Journal of Sustainable Development; Vol. 10, No. 5; 2017
ISSN 1913-9063 E-ISSN 1913-9071
Published by Canadian Center of Science and Education

A Quantitative Nexus Approach to Analyze the Interlinkages across the Sustainable Development Goals

Ali Karnib[1]

[1] Lebanese University, Hadath Campus, Baabda, Lebanon

Correspondence: Ali Karnib, Lebanese University, Hadath Campus, Baabda, Lebanon. E-mail: karnib.ali@gmail.com

Received: July 27, 2017 Accepted: August 22, 2017 Online Published: September 29, 2017

doi:10.5539/jsd.v10n5p173 URL: https://doi.org/10.5539/jsd.v10n5p173

Abstract

The 2030 Agenda for sustainable development comprises 17 Sustainable Development Goals (SDGs) that aimed at achieving universal access to basic needs and services for all. Moreover, the SDGs present a broad and comprehensive set of goals that cover social, economic and environmental aspects. The global SDGs are interlinked and they are either mutually supportive or conflicting. Informing about the interlinkages enables policy makers to harness synergies and manage any potential conflicts between policies engaged to achieve the SDGs. This paper introduces a framework to analyze interlinkages across the SDGs based on a bottom-up process which is supported by a quantitative nexus theoretical method to evaluate the direct and indirect quantitative interactions among SDG variables. Firstly, the general concept of analyzing interactions based on a bottom-up process is presented. Secondly, a quantitative nexus method based on input-output theory that permits the evaluation of the direct and indirect interaction effects among SDG variables is introduced. Lastly, a numerical experiment is presented and results are discussed.

Keywords: sustainable development goals, quantitative nexus approach, input-output theory

1. Introduction

The progress towards the achievement of the global SDGs will be monitored and reported upon through 169 targets and 232 indicators (UN 2017). The different dimensions of the sustainable development agenda are quantitatively interconnected (Georgeson, Maslin & Poessinouw 2017, OECD 2004, Bell & Morse 2008, Meadows 2008, UN 2007). Actions to achieve progress in one SDG may cause underachievement in another. Furthermore, a successful sustainable development initiative in one sector might create synergies for improvements in another (Pedercini & Barney 2010, Karnib 2016b). Therefore, the quantitative interlinkages and integrated nature of the sustainable development agenda will require a science-based quantitative nexus perspective for analyzing interlinkages across the SDGs.

Many studies have been developed to explore the integrated nature of the SDGs (UN Water 2016, Nilsson 2017, UNEP 2016, Le Blanc 2015, Shah 2016). Identifying links using the network analysis method introduced by Le Blanc (2015) are insufficient to support real-world sustainable development policies. Moreover, the study published by Weitz (2014) is lack of solid science-based systematic background of the interlinkage analysis, while Nilsson (2017), on the other hand, is proposing simple scoring approach using interaction scoring of seven-point scale where the rating scores are qualitative and could not informing about the indirect interlinkages across SDGs.

This study presents a conceptual quantitative nexus framework for exploring interlinkages across the SDGs based on a bottom-up process which will be supported by a detailed theoretical method to evaluate the direct and indirect quantitative interactions among SDG variables.

2. The Proposed Quantitative Nexus Approach for Analyzing Interlinkages across the SDGs

2.1 General Concept

The SDGs aim to guide global action on the achievement of a common set of social, environmental, economic and ecosystem development objectives for the coming fifteen years. Thus, goals are the broad aims used to shape the agreed sustainable development strategies. Specific Sustainable Development Targets (SDTs) are determined to give clear direction and objectives to achieve the SDGs. The Sustainable Development Indicators (SDIs) and their associated data variables (SDVs) are specific metrics which are used to track progress towards the achievement of the SDTs and SDGs. The SDG framework could be represented by the information pyramid shown in Figure 1.

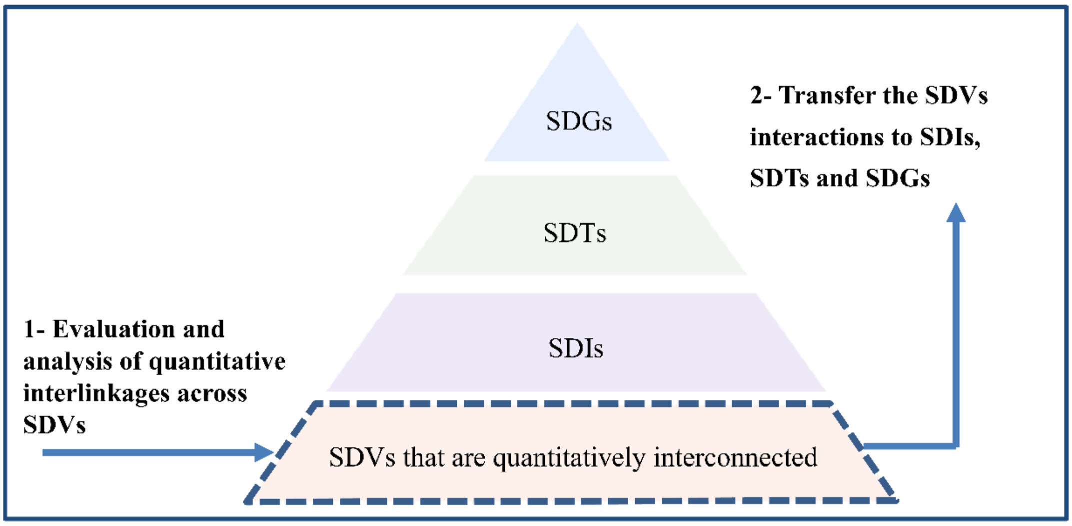

Figure 1. A bottom-up process for analysing interactions across SDGs

The elaboration of SDIs requires the combination of multiple SDVs; also, certain SDVs are shared across several indicators or may, themselves, be used as indicators. On the other hand, the use of an appropriate SDIs aggregation procedure is required to evaluate the SDTs and then the SDGs (Karnib 2016a,b). Accordingly, the entry point of evaluation progress towards achieving sustainable development goals is the assessment of the concerned indicators and the corresponding data variables. Taking variables as starting point, makes it easy to address the quantitative interdependencies and interactions across the resources they involve. The bottom-up process and SDVs nexus approach is well-suited with this principle.

Typically, SDVs that are taken into consideration to evaluate progress towards the achievement of the sustainable development goals are not independent of each other (UN, 2007; Karnib, 2016a,b, 2017a,b,c,d). For example, increasing food production to meet the needs of growing population and economies can result in increases in water, energy and land use, which may lead to potential negative impacts on ecosystems.

The evaluation and analysis of quantitative interdependence across SDVs will permit to map the actual interconnections across SDIs, thus, transmitting the interconnection information through the SDTs and then the SDGs (Figure 1).

Figure 2 shows the general concept of the proposed approach, in effect, the evaluation of interactions across SDVs is necessary to inform policy makers about the consequences of policy options on one or more sustainable development sectors or goals. Conceiving these interactions within a quantitative nexus simulator will enable policy makers to investigate valuable knowledge that the nexus simulation model may yield. Integrating the SDIs assessment methods within a nexus simulator will derive the greatest benefit by executing simulation of sustainable development policy options many times and evaluating the resulted progress towards the achievement of the desired sustainable development targets. Essential information related to SDGs interactions could be then drawn out to inform the sustainable development planning which may include: i) the combinations of sustainable development policy options that will lead to the best and worst performance of the SDGs; ii) the data variables that have the greatest and/or least influence on the SDGs being analyzed; iii) identification of the sustainable development policies that are more robust to variables variation than others.

As shown in Figure 2, coupling quantitative SDVs nexus model with the SDIs assessment system permits the analysis of the SDIs interactions based on different policy options. For example, the “Food Production” SDV is quantitatively interconnected with many other SDVs such as the “Water Use”, “Wastewater Safely Reused”, “Energy Production”, etc. Any change in the “Food Production”, which is an information element for SDG 2 (End hunger, achieve food security and improved nutrition, and promote sustainable agriculture), will lead to impacts on the other variables mentioned above which support the evaluation of many other SDGs (i.e. SDG 6 (Ensure availability and sustainable management of water and sanitation for all), SDG 7 (Ensure access to affordable, reliable, sustainable, and modern energy for all), SDG 11 (Make cities and human settlements inclusive, safe, resilient and sustainable)). The quantitative SDVs nexus simulator could be used to evaluate the new SDVs values due to any policy option and map any potential interactions between SDIs.

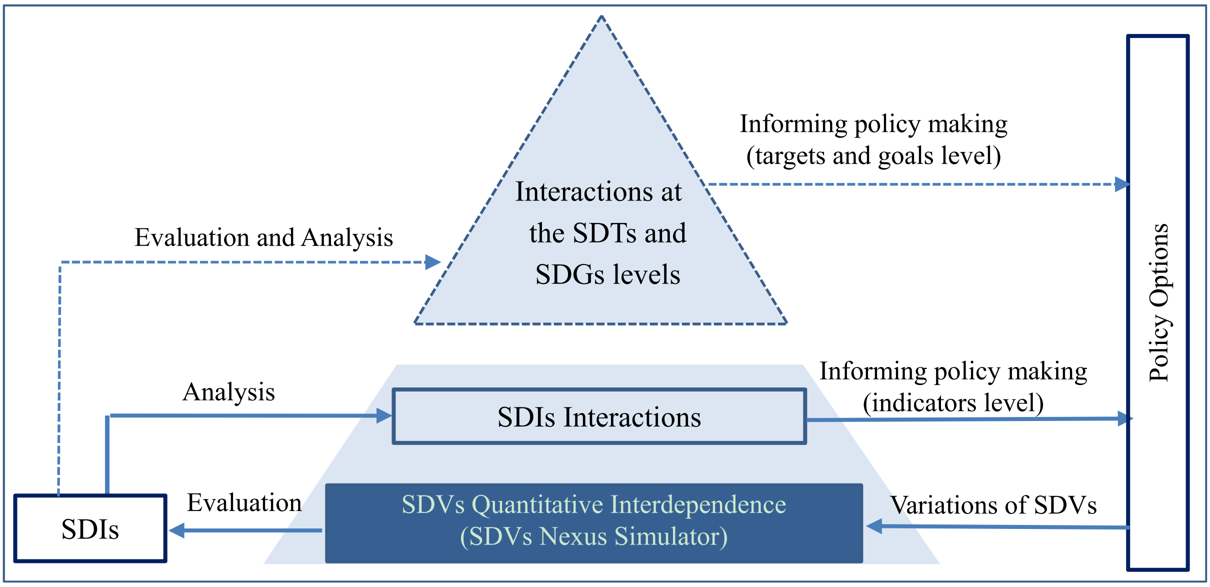

Figure 2. Proposed framework to evaluate and analyze interactions among SDVs, SDIs, SDTs and SDGs (Note 1)

This pairing of SDIs evaluation with SDVs quantitative nexus simulator can be used beneficially for many combinations of variables are being considered. The use of the proposed nexus framework for modeling interlinkages across the SDGs allows policy makers to simulate any changes in the SDVs and calculate the changes occurred in various SDIs. The detailed quantitative SDVs nexus theory will be presented in the next section.

2.2 The SDVs Quantitative Nexus Method

Many SDVs are interconnected through quantitative flows production functions (which termed production flows). The production flows of the interconnected SDVs can be viewed in matrix form with each element of the matrix representing the quantitative output of the row component used by the column component for total production quantities of that column component. This way of analysis can also be considered in an input-output table structure. Based on input-output theory, the quantity flows which leave the system, i.e. which have no consumer in the production system, such as component used by households, government, rest of the economy, losses, accumulation (storage) and exports are defined collectively as end use quantity flows.

Let the production matrix be V and its elements be v_{ij}. Let the end use vector be v with elements v_i. If we denote by:

n number of the quantitatively interlinked sustainable development variables (SDVs);

v_{ij}: the use of i^{th} SDV in the production of j^{th} SDV;

v_i^h : the use of i^{th} SDV for households demand;

v_i^g : the use of i^{th} SDV for government demand;

v_i^e : the use of i^{th} SDV for rest of the economy demand;

v_i^l : the losses of the i^{th} SDV;

v_i^s : the accumulation (storage) quantities of the i^{th} SDV;

v_i^x : the exported quantities of the i^{th} SDV;

v_i^t : the total quantities of the i^{th} SDV;

Then by applying the quantitative balance, the total quantities vector v^t, for each variable is

$$v_i^t = \sum_{j=1}^{n} v_{ij} + v_i^h + v_i^g + v_i^e + v_i^l + v_i^s + v_i^x \qquad (i=1, 2, \ldots, n) \qquad (1)$$

Let $u_i = v_i^h + v_i^g + v_i^e + v_i^l + v_i^s + v_i^x$

Then equation (1) will be:

$$v_i^t = \sum_{j=1}^{n} v_{ij} + u_i \qquad (i=1, 2, \ldots, n) \qquad (2)$$

Then let:

$$v_{ij} = a_{ij} v_j^t \qquad (3)$$

(The production quantities v_{ij} are expressed as linear function of the total quantities of v_j^t)

Where a_{ij} are the elements of the normalized production matrix A.

Substitution into equation (2) yields,

$$v_i^t = \sum_{j=1}^{n} a_{ij} v_j^t + u_i \qquad (i=1, 2, \ldots, n) \qquad (4)$$

Equation (4) can be restated in matrix form and solved for v^t:

$$v^t = Av^t + u \qquad (5)$$

Then

$$v^t = (I - A)^{-1} u = L^{-1} u \qquad (6)$$

Where I is the identity matrix, and L^{-1} $(=(I\text{-}A)^{-1})$ is known as the Leontief inverse (Miller & Blair, 2009). By assuming that technology of the SDVs production, as represented in A matrix, do not change, each $(I - A)_{ij}^{-1}$ element captures direct and indirect effects that the new end use demands have on v^t. These are the key elements to analysing the interdependence of each SDG variable on the other. For example, if the superscript "new" is used to represent the values of variables after the change in end use values, the required total outputs (v^{tnew}) caused by new end use quantities (u^{new}) could be then found using equation (6). In addition, the analysis of policy options by adopting efficient technology of the SDVs production flows could be also performed. Details of different policy alternatives that could be analysed by a quantitative nexus method and the related direct and indirect effects are presented in Karnib (2017d).

The theory presented in this study evokes two remarks:

Remark 1: The technology of the SDVs production flows, as represented in A matrix, could change with time, therefore, adjustment of the A matrix is necessary to simulate long time scenario analysis.

Remark 2: Complete SDVs production flow records may not be available in some countries, therefore, any records reconciliation could be done based on experts judgement that have profound knowledge of the real system.

3. Illustrative Example and Analysis of Results

A hypothetical example (a case study compatible with Lebanon setting) will be presented to illustrate the application of the foregoing approach. The following three policy options are considered and the resulting changes in the SDG 6.4.2 indicator (the available water resources used) will be analyzed:

Scenario1: This scenario consists of increasing 20 % the household demand of agricultural and food production, household use of energy and household use of water. All other end use demands are assumed unchanged.

Scenario 2: This scenario consists of reducing 20 % of the end use water losses and increasing 20 % of water use efficiency in agricultural production.

Scenario 3: The positive and negative impacts on the SDG 6.4.2 indicator resulted from scenario 1 and 2 will be analyzed. The aim of this scenario is to show how negative impacts of scenario 1 may be offset by the positive impacts of scenario 2 in a framework of nexus approach where the direct and indirect effects of policy options are calculated.

The quantitative direct and indirect impacts of the proposed three scenarios will be evaluated using the proposed approach.

The identification of the SDG indicators and their methods of calculation could be approached in different ways according to the specific conditions of each country. Therefore, the national sustainable development monitoring framework could extend beyond the scope of the global monitoring framework and may include a number of additional indicators not considered under the SDGs. To respond to the sustainable development issues considered in scenarios 1, 2 and 3 mentioned above, the following SDVs are used (Table 1):

Table 1. The considered SDVs and their units of measurement

Proposed SDVs	**Unit of measurement***	**Name**
Irrigated agriculture	kt/year	*v1*
Food production	kt/year	*v2*
Water use (surface water & groundwater)	Mm^3/year	*v3*
Wastewater safely reused	Mm^3/year	*v4*
Agricultural drainage water safely reused	Mm^3/year	*v5*
Desalinated water	Mm^3/year	*v6*
Energy production (excluding renewable energy)	ktoe/year	*v7*
Renewable energy	ktoe/year	*v8*
Industrial production	MUSD/year	*v9*

* kt: kilo tons; Mm^3: million cubic meter; ktoe: thousand tons of oil equivalent; MUSD: million United States dollars

The percentage of total available water resources used, taking environmental water requirements into account (Level of Water Stress) (SDI6.4.2) is calculated by the following equation (UN 2017):

$$\text{SDI6.4.2 (\%)} = 100 * \frac{\sum v_i^t}{RW-EW} \qquad (i=3,\ 4,\ 5,\ 6) \qquad (7)$$

Where

v_i^t: the total quantities of the i^{th} SDV

RW: the total renewable freshwater resources (Mm^3/year)

EW: the environmental water requirements (Mm^3/year)

In this case study, *RW* = 2400 Mm^3/year and *EW* = 600 Mm^3/year.

Table 2 presents the SDVs intersectoral use or production flows values (v_{ij}) and the corresponding end use values (v_i^h , v_i^g , v_i^e , v_i^l , v_i^s , v_i^x). These values represent the Business As Usual (BAU) scenario.

Table 2. SDVs production flows values and the corresponding end use values

	SDVs production flows (v_{ij})									End use					
	v1	*v2*	*v3*	*v4*	*v5*	*v6*	*v7*	*v8*	*v9*	v_i^h	v_i^g	v_i^e	v_i^l	v_i^s	v_i^x
v1	0	50	0	0	0	0	0	30	40	1913	1	19	10	0	225
v2	0	10	0	0	0	0	0	0	10	3016	2	58	50	0	211
v3	527	125	0	0	0	0	2	0	144	249	2	68	384	0	10
v4	3	0	0	0	0	0	0	0	0	0	0	1	1	0	0
v5	19	0	0	0	0	0	0	0	0	0	0	0	2	0	0
v6	0	0	0	0	0	0	0	0	20	5	0	5	0	0	0

v7	50	80	144	0	2	67	5	0	1426	1645	1	1371	1042	0	0
v8	1	0	1	0	0	0	0	0	1	96	0	10	15	0	0
v9	17	76	82	55	80	100	117	16	2372	8151	1	1000	100	1000	4395

The available water resources used (SDG6.4.2 indicator) value of the BAU scenario is 81 % (evaluated using equation (7)).

The scenario 1 will be now considered, the resulting changes in the variables total quantities (Δv_i^t) (direct and indirect outputs) caused by the changes in household end use quantities (Δv_i^h) are then evaluated using the SDVs nexus simulator. The results are presented in Table 3.

Table 3. Changes in the SDVs total quantities resulted from scenario 1

Δv_1^t	Δv_2^t	Δv_3^t	Δv_4^t	Δv_5^t	Δv_6^t	Δv_7^t	Δv_8^t	Δv_9^t
396.5	605.0	164.4	0.5	3.3	1.1	376.5	19.4	66.3

The new values of v_1^h, v_2^h and v_3^h may support various potential indicators related to many sustainable development goals. The increase of these variables values will lead to positive effects on many aspects related to SDGs 1, 2, 6, 7, 9 & 11. Furthermore, the SDG6.4.2 indicator is evaluated using equation (7) as function of the new values of the variables v_i^t (*i*=3, 4, 5, 6), the evaluated new ratio of the SDG6.4.2 indicator is 90 % which implies that policies of scenario 1 have negative impacts on the SDG6.4.2 indicator. To reduce water stress, policy options of scenario 1 should be coupled with policies to increase the safely wastewater and agricultural drainage water reuse, increasing intersectoral water use efficiency and reducing end use water losses.

By considering the scenario 2, the examined water use efficiency and end use water losses are 5.98 kg/m^3 and 307 Mm^3/year as alternatives to 4.98 kg/m^3 and 384 Mm^3/year, respectively. The evaluated new value of the SDG6.4.2 indicator is 70 %. This scenario reduced the level of water stress by 11 % compared to the BAU scenario (= 81% - 70%), which indicates that policies of scenario 2 have positive impacts on the SDG6.4.2 indicator.

Finally, by considering the scenario 3, the resulting value of the SDG6.4.2 indicator is 78 % which is slightly less than the value of the BAU scenario. The proposed nexus framework allows the evaluation of the direct and direct effects of policy options where the negative impacts on SDG6.4.2 indicator resulted from scenario 1 are offset by the positive impacts of scenario 2.

4. Conclusions and Further Developments

Many of SDG variables are quantitatively interconnected, some of them support the evaluation of more than one sustainable development indicator. A quantitative nexus approach among SDG variables coupled with bottom-up process to transmit the interconnection information to the SDTs and SDGs is an important tool to inform policy makers about the interlinkages and trade-offs among policies engaged to achieve the SDGs.

This paper introduces a quantitative nexus approach to evaluate the SDVs as an interconnected components that directly and indirectly affect one another. The proposed method allows the analysis of the interactions and informing about the multilateral consequences that affect the progress towards the achievement of the sustainable development goals. It helps policy makers to harness synergies and manage any potential trade-offs between policies engaged to achieve the SDGs based on realistic interlinkage relations. It allows also the evaluation of potential offsets due to several combined policy options.

The proposed approach could serve as an open knowledge platform built on a common conceptual framework that allows the sharing of knowledge between countries for many common challenges related to the achievement of the SDGs.

The application of the proposed quantitative nexus approach on a comprehensive set of interconnected SDVs is under development at our university.

References

Bell, S., & Morse, S. (2008). *Sustainability Indicators. Measuring the Immeasurable?* Earthscan publishing, London.

Georgeson, L., Maslin, M., & Poessinouw, M. (2017). The global green economy: a review of concepts, definitions, measurement methodologies and their interactions. *Geo: Geography and Environment Journal*, *4*(1), 1-23. https://doi.org/10.1002/geo2.36

Karnib, A. (2016a). A methodological approach for sustainability assessment: application to the assessment of the sustainable water resources withdrawals. *International Journal of Sustainable Development*, *19*(4), 402-417. https://doi.org/10.1504/IJSD.2016.080515

Karnib, A. (2016b). *Drawing on the MDG+ Initiative Framework for Informing the Water Related SDGs in the Arab Region,* working paper, Economic and Social Commission for Western Asia (ESCWA). Retrieved from https://www.unescwa.org/sites/www.unescwa.org/files/events/files/working_paper_on_mdg_for_informing_water-related_sdgs-31march16.pdf

Karnib, A. (2017a). Water-Energy-Food Nexus: A Coupled Simulation and Optimization Framework. *Journal of Geoscience and Environment Protection*, *5,* 84-98. Retrieved from http://www.scirp.org/Journal/PaperInformation.aspx?PaperID=75605

Karnib, A. (2017b). Evaluation of Technology Change Effects on Quantitative Assessment of Water, Energy and Food Nexus. *Journal of Geoscience and Environment Protection, 5*, 1-13. Retrieved from http://www.scirp.org/Journal/PaperInformation.aspx?PaperID=74111

Karnib, A. (2017c). Quantitative Assessment Framework for Water, Energy and Food Nexus. *Computational Water, Energy, and Environmental Engineering Journal*, *6*, 11-23. Retrieved from http://www.scirp.org/Journal/PaperInformation.aspx?PaperID=72359

Karnib, A. (2017d). Water, Energy and Food Nexus: The Q-Nexus Model, *10th World Congress of EWRA on Water Resources and Environment "Panta Rhei"*, *Athens Greece*, 701-709. Retrieved from https://www.researchgate.net/publication/318284443_Water_energy_and_food_nexus_The_Q-Nexus_Model.

Le Blanc, D. (2015). Towards integration at last? The Sustainable Development Goals as a network of targets. *Sustainable Development*, *23*(3), 176-87. https://doi.org/10.1002/sd.1582

Meadows, D. H. (2008). *Thinking in Systems: A primer.* Sustainability Institute, Earthscan, London.

Miller, R. E., & Blair, P. D. (2009). *Input-output analysis. Foundations and extensions* (2nd ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511626982

Nilsson, M. (2017). *Important interactions among the Sustainable Development Goals under review at the High-Level Political Forum 2017*, Stockholm Environment Institute, working paper. Retrieved from https://www.sei-international.org/mediamanager/documents/Publications/SEI-WP-2017-06-Nilsson-SDG-interact-HLPF2017.pdf

OECD. (2004). *Measuring Sustainable Development: Integrated Economic, Environmental and Social Frameworks*. OECD Publications, France.

Pedercini, M., & Barney, G. O. (2010). Dynamic analysis of interventions designed to achieve Millennium Development Goals (MDG): The case of Ghana. *Socio– Economic Planning Sciences*, *44*(2), 89-99. https://doi.org/10.1016/j.seps.2009.08.002

Shah, O. (2016). *Water energy & food nexus from model to Policy framework, towards the realization of SDGs: Case Study of Pakistan*. Thesis of Master's degree in Engineering & Public Policy at W. Booth School of Engineering Practices, McMaster University, Ontario, Canada.

UN Water. (2016). *Water and Sanitation Interlinkages across the 2030 Agenda for Sustainable Development*. Geneva. Retrieved May, 2017, from http://www.unwater.org/publications/publications-detail/ar/c/429651/

UNEP. (2016). *Sustainable Development in Practice: Applying an Integrated Approach in Latin America and the Caribbean*. UN Environment Programme, Panama City.

United Nations (UN). (2007). *Indicators of Sustainable Development - Guidelines and Methodologies, United Nations*. New York. Retrieved from http://www.un.org/esa/sustdev/natlinfo/indicators/guidelines.pdf

United Nations (UN). (2017). *Revised list of global Sustainable Development Goal indicators*. Retrieved May, 2017, from https://unstats.un.org/sdgs/indicators/indicators-list/

Weitz, N. (2014). *Cross-sectoral integration in the Sustainable Development Goals: a nexus approach*. Stockholm Environment Institute, Discussion Brief. Retrieved from https://www.sei-international.org/publications?pid=2474

Note

Note 1. The actions represented by dotted lines are not developed in this study.

Copyrights