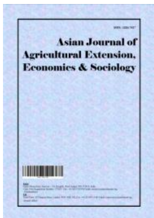

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Urban form and Urban-Agricultural Eco-Efficiency as an Indicator for Sustainable Urban Development in Huancayo Province, Peru

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Authors' contributions

This work was carried out in collaboration among all authors. Author MBP raised the research project, wrote the report and wrote the manuscript for review. Author RRA author managed the literature searches and methodologies. Authors BQR and SCF managed the analysis of the study and carried out the mathematical analysis using the software. All authors read and approved the final manuscript.

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ABSTRACT

Aims: The urban form of each district was estimated; the entry indicators and exit indicators of urban eco-efficiency; as well as the environmental costs and economic outcomes of agricultural eco-efficiency in the 28 districts of the Huancayo Province.
Study design: Descriptive-Correlational.
Place and duration of study: The research project lasted 1 year, the data collection of agricultural-urban eco-efficiency was carried out from January to December 2020 by district, as well as the delimitation of productive and non-productive agricultural areas.
Methodology: The World Business Council for Sustainable Development eco-efficiency model developed by Data Envelopment Analysis (DEA) was used. To estimate the Urban Form, the Landsat 8 OLI/TIRS satellite image was used. For the Ecoeficiencia Urban-Agricultural data was collected by interviewing field and respective households using probability sampling, to estimate

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the polluting gases by province, the Sentinel-5P satellite image was used. Pearson's r coefficient and bilateral Student's t-test were used for the statistical analysis [26; 2.05].

Results: The Urban Form presents compactness ratio 0.27, shape ratio 0.21, elasticity ratio 5.47 and population density 753.09hab/km^2. The Urban-Input indicators are urban water consumption 5889116.31ML/year electric energy consumption 2062019.23MW/year, food consumption 2664.56 ton/year. The Urban-Output indicators are emission of polluting gases 40335.11 ton/year, economic revenue 279.35PEN/year and wastewater discharge 90581.38ML/year. The Environmental Costs-Agricultural are water consumption for the agricultural sector 3348.34ML/year, fertilizer consumption 69.14 ton/year and phytosanitary consumption 46 ton/year. The Economic Outputs-Agricultural are agricultural production of 4779.79 kg/year, agricultural land rent 6390.3 PEN/year, gross value of production 4854.35 PEN/year. Agricultural Eco-efficiency [Eec-Ag]=0.89 and Urban Eco-efficiency [Eec-Ur]=0.98, ratio coefficient r=-0.13 and tc=0.64.

Conclusion: The 28 districts of the province of Huancayo have an Eec-Ur [Urban Eco-efficiency] of 0.98 and Eec-Ag [Agricultural Eco-efficiency] of 0.89 where it maintains the added value while generating 98% and 89% of its environmental pressures. There is no statistically significant relationship between urban eco-efficiency and agricultural eco-efficiency.

Keywords: Urban form; agricultural-urban eco-efficiency; product or service value; environmental influence; districts of the province of Huancayo.

1. INTRODUCTION

Currently the province of Huancayo is in an accelerated economic, urban, agricultural and environmental growth [1], the exploitation of natural resources is carried out in an uncontrolled manner [2], which due to its accelerated rural and urban growth causes impacts to the surface of agricultural crops and other important areas [3–5]. Currently the urban areas of Huancayo are dispersed as communities, producing conflict between urban and agricultural areas [1,5,6]. The current problem of the districts is the expansion of their urban areas [7]. To understand these changes happening throughout the districts it is preferable to resort to urban-agricultural sustainable development [8]. Sustainability employs urban eco-efficiency and form to determine the impact of consumption and deterioration of natural resources [9]. Stating that there may be a relationship directly between urban form and agricultural urban eco-efficiency [10,11].

Urban forms are closely related to accelerated urban population growth [12–14] and accessibility of natural resources [15,16] reducing open spaces [17], in order to know the sustainable situation that these urban forms are in, methods of urban development evaluation are included [14] employing density, spatial geometry, accessibility and their distance; which are better known as their urban structure [15]. A very important indicator also for urban development is eco-efficiency [10,18]; urban eco-efficiency is a tool for sustainability analysis that indicates how to perform economic activities efficiently [19]; where it applies an index of financial or beneficial result obtained with respect to the ecological or/and environmental or resource cost required by certain activities [20], collecting important data accessed by the inhabitants, these data are their input and output indicators [18], each indicator indicates the consumption made by the inhabitants [11,21] while their outputs are the emissions they may generate during or after their consumption [22,23].

The eco-efficiency for the agricultural sector reports on those factors related to consumption [24,25], production and impact produced towards the ecological environment during agricultural activities [19,26]; i.e. more agricultural products, in terms of quantity and quality, for less inputs of land, water, nutrients, energy, labor or capital [27,28]. In this opportunity, agricultural eco-efficiency evaluates environmental costs and economic outputs [24,27], although it has also been seen to apply agricultural status [29], where it analyzes agricultural area in integrated production and ecological agricultural areas [30]. A method that can be adapted when determining the eco-efficiency of urban and agricultural sectors is data envelopment analysis (DEA) [31,32], its purpose is to evaluate the efficiency of different units [31]. Therefore, the following research leads us to determine the urban form, the dimensions of urban agricultural eco-efficiency and their relationship that exists between both; in the province of Huancayo - Peru.

2. METHODOLOGY

2.1 Study Area

The province of Huancayo is located in the central highlands of Peru, its geographical location is Log:75°12'36.20"W Lat:12°4'5.36"S, at a sea level of 3254 m.a.s.l. Its 28 districts are dedicated to agricultural and livestock keeping activities, as well as a variety of macro and micro enterprises.

2.2 Methodology

- **Urban Form**

To determine the urban form of each district (28), the use of two Landsat 8OLI/TIRS satellite images [https://earthexplorer.usgs.gov/] band characteristics [ID: LC08_L1TP_006068_20200527_20200608_01_T1; Path: 6; Row: 68; Date: 2020/05/27] and [ID: LC08_L1TP_006069_20200527_20200608_01_T1; Path: 6; Row:69; Date: 2020/05/27] with 95% out of cloud cover; for the current land use classification, processed using Qgis 3 software.10; Urban form represents the following indicators:

- **Form relationship:** internal connection between cities Hortonton [33]:

$$Fr = \frac{A}{L^2} \quad (1)$$

Where: A: urban area (km^2), L: length of the long axis of the area (km).

- **Compactness ratio:** compactness between cities Stoddart [34]:

$$CR = \frac{A}{A'} \quad (2)$$

Where: A: urban area (km^2), A': smallest circle of the area (km^2).

Elongation ratio or elasticity: extension of a city Haggett [35]:

$$ER = \frac{L}{L'} \quad (3)$$

Where: L: length of the long axis of the region (km), L': length of the short axis of the region (km).

- **Population density:** number of inhabitants for km^2 Liu, Song, & Arp [11]:

$$PD = \frac{P}{A} \quad (4)$$

Where: P: total population of the urbanized area (number of inhabitants), A: total corresponding area (km^2).

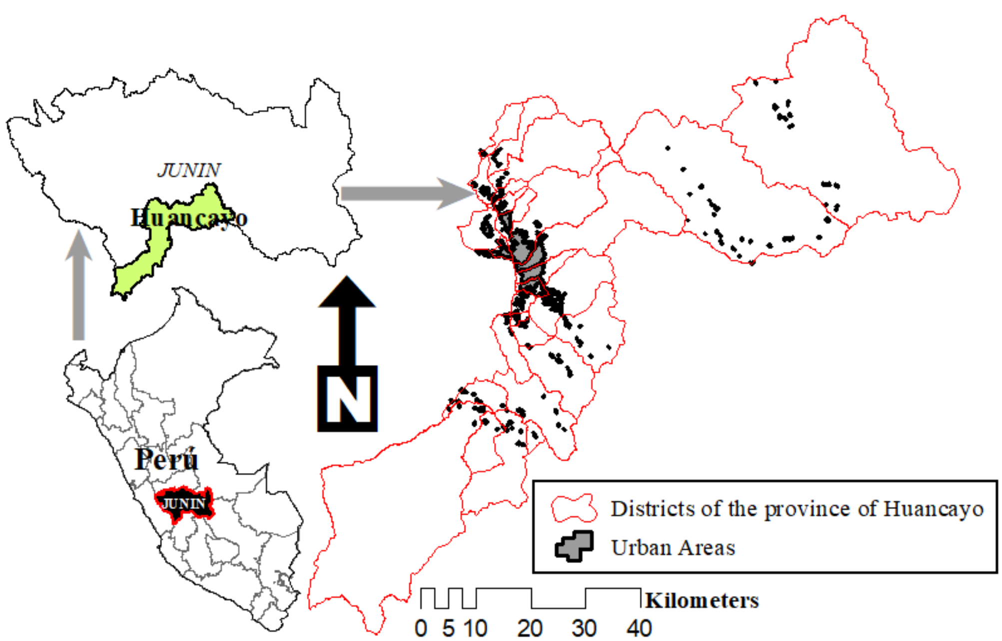

Fig. 1. Location map of the province of Huancayo and its 28 districts

- **Agricultural Ecoefficiency**

The Agricultural Eco-efficiency [Eec-Ag] presents its following evaluation dimensions: economic outputs [agricultural production (Kilograms: kg), agricultural land rent (Peruvian Soles: PEN) and gross value of production (Peruvian Soles: PEN)], environmental costs [agricultural water consumption (Mega Liters: ML), fertilizer consumption (Tons: Tons) and phytosanitary consumption (Tons: Tons)] and agricultural states [total agricultural area = productive and non-productive, agricultural area and agricultural area in integrated production] to obtain the data, a field visit was made to the 134 peasant communities of the agricultural sector [through surveys] of the 28 districts of the province of Huancayo; some equations that were used to evaluate agricultural eco-efficiency are:

- **Agricultural land rent:** [classical rent theory by von Thünen's 1826] Kellerman [36]:

$$R_{ij} = E_i(P_i - a_i) - E_i f_i k_j \quad (5)$$

Where: $\forall$ crops $i(i = 1,2,3,\ldots,n)$; $\forall$ the points $j(j = 1,2,3,\ldots,m)$R: economic rent (PEN), E: yield (kg), P: market price for unit of product (PEN/kg), a: production costs for unit of product (PEN/kg); f: transportation costs for unit of product (PEN/km); kj: distance from point i to the sales market [Huancayo Wholesale Market] (km).

- **Gross value of production:**

$$VBP_i = P_{tc:i} * pv_{m*kg:i} \quad (6)$$

Where: VBP: gross value of production (PEN); Ptc: total crop production (kg); pvm*kg: market selling price (PEN/kg); ; $\forall$ crops $i(i = 1,2,3,\ldots,n)$.

- **Agricultural water consumption FAO [37]:**

$$\text{CWU green}_{c:1,2,3,\ldots,n} = 10\sum_{d=1}^{lgp} \text{ET green} \quad (7)$$

$$\text{CWU blue}_{c:1,2,3,\ldots,n} = 10\sum_{d=1}^{lgp} \text{ET blue} \quad (8)$$

$$\text{ET green}_{c:1,2,3,\ldots,n} = \min[\text{ETc}, \text{Peff}] \quad \text{y/o} \quad \text{ET blue}_{c:1,2,3,\ldots,n} = \max[0, \text{ETc} - \text{Peff}]$$

$$\text{ETc}_{C:1,2,3,\ldots,n} = \text{Kc} * \text{ETo}$$

Where: $\forall$CWU – green : evaporated rainwater; $\forall$CWU – blue where: : irrigation water evaporated in the field; CWU: water use meeting crop needs; CWU: water use meeting crop needs; CWU: water use meeting crop needs; $\forall$crops $(c: 1,2,3,\ldots,n)$ CWU: water use that meets crop needs; CWU: water use that meets crop needs; $ET_{[green/blue]}$ ETc: potential crop evapotranspiration (mm); Peff: effective precipitation (mm); ETo: evapotranspiration over the reference crop (Penman-Monteith Equation) (mm); Kc: crop coefficient; mm: millimeters; the value 10 will convert the mm $ET_{[green/blue]}$ to m3 which in turn will transform the final value into ML (Mega Liters) for all crops. Water consumption from the planting stage to the harvest stage.

- **Fertilizer consumption and phytosanitary consumption FAO [38]:**

$$C_{[fe:fi]/A} = \frac{D_{fe:fi_{kg/ha}} * A_{ha}}{\%_{fe/fi} * 100} \quad (9)$$

Where: $\forall$ fertilizers $fe[fe = 1,2,3,\ldots,n]$; $\forall$ phytosanitary $fi[fi = 1,2,3,\ldots,m]$ $C_{[fe;fi]/A}$: fertilizer or phytosanitary consumption (ton); $Dfe_{;fi}$: fertilizer or phytosanitary dose (ton/ha); A: plot area (ha); %fe/fi: of fertilizers or phytosanitary; fe[1,2,3...,n]: urea, ammonium nitrate, lime nitrate NPK fertilizers, ammonium phosphate, among others. fi[1,2,3,...,m]: insecticides, fungicides, insecticides, acaricides, insect repellents, herbicides, biostimulants, nutrients, coadjuvants, among others.

- **Urban Eco-efficiency**

Urban Eco-efficiency [Eec-Ur] presents two evaluation dimensions: input indicator [water consumption (Mega Liters: ML), electricity consumption (Mega Watts: MW) and food consumption (Tons: ton)]; and output indicator [total economic collection (Millions of Peruvian Soles: PEN); wastewater discharge (Mega Liters: ML) and emission of polluting gases (Tons: ton)]; the data correspond to the sum January to December 2020; In collecting data on: water consumption, electricity consumption, food consumption, total economic collection, a household survey model (houses, buildings and condominiums) was used, the sampling was probabilistic, 95% confidence level, margin of error 5%, estimate of proportion 90%; the number of households was extracted from the INEI (National Institute of Statistics and Informatics) [39,36]; To know the discharge of wastewater, the statistical report of the SINIA (National System of Environmental Report) [37] was extracted; ESA/Copérnicus Sentinel-5P satellite images corresponding to the year 2020 were used to estimate the total emission of atmospheric polluting gases [CO2 nitrogen dioxide plus carbon monoxide CO] web page [https://s5phub.copernicus.eu/dhus/#/home] processed by Qgis 3.10; calculated for each district.

- **Data Envelopment Analysis [DEA] for Ecoefficiency [Eec-Ur and Eec-Ag]**

The eco-efficiency mentioned by World Business Council for Sustainable Development in 1996 [38] interprets eco-efficiency, where it is directly proportional to its product values among its environmental influences, which can be observed in the following equation:

$$\text{Eec} = \frac{\text{value of the product or service}}{\text{environmental influence}} = 1 \qquad (10)$$

Where value 1 is interpreted as: the district that maintains an added value while generating 100% of its environmental pressures [32]; both for [Eec-Ur // Eec-Ag]=1 presents an eco-efficient urban or agricultural area. In order to estimate this value the equation is subject to Data Envelopment Analysis (DEA) [40] where:

$$\text{Eec} = \text{Max}_{u,v} h_0 = \frac{\sum_{r=1}^{s} u_r y_{r0}}{\sum_{i=1}^{m} v_i x_{r0}} \qquad (11)$$

Subject to: $\text{Max}_{u,v} h_0 \leq 1;\ j = 1,2,3,\dots,n;\ u_r, v_i \geq 0$; where $X_{ij}(X_{ij} \geq 0)$ represents quantities of Input $i(i = 1,2,3,..,m)$ consumed by j-th units e $y_{rj}(y_{ij} \geq 0)$ represents observed quantity of output $r(r = 1,2,3,\dots s)$ produced by the j-th unit interpreted by Charnes et al. [41] and evolved by van Grinsven et al. and Zhang et al., [10,20]. Where used: x_{ij} $\text{Outputs}\ r(r = 1,2,3,\dots,s)$: Total Wage, Pollutant Gas Emissions, Wastewater Discharge, Agricultural Production, Agricultural Income, Gross Value of Production. y_{ij} $\text{Inputs}\ i(i = 1,2,3,\dots,n)$ Water Consumption, Electricity Consumption, Food Consumption, Water Consumption, Fertilizer Consumption, Phytosanitary Consumption. This was processed using Excel software [42,43].

- **Relationship coefficient and significance test**

For the association between the [Eec-Ur] and [Eec-Ag] dimensions and their final eco-efficient value, correlation analysis and hypothesis Karl Pearson [r]; William Sealy Gosset [t-student] and covariance statistics are used:

$$\text{cov}_{(x,y)} = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{N-1} \qquad (12)$$

$$r_{xy} = \frac{\sum_{i=1}^{N-k}(x_i-\bar{x})*(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{N-k}(x_i-\bar{x})^2}*\sqrt{\sum_{i=1}^{N-k}(y_i-\bar{y})^2}} \qquad (13)$$

$$t = \frac{r\sqrt{N-2}}{\sqrt{1-r^2}},\ df = N-2 \qquad (14)$$

Where: y: estimated values Eec-Ag and x: estimated values Eec-Ur; r: Karl Pearson relationship coefficient; N: total of districts; df: degrees of freedom; cov: covariance of [Eec-Ag/Eec-Ur]; rxy: relationship between two variables of [Eec-Ag/Eec-Ur]; t: t-student. The linear correlation coefficient r if the values are close to 1 or -1 will have a perfect correlation; the t-student statistical hypothesis with a bilateral significance level of [28 data at 0.05 // 2.05].

3. RESULTS AND DISCUSSION

3.1 Urban forms of the 28 Districts of the Province of Huancayo

Table 1, shows the relationship of form of the 28 districts of the province of Huancayo; the more a city presents an internal connection its value will be at 1, the district with the highest internal connection is Pariahuanca with a value of 0.37, followed by The Tambo with a value of 0.33 and the districts with low internal connection are Carhuacallanga with a value of 0.12 and Chupuro with a value of 0.07. The compactness ratio of the 28 districts of Huancayo presents contacts and exchanges of open spaces in each district, the closer its value is to 1, the better the relationship between urban and public space. The district with the highest compactness is Pariahuanca with a value of 0.47 followed by The Tambo with a value of 0.42 and the districts with the lowest compactness is Colca with a value of 0.13 and Chupuro with a value of 0.09; the district with the highest extension or elongation ratio is Chupuro with a value of 21.42 followed by the district San Pedro of Saño with the highest degree of extension of 15.95 and the districts with the lowest degree of extensions are Huancán with a value of 2.11 and Huayucachi with a value of 1.52. The density is demonstrated by the inhabitants of the 28 districts of the province of Huancayo, the district with the highest inhabitants for km^2 is Chilca with 11026.53 inhabitants/km^2, followed by the district of The Tambo with 2267.62 inhabitants/km^2 and the districts with the lowest inhabitants for km^2 are Santo Domingo of Acobamba with 13.01 inhabitants/km^2 and Chongos Alto with 3.44 inhabitants/km^2.

Table 1. Urban form data for the 28 districts of the province of Huancayo

Districts	Area		Urban form relationship				
	T. A. (km^2)	U. A. (km^2)	F.R.	C.R.	E.R.	T.P.	P.S.
Carhuacallanga	13.78	0.15	0.12	0.16	8.45	505	36.65
Chacapampa	120.72	0.64	0.23	0.29	7.13	2182	18.07
Chicche	43.43	0.81	0.22	0.29	7.21	2178	50.15
Chilca	8.33	9.27	0.26	0.33	2.91	91851	11026.5
Chongos Alto	701.75	0.65	0.21	0.27	2.34	2415	3.44
Chupuro	13.15	0.35	0.07	0.09	21.42	2745	208.75
Colca	113.06	0.45	0.15	0.13	8.93	1685	14.9
Cullhuas	108.01	0.46	0.17	0.21	5.67	2940	27.22
The Tambo	73.56	16.99	0.33	0.42	2.32	166806	2267.62
Huacrapuquio	24.18	0.82	0.15	0.19	2.69	1786	73.86
Hualhuas	24.82	1.03	0.19	0.24	3.77	4552	183.4
Huancán	12.01	6.06	0.22	0.28	2.11	24835	2067.86
Huancayo	237.55	12.87	0.18	0.23	3.43	122212	514.47
Huasicancha	47.81	0.23	0.25	0.32	2.14	1512	31.63
Huayucachi	13.37	2.41	0.29	0.37	1.52	9136	683.32
Ingenio	53.29	0.6	0.13	0.16	7.12	3200	60.05
Pariahuanca	617.5	1.67	0.37	0.47	5.08	10012	16.21
Pilcomayo	20.53	6.74	0.14	0.18	2.35	20055	976.86
Pucara	110.49	0.71	0.23	0.26	6.74	6184	55.97
Quichuay	34.79	0.33	0.19	0.24	2.36	2186	62.83
Quilcas	167.89	0.61	0.23	0.25	5.88	4233	25.21
San Agustin	23.09	4.72	0.29	0.37	2.58	12164	526.81
San Jeronimo of Tunan	20.99	1.84	0.31	0.39	5.12	10714	510.43
San Pedro of Saño	11.59	0.78	0.15	0.19	15.95	4260	367.56
Santo Domingo of Acobamba	778.02	0.99	0.25	0.32	4.99	10124	13.01
Sapallanga	119.02	3.61	0.18	0.22	6.53	18002	151.25
Sicaya	42.35	2.72	0.18	0.23	3.72	20011	472.51
Viques	3.57	1.05	0.26	0.33	2.83	2285	640.06
$\bar{X}$	131.29	2.84	0.21	0.27	5.47	20028	753.09
SD	209.27	4.05	0.07	0.09	4.36	39634.25	2092.65
$\sum$	3558.65	79.56	5.95	7.43	153.29	560770	21086.63

Note: TA: total area; UA: urban area; FR: form relationship; CR: compactness ratio; ER: Elongation ratio; TP: total population; PD: population density; $\bar{X}$: average; SD: standard deviation, Σ: sum total

3.2 Eec-Ur input and Output Indicators

Analyzing individually, it has been observed that the district with the highest water consumption is The Tambo with a total of 79723578.82 ML/year followed by Huancayo with 47623610.59 ML/year; these two districts are considered the highest water consumers in the entire province and the districts with the lowest water consumption are Carhuacallanga with 10514.69 ML/year and Huasicancha with 47484.36 ML/year, Fig. 2, which means that both districts consume less water than the rest of the districts. Similarly, the districts with the highest electricity consumption are Huancayo with a total of 40752589.56 MW/year and The Tambo 16437705.85 MW/year, and the districts with the lowest consumption are Huasicancha 68.79 MW/year and Cullhuas with 77.12 MW/year. In terms of food consumption, the districts of Huancayo and The Tambo are the highest consumers in the province with values of 12459.12 ton/year and 29381.11 ton/year respectively, while the districts of Carhuacallanga and Colca are the districts with the lowest food consumption with 41.77 ton/year and 138.15 ton/year respectively. The Tambo and Huancayo have the highest total economic revenue in terms of employment with a total of 3089.04 PEN/year and 1706.91 PEN/year respectively, while Carhuacallanga and Huasicancha have the lowest economic revenue with 3.14 PEN/year and 9.93 PEN/year. The Tambo and Huancayo are the most polluting gas emissions with 471534.62 tons/year and 300881.87 tons/year, while Carhuacallanga with 9.14 tons/year and Cullhuas with 29.64 tons/year are the least polluted places. The discharge of wastewater is interpreted by all its domestic, industrial and other activities in general; The Tambo leads with a total of 775554.22 ML/year followed by Huancayo with a total of 578342.18 ML/year, while Carhuacallanga with 2133.41 ML/year and Huacrapuquio with a total of 5785.55 ML/year are lesser in wastewater discharge.

3.3 Economic Outflows, Environmental Costs and Agricultural Status of Eec-Ag

Huancayo present a variety of crops where their agricultural production is according to their crop areas, sowing and harvesting time, these crops are garlic, dry grain peas, green grain peas, grain barley, red head onion, dry grain beans, dry grain beans, green grain beans, hard yellow corn, starchy corn, corn, corn, olluco, potato (potato of color, potato native), quinoa, wheat, carrot, tomato, cassava and pumpkin. Sicaya with a total of 27383.17 kg/year is the largest producer of these crops, followed by Cullhuas with a total of 15312.04 kg/year, while Chongos Alto with a total of 671.42 kg/year and Carhuacallanga 833.99 kg/year are less agricultural producers. Agricultural income is a function of their metropolitan areas, which range from the agricultural economy to the land use economy, that is, the geographic agricultural space where crops are planted and harvested and their respective economy. Sicaya has a good agricultural income, collecting a total of 43765.53 PEN/year, followed by The Tambo with a total of 17300.28 PEN/year; and the districts that have a very low income are Huasicancha and Chongos

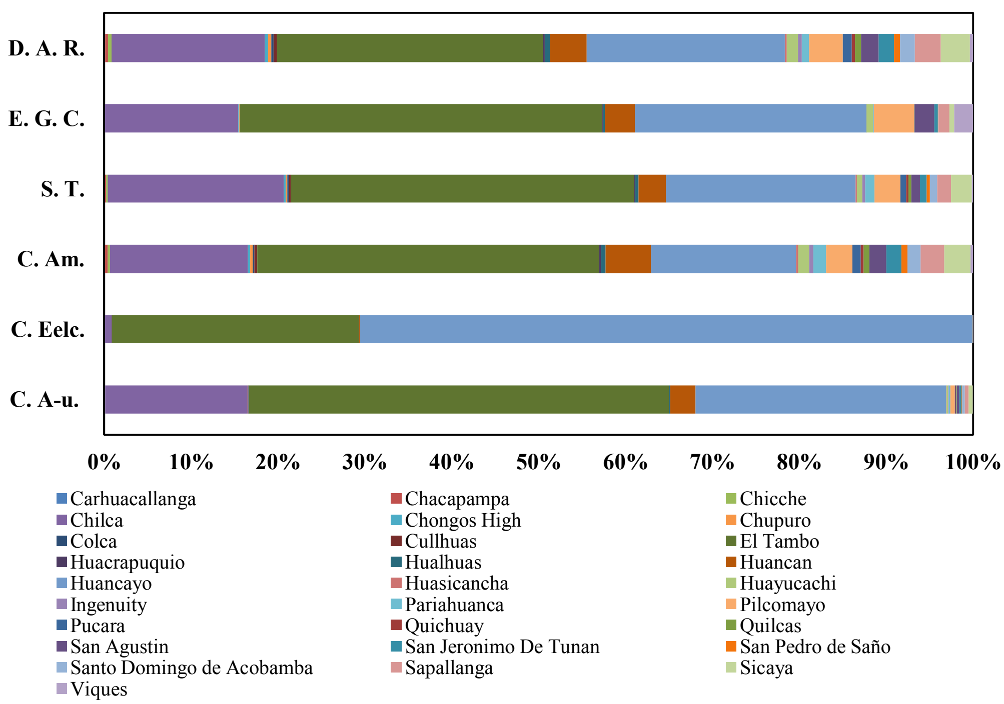

Fig. 2. Urban Eco-efficiency input and output indicators for the 28 districts of the province of Huancayo

Note: The stacked barrier shows the inputs and outputs of urban eco-efficiency; each indicator represents 100% of total consumption in the province of Huancayo. C.A-u: urban water consumption; $\bar{X}$=5889116.31ML/year; Σ=164895256.75ML/year; C.Eelc: electric energy consumption; $\bar{X}$=2062019.23MW/year; Σ=57736538.34MW/year; C.Am: food consumption; $\bar{X}$=2664.56ton/yr; Σ=74607.77ton/yr; S.T.: total wage collection in millions; $\bar{X}$=279.35PEN/year; Σ=7821.88PEN/year; E.G.C.: emission of pollutant gases into the atmosphere; $\bar{X}$=40335.11ton/year; Σ=1129383.03ton/year; D.A.R.: discharge of industrial and domestic wastewater; $\bar{X}$=90581.38ML/año; Σ=2536278.66ML/año

Alto with a total collection of 619.58 PEN/year and 533.65 PEN/year, respectively. The district with the highest gross value of production is Sicaya with a total of 28306.18 PEN/year followed by Pariahuanca with a total of 17857.12 PEN/year and the districts with the lowest gross value of production is Chongos Alto with a total collection of 752.93 PEN/year followed by Chicche with a total of 836.92 PEN/year.

Farmers consume water for their crops using irrigation canals, sprinklers and drip irrigation systems. The district that consumes the most water for its crops is Pariahuanca with a total consumption of 14588.24 ML/year followed by Sicaya with a total consumption of 17997.04 ML/year; while Chongos Alto and Chicche are the districts with the lowest water consumption with a total of 557.16 ML/year and 545.43 ML/year, respectively. The agricultural sectors of the districts of Huancayo generally use fertilizers such as urea, ammonium nitrate, lime nitrate NPK fertilizers, ammonium phosphate, among others to increase agricultural production; the highest consumption of fertilizers is in Pariahuanca with a total of 365.89 tons/year followed by Sicaya with a total of 317.49 tons/year; and the districts with the lowest consumption of fertilizers are Chongos Alto and Huancán with data of 12.16 tons/year and 13.85 tons/year. Due to problems such as pests, pathogens and agricultural diseases in the planting and development stage of crops, each district applies the appropriate phytosanitary; this can be composed of a variety of products such as insecticides, fungicides, insecticides acaricides, insect repellents, herbicides, biostimulants and regulators, nutrients, adjuvants among others; therefore, Pariahuanca and Sicaya leads in this list with their respective values 260.99 ton/year and 230.82 ton/year, while Chicche consumes the least amount of phytosanitary products with a total of 5.38 ton/year, followed by Huancán with a total of 7.84 ton/year.

3.4 Productive and Non-productive Agricultural Areas

According to Table 2 and Fig. 4, the district with the largest extension of agricultural production areas is Santo Domingo of Acobamba with 108.78km^2, followed by Sicaya with 43.04 km^2; while the districts with the greatest extension but with a non-productive agricultural area are Chongos Alto 698.75 km^2 and Huancayo 231.55 km^2. The integrated agricultural area is directly related to the agricultural practices carried out by farmers during the year, excluding grazing practices and the production of pastures for feeding livestock, also those agricultural areas that are in a state of rest, due to their low productivity and performance. The integrated agricultural area is equal to the current use of agricultural land minus the consumption of agricultural land without productive activity. The area of ecological agriculture is to produce food under the criteria of sustainable urban-rural development, which involves activities such as the cultivation of healthy plants, improvement of yields and soil fertility, soil and water management, avoiding the consumption of pesticides and conserving biodiversity. Therefore, in the 28 districts of Huancayo, these ecological agricultural practices do not exist, since the comments of the farmers affirmed that there is no support from local and national institutions to carry out such activities.

3.5 Ecoefficiency [Eec-Ur/Eec-Ag] using DEA

The Agricultural Eco-efficiency [Eec-Ag] of the 28 districts using DEA, showed that Chicche, Chilca, Chongos Alto, Cullhuas, The Tambo, Huancán, Huancayo, Ingenio, Pilcomayo, Quichuay, San Agustín and Sicaya are excellent eco-efficient districts with value equal to 1; while the rest of the districts present different values such as Carhuacallanga 0.96, Chacapampa 0.79, Chupuro 0.87, Colca 0.72, Huacrapuquio 0.76, Hualhuas 0.92, Huasicancha 0.95, Huayucachi 0.83, Pariahuanca 0.74, Pucara 0.82, Quilcas 0.88, San Jerónimo of Tunan 0.93, San Pedro of Saño 0.79, Santo Domingo of Acobamba 0.38, Sapallanga 0.77 and Viques 0.77; apparently, the agricultural coefficient presents very atypical values, such as Santo Domingo of Acobamba to Chongos Alto, since they are very different districts in agricultural situations.

The districts that present perfect Urban Ecoefficiency [Eec-Ur] are Carhuacallanga, Chacapampa, Chicche, Chilca, Cullhuas, The Tambo, Huacrapuquio, Huancán, Huancayo, Huasicancha, Pariahuanca, Pilcomayo, Pucara, Quilcas, San Agustín, San Jerónimo of Tunan, San Pedro of Saño, Santo Domingo of Acobamba, Sapallanga, Sicaya and Viques with a value equal to 1; while other districts present different eco-efficient values almost perfect as Chongos Alto 0.96, Chupuro 0.99, Colca 0.94, Hualhuas 0.88, Huayucachi 0.98, Ingenio 0.83 and Quichuay 0.97; this means that the consumption of their input and output indicators are in a state of equilibrium, where there is not much intervention by people on the natural resources in their respective urban areas.

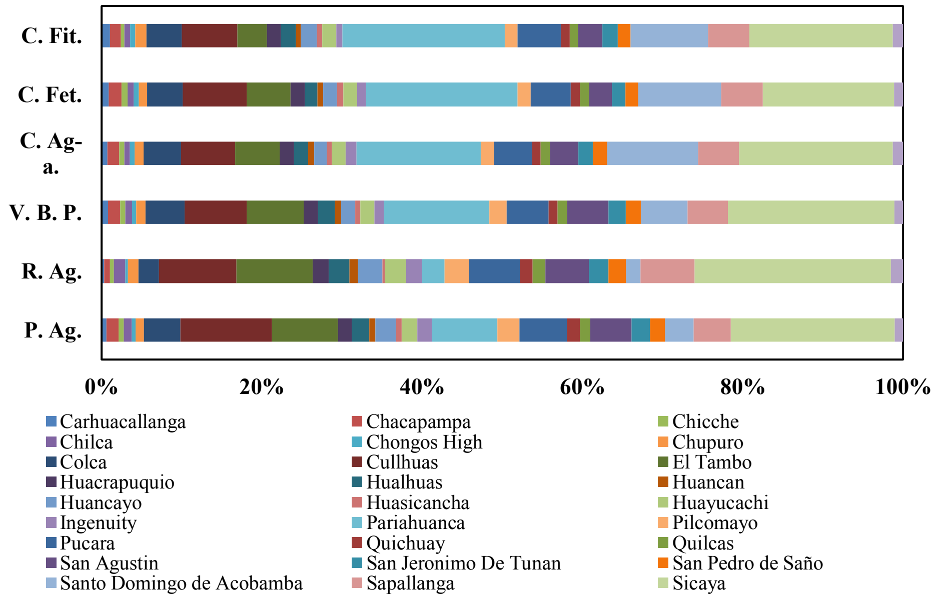

Fig. 3. Economic outputs and environmental costs of agricultural eco-efficiency in the 28 districts of the province of Huancayo

Note: The stacked barrier shows the economic outputs and environmental costs of agricultural eco-efficiency; each indicator represents 100% of total consumption in the province of Huancayo. P.Ag.: total agricultural production; $\bar{X}$=4779.79kg/year; Σ=133834.07kg/year; R.Ag.: total agricultural income; $\bar{X}$=6390.30PEN/year; Σ=178928.33PEN/year; V.B.P.: gross value of production; $\bar{X}$=4854.35; Σ=135921.86PEN/year; C.Ag-a: water consumption for the agricultural sector; $\bar{X}$=3348.34ML/year; Σ=93753.59ML/year; C.Fet: fertilizer consumption; $\bar{X}$=69.14ton/year; Σ=1935.91ton/year; C.Fit: phytosanitary consumption; $\bar{X}$=46.00ton/año; Σ=1288.08ton/año

Table 2. Analysis of agricultural and non-agricultural productivity of the 28 districts of the province of Huancayo

Districts	P-AA (km^2)	Np-AA (km^2)	Districts	P-AA (km^2)	Np-AA (km^2)
Carhuacallanga	2.76	19.83	Huayucachi	3.52	9.04
Chacapampa	4.38	118.72	Ingenio	2.44	201.13
Chicche	2.14	41.43	Pariahuanca	42.81	417.5
Chilca	1.65	5.33	Pilcomayo	3.17	3.17
Chongos Alto	1.94	698.75	Pucara	12.18	108.49
Chupuro	2.54	11.15	Quichuay	2.37	32.79
Colca	32.18	110.06	Quilcas	2.46	163.92
Cullhuas	16.87	106.01	San Agustin	7.15	23.09
The Tambo	12.2	70.98	San Jeronimo of Tunan	3.67	3.67
Huacrapuquio	3.93	21.18	San Pedro of Saño	3.57	10.59
Hualhuas	3.53	24.82	Santo Domingo of Acobamba	108.78	299.94
Huancán	1.53	1.53	Sapallanga	12.01	117.02
Huancayo	3.15	231.55	Sicaya	43.04	35.19
Huasicancha	2.05	44.3	Viques	2.41	2.41
$\bar{X}$ (P − AA)		12.16	$\bar{X}$ (Np − AA)		104.77
$\sum$ (P − AA)		340.43	$\sum$ (Np − AA)		2933.59

Note: Table 2 analyzes the agricultural and non-agricultural productive areas that the inhabitants of the Huancayo province carried out during the year 2021. Note: Np AA: Non-productive agricultural area; P-AA: productive agricultural area

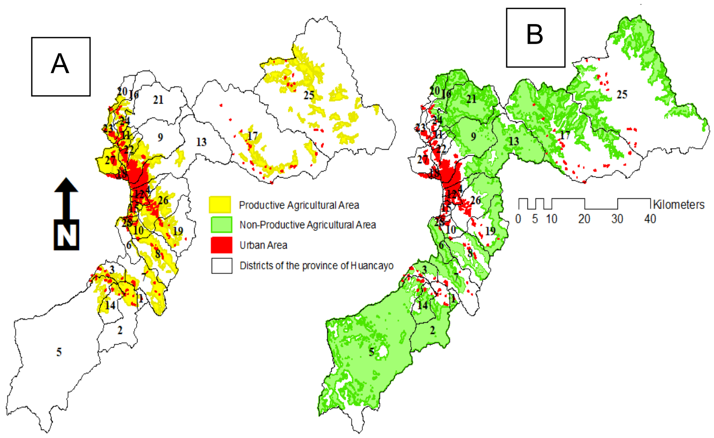

Fig. 4. Productive and non-productive agricultural areas in 28 districts of the province of Huancayo

Where; 1: Carhuacallanga, 2: Chacapampa, 3: Chicche, 4: Chilca, 5: Chongos Alto, 6: Chupuro, 7: Colca, 8: Cullhuas, 9: The Tambo, 10: Huacrapuquio, 11: Hualhuas, 12: Huancán, 13: Huancayo, 14: Huasicancha, 15: Huayucachi, 16: Ingenio, 17: Pariahuanca, 18: Pilcomayo, 19: Pucara, 20: Quichuay, 21: Quilcas, 22: San Agustin, 23: San Jeronimo of Tunan, 24: San Pedro of Saño, 25: Santo Domingo of Acobamba, 26: Sapallanga, 27: Sicaya, 28: Viques

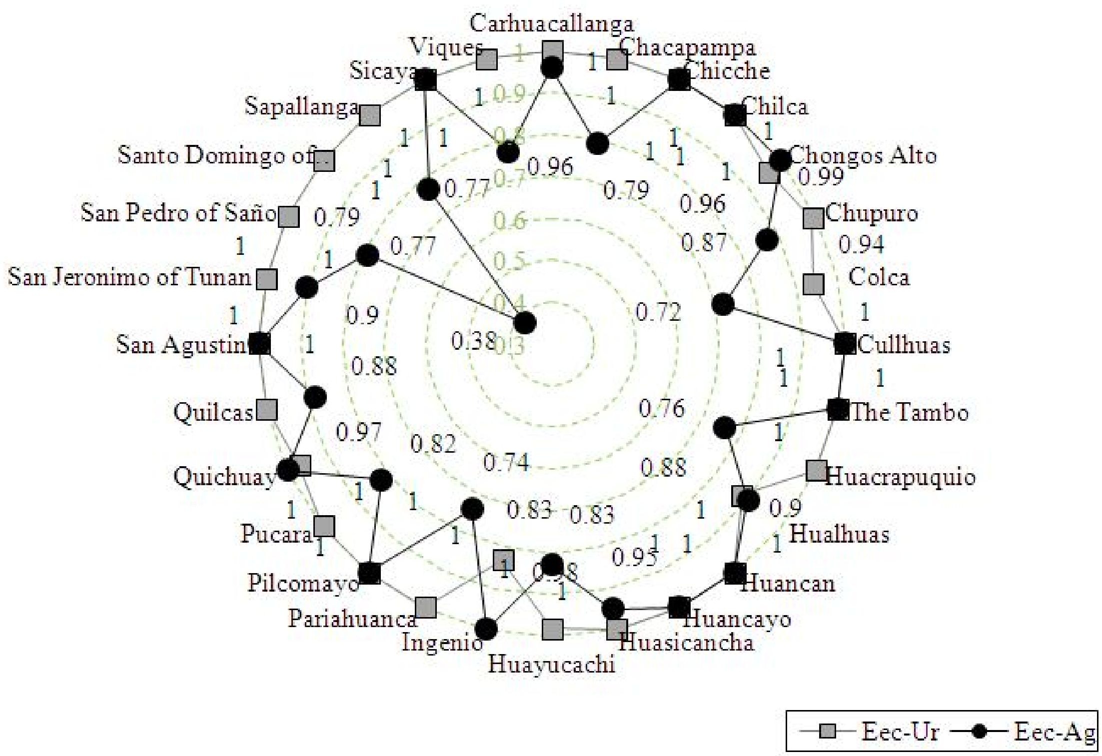

Fig. 5. Eec-Ur and Eec-Ag of the 28 districts of the province of Huancayo

Note: The radial surface plot explains the eco-efficiency between the interpolation of the input, output, environmental costs and economic output indicators that were processed by Data Envelopment Analysis [DEA]. $\bar{X}$*=[Eec-Ur]=0.98; SD[Eec-Ur]=0.04;* $\bar{X}$*=[Eec-Ag]=0.89; SD[Eec-Ag]=0.14. Where: Eec-Ur: Urban Eco-efficiency; Eec-Ag: Agricultural Eco-efficiency;* $\bar{X}$*: average; SD: standard deviation*

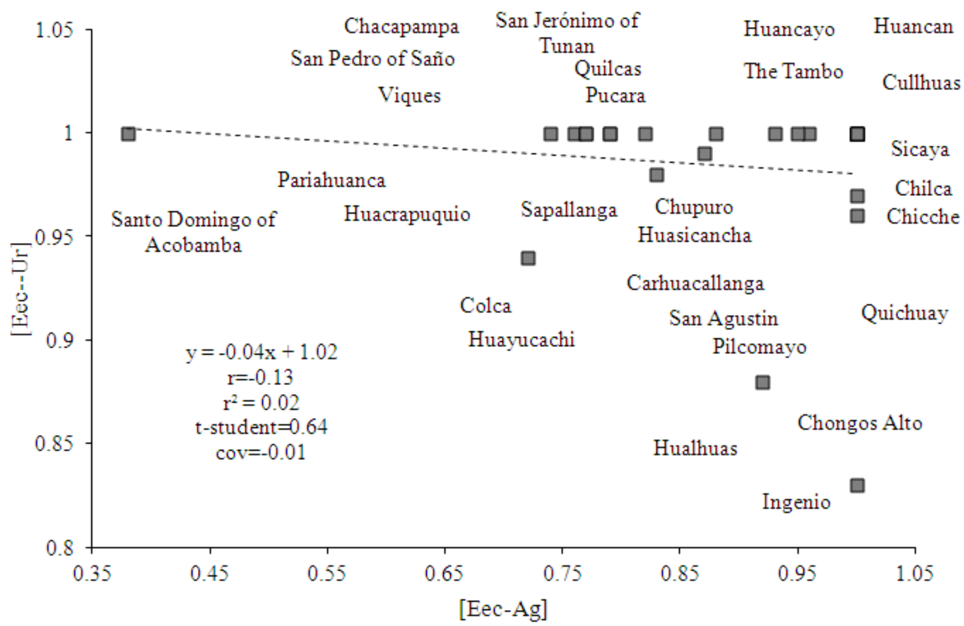

Fig. 6. Data dispersion and normal distribution line: [Eec-Ag/Eec-Ur]

Note: Note: the figure analyzes the dispersion of the values of the agricultural eco-efficiency and urban eco-efficiency of each of the 28 districts of the province of Huancayo; where a regression equation between the two eco-efficiencies is affirmed. y=-0.04x+1.02 where y=[Eec-Ur] and x=[Eec-Ag]; we also obtain r=-0.13; r^2=0.02; t=0.64; cov=-0.01

- **Relationship analysis and hypothesis testing**

The maximum eco-efficient values found in the 28 districts of Huencayo describe that there is a good eco-efficiency in their input and output activities, therefore in Fig. 6, the distribution of the eco-efficient data at the individual level shows that there is no statistical relationship between urban eco-efficiency and agricultural eco-efficiency. In other words, both are independent and their relationship does not depend directly on each other. Their relationship coefficient is r= -0.13 very low negative correlation, their t-student=0.64 < tb 2.05 (26;2.05) bilateral; therefore, there is no statistical relationship between Eec-Ag and Eec-Ur.

4. DISCUSSION

The province of Huancayo presents diverse urban forms, the district of greater urban form is Pilcomayo reducing its agricultural areas and increasing its urbanization, this can be a problem for the agricultural sector since there are very few areas about this activity; Other districts present urban forms distributed as dispersed communities, for example Pariahuanca and Santo Domingo of Acobamba making their urban accesses easier, the same happens in the districts of Chiche and Chongos Alto; it can be observed that there is a centralization of more urban forms towards the capital of the province, place where the greatest commercial activity takes place, while in the rest of the districts their activities are less progressive. Likewise, it can be inferred that the districts with the lowest population density are those that consume the least natural resources (water, electricity, food, etc.), although it can also be observed at a greater distance districts that in their basic needs are limited to the same resources present in their areas, such as the district of Chongos Alto, despite having a larger surface area, its needs are limited according to its urban areas and are basically limited to consuming fewer resources, unlike the district of Chilca; on the other hand, it can be observed that the districts with the greatest consumption of resources are those with a high population density, such as The Tambo, Huancayo and Chilca, because they are more centrally located localities, they have greater basic needs than other districts.

The districts that do not have perfect urban eco-efficiency are Hualhuas, Ingenio, Quichuay and Chongos Alto, the urban eco-efficiency of these three districts depends on their basic needs being limited in their respective districts so their consumption is neither excessive nor too large, therefore, their eco-efficiency is not very high, nor too low. As stated in the research of Lin et at. [9] in China, urban eco-efficiency decreases with excessive consumption of natural resources, at the same time it increases social welfare and it could be said that this is exactly what happens in the district of Ingenio. We can also collect many experiences of urban eco-efficiency for example Piedra [24] and Pang et al. [19] in Spain and China, expresses that the exorbitant use of water and electric energy can impact eco-efficiency although not its economic outputs according to the salary status of the inhabitants; as also Yin et al. [21] in China, states that an eco-efficient city can be efficient although there is an excess consumption of its resources as observed in the districts of The Tambo and Huancayo, despite being cities with perfect eco-efficiency, pollution has increased in atmospheric gases and other resources..

In the Fig. 4 a dominance of non-productive agricultural areas will clearly be observed, as well as the urban demographic displacement to the center of the capital Huancayo, thus reducing productive agricultural areas. No district in the province of Huancayo has an organic farming area, as it is essential to improve the natural financial status of farmers and maintain a profitable pattern of agricultural crops, where organic farming areas help improve land yields. In addition, using synthetic fertilizers and pesticides can harm the climate and people's well-being. There are different values of agricultural eco-efficiency, this is because farmers have different crop needs and geographical location. Improving agricultural eco-efficient skills in Huancayo is extremely lower than in other countries as mentioned Moutinho et al. [26] and van Grinsven et al. [20] as in Europe since it has the important national and international agreements for the development of high crop yields, being the supplier and exporter of its agricultural products to different destinations, while in Huancayo it does not have the support of national programs, as in the case of the districts Santo Domingo of Acobamba 0.38, Pariahuanca 0.74 and Colca 0.72; this means, these districts do not maintain an added value since it does not generate enough environmental pressures, such as contributing to an ecological economic state for continuous improvement. Although there is a high excessive pollution in agriculture in other countries van Grinsven et al. [20] by the use of agrochemicals, still maintains a stable eco-efficiency and worthy for human consumption, this experience has to be a clear example for the districts that still presents extensive agricultural areas since there is unreasonable use of fertilizers and pesticides in excess that damage the biotic environment and its surroundings, and thus be able to reduce any activity that can affect rural eco-productivity between urban and agricultural conflicts.

5. CONCLUSION

The internal connection between districts in the province of Huancayo is very low at 0.21, the compactness ratio between districts is low at 0.27, the extended elasticity ratio is medium at 5.47, and the population density is 753.09 inhabitants/km^2. Water consumption is 5889116.31 ML/year, electricity consumption is 2062019.23 MW/year, food consumption is 2664.56 ton/year, pollutant gas emission is 40335.11 ton/year, economic revenue is 279.35 PEN/year and wastewater discharge is 90581.38 ML/year. Agricultural production is 4779.79 kg/year, agricultural land rent is 6390.3 PEN/year, gross value of production is 4854.35 PEN/year, water consumption for the agricultural sector is 3348.34 ML/year, fertilizer consumption is 69.14 ton/year and phytosanitary consumption is 46 ton/year. Its Eec-Ur [Urban Eco-efficiency] is 0.98 and Eec-Ag [Agricultural Eco-efficiency] is 0.89 where it maintains the added value while generating 98% and 89% of its environmental pressures; the relationship between Eec-Ur and Eec-Ag presents a relationship coefficient of r=-0.13 [very low negative correlation] and tc=0.64, therefore, the province of Huancayo presents a good eco-efficiency, unlike that there is no statistical relationship that attests to it. It is recommended to use more input and output indicators in urban eco-efficiency, as well as environmental costs and economic outputs of agricultural eco-efficiency, to detail in greater depth the eco-efficiency of each district, and to monitor, follow up and raise awareness in the districts that have less eco-efficiency because their statistical records can vary over time and be used for future research.

CONSENT

As per international standard or university standard, Participants' written consent has been collected and preserved by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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