide evidence for the implementation, monitoring, and establishing future development goals for the localization of SDGs.

2. Social Network Analysis for WEA Nexus

Social Network Analysis(SNA) is a methodology that displays a structural intuition, systematic relational data, graphic images, and mathematical models among individuals or objects by using network model and graph theory(Freeman 2004; Kim & Kim 2016). SNA graph (G) is structured with nodes, also known as vertices(V; individual actors, elements, objects to observe in the network) and edges(E; relationship or interactions) that connect the nodes(Newman, M. E. J. 2003). The relationship of vertices connected to edges may be either directed or undirected. Undirected graphs represent the relationship of unordered pairs of vertices, and formally represented as $G=(V,E)$. The directed graphs show direction associated between ordered pairs of vertices through arrows (A), and it is formally represented as $G=(V,A)$(Bondy & Murty 1976; Bang-Jensen & Gutin 2000; Diestel 2005). Weighted graph refers to a graph that contains number, value or weight, to each edge(Fletcher et al. 1991). The strength of the weight is usually illustrated through the thickness of the edges linking vertices.

In order to identify the most important vertices, previous literatures usually adopt centrality analysis(Bonacich 1987; Borgatti 2005). “Importance” may be interpreted as the nodes that possess significant relationship across the network or inclusion in the cohesiveness of the whole network(Borghatti et al. 2006). Researchers have developed various types of centrality based on their analytical frameworks, however, four of them are frequently utilized for analysis: betweenness centrality, degree centrality, closeness centrality, and eigenvector centrality. Betweenness centrality measures the number of important vertex that acts as bridging role of the shortest path between a pair of other vertices(Freeman 1977). Vertex with high betweenness can thus be interpreted as pivot points within the network structure. Degree centrality simply quantifies the number of direct connections that vertices possess through indegree(number of ties directed to the vertex) and outdegree(number of ties directed from the vertex to others) centrality. Closeness centrality measures the distance of the vertex to all other vertices so the more close the vertex is, the close it is to all other nodes. Eigenvector centrality measures the connections of the vertex and its influence within the network.

The Social Network Analysis has been utilized not only in the field of social studies but also in WEA nexus analysis. For instance, researchers examined the governance and key actors that influence the relationship of water, energy, and food sectors in the Upper Blue Nile Region, Ethiopia(Stein et al. 2014), Laguna de Bay, the Philippines(Endo et al. 2015), and Phoenix, Arizona(White et al. 2017). Other studies applied social network analysis for the conceptualization of their nexus models(Kulat et al. 2019). Most of them were able to identify important stakeholders and actors in their frameworks, however, identification of important physical indicators of each WEA sector remained unknown.

Ⅳ. Data and Method

WEA nexus indicators in this study refer to the physical indicators that consider availability, sufficiency, accessibility, affordability, and types of resources, in relation to sustainable development goals. The authors collected provincial data on resources from Iloilo Provincial Profile(2012-2017), the data archive of the Department of Energy(DoE), and the Department of Agriculture(DA). Collected indicators were then categorized into water, energy, and agricultural sectors and focal points of the network(dependent variables) were codified as year-on-year changes in resource indicators and strength and direction of their relationships(independent variables) were identified based on the correlation coefficients between the indicators. The authors have created a correlation matrix of the indicators based on the linear regression analysis between independent variables and dependent variables. The focal nodes were codified according to their sector(water: W, energy: E, Agriculture: A) and the number given to the nodes. The dataset consists of 99 WEA nexus indicators(general: 2; water: 12; energy: 41; agriculture: 44). Based on the correlation matrix, the authors performed network analysis to create network graph (G) of the Iloilo Province's WEA nexus indicators through statistical package, R program. The graph plotting methods suggested by Epskamp et al.(2019), Qgraph function, was adopted to visualize the relationship between the vertices (V) and the edges (E) and to conduct centrality analysis. Each node represent indicators of WEA nexus and each edge represent the synergies and the trade-off relationship among them. Edges were illustrated as directed and weighted arrows in dark green(synergy) and red(trade-off) colors and thickness of the edges are scaled based on the edge betweenness centrality. To highlight the important edges and nodes more effectively, authors have omitted edges under absolute value of 0.5 in the graph. The graph is illustrated in the result section.

After plotting the network, centrality analysis(edge betweenness, degree, betweenness, closeness, eigenvector centrality) of the indicators were conducted to extract and examine influential nodes and edges within the network. The edge betweenness centrality is a measure that calculates the number of the shortest paths that pass through an edge in a graph or network(Girvan and Newman, 2002). An edge with high edge betweenness centrality value indicates that the edge acts as a bridge between many pairs of nodes that communicate through this edge as shortest path. Removal of this edge may result into the creation of two densely connected cliques(subnetworks). In this study, edge betweenness centrality indicates the degree of importance of the edge that acts as bridge-like connector between two different resource sectors.

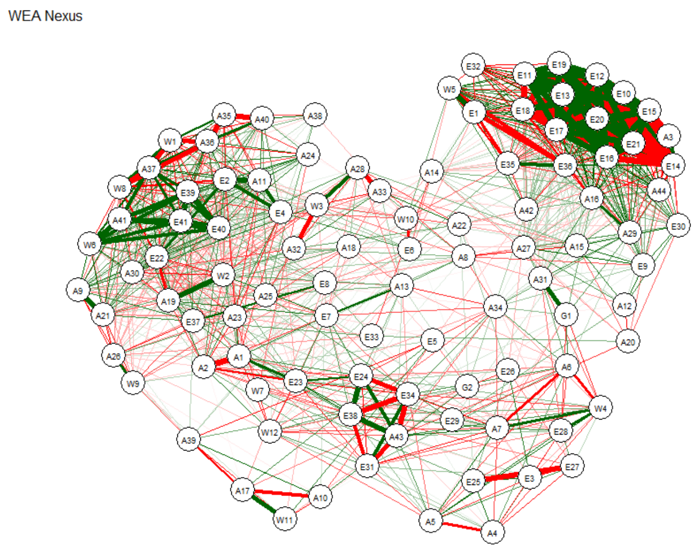
Quantification for vertex is conducted through degree, closeness, betweenness, and eigenvector centrality analysis. The degree centrality quantifies the number ties that the node possess. In this study, the degree centrality indicates the degree of the node's interaction with others. The closeness centrality quantifies the average distance of shortest path between the node and all other nodes in the network. The more close to other node is, the more central the node is within the network. In this study, closeness centrality identifies the degree of the influence of the node within the graph. The betweenness centrality calculates the number of times the node acts as a bridge-like connector between two other nodes(Freeman 1977). The betweenness centrality in this study betweenness centrality analysis highlights the important indicator that links two other nexus sectors within the network. Eigenvector centrality quantifies the influence of the node within the network(Newman 1982). In this study, eigen vector centrality of the nexus indicators refers to the degree of the importance that the node possess within the network.

Ⅴ. Results and Discussions

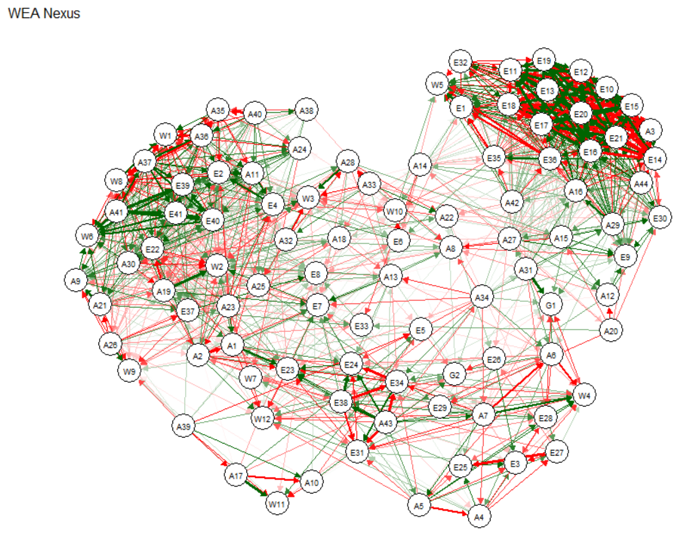
1. Iloilo WEA Nexus Network and Edge Betweenness Centrality

The configuration of the network structure of Iloilo Province's WEA nexus indicators are illustrated as graphical image in <Graph 1> and <Graph 2>. Graph 1 presents a weighted -undirected graph of WEA nexus structure to highlight the strength of the edges between two or more nodes. Green edges show positive relationship and red edges show negative relationship between the vertices.

<Graph 1> Weighted-undirected Iloilo WEA Nexus Network



<Graph 2> Weighted-directed Iloilo WEA Nexus Network



Graph 2 is the weighted-directed graph of WEA nexus indicators that shows the direction of the relationship between the nodes in the same graph, therefore indicates synergy and trade-off relationship between the indicators. To visualize the graph only with high centrality scores, authors disregarded edges with absolute weights of 0.5 are not shown, but not omitted.

The result of the network analysis of 99 WEA nexus indicators shows that there are no separate indicators and they are highly interrelated in both positive and negative ways. The strength and the direction of the edges are identified based on the correlation between the nodes, and the value range between ﹣1.0 and 1.0. Edges that link energy to energy indicators(E39, E40, E41, and others) has shown the greatest correlation value(1.0), and it is depicted as bundles of green edges in the upper right corner of the graph. Top 10 and bottom 10 correlation values among edges that links different sectors of WEA nexus are summarized in <Table 1>. Positive edges may be interpreted as that the changes in the indicators under <from> category have positive relationship to the changes in the indicators under <to> category. Negative edges represent the opposite. Detailed data description for each nodes is presented in <Table 5> of the appendix as reference.

It is notable that A3(percentage of rice farmers) is positively related with energy indicators E10(no. of consumers in PECO) and E14(no. of commercial consumers in PECO). Panay Electric Company (PECO) is the biggest and sole electricity provider in Iloilo City, thus changes in the number of rice farmers have positive correlation with residential and commercial energy consumption. Also, W2(irrigated area in dry season) and A19(area of mungo or mung beans planted) showed high correlation. Mung beans have the greatest planted area(3131.05 HA as of 2017) among legumes crops in the region, and serves as the cheapest source of protein for Illongos. About 3,000 farmers grow mungo beans in Iloilo and produce about 1,800 MT of mungo every year(PPD, 2017). Mung bean is usually planted prior to the rice planting or following rice harvest in the same spot, and as a region that adopts three crop system, Ilonggos farmers' water usage and irrigation in dry season impacts greatly on the area of mung bean planted. Also, the graph identified high negative correlation between A19(area of mungo bean planted) and A2(area of rainfed rice planted) since mungo beans frequently take the portion of the rice plantation. Their relationship may be interpreted as synergical since promotion of one indicator could enhance the other. For instance, increasing the area of irrigation during dry season could enhance the area of mungo beans planted and result into the increase in overall production.

Edges that show negative correlations or trade-off relationship among inter-sectoral indicators are also listed in <Table 1>. Among the identified edges in the network, line that stretches from W4(amount of non-revenue water) to A6(area of yellow corn harvested) shows logical reasoning. Non-revenue water refers to the water that is produced, yet is unable to reach the final consumer due to lost or leaks, and other causes. Iloilo-Batiano river basin, one of the major sources for crop irrigation, is exposed to increase in non-revenue water due to the presence of illegal or informal settlers along the river banks(Department of Environment and Natural Resources 2014).

<Table 1> Values of Edges that Links Different WEA Nexus Sectors

Positive Edges			Negative Edges		
From	To	Correlation	From	To	Correlation
A3	E14	0.999668	A3	E13	-0.99982
A3	E10	0.9996216	A3	E21	-0.99969
E18	E14	0.999143	E20	A3	-0.999652
A3	E18	0.9990435	W8	A37	-0.991276
A11	E2	0.9979166	W1	A36	-0.99013
W2	A19	0.993117	W3	A32	-0.985918
W6	A41	0.99287	W5	E36	-0.981987
E38	A43	0.9924847	W4	A6	-0.973141
W11	A17	0.9919789	E6	W10	-0.971306
W3	A28	0.9823222	E2	W8	-0.968102

Increase in non-revenue water over time would inevitably hamper not only the area of yellow corn production, but also for over all crop production. Ilonggos realizes the importance of sustainable water for their agriculture, so Metro Iloilo Water District(MIWD) and Metro Iloilo Bulk Water Supply Corporation(MIB) are operating non-revenue water reduction programs to diminish this trade-off relationship between water and agriculture sectors.

While correlation analysis examines the relational trend of the edges, authors have conducted edge betweenness centrality analysis to extract the edges that acts as bridge-like connector between two different sectors of the network. The removal of identified edges may affect the communication between many pairs of nodes through the shortest paths between them(Newman 2002). Top 10 edges with the high edge betweenness centrality were extracted and summarized in <Table 2>. The identified edge betweenness of indicators ranges from 0 to 25 for the edge that directs from W2(area of irrigated rice planted) to A8(percentage of corn farmers). High edge betweenness of these two indicators highlight the importance of the agricultural sector in the whole network and removal of this edge would result to separation of the network into two subnetworks. For the edges that connect energy-agriculture sector, an edge that directs from E26(percentage of dependable coal capacity) to A42(sugarcane production) implied high betweenness centrality. Iloilo’s energy depends heavily on the coal-fire power sources, yet bagasse, the residue that remains after sugarcane is extracted, are widely used as alternative sources for biomass energy production. Moreover, the identification of various edges between energy and agriculture sectors through edge betweenness centrality analysis indicates that energy and agriculture sectors are densely related in the Iloilo Province.

<Table 2> Top 10 Directed Edges with High Edge Betweenness

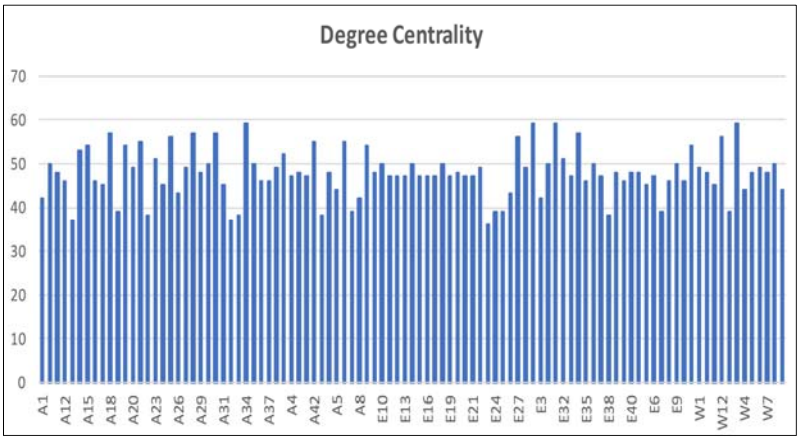
From	To	Edge Betweenness Centrality
W2	A8	25
E23	A34	23
E26	A42	23
E37	A14	23
E27	A22	22
W3	A15	22
E7	A34	21
W7	E28	21
E6	A1	20
E28	A31	20
W11	A27	19

2. Centrality Analysis on Iloilo WEA Nexus Indicators

Nodes, or vertices, also contain important information about the network. In order to identify the characteristics of the nodes, the authors have conducted four node centrality analysis: degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality analysis. In Iloilo WEA nexus network, an indicator with high degree centrality shows that it has wide interactions with other indicators. Degree centrality of the network ranges from 36 for E23(No. of industrial consumers in Iloilo Electricity Company 2) to 59 for E29(Percentage of installed biomass capacity). The statistical distribution of degree centrality is shown on

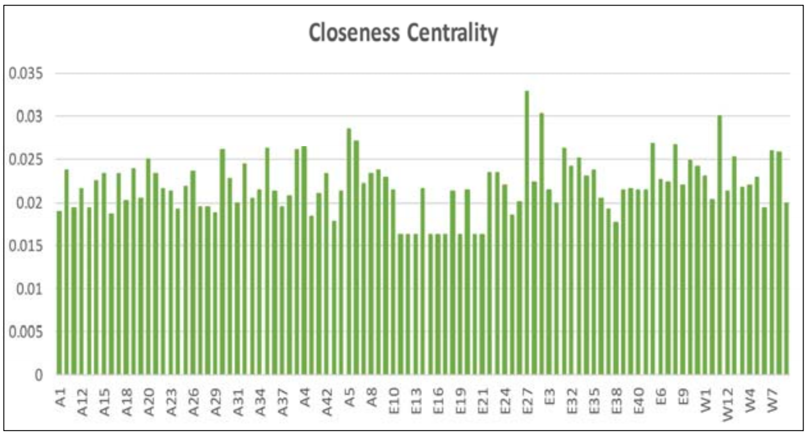
<Graph 3>. For this network, an indicator with high level of degree centrality indicate that it has wider connections with other indicators within the network. High level of degree centrality for the node E23 imply that changes in the biomass capacity over time may be potentially influenced by changes in other water, energy, or agriculture indicators connected with it. As shown in <Table 3>, E29(Percentage of installed biomass capacity), E31(Average rate of Residential electricity in PECO), W3 (Irrigated area in wet season), A34(Average rate of Residential electricity in Ileco3), E34(Average rate of Residential electricity in Ileco3), etc., are indicators with high degree centrality levels.

<Graph 3> Iloilo WEA nexus indicators measured by degree centrality



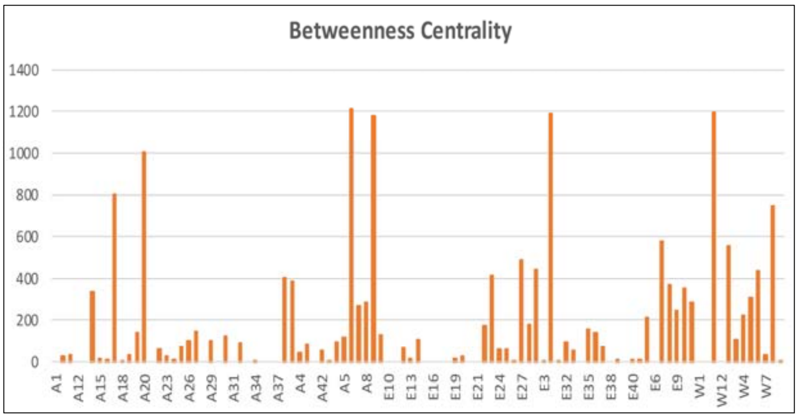
Closeness centrality of the network ranges from about 0.01 for E12 (No. of residential consumers in Ileco2) to 0.03 for E27 (Percentage of installed diesel capacity), and the statistical distribution of closeness centrality analysis is shown in <Graph 4>. Node with high closeness centrality indicates that the node is positioned close to other nodes and exercise more direct influence on others. Changes in the indicators with high level of closeness centrality may exert more direct influence on other nodes, and vice versa. <Table 3> shows that E27(Percentage of installed diesel capacity), E29 (Percentage of installed biomass capacity), W11(Rate of no. of water services billed per population with water connection), A5(Area of white corn planted), A6(Area of yellow corn harvested) and etc., are the nodes with high level of closeness centrality.

<Graph 4> Iloilo WEA nexus indicators measured by closeness centrality



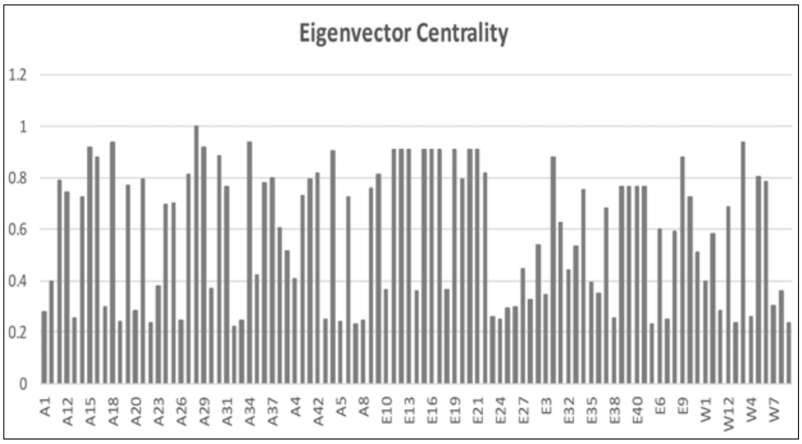
Betweenness centrality of the Iloilo WEA nexus network ranges from 0 for 27 indicators, including A35(Area of milkfish harvested in brackish water), E4(No. of total membership in Ileco2), and etc., to 1209 for A6(Area of yellow corn harvested). The statistical distribution of betweenness centrality is shown in <Graph 5>. The node with high level of betweenness centrality indicates that the node is an important point that bridges unconnected indicators. Thus, changes in the indicator with higher betweenness centrality acts as important medium that connects other indicators that do not have direct linkages. <Table 3> shows that nexus indicator A6(Area of yellow corn harvested), W11(Rate of no. of water services billed per population with water connection), E30(Percentage of dependable biomass capacity), A9(Area of Mango planted), A20(Area of peanut planted), etc. are identified as indicators with high betweenness centrality.

<Graph 5> Iloilo WEA nexus indicators measured by betweenness centrality



Eigenvector centrality measures the node's interaction with others and its level of strategic position in connection with neighboring indicators. Eigenvector centrality of nexus indicators ranges from about 0.26 for A32(Area of mungo harvested) to 1 for A18(Area of fruit veggies harvested). Indicators with high eigenvector centrality may be interpreted as that these indicators possess greater number of neighbors and important neighboring nodes. <Table 3> indicates that A28(Area of fruit veggies harvested), A18(Area of root crops planted), W3(Irrigated area in wet season), A34(Area of beans harvested), A15(Area of fruit veggies planted).

<Graph 6> Iloilo WEA nexus indicators measured by eigenvector centrality



<Table 3> Top 10 Iloilo WEA nexus indicators sorted according to the types of centrality analysis

Rank	Degree	Closeness	Betweenness	Eigenvector
1	E29	E27	A6	A28
2	E31	E29	W11	A18
3	W3	W11	E30	W3
4	A34	A5	A9	A34
5	E34	A6	A20	A15
6	A30	E5	A17	A29
7	A18	E8	W8	E12
8	A28	A4	E7	E16
9	E27	A35	W2	E15
10	A25	E31	E27	E11
11	W12	A3	E29	E17

Ⅵ. Conclusion and Policy Implications

The nexus perspective has potentials for addressing sustainable development when the indicators of inter-sectoral resources were identified and the policy makers adequately overcome the challenges on resource security through enhancing synergies among the nexus indicators. In this study, synergy and trade-off relationship and notable indicators among the water, energy, agriculture nexus indicators of the Iloilo province was illustrated through social network analysis and identified edges and nodes of the networks were analyzed with various centrality analysis. The general structure of the nexus network shows that many of the indicators in water, energy, and agriculture sectors are highly interrelated to one another. Thus, inter-sectoral approach that could promote positively related indicators and diminish the impact of negatively related nodes seems necessary. Furthermore, the classification of important indicators and links through various centrality analysis contributes to providing assistance for the construction of systems thinking among regional policy makers, decision makers, institutions, stakeholders, energy providers, water management board, farmers, consumers and many other stakeholders in the province of Iloilo, Philippines.

Based on the result of the network analysis, this paper provides following policy implications for combating foreseeable security challenges and for enabling the localized sustainable development by the stakeholders in the Iloilo province.

First, common understanding on the WEA nexus must be established among the stakeholders(farmers, water board members, energy providers, consumers, and other related officials) in Iloilo province. With common agreement on the establishment of nexus-related policies that could promote synergy and diminish the trade-off relationship among intersectoral indicators, stakeholders by then could build partnership for advanced resource management.

For instance, we have identified that W11(Rate of no. of water services billed per population with water connection) was one of the nodes with the highest betweenness centrality, and indicated that W11 had positive correlation with A17(area of spice planted) through edge betweenness centrality analysis. The results may imply that increasing the number of the water connection within the province may increase the area of spice planted and ultimately impact overall production of spices. Thus, Iloilo provincial government may strengthen the Metro Iloilo Water District's water connection projects if it attempts to increase the production of spices among farmers. Similar approaches may be constructed in water-energy or agriculture-energy sectors. The decision-makers may provide the basis for the partnership between the stakeholders and construct nexus-based local sustainable development plans through the examination of the result of this study.

Second, the Iloilo provincial government should consider localizing and applying SDG 17 targets for achieving WEA nexus based resource management. SDG 17 aims for the effective finance, assistance on technology, implementation of effective capacity building programs, policy and institutional coherence, multi- stakeholder partnerships, and improving data accountability(UN 2019).

When the concept of SDG 17 is scaled down to the local level with considerations of nexus perspective, the government of Iloilo province may seek to promote allocation of greater amount of funds for the nexus indicators that has synergy relationship to the other sectors and provide technological assistance to the stakeholders who are in need of innovation.

Furthermore, capacity building program for the farmers and other stakeholders about the nexus among resources and the implementation of sustainable development goals may expand their perspective on integrated resource management. Creation of knowledge sharing platform for discussing and planning WEA nexus policies tailored to the regional environment is also recommended. This platform could be created with official development assistance or international cooperation projects from countries that have experience of applying the WEA nexus perspective on regional resource management. Strengthening the institutional coherence for better management of inter-sectoral indicators through ordinances or appropriate policy drivers could further advance changes in action for the resource management. The enhancement of the data availability, credibility, and accessibility on the regional water, energy, and agriculture sectors would provide greater chances to expand the research on the resource nexus and its implication among the stakeholders and policy makers in the Iloilo province.

While this study provided overall nexus structure of Iloilo province's resources through the network analysis, further research on the stakeholders of these resources seems necessary. Analysis on the network of stakeholders in the region, based on their resource possession, may provide more vivid relationship among resources and create more concrete region-specific policy implications.

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Appendix

<Table 5> Data Description

	SDG	Abb.	Iloilo WEA Nexus Indicators	Unit
General	-	G1	Population	person
		G2	no. of household	unit
Water	Target 6.1	W1	Irrigation service area	HA
		W2	Irrigated area in dry season	HA
		W3	Irrigated area in wet season	HA
		W4	Non-revenue water	%
		W5	Household with access to improved safe water supply	%
	Target 6.4 Target 6.5 Target 6.6	W6	Domestic Water Connection	unit
		W7	Government Water Connection	unit
		W8	Commercial Water Connection	unit
		W9	Public Faucet Connection	unit
		W10	Bulk Water Connection	unit
		W11	Rate of no. of water services billed per population with water connection	%
		W12	Average water consumption by population with water connection per month	m3
Energy	Target 7.1	E1	Rate of household access to electricity	%
		E2	No. of total membership in PECO	unit
		E3	No. of total membership in Ileco1	unit
		E4	No. of total membership in Ileco2	unit
		E5	No. of total membership in Ileco3	unit
		E6	Houses connected with PECO	unit
		E7	Houses connected with Ileco1	unit
		E8	Houses connected with Ileco2	unit
		E9	Houses connected with Ileco3	unit
		E10	No. of residential consumers in PECO	unit
		E11	No. of residential consumers in Ileco1	unit
		E12	No. of residential consumers in Ileco2	unit
		E13	No. of residential consumers in Ileco3	unit
		E14	No. of commercial consumers in PECO	unit
		E15	No. of commercial consumers in Ileco1	unit
		E16	No. of commercial consumers in Ileco2	unit
		E17	No. of commercial consumers in Ileco3	unit

	Target 7.b	E18	No. of public building connected with PECO	unit
		E19	No. of public building connected with Ileco1	unit
		E20	No. of public building connected with Ileco2	unit
		E21	No. of public building connected with Ileco3	unit
		E22	No. of industrial consumers in Ileco1	unit
		E23	No. of industrial consumers in Ileco2	unit
		E24	No. of industrial consumers in Ileco3	unit
	Target 7.2	E25	Percentage of installed coal capacity	%
		E26	Percentage of dependable coal capacity	%
		E27	Percentage of installed diesel capacity	%
		E28	Percentage of dependable diesel capacity	%
		E29	Percentage of installed biomass capacity	%
		E30	Percentage of dependable biomass capacity	%
	Target 7.3	E31	Average rate of Residential electricity in PECO	Avg. rate per kwh
		E32	Average rate of Residential electricity in Ileco1	Avg. rate per kwh
		E33	Average rate of Residential electricity in Ileco2	Avg. rate per kwh
		E34	Average rate of Residential electricity in Ileco3	Avg. rate per kwh
		E35	Average rate of Commercial electricity in PECO	Avg. rate per kwh
		E36	Average rate of Commercial electricity in Ileco1	Avg. rate per kwh
		E37	Average rate of Commercial electricity in Ileco2	Avg. rate per kwh
		E38	Average rate of Commercial electricity in Ileco3	Avg. rate per kwh
		E39	Average rate of Industrial electricity in Ileco1	Avg. rate per kwh
		E40	Average rate of Industrial electricity in Ileco2	Avg. rate per kwh
		E41	Average rate of Industrial electricity in Ileco3	Avg. rate per kwh

Agriculture	Target 2.3 Target 2.4	A1	Area of Irrigated rice	HA
		A2	Area of Rainfed rice	HA
		A3	Percentage of rice farmers in total population	%
		A4	Area of yellow corn planted	HA
		A5	Area of white corn planted	HA
		A6	Area of yellow corn harvested	HA
		A7	Area of white corn harvested	HA
		A8	Percentage of Corn farmers in total population	%
	Target 2.3	A9	Area of Mango planted	HA
		A10	Area of Citrus planted	HA
		A11	Area of Banana planted	HA
		A12	Area of Pineapple planted	HA
		A13	Area of coffee planted	HA
		A14	Area of watermelon planted	HA
		A15	Area of fruit veggies planted	HA
		A16	Area of leafy veggies planted	HA
		A17	Area of spices planted	HA
		A18	Area of root crops planted	HA
		A19	Area of mungo planted	HA
		A20	Area of peanut planted	HA
		A21	Area of beans planted	HA
		A22	Area of Mango harvested	HA
		A23	Area of citrus harvested	HA
		A24	Area of Mango harvested	HA
		A25	Area of pineapple harvested	HA
		A26	Area of coffee harvested	HA
		A27	Area of watermelon harvested	HA
		A28	Area of fruit veggies harvested	HA
		A29	Area of leafy veggies harvested	HA
		A30	Area of spices harvested	HA
		A31	Area of root crops harvested	HA
		A32	Area of mungo harvested	HA
		A33	Area of peanut harvested	HA
		A34	Area of beans harvested	HA
	Target 2.3 Target 2.4 Target 6.6	A35	Area of milkfish harvested in brackish water	HA
		A36	Area of tilapia harvested in brackish water	HA

		A37	Area of tiger prawn harvested in brackish water	HA
		A38	Area of milkfish harvested in fresh water	HA
		A39	Area of catfish harvested in fresh water	HA
		A40	Area of oyster harvested in fresh water	HA
		A41	Area of seaweeds harvested in fresh water	HA
	Target 2.4	A42	Sugarcane production	L-kg
		A43	Cane milled	Tons
		A44	No. of sugar cane producers	person

<국문초록>

지속가능발전을 위한 물-에너지-식량 넥서스: 필리핀 일로일로 지역을 중심으로

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물, 에너지, 식량 자원 간의 연계(Water-Energy-Agriculture Nexus: WEA Nexus)는 기존의 분절된 자원 관리 시스템을 탈피하여 통합적인 사고를 요하는 패러다임 전환을 요구한다. 이 개념은 유엔(UN)이 추구하는 지속가능발전목표(Sustainable Development Goals: SDGs)의 상호연계성에 부합하며, 자원 간의 관계를 파악함으로써 보다 효율적인 자원 관리 시스템을 구축하데 도움을 줄 수 있다. 그러나 WEA 넥서스는 주로 국제적인 수준의 논의 또는 거대담론 및 개념화 단계에 머무르는 경우가 많았다. 따라서 본 연구의 목적은 사회적 연결망 분석과 지표 간의 중심성 분석을 통해 WEA 넥서스를 지역 수준에서 분석하는 것이다. 아울러 중요한 의미를 가지는 주요 지표를 색출함으로써 지역에 기반한 지속가능발전목표 달성(localizing the SDGs)을 위한 시사점을 얻고자 한다. 농업 중심 경제이며 기후변화, 인구 증가, 도시화 등 여러 문제로 말미암아 안전한 자원 확보가 필수적인 필리핀의 일로일로

(Iloilo) 지역을 대상으로 사회적 연결망 분석을 통해 지역 기반 WEA 넥서스의 지표 간의 관계와 방향성을 살펴보았다. 본 연구의 연구 결과를 통해 다양한 이해당사자 간의 파트너십을 형성하고 연계를 늘려가는 방안이 정책적 함의로 제시되었다. 본 연구의 결과를 통하여 정책 입안자 및 다양한 이해당사자들이 효과적인 지역 기반 발전 정책을 도출하기 위하여 자원 간의 연계성에 대해 이해하고 통찰을 가질 수 있기를 기대한다.

주제어: 물-에너지-식량 넥서스, 지속가능발전목표, 사회적 연결망 분석