HNUE JOURNAL OF SCIENCE DOI: 10.18173/2354-1067.2020-0080
Social Sciences, 2020, Volume 65, Issue 11, pp. 156-166
This paper is available online at http://stdb.hnue.edu.vn

CANONICAL ANALYSIS FOR MEASURING EQUILIBRIUM BETWEEN COMPONENTS OF SUSTAINABLE DEVELOPMENT IN VIETNAM

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Abstract. Sustainable development now becomes zeitgeist of our age which can be perceived as the development that guarantees the balance between economic development, social well-being and environmental component, to satisfy the needs of the present without compromising the ability of future generations to meet their own need. From one hand, it is a way to define the goals which a good society should achieve to ensure better quality of life for all inhabitants of the planet, both for the present generation and for future generations. From the other hand, sustainable development is a way to understand the world as a complex interaction within and between economic, social, environmental systems. This article aims to measure the intersystem equilibrium of sustainable development by analyzing the statistical relationships between the different dimensions of sustainability. All of the analysis use the complete raw existing data set provided for 24 indicators for the years 2016 of 63 administrative units of Vietnam. The results show that there is an average relationship between subsystems of sustainable development in Vietnam measured by the level of mutual explanation of original set of variables of each subsystem in the procedure of canonical correlation analysis.

***Keywords**:* intersystem equilibrium, canonical analysis, measuring sustainability, sustainable development.

1. Introduction

The need for a new development paradigm was widely recognized by the mid-1980s (Estes, 1993). In 1987, Brundtland report calls for a different form of growth, "changing the quality of growth, meeting essential needs, merging environment and economics in decision making" (WCED, 1987) with an emphasis on human development, participation in decisions and equity in benefits. Thus we arrive at sustainable development that guarantees the balance between economic development, social well-being and environmental component, to satisfy the needs of the present without compromising the ability of future generations to meet their own needs.

Received July 6, 2020. Revised September 2, 2020. Accepted October 1, 2020.
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Sustainable development is generally considered a new development model that emerged during the late 20th century (Waas et al., 2011) and has been accepted by the international community as a golden rule of our civilization in the 21st century (Christina Voigt, 2009). The term sustainable development has rapidly spread and become the central theme for international aid agencies, the jargon of development planners, the theme of conferences and learned papers, and the slogan of developmental and environmental activists, as well as the dominant paradigm of development at the regional and local levels in the countries (Lele, 1991; National Academy of Sciences, 1999; Enders and Remig, 2015).

In the complexity of term "sustainable", the particularly interesting is the discussion about the meaning of the term "sustainable" as "balance" which reveals the difficulty of measuring the operationalization of sustainable development (balance amid each component and among them). According to classical (physical) understanding of the question, the balance should be replaced by the evaluation based on the criteria: harmony, proportions, interdependence, general social efficiency, the efficiency of the operation, progress, justice, improving the quality, equity. Sustainable environment means closeness of ecosystem, biodiversity, trophic structure, resource renewal and its balanced relations with economy and society. Sustainable economy means diversity, efficiency, creativity and its balanced relations with society and environment. Finally, sustainable society is revealed by justice, diversity, security and its balanced relations with economy and environment. To keep the balance of a system, on the one hand, sustainable development requires a balance and holistic development, seeks to build a good society not only an economically prosperous society but also one that is also socially inclusive, environmentally sustainable (Sachs, 2015). On the other hand, sustainable development requires an understanding the relationship, the integration and the interactions between elements of a system.

Understanding the linkages in sustainable development, as well as measuring the relationship between its components is not easy task. In each pillar of sustainability, a lack of available data limits the possibility to assess the balance of the system. In some cases, the problem lies in the fact that the proposed criteria are equally difficult to operationalize as sustainable development. What is "appropriate diversification" or "right proportions" or "justice"? Many authors write that social diversity is a desired value, but ethnic diversity is often threatened by conflict. The social subsystem appears in social justice, diversity of demographic and social structures, and the development of social capital, education and culture. In the economy attributes "of balancing the sustainable system" can be specified as differentiation (industries, firm size, and ownership), the efficiency of the economy, the development of knowledge-based and creative areas and local resources.

Another question related to the relationships between components of sustainability is what conditions should fulfill each component to create better sustainability of others ones? For example, social pillar should include: ecological education, ecological awareness, life style and consumption model, which should protect against redundant (excessive) exploitation of resources. On the other side environmental subsystem should provide energy, food, aesthetic landscape, recreational areas. Economic subsystem should provide people with jobs, salaries and wages, technical infrastructure, while social subsystem should consist of people with suitable education, qualifications and creativity. Economic subsystem should apply technologies friendly for environment, exploits rationally resources, applies recycling to keep environment in good conditions and others. In fact, the set of applied indicators includes some such characteristics, but as Roush (2003) found that it is difficult to link indicators to systemic and holistic thinking, because of reductionist nature of indicators that divides a whole into individual parts. Discovery of measureable relationship between holistic thinking and sustainability still remains a big challenge for researchers. Hence indirect methods can be only applied to measure relatively the linkages and balance of the system of sustainable development.

This article seeks to answer for the question: what is the interconnectedness between subsystems of sustainable development in Vietnam? The question tends to identify the level of equilibrium between subsystems of sustainable development by analyzing the statistical relationships between them. In the conducted research, three subsets of sustainability were approved: economic, social and environmental, which means that this question aims to identify relationship of three pairs: economic - social, economic – environmental, and social – environmental. It is hypothesized that there is an average relationship between subsystems of sustainable development in Vietnam measured by the level of mutual explanation of original set of variables of each subsystem in the procedure of canonical correlation (canonical redundancy). It means that the total redundancy indices indicate that the mutual determination of the variability of the sets of subsystem variables is at least average when proportions of variance explained is over 50% with acceptable statistical significance. All of the analysis uses the complete raw existing data set provided for 24 indicators for the years 2016 of 63 administrative units of Vietnam.

2. Content

2.1. Selecting indicators and data resources

The research has used primary and secondary data from government agencies and academic institutes. Primary data are comprised of information gathered directly by technological monitoring, including satellite-derived estimates of air quality. Data for annual mean concentration of Particulate Matter 2.5 (μg/m3) by province was synthesized from the satellite data of air quality for Environmental Performance Index of Yale University of United States and retrieved from remote sensing data provided by the Department of Physics and Atmospheric Science, Dalhousie University in Canada. Secondary data include official statistical data formally reported by General Statistics Office (GSO) of Vietnamese government. The research has constructed 24 sustainable development indicators cover a wide range of issues with 8 indicators for each component of sustainability, as following (Truong VC, 2019):

- Economic component (8 indicators): GDP per capita (PPP current USD), GDP density (million USD PPP per km^2), Proportion of employment in agriculture (%), Incremental capital-output ratio (ICOR), Unemployment rate (% labor force), Percentage of trained employed workers (%), Competitiveness Index, and Budget surplus as percentage of GDP (%).

- Social component (8 indicators): Adult literacy rate (%), Proportion of household own permanent house (%), Poverty rate (%), Gini index, Female labor force participation rate (% male), Prevalence of underweight children, weight for age (% of children under 5), Average life expectancy at birth (year), and Proportion of death due to traffic accident (per 100.000 people).

- Environmental component (8 indicators): Forest cover (% total land area), Agricultural land per person (ha), Proportion of household with access to improved sanitation (%), Percentage of household access potable water (%), Proportion of rural households using solid fuels for cooking (%), Annual median concentration of Particulate Matter 2.5 (µg/m3), Total of collected solid waste per capita (kg/person/day), and Proportion of collected solid waste per day that are treated according to national standards (%).

2.2. Research method

Correlation may be used to also indicate a state of intersystem balance, which is extremely important for achieving a certain level of balance in the entire system. One of the assumptions of the study for sustainability of the territorial systems, in addition to determining the level of sustainability of each of the distinguished subsystems, is attempting to evaluate the mutual correlation of these subsystems (Alpert and Peterson, 1972; Mierzejewska, 2009). Canonical analysis is a relevant, useful and powerful technique for exploring the nature and strengths of relationships between sets of variables. The existence of relationships between two variable sets has traditionally been determined by testing the statistical significance of the canonical correlation coefficient. Therefore, canonical correlation would be the appropriate method of analysis.

In the conducted research, three subsets of variables were described: economic, social and environmental, which means considering the following three correlation systems: economic - social, economic – environmental, and social – environmental component. During the canonical analysis procedure, the original variables of each of the two subsets are transformed in such a way that the correlation coefficient between individual pairs of canonical variables is the largest. For convenience, the variables in the first set are called "U" variables and the variables in the second set are called "V" variables. Canonical analysis will conduct the canonical variates which are linear composites between Vi and Ui. A pair of canonical variates is called a canonical root. The number of possible canonical variates, also known as canonical dimensions, is equal to the number of variables in the smaller set. For example, in our research, the "U" set (the first set) has 8 variables and the "V" set (the second set) has 8 as well. Therefore we will have 8 pairs of canonical variates (or 8 roots).

The correlations between corresponding pairs of canonical variates are called canonical correlation that can be used to test the existence of relationships between two variable sets. A common method of assessing the overall relationship strength is to use redundancy index. The canonical correlations can be squared to compute the proportion of variance shared by the sum scores (canonical variates) in each set. If we multiply this proportion by the proportion of variance extracted, we arrive at a measure of redundancy that is how redundant one set of variables is given by the other set of variables. The total redundancy indices for significant pairs of canonical variables for each pair of subsystems indicate at the same time the size of the mutual determination of the variability of the sets of variables and the strength of their interaction.

2.3. Results

2.3.1. Canonical analysis between economic and social component

In an attempt to determine the relationship between the economic and the social subsystem, the appropriate subsets of canonical variables were derived from the set of original variables and the results of canonical correlations between them were determined by using tool for canonical analysis in STATISTICA and SPSS software.

The results show the canonical correlation coefficients in a sense of the correlation level of individual pairs of canonical variables. We only illustrate the structure of first three roots which explain significant association between two sets of variables. As an overall index of the canonical correlation between two sets of variables, it is customary to report the largest correlation, that is, the one for the first root. The correlations between successively extracted canonical variates are smaller and smaller, which are respectively: RU1V1 = 0.928, RU2V2 = 0.867 and RU3V3 = 0.682. The first three canonical roots account for more than 94.5% of the proportion of variance. In which, the first root accounts for 58.2%, the second root 28.2% and the third one 8.1%. The first pair of canonical variables with highest correlation consists of features describing economic development and quality of life (RU1V1), the second pair – quality of labor and living conditions (RU2V2), while the third pair – low level of economic development and inequality and safety level (RU3V3) (see Table 1).

Table 1. The correlation between original variable of economic and social subsystem with canonical variables of the first three roots

Economic subsystem			**Social subsystem**		
Canonical variable	*Original variable*	*R*	*Canonical variable*	*Original variable*	*R*
U1	GDP per capita	-0.58	V1	Adult literacy rate	-0.62
	GDP density	-0.59		Poverty rate	0.89
	Proportion of employment in agriculture	0.98		Prevalence of underweight children	0.91
	ICOR	0.49		Average life expectancy at birth	-0.72
	Unemployment rate	-0.65			
	Percentage of trained employed workers	-0.64			
	Competitiveness Index	-0.57			
	Budget surplus	-0.61			
U2	Unemployment rate	0.48	V2	Proportion of household own	-0.59

				permanent house	
	Percentage of trained employed workers	-0.59		Female labor force participation rate	-0.87
U3	GDP per capita	-0.67	V3	Gini index	-0.60
				Proportion of death due to traffic accident	-0.70

Source: own calculation

Table 2. Canonical Analysis summary for economic and social component

Canonical R: .92860 Chi²(64)=242.81 p=0.0000		
Component	**Economic**	**Social**
No. of variables	8	8
Variance extracted	100.0%	100.0%
Total redundancy given the other set	51.2%	52.4%

Source: own calculation

The research shows that the total complex canonical correlation coefficient is R=0.92860, which means its significance at the level of p = 0.0000. The calculation of total redundancy given the other set indicates that the subset of variables of the social subsystem (the right set) reflects 51.2% the level of development of the economic subsystem (the left set). In the case of reversal of relations, variables of the economic subsystem (the left set) reflects 52.4% the level of development of the social subsystem (the right set). This means that the variance of the features of the economic and social subsystem reflects each other at the same level. Therefore, it can be concluded that both considered subsystems are at an average level of statistical correlation and a state of relative equilibrium (see table 2).

2.3.2. Canonical analysis between economic and environmental component

In the analysis of mutual relations of economic and environmental component, the complex canonical correlation coefficients show higher values than in the previous case. Furthermore, it is worth to mention that the correlation coefficients of the first three pairs of canonical variables derived, which are RU1V1 = 0.968, RU2V2 = 0.858 and RU3V3 = 0.658, are quite important. The three first canonical roots account for more than 95.7% of the proportion of variance. In which, the first root accounts for 77.2%, the second root 14.6% and the third one 4.0%. Therefore, the canonical correlation of the first root can be used to represent for the overall correlation between two subsystems. The first pair of canonical variables consists of features describing economic development and rural-urban environment (RU1V1), the second pair – quality of labor and pollution (RU2V2), while the third pair – economic efficiency and rural environment (RU3V3) (see Table 3).

The results show that the complex canonical correlation coefficient is high with R = 0.96785, it was determined at a level of statistical significance (p = 0.0000). The calculation of total redundancy given the other set indicates that the subset of variables of the economic subsystem (the left set) reflects 56.9% the level of development of the environmental subsystem (the right set). In the case of reversal of relations, the subset of variables of the environmental subsystem (the right set) reflects 55.1% the level of development of the economic subsystem (the left set). This means that both considered subsystems are at an average level of statistical correlation and a state of relative equilibrium (see Table 4).

Table 3. The correlation between original variable of economic and environmental subsystem with canonical variables of the first three roots

Economic subsystem			**Environmental subsystem**		
Canonical variable	*Original variable*	*R*	*Canonical variable*	*Original variable*	*R*
U1	GDP per capita	0.60	V1	Agricultural land per person	-0.64
	GDP density	0.71		Proportion of household with access to improved sanitation	0.88
	Proportion of employment in agriculture	-0.97		Percentage of household access potable water	0.66
	ICOR	-0.45		Proportion of rural households using solid fuels for cooking	-0.78
	Unemployment rate	0.64		Total of collected solid waste	0.82
	Percentage of trained employed workers	0.71		Proportion of collected solid waste per day that are treated	0.50
	Competitiveness Index	0.53			
	Budget surplus	0.63			
U2	Unemployment rate	-0.46	V2	Forest cover	0.51
	Percentage of trained employed workers	0.56		Annual median concentration of Particulate Matter 2.5	0.68
U3	ICOR	0.47	V3	Agricultural land per person	-0.31
				Proportion of	-0.36

				household with access to improved sanitation	

Source: own calculation

Table 4. Canonical Analysis summary for economic and environmental component

Canonical R: .96785 Chi²(64)=287.40 p=0.0000		
Component	**Economic**	**Environmental**
No. of variables	8	8
Variance extracted	100.0%	100.0%
Total redundancy given the other set	55.1%	56.9%

Source: own calculation

2.3.3. Canonical analysis between social and environmental component

The complex canonical correlation coefficients are also reflected in the partial correlation coefficients, which take the following values: RU1V1 = 0.966, RU2V2 = 0.90, RU3V3 = 0.82. The three first pairs of canonical variables account for more than 90.3% of the proportion of variance. In which, the first root accounts for 61.7%, the second root 19.5% and the third one 9.0%. The analysis of the features in the derived canonical variables indicates some relationships that exist between the quality of life and the standard of living and rural – urban environment (RUIV1), which is rather obvious, condition of housing and female labor and the air pollution (RU2V2) and between the female labor force participation rate and the level of collected and treated solid waste (RU3V3) (see Table 5). The variables describing both distinguished subsystems (social and environmental) associated more significant than previous ones. The total canonical correlation coefficient is R = 0.96557 and it is significant at the level of p = 0.000. The results of total redundancy tell us that the variables of the social subsystem explain 65.8% of the variance in the characteristics of the environmental subsystem, while variables in the environmental subsystem explain 69.7% of the variance in the characteristics of the social subsystem. The intersystem balance is rather strong, higher than in the case of the canonical correlation of the features describing the economic – social and economic - environmental subsystems (see Table 6).

Table 5. The correlation between original variable of social and environmental subsystem with canonical variables of the first three roots

Social subsystem			**Environmental subsystem**		
Canonical variable	*Original variable*	*R*	*Canonical variable*	*Original variable*	*R*
	Adult literacy rate	0.76		Forest cover	-0.58
	Poverty rate	-0.96		Agricultural land per person	-0.67

U1	GINI	-0.50	V1	Proportion of household with access to improved sanitation	0.84
	Prevalence of underweight children	-0.87		Percentage of household access potable water	0.89
	Average life expectancy at birth	0.84		Proportion of rural households using solid fuels for cooking	-0.88
U2	Proportion of household own permanent house	-0.89	V2	Annual median concentration of Particulate Matter 2.5	-0.86
	Female labor force participation rate	-0.78			
U3	Female labor force participation rate	-0.43	V3	Total of collected solid waste per capita	-0.54
				Proportion of collected solid waste per day that are treated	-0.41

Source: own calculation

Table 6. Canonical Analysis Summary for social and environmental component

Canonical R: .96557 Chi²(64)=376.27 p=0.0000		
Component	**Social**	**Environmental**
No. of variables	8	8
Variance extracted	100.0%	100.0%
Total redundancy given the other set	69.7%	65.8%

Source: own calculation

3. Discussion and conclusions

The objective of this article is to figure out the intersystem equilibrium of sustainable development by analyzing statistical association between three components of sustainability based on 24 relevant indicators. We absolutely acknowledge that measuring the equilibrium of sustainability still remains as a big challenge for any researcher. Hence the quantitative methods we have used can be only applied to relatively measure the linkages and balance of the system of sustainability. In reality in Vietnam, statistical data for social indicators has been better developed than data for other sectors such as economy and environment. By contrast, selecting essential environmental indicators becomes an actual challenge for the research due to lacking available data. Indicators such as proportion of household with access to improved sanitation, percentage of household access potable water, and proportion of rural households using solid fuels for cooking can be considered as social indicators. Nevertheless, the limited number of environmental indicators forces us to move them into environmental component. They became core indicators of main factor of environmental dimension and they have high correlation with other indicators of social component. That explains why in the canonical analysis, the relationship (the intersystem equilibrium) between social – environmental component is higher than the other pairs. The results of total redundancy of canonical analysis show that social subsystem explain 65.82% of the variance in the characteristics of the environmental subsystem, while variables in the environmental subsystem explain 69.72% of the variance in the characteristics of the social subsystem. Meanwhile, regarding to the economic – environmental pair, the numbers are 56.89% and 55.10%, and with economic – social pair, the numbers are 52.36% and 51.18% respectively. The results confirm assumption that there is an average relationship between subsystems of sustainable development in Vietnam. For further research, some procedures in SPSS such as correlation analysis, regression analysis and principal component analysis will be utilized to measure the relationship within each subsystem of sustainability.

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