Relationship between the main economic, environmental and social impacts of hydroelectric dams

Determinação das relações entre os principais impactos econômicos, ambientais e sociais das usinas hidrelétricas

DOI:10.34117/bjdv8n10-100

Recebimento dos originais: 05/09/2022
Aceitação para publicação: 06/10/2022

Jose Andres Gomez Romero
Doctor in Management Sciences
Institution: Comisión Federal de Electricidad (CFE)
Address: Río Misisipi 71 piso 11, Colonia Cuauhtémoc, C.P. 06500, Alcaldía Cuauhtémoc - Ciudad de México, México
E-mail: jose.gomez@cfe.mx

Martin Gerardo Martínez Rangel
Doctor in Engineering and Applied Sciences with Terminal Option in Electrical Technology
Institution: Universidad Autónoma del Estado de Morelos
Address: Avenida Universidad, No. 1001, Colonia Chamilpa, C.P. 62209, Cuernavaca - Morelos, México
E-mail: mmtzr@uaem.mx

Jose Alberto Hernández Aguilar
Doctor in Engineering and Applied Sciences with Terminal Option in Electrical Technology
Institution: Universidad Autónoma del Estado de Morelos
Address: Avenida Universidad, No. 1001, Colonia Chamilpa, C.P. 62209, Cuernavaca - Morelos, México
E-mail: jose_hernandez@uaem.mx

Adriana Valencia Valencia
Master's in Management and Development of Education
Institution: MacMillan
Address: Avenida Insurgentes Sur, 1457, piso 25, Colonia Insurgentes Mixcoac, C.P. 03920, Alcaldía Benito Juárez - Ciudad de México, México
E-mail: avalenciavale@gmail.com

José Carlos Alberto Ortíz Acle
Doctor in Management Sciences
Institution: Secretaría de Educación (SEP)
Address: Avenida Hidalgo, 62, Colonia del Carmen, C.P. 04000, Alcaldía Coyoacán - Ciudad de México, México
E-mail: osortac@gmail.com

Leonardo de Jesús Ramos Gutiérrez
Master in Construction Administration
Address: Río Misisipi, 71, piso 11, Colonia Cuauhtémoc, C.P. 06500, Alcaldía Cuauhtémoc - Ciudad de México, México
E-mail: leonardo.ramosg@cfe.mx

Hugo Armando Fragoso Cano
Doctor in Management Sciences
Institution: Televisa group by Itera
Address: Avenida Vasco de Quiroga, 200, Colonia Santa Fe, C.P. 01210, Alcaldía Álvaro Obregón - Ciudad de México, México
E-mail: harmasoho@gmail.com

ABSTRACT
Hydroelectric power plants have been a growth tool to supply communities with water resources and electricity. In the last seven decades, large dams increased their environmental and social impacts, which caused the fragmentation and transformation of rivers. It is estimated that around 80 million people are displaced by its construction and operation; and its greatest impact comes from reservoirs by flooding large tracts of land permanently. In this sense, this study seeks to determine the relationship between the main economic, environmental and social impacts of the construction of hydroelectric power plants.It addresses the different non-participatory methods, such as secondary data, documents, records and databases were reviewed. From this information, principal component analysis, simple regression, correlations, multivariate and 3D dispersion graphs were performed. Once the different methods were applied, a significant correlation was identified between the variables of installed capacity and number of displaced people. The study concludes that natural resources are a source of attraction for people to settle around them, the water resource is of special interest, therefore, it is not strange that when establishing a hydroelectric project, there is invariably displacement of people in order to benefit a greater number of them through the generation of energy, prevent floods and droughts among other benefits, depending on the category that the dam have, as there are single purpose and multiple purpose. It is undeniable that there is a very strong correlation between the construction of dams and the economic development of a region, however, the correlation that exists between the construction of dams and the displacement of people is also undeniable, hence the importance of this study that is presented, since it allows having clearer economic, environmental and social perspectives that allow identify whether large hydroelectric project construction projects succeed or fail in their purpose of sustainable regional development.The results indicate that by increasing the installed capacity, there is a social impact as it will increase the displacement of people due to the construction or operation of hydroelectric power plants.

Keywords: dams, barrages & reservoirs, environment, hydrology & water resource, management, social impact, sustainability.

RESUMO
As usinas hidrelétricas têm sido uma ferramenta de crescimento para abastecer comunidades com recursos hídricos e energia elétrica. Nas últimas sete décadas, as grandes barragens aumentaram seus impactos ambientais e sociais, o que provocou a fragmentação e transformação dos rios. Estima-se que cerca de 80 milhões de pessoas sejam deslocadas por sua construção e operação; e seu maior impacto vem dos

reservatórios, inundando grandes extensões de terra permanentemente. Nesse sentido, este estudo busca determinar a relação entre os principais impactos econômicos, ambientais e sociais da construção de usinas hidrelétricas.Aborda os diferentes métodos não participativos, como dados secundários, documentos, registros e bancos de dados foram revisados. A partir dessas informações, foram realizadas análises de componentes principais, regressão simples, correlações, gráficos multivariados e de dispersão 3D. Uma vez aplicados os diferentes métodos, identificou-se uma correlação significativa entre as variáveis de capacidade instalada e número de deslocados. O estudo conclui que os recursos naturais são uma fonte de atração para as pessoas se estabelecerem ao seu redor, o recurso hídrico é de especial interesse, portanto, não é estranho que ao se estabelecer um projeto hidrelétrico, haja invariavelmente o deslocamento de pessoas para beneficiar um maior número delas através da geração de energia, evitar enchentes e secas entre outros benefícios, dependendo da categoria que a barragem possui, pois existem finalidade única e finalidade múltipla. É inegável que existe uma correlação muito forte entre a construção de barragens e o desenvolvimento econômico de uma região, porém, a correlação que existe entre a construção de barragens e o deslocamento de pessoas também é inegável, daí a importância deste estudo que é apresentado, pois permite ter perspectivas econômicas, ambientais e sociais mais claras que permitem identificar se os grandes projetos de construção de projetos hidrelétricos são bem sucedidos ou fracassam em seu propósito de desenvolvimento regional sustentável.Os resultados indicam que ao aumentar a capacidade instalada, há um impacto social, pois aumentará o deslocamento de pessoas devido à construção ou operação de usinas hidrelétricas.

Palavras-chave: barragens, barragens e reservatórios, meio ambiente, hidrologia e recursos hídricos, gestão, impacto social, sustentabilidade.

1 BACKGROUND

Water has been the most sought after resource in the establishment of communities; rivers, the variety of plants and animals that develop in their basins, supply societies and agriculture with the irrigation of their crops. Rivers have also served to supply cities and industries with electricity generation, so dams were the instruments to divide or distribute the waters of rivers since 3,000 A.C. as in what is now known as the Jordan River (McCully, 2004). From the Middle Ages until the Industrial Revolution, the energy of the water current in rivers and channels was used to drive mills, metallurgical hammers and shipment of goods through boats, which contributed to the industrial and economic development of several countries (Baroja, cited in Méndez, 1997). According to the World Commission on Dams (WCD, 2000), the mission of dams is to provide water for irrigation, prevent floods and droughts, generate electricity, regulate the flow of watersheds, among others (see Table 1). Dam construction grew, and reached its peak in the 1970s when, on average on the planet, 2 to 3 dams per day were inaugurated. Its decline occurred in North America and Europe where the sites with the greatest potential, from the technical point of view, had already built dams (WCD, 2000). For international commission on large dams (ICOLD, 2020a), more than 58,000 large dams were built in the world, with curtains greater than 15 meters. 70 percent of these have heights below 30 meters and 1 percent exceeds 100 meters high.

Table 1. Number and purposes of the dams in the year 2000.

Description	Dams with a single purpose	Multipurpose dams
Flood control	2539	4911
Aquaculture	42	1487
Hydroelectricity	6115	4135
Irrigation	13580	6278
Navigation	96	579
Recreation	1361	3035
Water supply	3376	4587
Mine dump	103	12
Other	1579	1385
Total	28791	26409

Source: ICOLD (2020b).

Dams fall into two categories: single-purpose and multipurpose. The demand for water is constantly increasing and would reach between 2 to 3% annually for the next few decades. With their current storage of approximately 7,714 km^3, the dams make a contribution to the efficient management of finite water resources. 49% of dams are single-purpose and in the case of hydroelectric dams, they represent 17.5% ICOLD (2020b).

The link between dams and development was due to the fact that they were a growth tool for communities to stock up on water and electricity resources. What can be obtained from the construction of the dams is sustainable development that results from the balance between the stakeholders and, also, from the supply of electricity. The construction of dams represents a worldwide problem due to the economic, environmental and social perspectives, where the discussion revolves around how hydroelectric projects succeed or lose to achieve their purpose of sustainable development (Acosta, 2004; Barriga & Pinto, 2019).

In the last seven decades, the problematic of large dams and their environmental and social impacts stand out, since they fragmented and transformed the planet's rivers. Between 40 and 80 million people were identified as displaced by the construction and operation of the dams. For Suárez and Peirano (2010), during the construction of these projects the problems of different types arise. Among them are emphasized the movement of earth, the extraordinary movement of construction materials, goods and people, the generation of noise and dust, erosion, the collapse of the road system, the construction of transmission lines, access roads (Lemos et al., 2019). This causes modifications to the vegetation, in the wild lands, fauna, soils, fishing, climate and villages of the project area. But the greatest impact emanates from the water reservoir, as it permanently floods large tracts of land. The waters of the river ran freely, now they are in a lake that captures them, creating enormous hydrographic changes and the loss of the ecosystem (Suárez and Peirano, 2010).

According to Chatzimouratidis and Pilavachi (2008), the land required by each power plant is a matter of great concern for evaluation (see Table 2). The quality of life is directly affected by the land occupied by the power plants, as it could have been used for the creation of parks and recreation centers. Optical disturbance caused by buildings and noise from power plant equipment, such as wind generators, is difficult to assess economically, but it definitely negatively impacts the quality of life. In addition to the optical and acoustic disturbances caused by buildings and equipment, excavations, tunnels and other work necessary for the operation of the plant destabilize the flora, fauna and ecosystem in general. For Wang et al. (2009), land use can also be a social criterion for assessing the energy system. It represents one of the most critical factors for the intervention site, especially where human activities are relevant factors of environmental pressure.

Table 2. Land required by each type of power plant based on global data.

Type of power plant	**Land requirement (km^2 / 1000 MW)**
Charcoal	2.5
Petroleum	2.5
Natural gas turbine	2.5
Combined cycle	2.5
Nuclear	2.5
Hydroelectric	750
Wind	100
Photovoltaic	35
Biomass	5000
Geothermal	18

Source: Self-elaboration based on (Afgan & Carvalho, 2002; Beccali et al., 2003; Chatzimouratidis & Pilavachi, 2008; Ottinger et al., 1991; Pimentel et al., 1994; San Martin, 1989; Troldborg et al., 2014; Walker, 1995; Wang et al., 2009)

Different energy systems occupy different terrains, while the products are the same. In particular, biomass, hydroelectric and wind energy supply systems require a large amount of land. Land use is necessarily considered for decision-making on energy issues.

According to Clar (2013), the impacts of hydroelectric plants on the environment, society and the economy are of different intensity and levels, some of these are presented below:

To society: Of the health repercussions that are identified as a result of displacement are malaria, dengue and yellow fever since the stagnation of water provides an adequate environment for the reproduction of mosquitos. Likewise, the disintegration of communities is caused by the separation and displacement of their members and the inadequate programs for the resettlement, mitigation and development of the displaced.

To the environment: The alteration of the hydrological regime of the river, deforestation by the construction of access roads, the change of the habitat of the water that flows oxygenated and with luminosity, to a still, dark and with little oxygen, invasion of strange species alien to that habitat, propagation of floating aquatic plants, by their rapid reproduction and adaptation, are identified, that replace the existing flora. Generation of methane by not deforesting the trees that remain underwater and die. Installation of agricultural industries in the vicinity of the reservoir. Water pollution by hydrogen sulfide, pesticides, organic matter and fertilizers, among others. Changes in land use due to the expansion of agriculture and associated deforestation, which impacts biodiversity, climate, soil quality and flooding of large areas.

To the economy: This result in more impoverishment, loss of socio-economic activities such as tourism and fishing; environmental and social costs that will be borne by future generations. In addition, hydroelectric dams can be a source of corruption to get them approved, as government officials and politicians can appropriate a percentage of the funds earmarked for construction.

Based on the above, the following research question is considered.

What is the relationship between the main economic, environmental and social impacts of the construction of hydroelectric power plants?

1.1 OBJECTIVE

Determine the relationships between the main economic, environmental and social impacts of the construction of hydroelectric power plants.

Hypothesis Approach

H_1. There is a significant correlation between displaced people and installed capacity in hydroelectric plants

H_2. There is a significant correlation between flooded hectares and installed capacity in hydroelectric plants

H_3. There is a significant correlation between flooded hectares and displaced people

2 METHODOLOGY

For the elaboration of this work, non-participatory methods were used, such as secondary data, which involves the review of documents, public records and physical or electronic archives (Hernández, Fernández and Baptista, 2010). Subsequently, Table 3 was created with the following fields: hydroelectric, country(s), installed capacity in Mega Watts (MW), flooded hectares, displaced people and Region. This table was reprocessed by cleaning up incomplete data or in text form. Once the table was cleaned, a principal component analysis, a simple regression analysis, a correlation analysis, as well as a multivariate analysis, and 3D dispersion graphs were performed to describe the phenomenon (Ritchey, 2008, Griffith, 2010).

Table 3. Personas displaced as a result of the construction of hydroelectric dams.

Grip	Country	Region	Installed capacity (MW)	Reserved areas (ha)	Displaced persons
Kedung Ombo	Indonesian	Asia	29	4,600	29,000
Victoria	Sri Lanka	Asia	210	2,270	45,000
Brokopondo Hotels	Suriname	Asia	30	160,000	5,000
Bayano	Panama	South America	30	35,000	4,400
Little Moon	Thailand	Asia	34	6,000	4,945
Kompienga	Burkina Faso	Africa	14	20,000	1,842
Cabora Bassa	Mozambique	Africa	2075	380,000	250,000
Akosombo	Ghana	Africa	833	848,200	80,000
Mangla	Pakistan	Asia	1000	25,300	90,000
Narmada Sagar	India	Asia	1000	90,820	80,500
Three Gorges	China	Asia	18200	110,000	1,300,000
Kainji	Nigeria	Africa	760	126,000	50,000
Sobradinho	Brazil	South America	1050	415,000	65,000
Aswan High	Egypt	Africa	2100	400,000	100,000
Kariba	Zambia/Zimbabwe	Africa	1260	510,000	57,000
Tehri	India	Asia	2400	4,200	100,000
Khao Laem	Thailand	Asia	300	38,800	10,800
Tarbela	Pakistan	Asia	3478	24,280	96,000
Ataturk	Turkey	Europe	2400	81,700	55,000

Grip	Country	Region	Installed capacity (MW)	Reserved areas (ha)	Displaced persons
Nam Theun-Hinboun	Laos	Asia	210	294,200	4,800
Nanyu	Laos	Asia	150	37,000	3,000
Yacyreta	Argentina/Paraguay	South America	3100	165,000	50,000
Urra I	Colombia	South America	340	7,400	6,200
Arenal	Costa Rica	South America	157	7,000	2,500
The drawer	Honduras	South America	300	11,200	4,000
Salvajina	Colombia	South America	270	2,030	3,272
Chixoy	Guatemala	South America	300	1,400	3,445
Zimapan	Mexico	South America	280	2,300	2,800
Ernest	China	Asia	3300	10,100	30,000
Porto Primavera	Brazil	South America	1815	225,000	15,000
Tucurui	Brazil	South America	3980	243,000	30,000
Guavio	Colombia	South America	1000	1,530	959
Itaipu	Brazil/Paraguay	South America	12600	135,000	59,000
Nam Theun II	Laos	Asia	1086	45,000	5,700
Big Jump	Argentina/Uruguay	South America	1890	78,300	8,000
Bakun	Malaysia	Asia	2400	70,000	9,000
Balbina	Brazil	South America	250	236,000	1,000
Kararao/Belo Monte	Brazil	South America	8381	116,000	20,000
Arun II	Nepal	Asia	402	43	775
Grand Coulee	United States	North America	6494	33,306	10,000
Single Island	Brazil	South America	3200	125,700	6,150
Pehuenche	Chile	South America	500	400	1,000
Aguamilpa	Mexico	South America	960	13,000	1,000
Bethany	Colombia	South America	510	7,370	544
Fortune	Panama	South America	300	1,050	446
Ghazi Barotha	Pakistan	Asia	1450	2,640	899
Churchill Falls	Canada	North America	5225	665,000	3,200
Guri Complex	Venezuela	South America	10300	426,000	1,500
Pangue	Chile	South America	450	500	50
Aswan	Egypt	Africa	2100	525,000	90,000
Aswan	Egypt, Sudan	Africa	1825	650,000	120,000
Baihetan (c)	China	Asia	16000	20,924	69,000
Bakolori	Sokoto	Africa	3	12,000	13,000
Bang Lang	Thailand	Asia	72	5,100	3,300
Severely	India	Asia	105	809,000	113,000
Ai Stem	Malaysia	Asia	92	8,500	3,000
Bhima (Ujjani)	India	Asia	12	3,400	57,000
Blvamibol	Thailand	Asia	535	36,000	20,000
Golden Hill	Mexico	South America	10.8	17,000	26,000
Changma	China	Asia	630	74,000	96,000
Chiew Larn	Thailand	Asia	240	16,500	1,600
Chung ju	South Korea	Asia	460	9,700	46,500
Cirata	Indonesian	Asia	500	6,200	56,000
Daguangba	China	Asia	240	9,900	28,200
Danjiangkou	China	Asia	900	15,500	347,200
Ten	Iran	Asia	840	6,300	17,000
Dhom (Dhom)	India	Middle East	4	2,500	39,000
Dongjiang	China	Asia	500	16,000	53,000
Furmas	Brazil	South America	1216	144,000	8,500
Geheyan	China	Asia	1200	7,200	26,700
Hirakud	India	Asia	270	74,300	110,000

Grip	Country	Region	Installed capacity (MW)	Reserved areas (ha)	Displaced persons
Huajun	Vietnam	Asia	1920	20,000	58,000
Hualiangting	China	Asia	40	188,000	61,124
Itumbiara	Brazil	South America	2080	76,000	3,700
Cabin	India	Asia	32	6,100	15,000
Kaptai	Bangladesh	Asia	230	77,700	100,000
Karakaya	Turkey	Europe	1800	29,600	20,000
Keban	Turkey	Europe	1360	67,500	30,000
Kiambeve	Kenya	Africa	142	2,500	7,000
Kossou	Ivory Coast	Africa	0.89	170,000	85,000
Kotmale	Sri Lanka	Asia	200	950	13,000
Kpong	Ghana	Africa	160	3,500	7,000
Kuibyshev	Russia	Europe	2315	645,000	150,000
Kulekhani	Nepal	Asia	92	220	2,500
The Angostura	Mexico	South America	1100	64,400	15,480
LaGrande Project	Canada	North America	15719	75,600	1,900
Longtan	China	Asia	6426	9,850	75,100
Lubuge I	China	Asia	450	400	5,000
Magat	Philippines	Asia	360	4,500	1,500
Manancali	Mali	Africa	200	48,000	11,000
Marsayangdi	Nepal	Asia	69	60	3,000
Mtera	Tanzania	Africa	280	65,000	3,000
Nagarjunasagar	India	Asia	810	28,500	28,000
Nangbeso	Togo, Benin	Africa	63	18,000	12,000
Netzahualcoyotl	Mexico	South America	1080	29,200	3,000
New Bridge	Brazil	South America	510	44,300	5,000
Pantabangan	Philippines	Asia	100	8,900	13,000
Eagle Stone	Argentina	South America	1400	29,200	9,000
Iron Gates (Iron Gates)	Romania, Yugoslavia	Europe	2100	5,200	23,000
Rajghat	India	Asia	45	22,400	19,000
Rengali	India	Asia	60	41,400	80,000
Anonymous	Spain	Europe	680	2,000	3,100
Riband (Singrant)	India	Asia	300	46,900	60,000
Roseires	Sudan	Africa	280	29	70,000
Rybinsk	Russia	Europe	366.4	458,000	116,700
Sagulting	Indonesian	Asia	700	5,300	65,000
Santiago Falls	Brazil	South America	2000	22,500	1,500
Samuel	Brazil	South America	216	57,900	1,800
Sanmenxia	China	Asia	400	235,000	370,000
Simao Star	Brazil	South America	2689	68,000	14,000
Saravathi (Sharavathy)	India	Asia	510	5,900	12,500
Sardar Sarovar	India	Asia	1450	37,533	66,500
Secret	Brazil	South America	1260	8,200	2,700
Selingue	Mali	Africa	44	40,900	12,500
Shuikou	China	Asia	1400	93,000	67,000
Sidi Salem	Tunisia	Africa	36	55,000	3,500
Sir	Tunisia	Africa	284	4,800	7,000
Sri Ramu Sagar	India	Asia	36	43,400	16,000
Srinakharin	Thailand	Asia	720	41,900	9,400
Srisailam	India	Asia	440	24,700	330,000
Tabqua	Syria	Asia	800	60,000	60,000

Grip	Country	Region	Installed capacity (MW)	Reserved areas (ha)	Displaced persons
(Thawra/Assad)					
Temascal	Mexico	South America	354	47,800	22,000
Tres Brothers	Brazil	South America	1292	82,000	1,600
Ubolratana	Thailand	Asia	25	41,000	30,000
Ukai	India	Asia	300	60,000	88,000
Votkinsk	Russia	Europe	1065	112,000	61,000
Wuqiangai	China	Asia	1200	17,000	84,800
Xiangjiaba	China	Asia	6448	9,560	89,800
Xiaolangdi	China	Asia	1836	1,280	175,600
Xin'anjiang	China	Asia	845	57,300	271,550
Xinfengjiang	China	Asia	292.5	37,000	106,000
Zhexi	China	Asia	947.5	4,880	139,522

Source: Adaptation of ICOLD (2020c) and Gleick (1998).

3 DATA ANALYSIS

For the analysis of the data collected (see Table 3), information was available on 132 mega projects or dams built around the world for the generation of hydroelectricity, taking into account important elements such as the installed capacity in Megawatts (economic element), reserved areas (environment) and displaced people (social environment), resulting in the following (see Table 4 and Figure 1):

Principal Component Analysis

Data/Variables:

Reserved areas in Ha

Installed Capacity in MW

Displaced persons

Data entry: observations

Number of complete cases: 132

Standardize: Yes

Number of components removed: 1

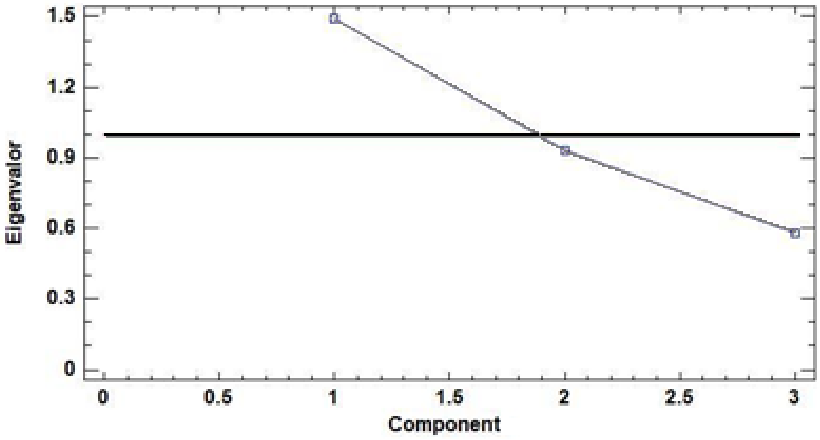
Table 4. Principal Component Analysis

Component Number	**Eigenvalue**	**Percentage of Variance**	**Cumulative Percentage**
1	1.48943	49.648	49.648
2	0.932368	31.079	80.727
3	0.578203	19.273	100.000

Source: Own elaboration.

This procedure runs a principal component scan. The purpose of the analysis is to obtain a few linear combinations of the 3 variables that explain the greatest variability in the data. In this case, a component has been extracted (Reserved Areas in Ha), since it is the only component with an eigenvalue greater than or equal to 1.0 which explains 49.6476% of the variability in the original data.

Figure 1. Sedimentation graph.



Source: Own elaboration.

Because the main components' method has been selected, the initial estimate of commonality has been established to assume that all variability in the data is due to common factors, in this case the greatest impact of the development of mega projects for the generation of hydroelectricity is on the environment (hectares used for its construction, component 1), which results in an impact on the social part (displaced persons, component 3) and that both components (hectares used and displaced persons) are strongly linked to installed capacity (component 2) with a strong correlation between component 2 and 3 as can be seen in the following analysis (see Tables 5 and 6):

Simple Regression-Displaced persons (component 3) vs Installed Capacity in MW (component 2)

Dependent variable: Displaced persons

Independent variable: Installed Capacity in MW

Linear Function:

$$Y = a + b * X \qquad (1)$$

Table 5. Coefficients

Parameter	Least Squares Dear	Standard Error	Statistical T	P-value
Interceptor	26900.7	11432.8	2.35294	0.0201
Earring	17.984	3.39347	5.29959	0.0000

Source: Own elaboration.

Table 6. Analysis of Variance

Fountain	Sum of Squares	Gl	Middle Square	F-Reason	P-value
Model	3.79671E11	1	3.79671E11	28.09	0.0000
Residue	1.75738E12	130	1.35183E10		
Total (Corr.)	2.13705E12	131			

Source: Own elaboration.

Correlation Coefficient = 0.421499

R-square = 17.7661 percent

R-square (adjusted for g.l.) = 17.1335 percent

Standard error of the est. = 116268.

Average absolute error = 58266.4

Statistic Durbin-Watson = 1.78736 (P=0.1116)

Autocorrelation of waste in delay 1 = 0.103722

The output shows the results of adjusting a linear model to describe the relationship between Displaced Persons and Installed Capacity in MW. The equation of the adjusted model is

$$\text{Displaced people} = 26900.7 + 17.984 * \text{Installed capacity (MW)} \quad (2)$$

Since the P-value in the ANOVA table is less than 0.05, there is a statistically significant relationship between Displaced Persons and Installed Capacity in MW with a confidence level of 95.0%.

The R-Square statistic indicates that the adjusted model explains 17.7661% of the variability in displaced persons. The correlation coefficient is equal to 0.421499, indicating a relatively weak relationship between the variables. The standard error of the estimate indicates that the standard deviation of the waste is, 116268. This value can be used to construct prediction limits for new observations by selecting the Forecasts option from the text menu.

The mean absolute error (MAE) of, 58266.4 is the average value of the waste. The Durbin-Watson Statistic (DW) examines the residuals to determine if there is any significant correlation based on the order in which they are presented in the data file (see Table 7). Since the P-value is greater than 0.05, there is no indication of a serial autocorrelation in residues, with a confidence level of 95.0%.

Table 7. Atypical Waste

			Predictions		Waste
Row	**X**	**And**	**And**	**Waste**	**Studentized**
11	18200.0	1.3E6	354209.	945791.	16.28
52	16000.0	69000.0	314645.	-245645.	-2.38
65	900.0	347200.	43086.3	304114.	2.69
86	15719.0	1900.0	309591.	-307691.	-3.01
109	400.0	370000.	34094.3	335906.	2.99
120	440.0	330000.	34813.6	295186.	2.61
130	845.0	271550.	42097.1	229453.	2.00

Source: Own elaboration.

Table 7 of atypical residues lists all observations that have Studentized residues greater than 2, in absolute value. The Studentized residuals measure how many standard deviations each observed value of Displaced Persons deviates from the adjusted model, using all data except that observation. In this case, there are 7 Studied wastes greater than 2, 2 greater than 3. Observations with residues greater than 3 should be carefully examined to determine whether they are aberrant values that should be removed from the model and treated separately.

3.1 MULTIVARIATE ANALYSIS

Data/Variables:

Reserved areas in Ha

Installed Capacity in MW

Displaced persons

This procedure is designed to summarize multiple columns of quantitative data. It will calculate various statistics, including correlations, covariances, and partial correlations. A series of multivariate graphs are also included in the procedure, which provide interesting views of the data.

Table 8. Statistical Summary

	Reserved areas (Ha)	Installed Capacity (MW)	Displaced persons
Recount	132	132	132
Average	93003.2	1567.56	55091.7
Standard deviation	165623.	2993.52	127724.
Coefficient of Variation	178.083%	190.967%	231.839%
Minimal	29.0	0.89	50.0
Maximum	848200.	18200.0	1.3E6
Rank	848171.	18199.1	1.29995E6
Standardized Bias	13.0392	17.6505	35.2494
Standardized Kurtosis	18.0259	35.9813	163.871

Source: Own elaboration.

Table 8 shows the statistical summary for each of the selected variables. It includes measures of central tendency, variability and form. Of particular interest here is standardized bias and standardized kurtosis, both of which can be used to determine whether the sample comes from a normal distribution. Values of these statisticians outside the range of -2 to +2 indicate significant deviations from normality, which would tend to invalidate many of the statistical procedures that are commonly applied to these data. In this case, the three variables used show values of standardized bias and standardized kurtosis outside the expected range. In this sense, the following table shows the frequency table for reserved areas in Ha, as can be seen in Table 9. In it, 23 classes were constructed, each with a lower limit and an upper limit in hectares, being class 2 with an upper limit of 40,909.1 Ha with a frequency of 75 mega projects with those dimensions, which explains why variable 1 (reserved areas) show values of standardized bias and standardized kurtosis outside the expected range.

Table 9. Frequencies for reserved areas in Ha

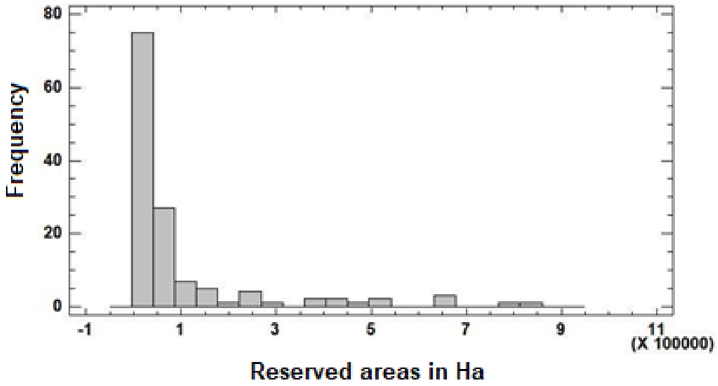
Class	Limit Inferior less equal	Limit Superior -50000.0	Midpoint	Frequency 0	Frequency Its 0.0000	Frequency Accumulated 0	Frequency Rel. Now. 0.0000
1	-50000.0	-4545.45	-27272.7	0	0.0000	0	0.0000
2	-4545.45	40909.1	18181.8	75	0.5682	75	0.5682
3	40909.1	86363.6	63636.4	27	0.2045	102	0.7727
4	86363.6	131818.	109091.	7	0.0530	109	0.8258
5	131818.	177273.	154545.	5	0.0379	114	0.8636
6	177273.	222727.	200000.	1	0.0076	115	0.8712
7	222727.	268182.	245455.	4	0.0303	119	0.9015
8	268182.	313636.	290909.	1	0.0076	120	0.9091
9	313636.	359091.	336364.	0	0.0000	120	0.9091
10	359091.	404545.	381818.	2	0.0152	122	0.9242
11	404545.	450000.	427273.	2	0.0152	124	0.9394
12	450000.	495455.	472727.	1	0.0076	125	0.9470
13	495455.	540909.	518182.	2	0.0152	127	0.9621
14	540909.	586364.	563636.	0	0.0000	127	0.9621
15	586364.	631818.	609091.	0	0.0000	127	0.9621
16	631818.	677273.	654545.	3	0.0227	130	0.9848
17	677273.	722727.	700000.	0	0.0000	130	0.9848

18	722727.	768182.	745455.	0	0.0000	130	0.9848
19	768182.	813636.	790909.	1	0.0076	131	0.9924
20	813636.	859091.	836364.	1	0.0076	132	1.0000
21	859091.	904545.	881818.	0	0.0000	132	1.0000
22	904545.	950000.	927273.	0	0.0000	132	1.0000
	greater than	950000.		0	0.0000	132	1.0000

Mean = 93003.2 Standard Deviation = 165623.
Source: Own elaboration.

This analysis for reserved areas in hectares runs a tabulation of frequency by dividing the range of reserved areas in Ha into intervals of the same width, and counting the number of data in each interval. The frequencies show the number of data in each interval, while the relative frequencies show the proportions in each interval, as can be seen in Figure 2.

Figure 2. Histogram.



Source: Own elaboration.

The following correlation analysis shows between the 3 components involved in the construction of dams for the generation of hydroelectricity, the strongest correlation occurs between the component of installed capacity in MW and displaced people, this correlation being 0.4215.

Table 10. Correlation Analysis

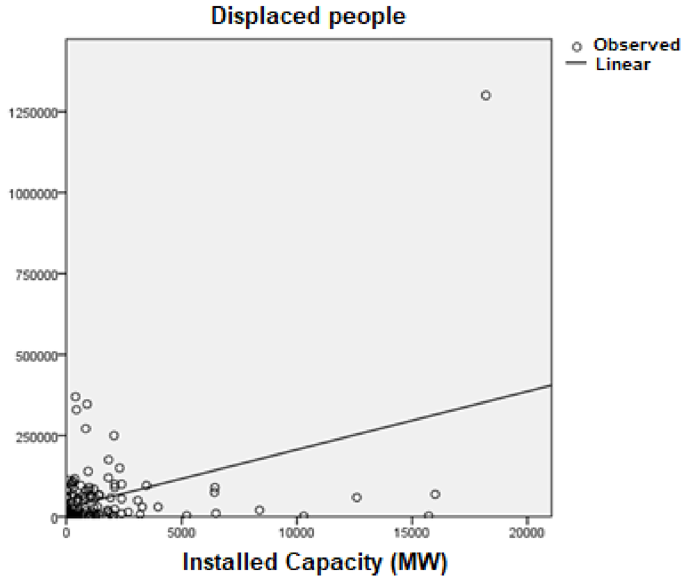
	Reserved Areas (Ha)	**Installed Capacity (MW)**	**Displaced persons**
Reserved Areas (Ha)		0.1214 (132) 0.1657	0.1365 (132) 0.1187
Installed Capacity (MW)	0.1214 (132) 0.1657		0.4215 (132) 0.0000
Displaced persons	0.1365 (132) 0.1187	0.4215 (132) 0.0000	

Source: Own elaboration.

Table 10 shows the Pearson moment correlations between each pair of variables. The range of these correlation coefficients ranges from -1 to +1, and they measure the strength of the linear relationship between the variables. It also shows, in parentheses, the number of data pairs used to calculate each coefficient. The third number in each block of the table is a P-value that proves the statistical significance of the estimated correlations. P-values below 0.05 indicate significantly different correlations from zero, with a confidence level of 95.0%. As already mentioned, the greatest correlation is between component 2 and component 3, a pair of variables with P-values below 0.05.

Finally, an analysis of (displaced) people in relation to installed capacity is presented, finding that the hypothesis can be refuted that the greater the installed capacity in MW, the greater the number of displaced people, as can be seen in the following figure, only one mega project (of the 132 projects analyzed) with an installed capacity greater than 18,000 MW has a displaced population of more than 1,200,000 people. This mega project is located in the Asian continent and corresponds to China, which contrasts very strongly with the mega project whose installed capacity is 16,000 MW, 2,000 MW less than the previous one and which corresponds to only 5% of displaced people equivalent to 69,000 people, from the same country (China). Figure 3 shows the highest density of projects is below 2,000MW, as well as the highest density of displaced people does not exceed 100,000 people. Figure 4 shows the reserved area versus installed capacity. And in Figure 5 areas reserved against displaced people.

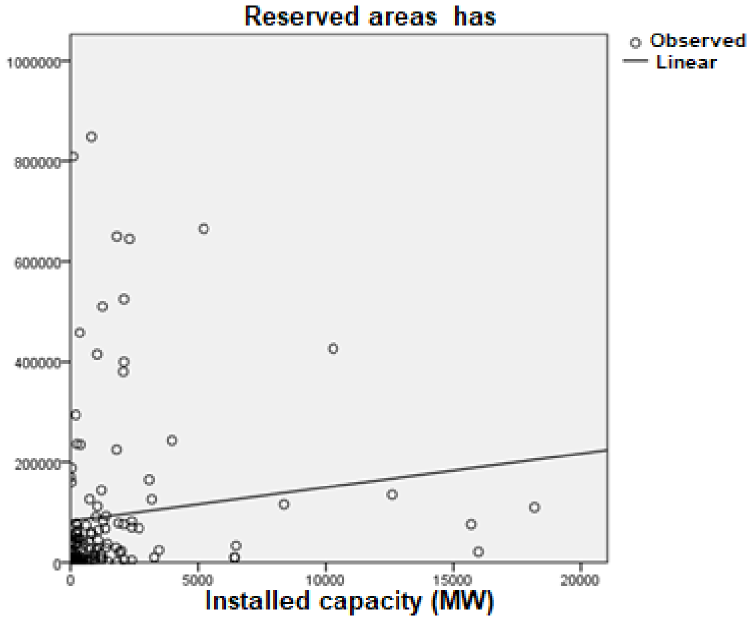
Figure 3. Adjusted Model Chart.



Source: own elaboration, made with the software (SPSS version 22).

$$\text{Reserved area (ha)} = 82447.526 + 6.715 * \text{Installed capacity (MW)} \quad (3)$$

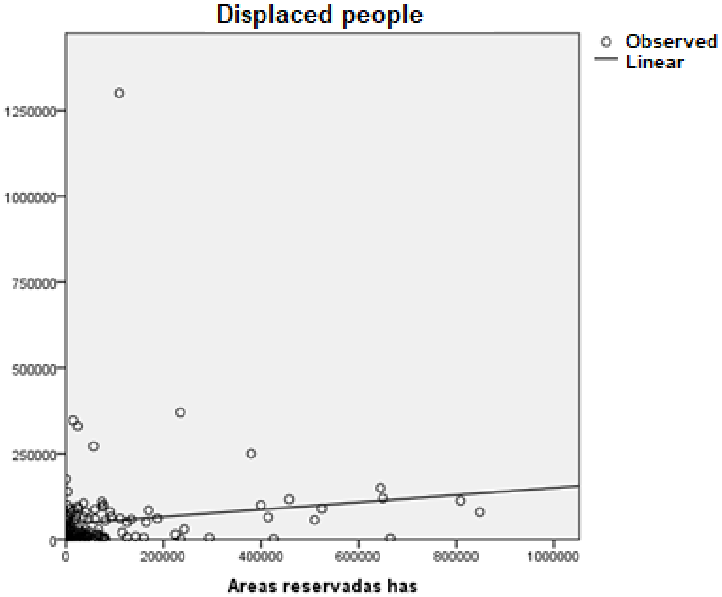
Figure 4. Adjusted Model Graph Reserved area in hectares' vs Installed capacity in MW.



Source: Own elaboration, made with the software (SPSS version 22).

$$\text{Displaced persons} = 45303.993 + 0.105 * \text{Reserved area (ha)} \quad (4)$$

Figure 5. Adjusted Model Graph Reserved area in hectares' vs Displaced persons.



Source: own elaboration, made with the software (SPSS version 22).

Simple Regression - reserved areas in Ha vs. Displaced persons

Dependent variable: reserved areas in Ha

Independent variable: Displaced persons

Linear: Y = a + b*X

Table 11. Coefficients

Parameter	Least Squares Dear	Standard Error	Statistical T	P-value
Intercepto	83254.1	15621.6	5.32942	0
Earring	0.176961	0.112666	1.57067	0.1187

Source: Own elaboration.

Correlation Coefficient = 0.136468

R-square = 1.86235 percent

R-square (adjusted for g.l.) = 1.10744 percent

Standard error of the est. = 164703.

Average absolute error = 103168.

Statistic Durbin-Watson = 1.66504 (P=0.0270)

Autocorrelation of waste in delay 1 = 0.164981

The output of the analysis (see Table 11) shows the results of adjusting a linear model to describe the relationship between reserved areas (Ha) and displaced persons. The equation of the adjusted model is:

$$Reserved\ area\ (Ha) = 83254.1 + 0.176961 * Displaced\ persons \quad (5)$$

Since the P-value in the ANOVA table is greater than or equal to 0.05, there is no statistically significant relationship between reserved areas (Ha) and displaced persons with a confidence level of 95.0% or more.

The R-Square statistic indicates that the adjusted model explains 1.86235% of the variability in reserved areas in Ha. The correlation coefficient is equal to 0.136468, indicating a relatively weak relationship between the variables reserved areas vs displaced persons. The standard error of the estimate indicates that the standard deviation of the waste is, 164703. This value can be used to construct prediction limits for new observations on reserved areas vs displaced people.

Simple Regression - Displaced People vs. Reserved Areas in Ha

Dependent variable: Displaced persons

Independent variable: reserved areas in Ha

Linear: Y = a + b*X

Table 12. Coefficients

Parameter	Least Squares Dear	Standard Error	Statistical T	P-value
Intercepto	45304	12690.5	3.5699	0.0005
Earring	0.10524	0.0670036	1.57067	0.1187

Source: Own elaboration.

Table 13. Analysis of Variance

Fountain	Sum of Squares	Gl	Middle Square	F-Reason	P-value
Model	3.98E+10	1	3.98E+10	2.47	0.1187
Residue	2.10E+12	130	1.61E+10		
Total (Corr.)	2.14E+12	131			

Source: Own elaboration.

Correlation Coefficient = 0.136468

R-square = 1.86235 percent

R-square (adjusted for g.l.) = 1.10744 percent

Standard error of the est. = 127015.

Average absolute error = 53645.1

Statistic Durbin-Watson = 1.90752 (P=0.2986)

Autocorrelation of waste in delay 1 = 0.0440795

Tables 12 and 13 show the results of adjusting a linear model to describe the relationship between Displaced Persons and Reserved Areas (Ha). The equation of the adjusted model is:

$$Displaced\ persons = 45304 + 0.10524 * Reserved\ area\ (Ha) \quad (6)$$

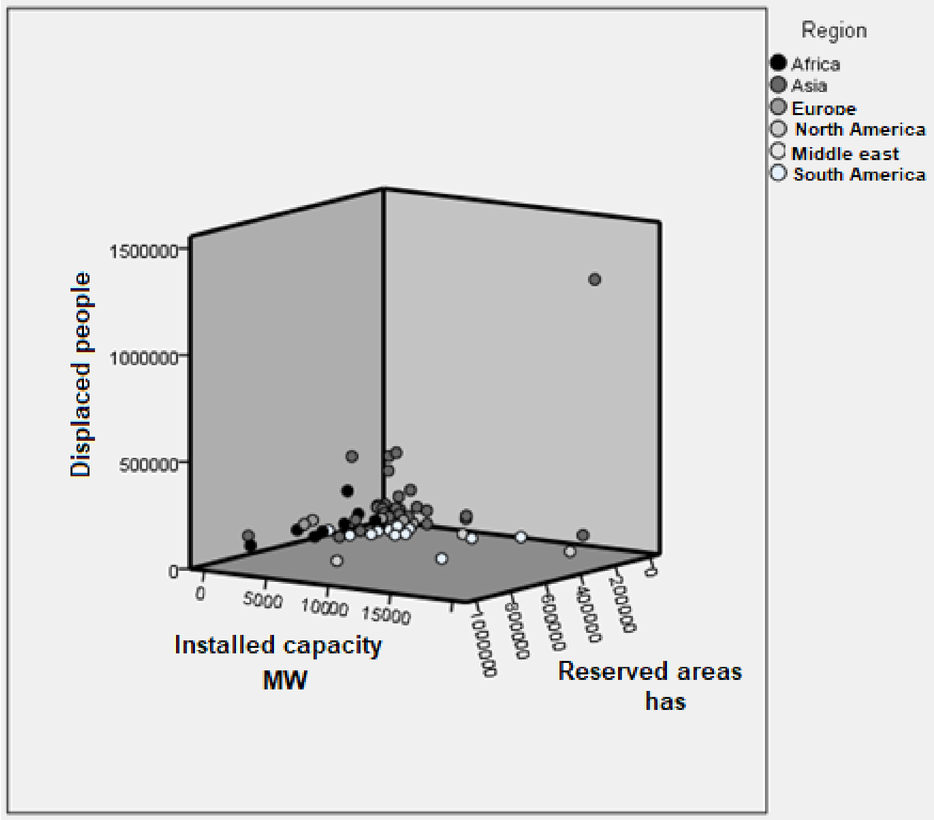
Since the P-value in the ANOVA table is greater than or equal to 0.05, there is no statistically significant relationship between displaced persons and reserved areas in Ha with a confidence level of 95.0% or more.

The R-Square statistic indicates that the adjusted model explains 1.86235% of the variability in displaced persons. The correlation coefficient is equal to 0.136468, indicating a relatively weak relationship between the variables.

The standard error of the estimate indicates that the standard deviation of the waste is, 127015.

The above can be seen in sector graphs (see Figure 6), where when classifying hydroelectric plants by regions in: Africa, Asia, Europe, South America and North America, and when plotting them by dispersion, the following is observed:

Figure 6. Graph of displaced persons' sectors vs installed capacity (MW) and reserved areas (ha).



Source: Own elaboration, made with the software (SPSS version 22).

The Asia region has displaced the largest number of people, followed by South America, and then Africa. It is perceived that in Africa the installed capacity is lower and in Asia the greater. This graph also reveals that there are hydroelectric plants with a high installed capacity and that required the displacement of a few people.

4 RESULTS AND DISCUSSION

The H_1 hypothesis is true, the above allows us to affirm that if you want to expand the installed capacity this will involve moving people.

Hypothesis 1 is supported by the criteria for considering the environmental, social and economic impacts of hydropower projects (Anderson, 2013), which indicates as a criterion the involuntary displacement of people, which is measured by the relationship between the number of displaced people and MW, and the relationship between the number of people from vulnerable groups (for example, indigenous, women and minorities) and MW, and a low relationship is set as a target.

In this sense, it is known that hydroelectric works are responsible for 63% of population displacements (World Commission on Dams, 2000) due to environmental causes.

The H_2 hypothesis is false, depending on where the hydroelectric plants are located (flooded hectares) they may have a greater or lesser effect, but this is not significantly correlated with the installed capacity.

Although this hypothesis turned out to be false, we must not lose sight of the fact that, although there is no significant correlation, it could be due to the efficiency of the technology installed in the hydroelectric plant, and that it could be evident using state-of-the-art control systems and turbines.

The H_3 hypothesis is false, depending on where the hydroelectric plants are located (flooded hectares) these may have a greater or lesser effect, but this is not significantly correlated with the number of displaced people.

Although according to our study there is no significant correlation between flooded hectares and displaced people, it is necessary carry out a study for each new project, because the impact is more qualitative and has a direct impact on the quality of life of displaced people.

5 CONCLUSIONS AND FUTURE WORK

A significant correlation is shown between installed capacity and the number of displaced persons of 0.421. That is, if you want to increase the installed capacity in MW, this will have a social impact because it will require the displacement of people. Therefore, in the construction of hydroelectric projects, a low relationship between the number of displaced people and MW should be sought.

According to this study, the greatest perceived impact of the construction of mega projects of this nature is in the amount of reserved areas (hectares), which inevitably cause the displacement of people.

Ideally, from the planning for the construction of large dams these should be of a multipurpose type in order to mitigate the environmental, economic and social impacts.

As future work, it is proposed to carry out a deeper analysis on the purpose of the construction of Hydroelectric Plants: Aquaculture, Hydroelectricity, Irrigation, Navigation, Recreation, Water Supply, Mine Dump, among others, and their impacts.

Develop a state of the art that allows us to contrast with other researchers, "The similarities and differences that other studies have with the results of this research", as this may be useful for decision-making in the development of hydroelectric dams in the world.

REFERENCES

Acosta, C. (2004). *Effect of transnational corporations on indigenous communities: Endesa and the Mapuche-Pehuenche community* (Bachelor's degree in international relations). University of the Americas.

Afgan, N., & Carvalho, M. (2002). “Multi-criteria assessment of new and renewable energy power plants”. *Energy*, 27(8), pp.739-755.

Barriga, V. & Pinto, S. (2019). Even hunting has no reason, because with the hydroelectric all animals are gone”: UHE historic, conflicts and socio-environmental impacts in Ferreira Gomes / A mesma caça não tem nenhuma razão, pois com a hidrelétrica todos os animais são utilizados ”: UHE histórico, conflitos e impactos socioambientais em Ferreira Gomes. *Brazilian Journal of Development*, 5(7), 9198–9210.

Beccali, M., Cellura, M., & Mistretta, M. (2003). “Decision-making in energy planning. Application of the Electre method at regional level for the diffusion of renewable energy technology”. *Renewable energy*, 28(13), pp. 2063-2087.

Chatzimouratidis, A. & Pilavachi, P. (2008). “Multicriteria evaluation of power plants impact on the living standard using the analytic hierarchy process”. *Energy policy*, 36(3), pp. 1074-1089.

Clar, A. (2013). "Megarepresas and their environmental impacts". *Ecoportal*, 12 April 2013. Available in http://www.ecoportal.net/Temas_Especiales/Energias/Megarepresas_y_sus_impactos_ambientales [Consulted 23-.3-2021]

Gleick, Peter H. (1998). *The World's Water 1998-1999: The Biennial Report On Freshwater Resources*. Washington: Island Press.

Griffith, A. (2010). *SPSS for dummies, 2nd edition*. New Jersey, Wiley Publishing, Inc.

Hernández, Fernández, C. & Baptista, P. (2010). *Research Methodology*. Mexico: Mc Graw-Hill.

ICOLD (2020a). “World Register of Dams: The History of the World Register of Dams”. Disponible en: https://www.icold-cigb.org/GB/world_register/history.asp [Consultado 25-06-2021].

ICOLD (2020b). “World Register of Dams: General Synthesis”. Disponible en: http://www.icold-cigb.org/article/GB/world_register/general_synthesis/general-synthesis [Consultado 25-06-2021].

ICOLD (2020c). “World Register of Dams: Classification By Resettled Persons”. Disponible en: http://www.icold-cigb.org/article/GB/world_register/general_synthesis/classification-by-resettled-persons [Consultado 25-06-2021].

Lemón, V. G., Pereira, G., de Holanda, M. J., Gomes, A. T., Monteiro, A. C., de Almeida, A. C., Henrique, D. L., dos Santos, J. S., Alves, V. C. & Mota, R. (2019). Socio-environmental impacts caused by hydroelectric dams in northeastern Brazil / Impactos socioambientais causados por barragens hidrelétricas no nordeste do Brasil. *Brazilian Journal of Development*, 5(11), 22846–22853.

McCully, P. (2004). *Silenced rivers: ecology and politics of large dams*. Buenos Aires: Ediciones Proteger.

Mendez, E. (1997). *Renewable Energies: A green public approach*. Madrid: Los libros de Catarata.

Ottinger, R., Wooley, D., Robinson, N., Hodas, D., Babb, S., Buchanan, S. & Fritsche, U. (1991). *Environmental costs of electricity*. New York: Oceana Publications.

Pimentel, D., Rodrigues, G., Wang, T., Abrams, R., Goldberg, K., Staecker, H., & Boerke, S. (1994). "Renewable energy: economic and environmental issues". *BioScience*, 44(8), pp. 536-547.

Ritchey, F.J. (2008). *Statistics for the Social Sciences, second edition*. Mexico, D.F. Mc-Graw-HillInteramerican.

San Martin, R. (1989). *Environmental emissions from energy technology systems: The total fuel cycle*. Deputy Assistant Secretary for Renewable Energy, US Department of Energy, Washington, DC.

Suárez, R. & Peirano, M. (2010). *Socio-environmental impacts of mega dams: The Garabi case*. Available inhttp://www.mbigua.org.ar/uploads/RepresaGarabi2010.pdf [Consulted 2021-06-21].

Troldborg, M., Heslop, S., & Hough, R. L. (2014). "Assessing the sustainability of renewable energy technologies using multi-criteria analysis: Suitability of approach for national-scale assessments and associated uncertainties". *Renewable and sustainable energy reviews*, 39, pp. 1173-1184.

Walker, G. (1995). Energy, land use and renewables: a changing agenda. Land Use Policy, 12(1), 3-6.

Wang, J., Jing, Y., Zhang, C. & Zhao, J. (2009). "Review on multi-criteria decision analysis aid in sustainable energy decision-making". *Renewable and sustainable energy reviews*, 13(9), pp. 2263-2278.

World Commission On Dams (2000). *Dams and development: A new framework for decision-making: The report of the World Commission On Dams.* Earthscan: WCD.