Identification and Measurement of Complementarity Variables in Strategic Projects of Water Irrigation from the Sustainability Practices. Case: Republic of Ecuador

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Abstract Based on the assessment of water resources in Ecuador and strategic water projects in this country, questions were raised about the need to complement these projects under the sustainability approach, effectively balancing the original intentions, needs and environments with the services currently offered. To do so, 32 variables of complementarity were identified and characterized: 7 economic variables, 11 environmental variables and 14 social variables. These variables were used to perform an expert panel assessment of 16 strategic projects from the irrigation water sector in Ecuador. Experts assessed the current implementation of such practices, the performance level achieved and their relative importance. The results

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allow to identify, assess and prioritize gaps in such projects, in existing complementarity from the initial planning stages, providing a basis to address these gaps in future projects.

Keywords Sustainability · Complementarity variables · Complementarity gaps · Strategic projects · Irrigation projects

1 Introduction

Those projects, which due to their importance and magnitude have decisive economic, social, political or environmental influence, are identified as strategic projects (also known as flagship projects) within which water projects are included. These projects should be oriented to the full development of rights and social interest. Given their importance, in the Republic of Ecuador they are contained in the Art. 313 of the Constitution of Ecuador (2008). Water projects can also be undertaken for various purposes: drinking water, irrigation, hydropower or multipurpose. This research focuses on water irrigation projects, and for this purpose, 16 projects in the Republic of Ecuador were studied. This work has been possible thanks to the collaboration provided by the Ecuadorian national water authorities.

The projects have a reality in the planning stage and other when they are being developed or after completion; this causes a deficit on the services which are finally offered and a gap between the original intentions and the current needs, generating outbreaks of civil unrest and operating conditions not suitable for their installed capacity. This situations cause gaps of complementarity which can be **Non-constructive or Constructive**.

Non-Constructive gaps are those that emerge when trying to effectively balance the original intentions, current needs and environments with the services offered by the infrastructure finally built, while Constructive gaps are the differences that occur when comparing the planned constructive processes of the project infrastructure with their status during the construction stage, if these gaps do not allow to achieve the constructive objectives of the project. Some examples are: items originally not included in the planning but essential for the completion and operation of the civilian infrastructure, work volumes not included in the original plan, adequacy of materials and technologies used to optimize construction processes and implementation of contingency plans for unforeseen events or force majeure. All these gaps are collected through work orders that after being approved are implemented and become part of the final work of infrastructure. They are included in the final acceptance of the project and, thus, become part of the final budget that generally differs from the originally planned budget.

The aim of this study is the measurement of **Non-Constructive Gaps**. The best sustainability practices of non-constructive variables were chosen to be evaluated in the strategic water irrigation projects, for the economic, environmental and social complementarity characteristics of the built infrastructures (ECLAC 2001).

The measurement and evaluation of the non-observance and/or unfulfillment of these practices or variables will help identify the different types of non-constructive gaps generated in water and irrigation projects, which simultaneously pose risks for the sustainability achievement of the project.

Therefore, the Non-Constructive Variables, hereafter referred as Complementarity Variables, or in other words, the sustainability variables, are the vehicle that allows to calculate the Non-Constructive Complementarity Gaps.

The complementarity variables were obtained from a scientific documentation review containing studies on sustainability indicators, which provided the basis for identifying the best sustainability practices applicable to irrigation projects in the water sector. These were finally validated by industry experts and the opinion of the authors.

1.1 The State of the Art in the Complementarity Variables

A large amount of information was found in the scientific literature reviewed, on the development, generally by the central governments, of scale or national coverage indicators. Moreover, civil society's organizations and sectoral or territorial government departments have been developing sustainability indicators that highlight local (cities), regional (basin, bays), thematic (e.g. biodiversity, water) or sectoral (energy, transport, agriculture) phenomena (ECLAC 2001). Two research projects, were also found, that aim to create a standard for indicator systems used to evaluate sustainability in the construction sector and try to solve the problems posed by the diversity of indicator systems co-existing in this sector. One is the research project LEnSE (Sixth Research Programme of the EU), and the other is supported by the WCCE (World Council of Civil Engineers). States that for more than a decade the concept of sustainable planning, based on the Agenda 21 program, has been applied to urban and building planning. In fact, a significant number of studies have focused their analysis on the environmental and economic dimensions of sustainability; however, there are few studies regarding the social dimension and even less studies applied to the construction sector (Fernández and Rodriguez 2010). Therefore, the term "sustainable construction" was focused almost exclusively on buildings, and gradually, sustainability goals have been introduced in civil engineering projects (Valdes and Klotz 2013). In this new context, sets of sustainability indicators found for civil engineering projects, have been used in bridges and viaducts such as the SUSAIP model (Sustainability Appraisal in Infrastructure Projects) consisting of criteria identified through interviews and surveys to participants in the different stages of the project life cycle (Ugwu et al. 2006); and ETI (Technical Sustainability Index) proposed by Dasgupta and Tam (2005), where indicators have been created based on the existing scientific literature. Sustainability indicators, mainly related to water irrigation projects, have been reported for hydroelectric projects and are collected in the article Sustainability indicators for run of the river (RoR) hydropower projects in hydro rich regions of India (Kumar and Katoch 2014), including 20 social, 22 environmental and 19 economic indicators, from 22 different scientific articles.

Consequently, given that the construction sector is moving towards an increase and a development of the series and the type of social, economic and environmental indicators (Zhang et al. 2008); and that the development of categories or sets of appropriate indicators for common types of civil infrastructure systems could streamline the sustainability analysis (Dasgupta and Tam 2005), it is important to identify sustainability good practices, specifically for water projects of the irrigation sector that can be used for identification and measurement of a smaller number of indicators for the sustainable management of water irrigation projects. This has to be done from the point of view of binding or third generation indicators, because they represent the most important challenges concerning the state of the art review of environmental sustainability and sustainable development indicators performed by the Division of Environment and Human Settlements, which was published by the United Nations in 2001.

1.2 The Water Basins in the Republic of Ecuador

The water basins of the Republic of Ecuador with abundant renewable water flow from two hydrographical groups: the Pacific and the Amazon. They offer 430.2 km^3/year of available water resources (AWR) and 143.4 km^3/year of usable water resources (UWR), and they do not show signs of shortages at the construction stage of 16 strategic mega projects of the irrigation water sector during the 2012–2017 period. According to a recent research, (a summary is shown in Table 1) only 3.72% of UWR (Gallardo et al. 2014) will be used. On the other hand, the referential investment goals in water megaprojects that the Ecuadorian government is planning to implement through the National Water Secretariat (SENAGUA) in the period 2012–2017, reach 2745.94 million dollars over these two basins. The increase of consumptive and non-consumptive demands that these constructions will generate, raises questions about the need to supplement water projects and efficiently balance the original intentions, needs and current environments, with the finally offered services, with a focus on sustainability and about the inherent risks that need to be identified, monitored, evaluated and mitigated.

These facts allow justifying this study proposal, to potentiate and optimize water projects through the reduction of risks caused by no-constructive gaps before, during and after construction, with a sustainability approach.

Table 1 Criteria for determine water scarcity in Ecuador

Falkenmark (1986)	Availability index	Renewable water resources (which are considered constant over time)/ population	1.000 m^3 and 2.000 m^3/ person/year	Country has water problems (UK, India, Pakistan, and Tanzania)	Ecuador 29.700 m^3/ person/year. No scarcity problems
			Less than 1.000 m^3/ person/year	Country suffers water scarcity	
Otros ONU (1997	Level regulation	Consumption/renewable water reserves in an area in a given year	When the freshwater use exceeds 10% of annual renewable water resources	Country, begins scarcity	Ecuador 143.4 km^3 UWR used/year, will use 3717% no scarcity problems
			When over 20% of annual renewable water resources	Country with pronounced sca rcity	

Source Falkenmark (1986), ONU/United Nations, Department for Policy Coordination and Sustainable Development (DPCSD) (1997)
Elaboration Prepared by the authors

2 Objectives

Research general purpose:

Identify, characterize, measure and prioritize the complementarity variables in strategic irrigation projects, through the case study of the strategic water irrigation projects in the Republic of Ecuador.

Specific research objectives:

SPECIFIC OBJECTIVE I SO I. Identify and characterize the complementarity variables in the strategic projects of the irrigation water sector.

SPECIFIC OBJECTIVE II SO II. Measure and prioritize by their use and performance the complementarity variables identified in the strategic projects of the irrigation water sector.

SPECIFIC OBJECTIVE III SO III. Identify groups, among the 16 strategic water irrigation projects in the Republic of Ecuador, with similar average performance levels of the economic, environmental and social variables used in the study.

3 Methodology

The steps for this research were closely linked with the sequential implementation of the specific objectives as follows:

SO I—To identify and characterize the complementarity variables, the best sustainability practices applicable to projects in the irrigation water sector were used, obtained through a review of the scientific literature, and subject to the industry experts criteria and the authors' experience prior to their definition and final characterization.

SO II—The identified complementarity variables were measured in their State of Actual Situation through surveys to managers, executives and technical and operational staff involved in some stage of the life cycle of the 16 strategic projects of irrigation water in the Republic of Ecuador, from the year 2011 on, and their prioritization was made according to their use and practical performance to achieve project sustainability.

SO III—A hierarchical cluster analysis was performed to group projects with similar results in the average performance levels of the economic, environmental and social variables.

4 Materials and Methods

How are the Complementarity Variables identified?

Complementarity variables were identified and characterized through the review of scientific documentation containing studies on sustainability indicators. To do this, the Sustainability Reporting Guidelines G3.1 and G4 Global Reporting Initiative (2011) and (2013) were reviewed, finding 9 indicators of economic performance, 30 environmental, 14 of labor practices and work ethic, 11 of human rights, 8 of society, and 9 of product, for a total of 81. And for G4, 91 indicators in total were found. Moreover, 49 indicators for hydroelectric projects were reviewed, as suggested by Kumar and Katoch (2014), in addition to the 61 indicators reported in 22 different scientific articles, complemented with a review of studies on environmental impact of water projects. This review yielded the best sustainability practices applicable to projects in the irrigation water sector, which were subsequently filtered and validated by industry experts and the opinion of the authors. Finally, 32 variables or sustainability practices (detailed in Results Table 4) were identified.

How are the Complementarity Variables measured?

The difference between the Actual State and the Projected State, gives as a result the magnitude of the Complementarity Variable.

The Actual State of the complementarity variables measurement at a given time was obtained from surveys to experts from the irrigation water sector in the Republic of Ecuador, involved in some stages of their life cycles: planning, construction or operation. They issued their assessments and comments on 32 identified good sustainability practices, for 16 irrigation water projects; and they were compared with the Projected State, which is set based on the optimal parameters/thresholds of usage for these good sustainability practices, to stablish the state of the art in the application of these practices.

The activity levels measurement for each of the complementarity variables in their actual state was based on two parameters: the usage level and the performance level, and they were obtained from a survey designed with quantitative assessment scales. The results were compiled in a Gap Assessment Matrix with 32 variables and 2 levels of activity.

The performance level was chosen to evaluate usage quality of the variables, because being used, does not guarantee efficient use, and to that end, the following scales were used (Table 2):

The column "Do not apply" was included for those cases in which the evaluated variable was not of the interviewee's competence, for that stage of the life cycle.

Sample size:

The study originally included 16 strategic water projects containing the irrigation component in the Republic of Ecuador which were in the planning or construction life cycle stages. At the study's starting date, 10 were in the planning stage and the remaining 6 under construction. They constituted, at that point, the entire strategic

Table 2 Measuring scales

Level of utilization (Frequency use this practice in the project)					
Always (yes)	Almost always (yes)	Sometimes (yes)	Rarely (yes)	Never (no)	Do not apply
5	4	3	2	1	0
Performance level (How efficiently do this practice in the project)					
Excellent	Great	Competent	Need to improve	Deficient	Do not apply
5	4	3	2	1	0

Table 3 List of evaluated projects

No.	PROYEC TO
1	CONTROL DE INUNDACIONES MILAGRO CIM
	PROYECTO MULTIPROPOSITO PURUHANTA-PIMAMPIRO-YAHUARCOCHA
2	PROYECTO MULTIPROPOSITO JAMA
3	PROYECTO PROPOSITO MULTIPLE COAQUE
4	PLAN DE APROVECHAMIENTO Y CONTROL DE AGUA DE LA PROVINCIA DE LOS RIOS PACALORI
5	ESTUDIOS: PROYECTO DE TRASVASE RIO DAULE - PEDRO CARBO (INP)
6	PROYECTO MULTIPROPOSITO TUMBABIRO
7	PROYECTO MULTIPROPOSITO PUMA
8	PROYECTO CHALUPAS
9	OPTIMIZACION PROYECTO MULTIPROPOSITO TAHUIN
10	TRASVASE DAULE - VINCES (DAUVIN)
11	TRASVASE CHONGON -SAN VICENTE
12	CONTROL DE INUNDACIONES BULUBULU
13	CONTROL DE INUNDACIONES CANAR
14	CONTROL DE INUNDACIONES NARANJAL
15	MULTIPLE CHONE
16	MULTIPROPOSITO BABA

Source Public water company of Ecuador EPA

water projects that contained the irrigation component in these life cycle stages. In April 2015, the Chongón Diversion Project—San Vicente entered the operation stage. Finally, of the remaining 15 projects that were evaluated, it was not possible to assess the Puruhanta—Pimampiro—Yahuarcocha project, reported in April 2015 by the PWC public water company as non-viable; instead, the Baba Multipurpose Project (currently in operation) was assessed in its planning stage, according to details in Table 3.

Interviewed people

In order to get the more real results for the 16 studied projects, 16 surveys were distributed between project managers and professionals of both the PWC and its counterpart (construction and inspection companies) and their results, which included the pronouncement of 16 industry experts, were obtained.

How were the levels of usage and performance of the identified variables in each of the 16 water projects verified?

Based on the calculation of the different projects' average performance levels in the economic, environmental and social dimensions and using a hierarchical cluster analysis, project groups with similar variables performance levels were identified. This was done for projects belonging to the same group and different projects belonging to different groups. To this end, the between-group method and squared Euclidean distance measure were used.

5 Results

SO I. As a final result, a total of 32 complementarity variables or sustainability practices were identified, which were divided into 7 economic variables, 11 environmental variables and 14 social variables, detailed in Table 4.

Table 4 Variables of complementarity

1	*Economic practices*
1.1	Having enough reliable financial flows
1.2	Having financing for cases of unforeseen unconstructive as resettlement, rehabilitation of people affected, road construction/additional routes
1.3	Including in the initial budget funding for development of agricultural activities (crop changes and improvements, training in irrigation, increased production and marketing)
1.4	Including in the initial budget funding for plans and/or programs that contribute to generating positive economic impacts over trade, industry and tourism in the region
1.5	Including in the initial budget funding for plans and/ or environmental and social programs
1.6	Having timely funding sources
1.7	Consider public assistance and/or subsidies to fund productive activities of vulnerable groups

(continued)

Table 4 (continued)

2	*Environmental practices*
2.1	Plan or program to control the generation and disposal of waste and debris
2.2	Plan or environmental control program of the impact caused by the stream deflection (length and scope)
2.3	Monitoring the amount of slime in the stream before, during and after project implementation
2.4	Plan or monitoring program of air quality, surface/ ground water, acoustic and ground changes
2.5	Plan or program to preserve existing national parks up to a 10 km radius from the project
2.6	Plan or prevention program for environmental damage caused by mining operations in quarries
2.7	Plan or program for the preservation of ecological flow and impact on aquatic life.
2.8	Plan or preservation program for land animal and bird species
2.9	Plan or Program for identification and control of risk areas subject to natural disasters (landslides, floods, earthquakes …)
2.10	Raising awareness of climate change threats
2.11	Conducting environmental audits and socio-environmental control
3	*Social practices*
3.1	Plan or program for direct formal employment generation
3.2	Make a cadastre and theme mapping of: spatialization and spatial analysis of lack of airport infrastructure, electricity, health, tourism, industry, communication; socio-cultural analysis of health and education coverage; PEA, housing vulnerability, basic services availability
3.3	Management plan for people displaced by the project
3.4	Management plan for warm public space (parks, gardens, hospitals, schools) and other quality basic services
3.5	Plan or program for conflict resolution between local people and migrant workers
3.6	Identify and assess the impact on transport and communication means and infrastructure
3.7	Practices to prevent housing damage due to operations (blasting, earthmoving)
3.8	Actions to avoid possible time losses, movement restrictions or changes during the execution of the project
3.9	Plan or program to preserve cultural heritage of the area
3.10	Plan or program to promote community cohesion and identity as well as integration and participation of minorities
3.11	Efficient and coordinated participation and activity of local, regional and national authorities
3.12	Anti-corruption policies and procedures employee training
3.13	Include local community participation in decision-making
3.14	Plans or programs to improve the living standards of the population in the area affected by the project

Prepared by the authors

5.1 *Variables Results*

SO II—Results obtained from the measurement and prioritizing of variables by usage frequency and performance level are presented below.

Usage frequency of economic variables

Variable	1	2	3	4	5	6	7
Usage	16	14	11	13	15	14	15
No Usage	0	2	5	3	1	2	1
% Usage	100%	88%	69%	81%	94%	88%	94%

Usage frequency of environmental variables

Variable	8	9	10	11	12	13	14	15	16	17	18
Usage	16	13	14	13	11	13	11	12	13	12	13
No Usage	0	3	2	3	5	3	5	4	3	4	3
% Usage	100%	81%	88%	81%	69%	81%	69%	75%	81%	75%	81%

Usage frequency of social variables

Variable	19	20	21	22	23	24	25	26	27	28	29	30	31	32
Usage	13	10	12	8	10	10	11	12	12	11	16	14	10	12
No Usage	3	6	4	8	6	6	5	4	4	5	0	2	6	4
% Usage	81%	63%	75%	50%	63%	63%	69%	C	75%	69%	100%	88%	63%	75%

HIGH LEVEL USE ≥ 85%

MIDDLE LEVEL USE ≥ 70% and <85%

LOW LEVEL USE < 70%

Performance level of economics variables

Variable	1	2	3	4	5	6	7
Average	4.2500	4.0000	3.5625	3.5625	3.8750	3.8750	3.6875
Std. dev.	0.4472	0.5164	0.9639	1.0308	0.7188	0.6191	0.7932

Performance level of environmental variables

Variable	8	9	10	11	12	13	14	15	16	17	18
Average	4.0625	3.8000	3.7500	3.8125	3.6250	3.7500	3.6875	3.6250	3.6875	3.6250	3.6250
Std. dev.	0.4425	0.6761	0.6831	0.5439	0.6191	0.5774	0.7932	0.8062	0.7932	0.7188	0.8851

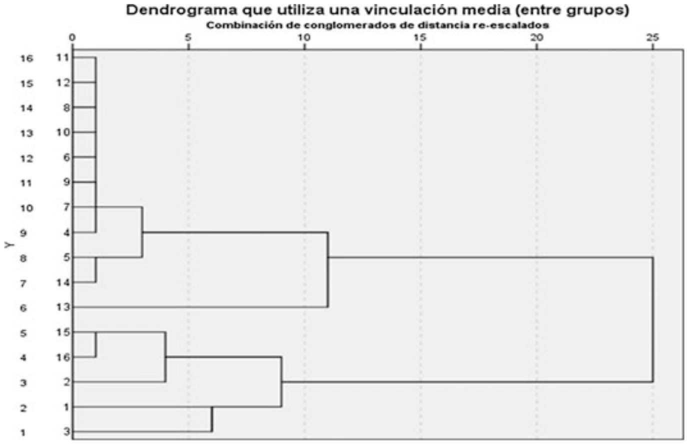
Performance level of social variables

Variable	19	20	21	22	23	24	25
Average	3.6250	3.2667	3.3125	3.0000	3.0667	3.1875	3.3333
Std. dev.	0.7188	1.2228	1.1955	1.2111	1.2228	1.1673	1.1127
Variable	26	27	28	29	30	31	32
Average	3.6000	3.2500	3.4375	3.9375	3.7500	3.3125	3.3125
Std. dev.	0.8281	1.2910	1.0935	0.2500	0.7746	0.9465	1.3022

5.2 *Project Results*

SO III—Two projects performance levels were obtained after the cluster analysis are shown:

Averages	Conglomerate 1	Conglomerate 2
	Projects: 4, 5, 6, 7, 8, 9, 10, 11, 12 y 13	Projects: 1, 2, 3, 14, 15 y 16
Performance economics variables	4071	3429
Performance environmental variables	4036	3220
Performance social variables	3950	2452



6 Discussion of Results

6.1 Discussion Per Variable

The results of the level of use of the 32 complementarity variables indicate that, according to experts, 19 variables have medium and high usage in situ; namely, they are used in over 70% of the projects. Only the remaining 7 variables, mostly social as shown in Fig. 1, have a low usage rate. That is to say, that they are used in less than 70% of the projects but not less than in 50% of the projects. This means, for example, for the extreme cases, that the practice or economic variable "Having enough reliable financial flows" is used in 100% of the projects, whereas the social practice of 'management of public space (gardens parks, hospitals, schools) and other quality basic services' is used in 50% of projects. These results are interpreted as a validation of the choice of practices identified by reviewing scientific literature, for 79% of practices have a high and medium level of usage and only a social practice is used only in 50% of the projects.

The results mentioned above are confirmed in Fig. 2, where a slight tendency of less use of the environmental and social variables is shown, when comparing to the economic variables. This is consistent with the evolution of the variables' use, as historically financial profitability was privileged with a clear focus on economic and financial feasibility over the environmental and social.

VARIABLES	No.		USAGE RATE IN SITU
ECONOMIC	3	Including in the initial budget funding for development of agricultural activities (crop changes and improvements, training in irrigation, increased production and marketing)	69%
ENVIRONMENTAL	5	Plan or program to preserve existing national parks up to a 10 km radius from the project	69%
SOCIAL	4	Management plan for warm public space (parks, gardens, hospitals, schools) and other quality basic services	50%
	5	Plan or program for conflict resolution between local people and migrant workers	63%
	6	Identify and assess the impact on transport and communication means and infrastructure.	63%
	7	Practices to prevent housing damage due to operations (blasting, earthmoving)	69%
	13	Include local community participation in decision-making	63%

Fig. 1 Variables with low usage rate

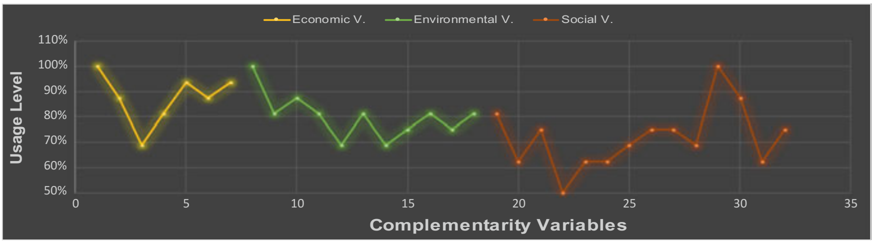


Fig. 2 Level of usage of complementarity variables

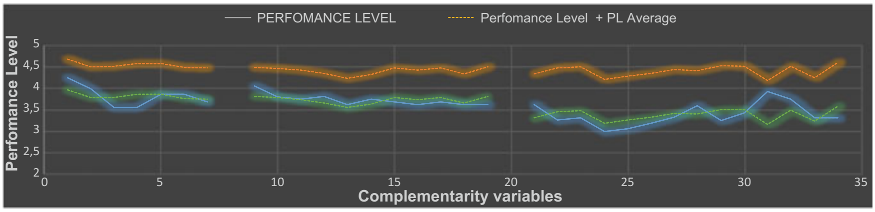


Fig. 3 Average performance level of the complementarity variables

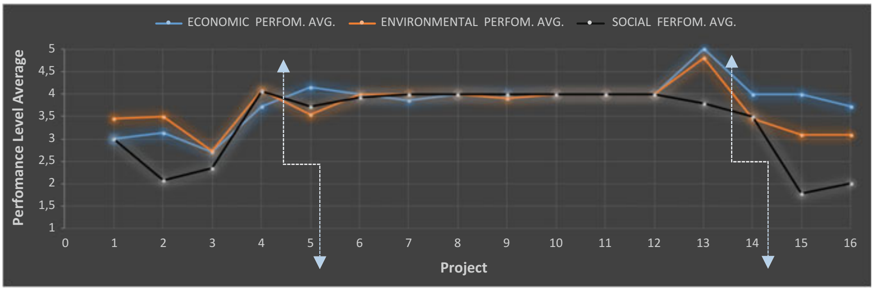


Fig. 4 Average level of complementarity variables performance per project

Figure 3 shows that the economic variable 1, which obtained a high use rate, is executed and/or implemented with the average variable efficiency within its sector, confirming the consistency of the results. The 12 variables which are not covered or not running as efficiently as the average of other variables in the sector, are respectively the following variables: Economic 3 and 4, environmental 8, 9 and 11, and Social 2, 3, 4, 5, 6, 7 and 9, coinciding mostly with low use variables. These results emphasize the need to work on their training and management. This is the case of the particular behavior of the economic variable 3 "Contemplating in the initial budget for financing agricultural development activities (conversion and crop improvements, training in irrigation, increased production and marketing)", which in addition to having a low use rate, is executed below the average level of efficiency of the variables in its sector and, therefore, generates greater risk of gaps of complementarity.

6.2 *Discussion Per Project*

Analysing the performance level results for each of the 16 projects, two large groups of projects were obtained. The first group comprised 10 projects which were the majority. The second group, with a clear dispersion of average performance levels as shown in Fig. 4, comprised 6 projects: 1, 2, 3, 14, 15 and 16, which have in common that they are implanted in the river basins of the Pacific slope, where

80% of the Ecuadorian population are based and where social and environmental practices have not been adequately addressed. In the second phase, by increasing the number of experts interviewed, it is expected to identify new groups of projects with similar patterns of performance level.

7 Conclusions

After reviewing the scientific literature containing sustainability indicators studies and with the input from experts in the water sector, 32 variables applicable to complementary strategic water irrigation projects were identified (7 economic, 11 environmental and 14 social).

There were only seven variables or practices that were identified by experts in the field with a low use rate, less than 70% of use: 1 economic, 1 environmental and 5 social. The remaining 24 variables that represent 79% of all variables (the majority) have a medium and high frequency of use, over 70%. These results minimize the risk of getting a wrong sustainability indicator by using 32 identified variables, ensuring the continuity of the study with a broader base of experts to interview.

From the study of the complementarity variables, in 16 projects in the Republic of Ecuador, 2 groups of projects with common characteristics were identified. The first group consists of 10 projects that have a high economic performance and moderate environmental and social performance, which for the case study was the majority (Nos. 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13). The second group, 37.5%, comprises the remaining 6 projects which have a moderate level of performance in the economic and environmental variables, and low social performance, in the case of study (Nos. 1, 2, 3, 14, 15 and 16) and they have in common that they were implemented in the water basins of the Pacific slope, where 80% of the population is based, and, therefore, the most populated water basins trigger higher social and environmental demands.

Finally, the results obtained through the behavior of the complementarity variables identified, applied to strategic irrigation projects in the Republic of Ecuador, allow encouraging the study continuity in order to develop an algorithm that calculates the gaps of unconstructive complementarity. This algorithm may be useful for policy and decision makers on such water projects, to help the sustainable development of water irrigation projects implemented in natural regions and concrete water basins of Ecuador and throughout the world in general.

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