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QUANTITATIVE MEASUREMENT OF THE INTRA-SUBSYSTEM AND INTER-SUBSYSTEM RELATIONSHIP IN THE SUSTAINABLE DEVELOPMENT OF VIETNAM

Pomiar ilościowy relacji wewnątrz podsystemów i między podsystemami w zrównoważonym rozwoju Wietnamu

Abstract: Sustainable development 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 needs. Sustainable development now becomes zeitgeist of our age. 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 subsystems. This article aims to measure the intra-subsystem and inter-subsystem relationship in sustainable development which can be used to reflect the level of equilibrium by analyzing the statistical relationships within and between the three main subsystems of sustainability (economic, social and environmental). All of the analysis use the complete raw data set provided for 24 indicators for the year 2016 of 63 administrative units of Vietnam. The results show that there is an average relationship within each subsystem of sustainable development in Vietnam expressed by the latent dimensions extracted in the procedure of principal component analysis. There is also 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).
Zarys treści: Zrównoważony rozwój można postrzegać jako rozwój, który gwarantuje równowagę pomiędzy rozwojem gospodarczym, dobrostanem społecznym i komponentem środowiskowym, służącą zaspokajaniu potrzeb obecnych pokoleń bez uszczerbku dla możliwości zaspokajania potrzeb przyszłych pokoleń. Zrównoważony rozwój reprezentuje ducha naszych czasów. Z jednej strony jest sposobem na określenie celów, które współczesne społeczeństwo powinno osiągnąć, aby zapewnić lepszą jakość życia wszystkim mieszkańcom planety, zarówno obecnym, jak i przyszłym pokoleniom. Z drugiej strony, zrównoważony rozwój pomaga zrozumieć świat jako złożone relacje wewnątrz i pomiędzy podsystemami: gospodarczym, społecznym i środowiskowym. Celem artykułu jest pomiar powiązań wewnątrz i pomiędzy komponentami zrównoważonego rozwoju, który pozwoli określić poziom równowagi dzięki analizom zależności statystycznych wewnątrz trzech głównych wymiarów zrównoważonego rozwoju (ekonomicznego, społecznego i środowiskowego) oraz pomiędzy nimi. We wszystkich analizach wykorzystano kompletny zestaw dostępnych danych nieprzetworzonych dla 24 wskaźników, obrazujących sytuację 63 jednostek administracyjnych Wietnamu w roku 2016. Wyniki dowodzą, że w Wietnamie istnieje umiarko-

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wana zależność w ramach każdego podsystemu zrównoważonego rozwoju, którą wyrażają ukryte zmienne, wyodrębnione w analizie składowych głównych, a także umiarkowana zależność pomiędzy podsystemami zrównoważonego rozwoju, mierzona poziomem wzajemnego powiązania zestawu zmiennych odnoszących się do każdego podsystemu, zidentyfikowana w procedurze korelacji kanonicznej (redundancja kanoniczna).

Key words: Sustainable development, intra-subsystem relationship, inter-subsystem relationship, principal component analysis, canonical analysis**,** Vietnam
Słowa kluczowe: Zrównoważony rozwój, relacje wewnątrz podsystemów, relacje między podsystemami, analiza składowych głównych, analiza kanoniczna, Wietnam

INTRODUCTION

The threat of economic collapse, based on business as usual predictions, is what has driven experts to reexamine traditional development models and find ways to better incorporate ecological limits (Seitz, Hite 2012). The need for a new development paradigm was widely recognized by the mid-1980s (Estes 1993). In 1987, the 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 trajectory 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.

In the complexity of the term "sustainable", particularly interesting is the discussion about the meaning of the term "sustainable" as "balanced" which reveals the difficulty of measuring the operationalization of sustainable development (balance within each component and between 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. To keep the balance of the systems, on the one hand, sustainable development is a way to define the objectives and requires a holistic development, seeks to build a good society not only an economically prosperous society but also one that is socially inclusive and environmentally sustainable. On the other hand, sustainable development requires an understanding of the relationship, the integration and the interactions within and between elements of a system, and application of our knowledge of the interconnections to achieve the sustainable development goals (Sachs 2015).

This article seeks to answer for the question: what is the level of interconnectedness within and between subsystems of sustainable development in Vietnam? The question tends to identify the level of equilibrium within and between subsystems of sustainable development by analyzing the statistical relationships within and between them. Two hypotheses were put forward. The first one is that there is an average relationship within each subsystems of sustainable development in Vietnam expressed by the latent dimensions extracted in the procedure of principal component analysis. The second one is 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).

All of the analysis uses the complete raw data set provided for 24 indicators for the year 2016 of 63 administrative units of Vietnam. However, due to the fact that not all statistical data for one year (2016) for all of the indicators are available, in some cases relevant data of proximate years was collected for provinces.

THE CHALLENGES OF MEASURING THE LINKAGES IN SUSTAINABLE DEVELOPMENT

While the three dimensions (economic, social and environmental) are widely recognized in the literature, understanding the linkages in sustainable development remains controversial. For instance, can a high level of economic development be substituted for a low level of environmental quality? Whether or not sustainability allows for substitution between natural sustainability and human development? (Wu, Wu 2012). It is conventionally believed that there are important trade-offs in pursuing economic, social, and environmental goals. For example, society can aim to be rich, or it can aim to be equal; but if it aims for more equality, it will end up less rich (Sachs 2015). In such a view, income and equality are substitutes. In response to the trade-offs between the needs of people and the needs of the ecosystem, a distinction is often drawn between 'strong' sustainability (where such trade-offs are not allowed or are restricted) and 'weak' sustainability (where they are permissible) (Adams 2006). Weak sustainability tries to maintain total capital composed of natural and manufactured capitals as interchangeable with technology able to fill human produced gaps in the natural environment (Daly 1990). Meanwhile, if one believes that sustainability should be strong, then no trade-off between economic gains and environmental quality is acceptable, the 'critical' natural capital cannot be substituted for technology, and must be preserved absolutely (Dresner 2008, Redclift 2005). The strong sustainability argument implies that the environment is critical for our and our children's survival, and any damage will have negative repercussions (Bell, Morse 2008). In practice, however, of these two the weak sustainability form is the one that currently dominates in the global economy. Many community planners believe that their basic mission is essentially economic development. Similarly, many policy makers believe that economic development is the foundation for social development. In other words, when a community achieves satisfactory levels of economic development, social development follows (Sirgy 2011). As Adams (2006) asserted that governments, businesses and other actors do allow trade-offs in decision making and they often put greatest emphasis on the economy above other dimensions of sustainability. This is a major reason why the environment continues to be degraded and development does not achieve desirable equity goals.

Measuring the relationship within and between components of sustainable development is not an 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 economic 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 other ones? For example, the social subsystem should include: ecological education, ecological awareness, life style and consumption model, which should protect against redundant (excessive) exploitation of resources. On the other side, the environmental subsystem should provide energy, food, aesthetic landscape, recreational areas. The economic subsystem should provide people with jobs, salaries and wages, technical infrastructure, while the social subsystem should consist of people with suitable education, qualifications and creativity. The economic subsystem should apply environmentally friendly technologies, exploit resources rationally, apply recycling to keep environment in good conditions, etc. In fact, the set of applied indicators includes many such characteristics, but as Roush (2003) found, it is difficult to link indicators to systemic and holistic thinking, because of reductionist nature of indicators that divides a whole issue into individual parts. Discovery of measureable relationship between holistic thinking and sustainability still remains a big challenge for researchers. Hence, indirect methods can only be applied to measure the linkages and balance of the sustainable development system.

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/m^3) by province was synthesized from the satellite data of air quality for Environmental Performance Index of Yale University in the United States (2018) and retrieved from remote sensing data provided by the Department of Physics and Atmospheric Science, Dalhousie University in Canada ([no date]). Secondary data include official statistical data reported by General Statistics Office (GSO) of Vietnamese government (2010, 2015, 2017, [no date]). The sustainable development indicators, elaborated in this research, cover a wide range of issues with 8 indicators for each of the 3 subsystems of sustainability, as following (Truong 2019):

- Economic subsystem (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 subsystem (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 subsystem (8 indicators): Forest cover (% total land area), Agricultural land per person (ha), Proportion of household with access to improved sanitation (%), Percentage of household with access to 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 (%).

MEASURING THE INTRA-SUBSYSTEM RELATIONSHIP OF SUSTAINABILITY BY USING PRINCIPAL COMPONENT ANALYSIS (PCA)

Research method

Interaction analysis of the complex sustainability system, which includes many intricate relationships, is a complicated process. The principal component analysis (PCA) method, which focuses on the main factors and the contribution of various state indices to these factors, can be used as an effective way to analyze the multifarious relationships (Zhang, Yang, Yu 2006). This study aims to group quantitative variables that reflect important aspects of each component of sustainable development of localities in Vietnam into a number of limited dimensions (factors, principal components). In each dimension, variables are more closely correlated with other variables in the same dimension, rather than with variables of other dimensions. It is therefore possible to interpret each dimension according to the meaning of the loadings of principal component assigned to variables. The loadings (correlation coefficients) mean how many percent of the variance of the i-th variable is explained by the j-th principal component. The reduction of the number of variables allows to better identify the characteristics of the research object, which is the sustainable development of provinces and cities. Principal components describe the significant predictors of sustainability in each subsystem and show the nature of linkages within each pillar of sustainability, its intra-system equilibrium. One of the rules used in the analysis assumes that cumulatively retained principal components should explain at least 60–70% of total variance.

First of all, Kaiser-Meyer-Olkin (KMO) and Bartlett's Test were used to test the assumption that variables are not correlated with each other in the whole (the null hypothesis – H0). The results from the KMO and the Chi-Square test (measure of sampling adequacy) for three subsystems have a large value, with higher value for the economic and social subsystem (0.788 and 0.713 respectively) and lower value for the environmental subsystem (0.649). Hence, the initial assumption, the null hypothesis, is rejected, and the factor analysis method for each component of sustainability is accepted. The rotation method (Varimax with Kaiser Normalization) was applied only for the economic subsystem to minimize the number of variables which have high coefficient in one factor, and to avoid one variable with high coefficient in other factor, therefore, the meaning of factors can be explained clearly. The number of factor was determined based on Initial Eigenvalues >1.

Principal component analysis for economic subsystem

The results for factor analysis of economic subsystem are illustrated in the table 1. The table shows that there are 3 main factors that explain 77.705% of the total variation of economic component. Before rotation, factor 1 explains 49.465%, while factor 2 explains 15.189% and factor 3 explains 13.051%. However, the factors matrix table shows that the factor loading of some indicators such as GDP density, budget surplus as percentage of GDP, Competitiveness Index, percentage of trained employed workers, and Incremental capital-output ratio is quite high in the two other factors. Therefore, the procedure to rotate the factors has been carried out. After rotation, factor 1 explains 28.595%, while factor 2 explains 26.508% and factor 3 explains 22.601% of the total variation.

Factor 1 represents the prosperity of economy with the main weights belong to GDP density, GDP per capita, percentage of trained employed workers, and proportion of employment in agriculture. **Factor 2** represents the competitiveness of economy with the main weights belong to Competitiveness Index and unemployment rate. With high values for Incremental capital-output ratio and budget surplus as percentage of GDP, **factor 3** is the factor representing the production efficiency. The results confirm that extracted components describe better the structure of the economic subsystem of sustainability and show the average level of the intra-system relationships.

Factor scores of each factor for each province were calculated and saved in the original file in SPSS (Statistical Package for the Social Sciences). The results then were illustrated on maps in MapInfo software (see figure 1). In these maps, the legends were divided into 5 ranges using the natural break method in MapInfo, in order to differentiate between the values of the data and the average value. This is considered a good way to reduce errors and show the data in a more realistic way (Nguyen Viet Thinh, Do Thi Minh Duc 2005).

Table 1. Results of PCA (Principal Component Analysis) for economic subsystem of sustainability in Vietnam
Tabela 1. Wyniki PCA dla komponentu ekonomicznego rozwoju zrównoważonego w Wietnamie

a) Proportion of the total variance explained by three main factors

Factor	Extraction sums of squared loadings			Rotation sums of squared loadings		
	Eigenvalues	% of variance	Cumulative %	Eigenvalues	% of variance	Cumulative %
1	3.957	49.465	49.465	2.288	28.595	28.595
2	1.215	15.189	64.654	2.121	26.508	55.104
3	1.044	13.051	77.705	1.808	22.601	77.705

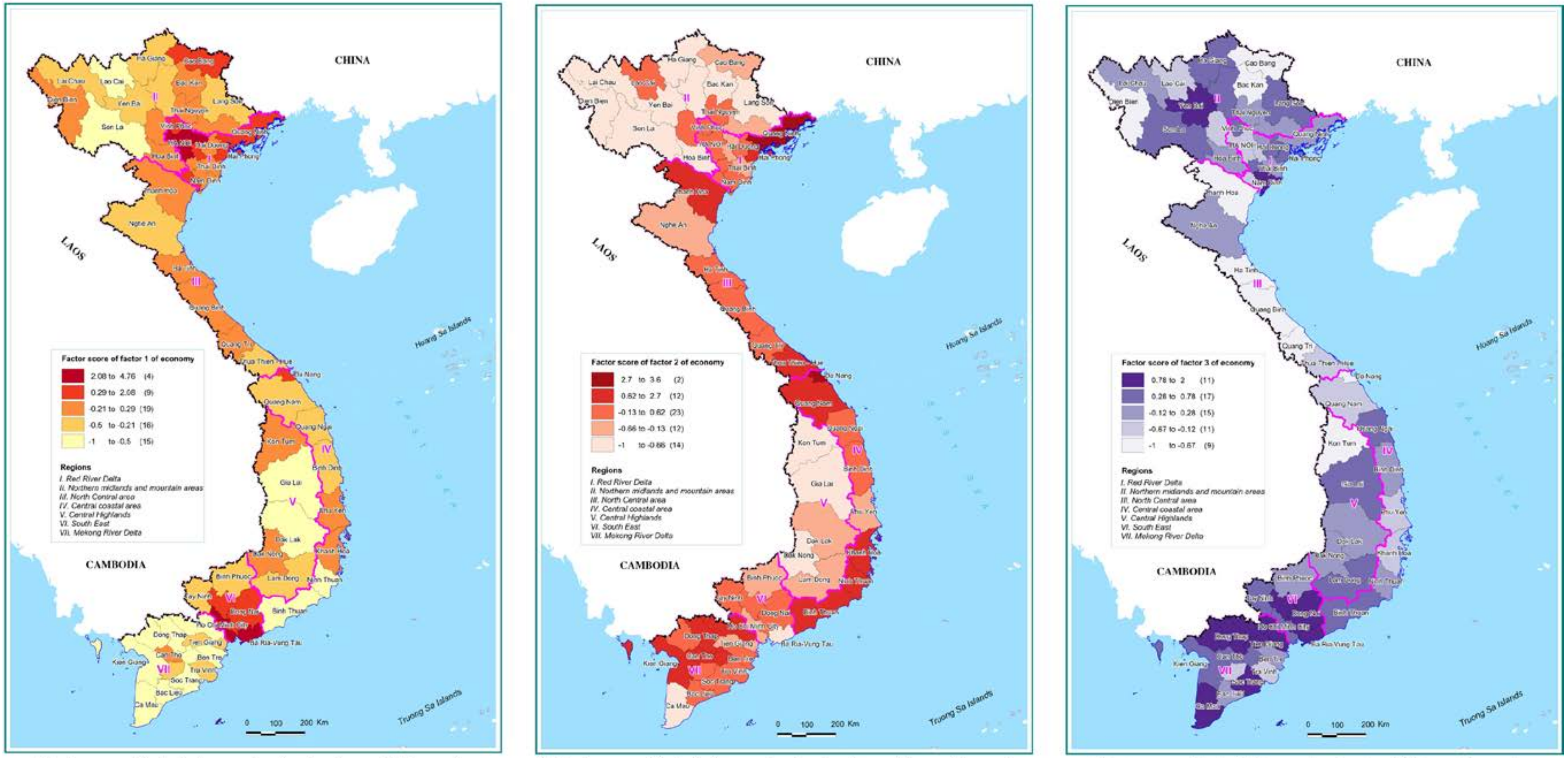
b) Rotated component matrix

	Factor		
	1	**2**	**3**
GDP density	0.889	0.057	0.192
GDP per capita	0.727	0.129	0.362
Percentage of trained employed workers	0.700	0.480	-0.171
Competitiveness Index	0.134	0.837	0.160
Unemployment rate	0.130	0.836	0.213
Proportion of employment in agriculture	-0.604	-0.625	-0.271
Incremental capital-output ratio	-0.083	-0.146	-0.910
Budget surplus as percentage of GDP	0.266	0.243	0.799

Source: author's own elaboration.
Źródło: opracowanie własne.

If one province (one case) has a high factor score, the province must have high a value for variables with positive numbers and low value for variables with negative numbers. By contrast, if one province has a low factor score, the province must have a low value for variables with positive numbers and a high value for variables with negative numbers. For example, in the factor 1, Hanoi, Bac Ninh, Hai Phong, Da Nang, Ho Chi Minh City, Binh Duong, and Ba Ria – Vung Tau have high factor scores, because they have high values for positive variables such as GDP density, GDP per capita, and percentage of trained employed workers. On the other hand, most of provinces of Mekong River Delta, and Central Highlands have low scores for the factor 1, because of high proportion of employment in agriculture, meanwhile, low values of GDP density, GDP per capita, and percentage of trained employed workers.

Most of provinces in the delta and coastal regions have higher factor scores for the factor 2 than ones in the mountain regions (Northern midlands and mountain areas, and Central Highlands), because these provinces have higher values for Competitiveness Index, unemployment rate, and lower value for proportion of employment in agriculture. The provinces in South East, Mekong River Delta region have higher scores for the factor 3 than others, due to the fact that they have higher values for budget surplus as percentage of GDP, meanwhile, lower score for Incremental capital-output ratio.



a) Factor score of factor 1 of economic subsystem (prosperity) by province

b) Factor score of factor 2 of economic subsystem (competitiveness) by province

c) Factor score of factor 3 of economic subsystem (efficiency) by province

Fig. **1**. Three main factors of economic component of sustainability

Ryc. **1**. Trzy główne czynniki komponentu ekonomicznego zrównoważonego rozwoju

Source: author's own elaboration.

Źródło: opracowanie własne.

Principal component analysis for social subsystem

The same procedures of factor analysis were applied for the social component. The results are illustrated in table 2. The table shows that there are 3 main factors that explain 83.084% of the total variation of social component. Due to the fact that no indicators have high correlation coefficients with other components, procedure for rotation is not necessary. The factor 1 explains 46.568%, the factor 2 explains 23.730% and the factor 3 explains 12.786%.

The **factor 1** represents the quality of life with the main weights belong to poverty rate, average life expectancy at birth, prevalence of underweight children, and adult literacy rate. The **factor 2** can be used to show the equality with the main weights belong to Gini index, proportion of household own permanent house, and female labor force participation rate. With only one indicator for proportion of death due to traffic accident, the **factor 3** is the factor representing insecurity of traffic. The results confirm that the extracted components adequately describe the structure of the social subsystem of sustainability and show its intra-system relationships. Quality of life and social equality are common indicators of social component of sustainability. Last principal component has a very high loading in one original variable and it is difficult to accept that it can be treated as universal indicator of security in the society.

Table 2. Results of PCA for social subsystem of sustainability in Vietnam
Tabela 2. Wyniki PCA dla komponentu społecznego rozwoju zrównoważonego w Wietnamie

a) Proportion of the total variance explained by three main factors

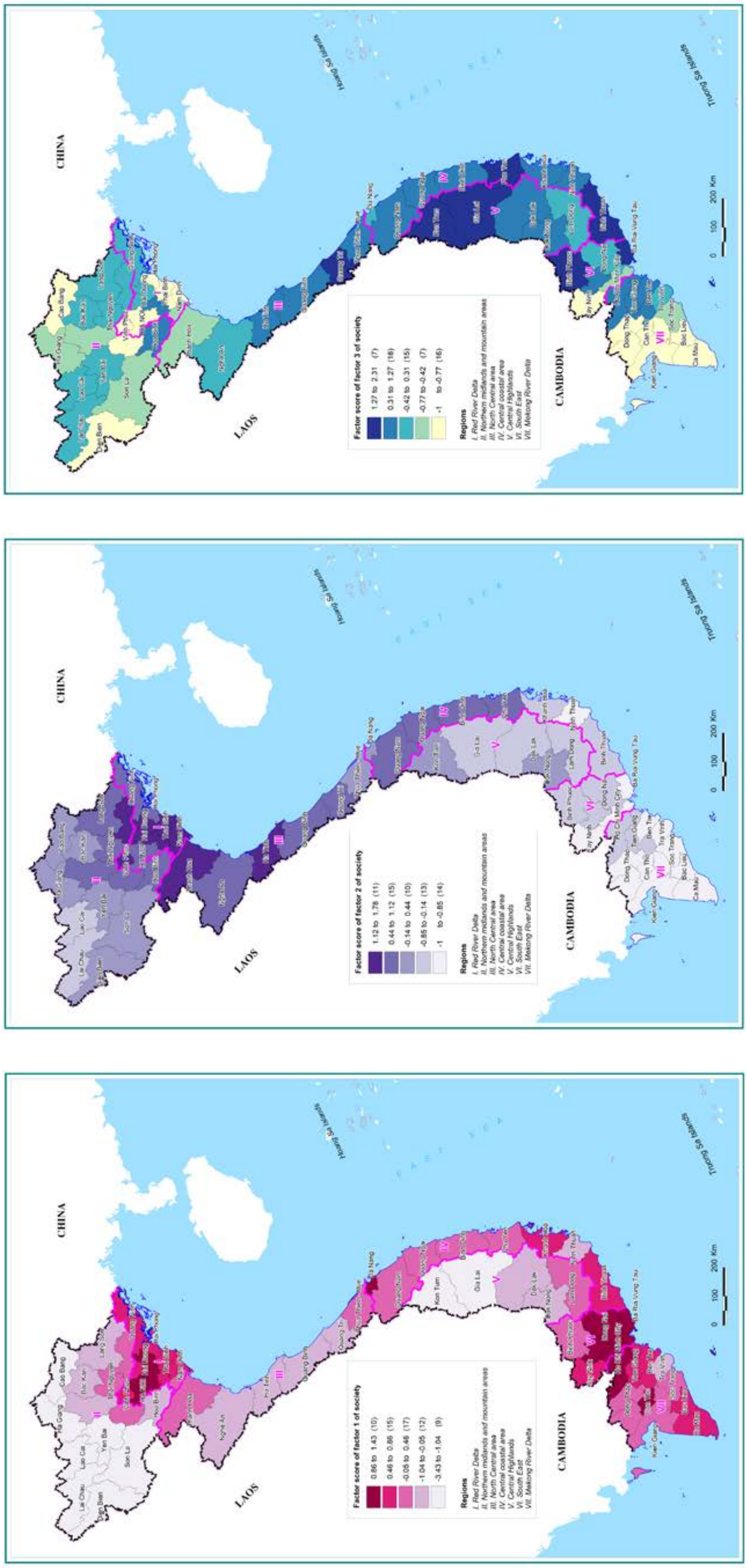
Factor	Initial eigenvalues			Extraction sums of squared loadings		
	Eigenvalues	% of variance	Cumulative %	Eigenvalues	% of variance	cumulative %
1	3.725	46.568	46.568	3.725	46.568	46.568
2	1.898	23.730	70.298	1.898	23.730	70.298
3	1.023	12.786	83.084	1.023	12.786	83.084

b) Component matrix

	Factor		
	1	**2**	**3**
Poverty rate	-0.949	0.057	-0.038
Average life expectancy at birth	0.931	-0.137	-0.134
Prevalence of underweight children, weight for age	-0.864	0.137	0.131
Adult literacy rate	0.846	0.287	0.069
Gini index	-0.539	-0.407	-0.333
Proportion of household own permanent house	0.192	0.924	-0.011
Female labor force participation rate	-0.411	0.821	0.102
Proportion of death due to traffic accident	0.009	-0.284	0.927

Source: author’s own elaboration.
Źródło: opracowanie własne.

Factor scores of each factor for each province were calculated and saved in the original file in SPSS. The results were illustrated on maps in MapInfo software with the legend was divided into 5 ranges using the natural break method. Figure 2a shows the factor 1 (Quality of life) which can explain 46.568% of the total variation. Figure 2b is for factor 2 (Inequality) and figure 2c intends to factor 3 (Insecurity of traffic).



a) Factor score of factor 1 of social subsystem (Quality of life) by province

b) Factor score of factor 2 of social subsystem (Equality) by province

c) Factor score of factor 3 of social subsystem (Insecurity of traffic) by province

Fig. **2**. Three main factors of social component of sustainability

Ryc. **2**. Trzy główne czynniki komponentu społecznego zrównoważonego rozwoju

Source: author's own elaboration.

Źródło: opracowanie własne.

The map in figure 2a shows that Hanoi and other provinces of Red River Delta, Da Nang, and provinces of South East region have high factor scores for the factor 1 of quality of life, because they have high values for positive variables (average life expectancy at birth, and adult literacy rate) and low values for negative variables such as poverty rate and prevalence of underweight children. Meanwhile, due to low factor scores for positive variables and high factor scores for negative variables, most of provinces of Northern midlands and mountain areas, and Central Highlands have low scores for quality of life. Regarding the factor 2, with high values of proportion of household own permanent house, female labor force participation rate and low values of Gini index, most of provinces of Red River Delta and North Central area have higher scores for the factor 2 than others. Figure 2c illustrates that the proportion of death due to traffic accident is higher in the regions in the South of Vietnam, such as Central Highlands, North Central area, Central Coastal area, and South East.

Principal component analysis for environmental subsystem

The same procedures of factor analysis will be applied for environmental component. The results are illustrated in table 3. The table shows that there are 2 main factors that explain 64.086% of the total variation of environmental component. As for the social component, the procedure of rotation is not necessary with the environmental component, because no indicators have high values with other components. The factor 1 explains 44.823%, while the factor 2 explains 19.263%. The **factor 1** represents urban-rural living environment with the main weights belong to proportion of rural households using solid fuels for cooking, proportion of household with access to improved sanitation, percentage of household with access to potable water, total of collected solid waste per capita, agricultural land per person, forest cover. The **factor 2** can be used to represent pollution with the main weights belong to Annual median concentration of Particulate Matter 2.5, and proportion of collected solid waste per day that are treated according to national standards. Factor scores of each factor for each province were calculated and saved in the original file in SPSS. The results then were illustrated on maps in MapInfo software with the legend divided into 5 ranges using the natural break method (see figure 3).

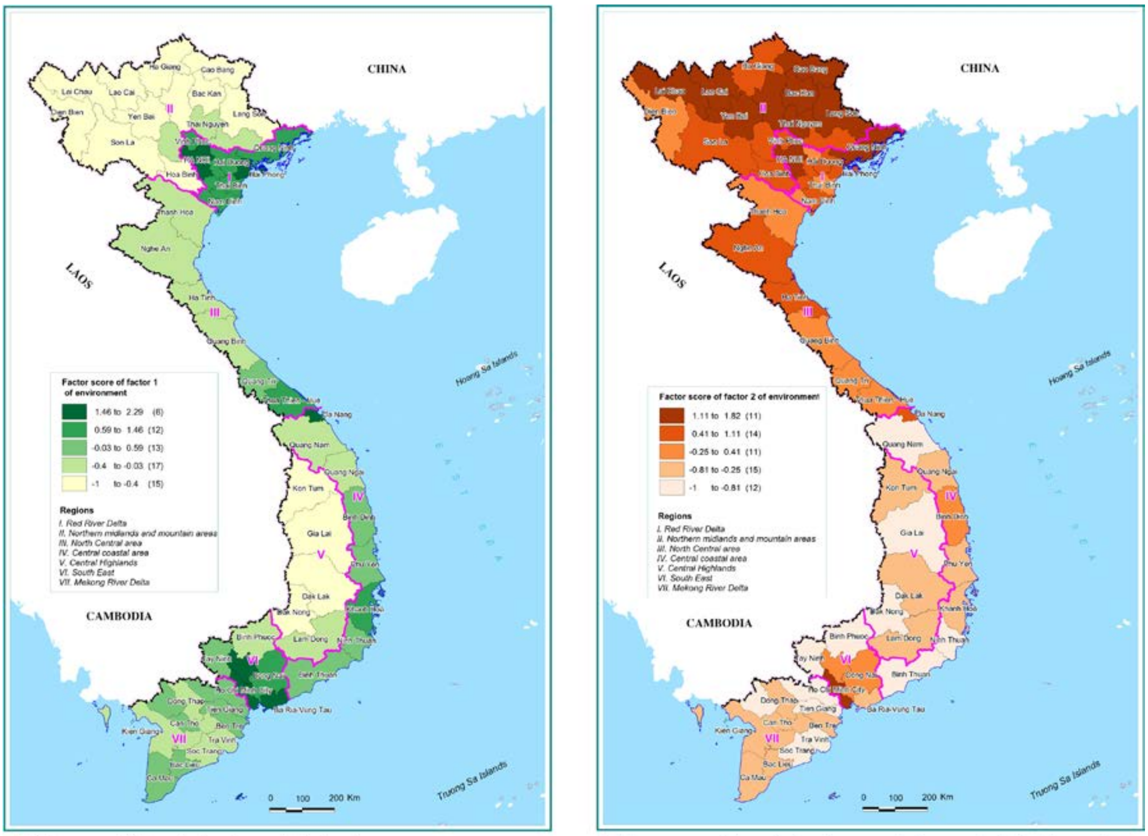
Table 3. Results of PCA for environmental subsystem of sustainability in Vietnam
Tabela 3. Wyniki PCA dla komponentu środowiskowego rozwoju zrównoważonego w Wietnamie
a) Proportion of the total variance explained by three main factors

Factor	Initial eigenvalues			Extraction sums of squared loadings		
	Eigenvalues	% of variance	Cumulative %	Eigenvalues	% of variance	Cumulative %
1	3.586	44.823	44.823	3.586	44.823	44.823
2	1.541	19.263	64.086	1.541	19.263	64.086

b) Component matrix

	Factor	
	1	**2**
Proportion of rural households using solid fuels for cooking	-0.903	0.175
Proportion of household with access to improved sanitation	0.879	-0.176
Percentage of household with access to potable water	0.814	-0.349
Total of collected solid waste per capita	0.632	0.367
Agricultural land per person	-0.615	-0.424
Forest cover	-0.558	0.354
Annual median concentration of Particulate Matter 2.5	0.035	0.781
Proportion of collected solid waste per day that are treated according to national standards	0.494	0.555

Source: author's own elaboration.
Źródło: opracowanie własne.



a) Factor score of factor 1 of environmental subsystem

b) Factor score of factor 2 of environmental subsystem (pollution) by province

Fig. **3**. Two main factors of the environmental component of sustainability
Ryc. **3**. Dwa główne czynniki komponentu środowiskowego zrównoważonego rozwoju

Source: author's own elaboration.
Źródło: opracowanie własne

With respect to the factor 1 of urban-rural living environment, most of provinces of Red River Delta, South East, and Central Coastal area have higher scores than other regions, because they have higher values for two positive variables which represent for urban living environment: percentage of household with access to potable water, and proportion of household with access to improved sanitation. Meanwhile, these provinces have lower values for negative variables which represent for rural living environment, such as proportion of rural households using solid fuels for cooking, and forest cover. By contrast, provinces of Central Highlands, Northern midlands and mountain areas, and North Central area have higher scores for variables of rural living environment and lower values for variables of urban living environment.

The dual-polarized structure of this principal component (urban – rural living environment) is a difficult problem in the analysis of sustainability, because these two living environments include stimulants and destimulants of sustainability. Hence, it is impossible to state clearly, on the basis of the values of factor-scores, which type of environment is really more sustainable. In fact, it is difficult to accept the result that urban areas are more sustainable, because of better sanitation, accessible potable water, collected wastes, though rural areas have less modified environment, because of vast forest cover and more agricultural land (its area is very low even in rural areas, taking into account the number of population). Unfortunately, the variable 'using the solid fuels for cooking', which should be treated as destimulant of sustainability, has the highest loading (-0.903) of this principal component.

Regarding to the factor 2 of pollution, figure 3b shows that provinces which are located north from Da Nang have higher levels of pollution than the southern provinces, because they have higher scores for positive variables such as proportion of collected solid waste per day that are treated according to national standards, annual median concentration of Particulate Matter 2.5, and total of collected solid waste per capita. The map also shows that the provinces of Red River Delta and South East where most of big cities concentrate have higher level of pollution than others. In fact, this is a clear indicator of environmental degradation in the country, because it concerns also rural areas (especially in northern part of the country), and it is not associated with previous dimension of environmental subsystem.

MEASURING THE INTER-SUBSYSTEM RELATIONSHIP OF SUSTAINABILITY BY USING CANONICAL ANALYSIS

Research method

Correlation may be used to indicate a state of inter-subsystem balance, which is extremely important for achieving a certain level of balance in the entire system. One of the assumptions of the study of 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, 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 the following three correlations should be considered: economic – social, economic – environmental, and social – environmental subsystem. 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 **V** variables and **U** variables. 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 this proportion is multiplied by the proportion of variance extracted, a measure of redundancy is obtained that indicates 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. 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.

Canonical analysis between economic and social subsystems

In an attempt to determine the relationship between the economic and the social subsystems, 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. The research only illustrates 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 for 28.2% and the third one for 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 4).

Table 4. The correlation between the original variable of economic and social subsystems with canonical variables of the first three roots

Tabela 4. Korelacja między pierwotną zmienną podsystemu ekonomicznego i społecznego a zmiennymi kanonicznymi pierwszych trzech pierwiastków

<table>
<tr><th colspan="3">Economic subsystem</th><th colspan="3">Social subsystem</th></tr>
<tr><th>Canonical variable</th><th>Original variable</th><th>R</th><th>Canonical variable</th><th>Original variable</th><th>R</th></tr>
<tr><td rowspan="8">U1</td><td>GDP per capita</td><td>-0.58</td><td rowspan="8">V1</td><td>Adult literacy rate</td><td>-0.62</td></tr>
<tr><td>GDP density</td><td>-0.59</td><td>Poverty rate</td><td>0.89</td></tr>
<tr><td>Proportion of employment in agriculture</td><td>0.98</td><td>Prevalence of underweight children</td><td>0.91</td></tr>
<tr><td>ICOR</td><td>0.49</td><td rowspan="5">Average life expectancy at birth</td><td rowspan="5">-0.72</td></tr>
<tr><td>Unemployment rate</td><td>-0.65</td></tr>
<tr><td>Percentage of trained employed workers</td><td>-0.64</td></tr>
<tr><td>Competitiveness Index</td><td>-0.57</td></tr>
<tr><td>Budget surplus</td><td>-0.61</td></tr>
<tr><td rowspan="2">U2</td><td>Unemployment rate</td><td>0.48</td><td rowspan="2">V2</td><td>Proportion of household own permanent house</td><td>-0.59</td></tr>
<tr><td>Percentage of trained employed workers</td><td>-0.59</td><td>Female labor force participation rate</td><td>-0.87</td></tr>
<tr><td rowspan="2">U3</td><td rowspan="2">GDP per capita</td><td rowspan="2">-0.67</td><td rowspan="2">V3</td><td>Gini index</td><td>-0.60</td></tr>
<tr><td>Proportion of death due to traffic accident</td><td>-0.70</td></tr>
</table>

Source: author’s own calculation.

Źródło: opracowanie własne.

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 subsystems 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 5).

Table 5. Canonical Analysis summary for economic and social subsystems
Tabela 5. Podsumowanie analizy kanonicznej dla komponentu ekonomicznego i społecznego

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: author's own calculation.
Źródło: opracowanie własne.

Canonical analysis between economic and environmental subsystems

In the analysis of mutual relations of economic and environmental subsystem, 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 for 14.6% and the third one for 4.0%. Therefore, the canonical correlation of the first root can be used to represent 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 6).

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 7).

Table 6. The correlation between original variable of economic and environmental subsystems with canonical variables of the first three roots
Tabela 6. Korelacja między pierwotną zmienną podsystemu ekonomicznego i środowiskowego a zmiennymi kanonicznymi pierwszych trzech pierwiastków

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 with access to 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 household with access to improved sanitation	-0.36

Source: author's own calculation.
Źródło: opracowanie własne.

Table 7. Canonical Analysis summary for economic and environmental subsystems
Tabela 7. Podsumowanie analizy kanonicznej dla komponentu ekonomicznego i środowiskowego

Canonical R: .96785 $Chi^2(64)=287.40$ p=0.0000		
Component	**Economic**	**Environmental**
No. of variables	8	8
Variance extracted	100.000%	100.000%
Total redundancy given the other set	55.1%	56.9%

Source: author's own calculation.
Źródło: opracowanie własne.

Canonical analysis between social and environmental subsystems

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 for 19.5% and the third one for 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 8).

Table 8. The correlation between original variable of social and environmental subsystems with canonical variables of the first three roots
Tabela 8. Korelacja między pierwotną zmienną podsystemu społecznego i środowiskowego a zmiennymi kanonicznymi pierwszych trzech pierwiastków

Social subsystem			**Environmental subsystem**		
Canonical variable	Original variable	**R**	Canonical variable	Original variable	**R**
U1	Adult literacy rate	0.76	**V1**	Forest cover	-0.58
	Poverty rate	-0.96		Agricultural land per person	-0.67
	GINI	-0.50		Proportion of household with access to improved sanitation	0.84
	Prevalence of underweight children	-0.87		Percentage of household with access to 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: author's own calculation.
Źródło: opracowanie własne.

The variables describing both distinguished subsystems (social and environmental) associated with each other 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 the 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 inter-subsystem 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 9).

Table 9. Canonical Analysis Summary for social and environmental subsystems
Tabela 9. Podsumowanie analizy kanonicznej dla komponentu społecznego i środowiskowego

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: author's own calculation.
Źródło: opracowanie własne.

CONCLUSION AND DISCUSSION

The objective of this article is to determine the intra-subsystem and inter-subsystem relationship which can be used to reflect the balance of sustainable development, analyzed by statistical associations within and between three subsystems of sustainability based on 24 relevant indicators of 63 administrative units of Vietnam. I absolutely acknowledge that understanding the linkages in sustainable development still remains controversial and measuring the intra-subsystem and inter-subsystem relationship of sustainability still remains as a big challenge for any researcher. Hence the quantitative methods we have used can only be applied to measurements of relative linkages and equilibrium 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 limited availability of the data.

The results of the principal component analysis have illustrated the higher level of relationship, equilibrium in the social dimension than in the others. The main factors of the social subsystem can explain 83.1% of total variation. Meanwhile, in economic subsystem, the main factors explain 77.7% and main factors of environmental subsystem only explain 64.1% of total variations. The results of PCA confirm the assumption that there is an average relationship within each subsystems of sustainable development in Vietnam. In this research, some indicators such as proportion of household with access to improved sanitation, percentage of household with access to potable water, and proportion of rural households using solid fuels for cooking can be considered as social indicators. Nevertheless, due to the limited number of environmental indicators, the research has moved them into environmental component. They became the core indicators of the main factor (factor 1) of the environmental subsystem and they have high correlation with other indicators of the social subsystem. The canonical analysis results have showed that the relationship between social – environmental subsystems is higher than the other pairs. The results of total redundancy of canonical analysis illustrated that the 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 the economic – environmental pair, the numbers are 56.89% and 55.10%, and with the economic – social pair, the numbers are 52.36% and 51.18% respectively. The results of the canonical analysis confirm the assumption that there is an average relationship between subsystems of sustainable development in Vietnam.

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