ENERGY EFFICIENCY IN AGROFORESTRY PARCELS IN ALLUVIAL MINING AREAS UNDER ECOLOGICAL SUCCESSION IN THE MUNICIPALITY OF EL BAGRE - ANTIOQUIA (COLOMBIA) †

[EFICIENCIA ENERGÉTICA EN PARCELAS AGROFORESTALES EN ÁREAS DE MINERÍA ALUVIAL BAJO SUCESIÓN ECOLÓGICA EN EL MUNICIPIO DE EL BAGRE – ANTIOQUIA (COLOMBIA)]

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SUMMARY

Background. The agroforestry parcels are processes of ecological succession that, through technical activities applied to the soil, the areas intervened by the intensive mining operation of deep alluvium are recovered and adapted to biodiverse areas that transform the intervened landscape into productive and environmentally healthy areas with a very marked concept towards family farming. **Objective.** To analyze the energy efficiency in the production of agroforestry plots located in alluvial mining areas in processes of ecological succession, in the municipality of El Bagre - Antioquia. **Methodology.** A field evaluation was carried out in the "agroforestry parcels" located in the municipality of El Bagre, department of Antioquia - Colombia. A sustainability analysis was carried out through the evaluation of indicators and complementary methods such as the rapid evaluation of biodiversity (Institute for Plant Health Research - INISAV, Havana, Cuba), measurement of energy flows and uses, and the application of the Shannon index, as indicators of diversity. **Results.** The findings of this research show the level of energy efficiency of each studied agroforestry parcel and the agroecological characteristics, in terms of sustainability and resilience of the restored areas in the agricultural context of the region. **Implications.** Defining the recovery process of other agroforestry parcels as a successful experience based on the evaluation of agroecology principles, that is, relations of production, society and culture, among other dimensions, can become a tool applicable to the evaluation of recovery processes of ecosystems intervened and degraded by extractive mining practices and support agricultural planning processes. **Conclusions.** These conservation and recovery processes of soils affected by mining may show positive transformations that respond to ecological principles, and this can be demonstrated through the evaluation of sustainability indicators.
Key words: Agroecology; agroforestry parcels; biodiversity; complex systems; energy efficiency; ecological restoration.

RESUMEN

Antecedentes. Las parcelas agroforestales son procesos de sucesión ecológica que mediante actividades técnicas de aplicación al suelo, las zonas intervenidas por la operación minera intensiva de aluvión profundo se recuperan y se convierten en áreas biodiversas que transforman el paisaje intervenido en zonas productivas y ambientalmente sanas y con un concepto muy marcado hacia la agricultura familiar. **Objetivo.** Analizar la eficiencia energética en la producción de las parcelas agroforestales ubicadas en zonas aluviales mineras en procesos de sucesión ecológica, en el municipio de El Bagre – Antioquia. **Metodología.** Se realizó una evaluación en campo en las “parcelas agroforestales” ubicadas en el municipio de El Bagre, departamento de Antioquia – Colombia. Se realizó un análisis de sostenibilidad por medio de la evaluación de indicadores y métodos complementarios como la evaluación rápida de la biodiversidad (Instituto de investigaciones de sanidad vegetal – INISAV, Ciudad de la Habana, Cuba), medición de flujos y usos energéticos, y la aplicación del índice de Shannon, como indicadores de diversidad. **Resultados.** Los hallazgos de esta investigación dan cuenta del nivel de eficiencia energética de cada parcela agroforestal estudiada y de las características agroecológicas, en términos de sostenibilidad y resiliencia de las áreas restauradas en el contexto agrario de la región. **Implicaciones.** Definir como experiencia exitosa el proceso de recuperación de estas parcelas

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agroforestales a partir de la evaluación de principios de la agroecología, es decir, relaciones de producción, sociedad y cultura, entre otras dimensiones, puede convertirse en una herramienta aplicable a la evaluación de procesos de recuperación de ecosistemas intervenidos y degradados por prácticas extractivas mineras y apoyar procesos de planificación agrícola. **Conclusiones.** Los procesos de conservación y recuperación de suelos afectados por minería evidencien transformaciones positivas que responden a principios ecológicos, y esto pueda ser demostrado por medio de la evaluación de indicadores de sostenibilidad.
Palabras clave: Agroecología; biodiversidad; eficiencia energética; parcelas agroforestales; restauración ecológica; sistemas complejos.

INTRODUCTION

In Colombia, 32% of the total population, located in the 75% of the municipalities belong to the rural sector (PNUD, 2011). More than 80% of such rural population is constituted by farmers that make their living out of a local market economy and a family-based production structure (Forero, 2003). According to a socio-economical study carried out in an area of the national territory (Bernal *et al.*, 1972), in the eighties, the family-based farming structure kept some of the primary characteristics of the first agricultural dynamics in the region, that is, a society of peasant landowners dedicated to subsistence agriculture, scarcely aimed at national markets. In time, agricultural society transformation inside many national areas, gave rise to new concepts and definitions that led the way to industrial or capitalist development in different regions.

In the field of agroecology, energy available is based on the principle that energy in the agroecosystems is supplied by two primary sources: The first, ecological energy (natural source: nonrenewable and renewable resources) and cultural or anthropic energy, represented in the labor force (wage). Studies on energy flows in the agroecosystems link human nutrition to energy employed in food production and labor force measured in Joules (Gliessman, 2000). The second key approach to energy efficiency is solar energy conversion into biomass: photosynthetic efficiency and vegetal physiology (Pimentel *et al*., 2008; Martínez and Leyva, 2014).

From such perspective, three production systems called *Agroforestry Parcels* were characterized. These cover a total area of 399 hectares, divided in 28 parcels, which provide benefits to 28 peasant families under a share tenancy system (*aparcería*). Each family is made up by 5 members in average. There are two community parcels which benefit more than 10 peasant farmers.

The studied area is located in the geological unit known as deep alluvium, as it is composed by recent unconsolidated sediment of gravel, sand, silt and clay. These quaternary deposits contain the highest concentration of alluvial gold in the country. This area is characterized by a large flood plain, especially around the Nechi River before it meets the Cauca River. A particular characteristic of this relief unit is the high degree of informal anthropic intervention due to historical gold mining in terraces, paleochannels and floodplains, in addition to timber and fauna extraction.

The Agroforestry Parcels program aims at restoring the areas affected by mining operation carried out by MINEROS S.A. The bodies of water and the rock and sand deposits resulting from mining activity go through a process of recovery and restoration once the alluvial mining operation come to an end. At a first stage, heavy machinery is employed in profiling works (leveling), followed by the immediate installation of natural covers composed by forest species and leguminous fodder plants such as the tropical Kudzu (*Pueraria phaseoloides*) and velvet bean (*Mocuna deeringianum*). The restored areas then become agroforestry ecosystems. These lands currently provide benefits to more than 21 marginalized peasant families with high levels of poverty, who have found in them a real source of social-economical and food support they did not have before. The families selected by the company now possess adequate housing and monthly financial support as the parcels become productive.

This study was aimed to analyze the energy efficiency in the production of the agroforestry parcels located in alluvial mining areas undergoing ecological succession processes, in the municipality of El Bagre – Antioquia. Other objectives of this work were the identification of the diversity index, organizational capacity and profitability, as indicators of agroecological productive efficiency.

MATERIALS AND METHODS

Type of study

A mixed-method study was carried out to evaluate energy efficiency. The information about agroforestry parcels management and design was obtained through qualitative analysis methods, such as interviews and discussion groups.

Description of the study area

The Bajo Cauca is one of the nine subregions that constitute the department of Antioquia (Figure 1). It is located to the northwest of the department, in the foothills of the Central Mountain range, within both banks of the river, Ayapel and San Lucas Mountains, on the borders with Córdoba, Sucre and Bolivar departments. (Gobernación de Antioquia, 2009).

The region comprises the municipalities of Caceres, Caucasia, El Bagre, Nechi, Taraza and Zaragoza and covers 8.485 km^2, which is 13.5 % of the total department area. Taraza River basin is characterized by mountainous systems that reach 3000 m.o.s.l on their highest parts, most of them located over the borders with Cordoba, in their turn defined by the Ayapel Mountains and the Cuchilla Planadas ridge. The rest of the territory is constituted by low alluvial plains along the Cauca River. (Gobernación de Antioquia, 2009).

The Agroforestry Parcels Program is a private company initiative taken by MINEROS S.A. The parcels are defined as ecological succession processes in areas affected by deep alluvial mining, that are transformed into productive lands under an agrosilvopastoral scheme through incorporation of organic materials, green manures and afforestation plans. These cover a total area of 399 hectares, divided in 28 parcels, which provide benefits to 28 peasant families under a share tenancy system (*aparcería*), which is a group of farms run by families of five family members in average and two community parcels assigned to more than 10 peasants.

Figure 1. Map of the Bajo Cauca Antioquia region.

Population in the study area

The social organization in the subregion is a result of historical migrations from the south of Bolivar, Cordoba, Sucre, central Antioquia, Afro-Colombians from the Pacific Coast and indigenous people from the north of Antioquia and Córdoba. The situation has enabled closer cultural interaction between the inhabitants of the Bajo Cauca and the ones in the lower part of the San Jorge River basin, than there is between the latter and the people from Northern Antioquia. The economy of this subregion is mainly based on timber exploitation and cassava, yam and rice crops.

According to Gobernación de Antioquia (2022) 80% of the rural population in Nechí, El Bagre and Zaragoza live under squalor and poverty. Such figures are not compatible with the vast mineral resources and biodiversity in soils and waters of the region, which is characterized by rich soils, which are the product of alluvial sedimentation in the Nechi River and its affluent. All things considered; this land could easily provide the whole of the population with viable economic opportunities.

Nowadays, the main problem affecting the region is the land ownership concentration, which is mostly related with violence, drug trafficking, extensive stock-raising, and illegal mining, among others. Along these lines, the internal conflict has contributed to inequality, since illegal profits have been employed in the acquisition of land since the early 80s and financing of illegal armed groups. In addition, the historical lack of state presence and financial waste caused by some corrupt leaders in municipal administrative institutions throughout the years should be added to the illicit crops problem (Gobernación de Antioquia, 2022).

The conflict in the region is also related to social phenomena such as the migration of inhabitants, who in search of better opportunities in mining, end up working for drug dealers or irregular forces that manage to hire a permanent and underpaid labor force. As mentioned above, the land is owned by a few and the small-scale producers that possess some lands do not have ownership rights. This is a matter of great importance that suggests that marginality originates in the lack of governance, little land use planning and a weak political structure.

The population, constituted of indigenous and African-descended communities, has received cultural influence from other ethnic groups that have arrived to the region over the years. Accordingly, the population Census carried out in 2005 resulted in 4.517 indigenous people, which represents 14.7% of the total population in the department. As its population rises up to 1.822 indigenous people, Zaragoza is the most populated municipality. There are 47.375 Afro-Colombians and/or inhabitants of African descent which means 7.7% of the total population in Antioquia. In almost every locality, there is an important number of people belonging to this ethnic group.

The Indigenous population belongs to the Zenu ethnic group, formerly located in Córdoba. About 5.000 indigenous people live in both municipalities, only 1.200 of which are members of an organization called "FIBRARTE" (*Asociación Multiactiva de Cañaflecha del Bajo Cauca*). The community is not organized in ethnic governments such as *cabildos*, but in social organizations to enable access to state help.

Inclusion criteria

This study focused on three plots (or agroforestry parcels) located in the municipalities of El Bagre and Zaragoza, in Antioquia. The following inclusion criteria were considered:

1. Recovery or ecological succession time in the parcels: 2 years, 5 years and more than 8 years

2. Producers associated to the agroforestry program of MINEROS S.A. that show significant advance in agricultural production.

According to such criteria, the parcels selected for analysis were:

- Parcel 22, called "La Granja" (El Bagre): 2-year production process.
- Parcel 10, called "El Triunfo" (El Bagre). Over 5-year production process.
- Parcel 5, called "La Tierra Prometida" (Zaragoza): Over 7-year production process.

Each parcel constituted a unit of analysis, where the following variables were observed:

- Biophysical components of the system (soil, biodiversity, crop type, waters).
- Required and extracted supplies (input and output) in the system.
- Agricultural, livestock and forest practices involved in each system.
- Socio-economical characteristics of the producers, as well as level and type of organizations.
- Interactions and connections between systems and subsystems.

Instruments and methods

The following instruments were employed in the analysis of the production systems:

Instrument 1- Energy 3.01 software. (Funes, 2009). This program enables the interpretation of data about farming in terms of energy efficiency generated by the production system. The program assists in the storage and processing of data about energy functioning in the agroecosystems. Data saved in the program determine the amount of input, human labour and the levels of consumption and production in an agroecosystem during a year. Such data allows the calculation of energetic balance parameters and the elaboration of graphics. This is public software available on the World Wide Web.

Instrument 2 - Rapid biodiversity assessment: Instrument designed by the *Instituto de investigaciones de sanidad vegetal* (Research Institute for Plant Health-INISAV) in Havana, Cuba (Vázquez *et al*., 2009). This tool is used to enable systematization and interpretation of functional and productive biodiversity in the system.

Instrument 3 - Shannon index: Instrument employed to determine and analyze agroecosystem diversity and land use index. Originally developed to assess natural ecosystems, Shannon index is a proper measure for agroecosystem diversity analysis since it gives insight into how crop and animal diversity contribute to increased productivity and efficacy, as well as financial measurement of integrated systems.

Shannon index originates in information theory and therefore, in the probability of finding certain individuals among an ecosystem. The index values tend to be higher when there is a more even distribution of species and individuals. In the case of relatively diverse natural ecosystems, values range between 0 and 3 (Gliessman, 2000). This measurement includes the total production of each agricultural product or each system -production diversity-. In addition, it includes the number of fruits, timber trees and live barriers - tree diversity.

For social, cultural and institutional analysis

Instrument 1: Regarding primary information, instruments such as in-depth interviews, guides for personal interviews and field observation will be employed as support in the systematization and interpretation of results.

Instrument 2: For support in the systematization and interpretation of results, secondary information available in maps, laboratory analysis (soils and waters), basic cartography of the region, climatic data from environmental authorities and the National Institute of Hydrology, Meteorology and Environmental studies (IDEAM) and studies from institutions in the region (universities, NGOs, environmental corporations, among others).

Analysis plan

In general, the concept of energy efficiency refers to the balance between energy invested and produced as it is expressed in food production/Ha/year. Other additional data such as labor force intensity, productive performance, and people fed by the energy produced, among others, are energy indicators that enable an integral analysis of farm management in terms of food production efficiency. The energy consumed (food) is a product of transformation and dissipative processes inside the agroecosystems, represented by the photosynthesis in plants (ecological energy); on the other hand, the energy spent has cultural origins, as it is provided by humans to optimize biomass production in the agroecosystems (Gliessman, 2000).

Funes (2009) claims that understanding the energy flows and balances is a basic element to accomplish energy sustainability, due to economic, as well as social and ecological reasons. Acknowledgment and quantification of energy efficiency of the production systems should constitute a fundamental tool in the design of strategies of agricultural management. Energy efficiency was analyzed in the evaluation of productive systems, in terms of two main sub-indicators as follows:

a) Energy Cost: indicator defined as the relation between energy invested in the system (inputs: supplies, workforce, fuel, machinery, among other invested energy) and energy produced (output: food and biomass)

b) Energy used: energy use refers to the resultant of agricultural production measured in Kg/Ha and evaluated on basis of the regional production, rather than the national one, as it is a common practice for conventional systems. Another indicator of energy use is human labor intensity, whether it is provided by family members or through labor recruitment. Human labor provides information about the amount of human effort (anthropic energy) invested in a productive system. This is a key indicator since its intensity is related with problems inside the system and the sociocultural environment that in many of cases influences the relations among family members, neighbors and in general, within the local community.

Other energy uses are related to the amount of people that are fed by hectare. One of the key principles promoted by agroecology in productive systems management is food security. Studies carried out in Cuba (Funes, 2009) show that in a small-scale farm, a hectare of land can provide food to 8 to 15 people, provided that there is low external input and strategic management. In small and medium-scale farm production, food security should be regarded as a fundamental principle for population stability and resilience in a determined region.

Diversity

Production diversity by means of the Shannon index is calculated by dividing the production of each component by the total production. Production Diversity, DP= -Σ (pi/N) (ln pi/N), where pi/N= certain component production level divided by overall production.

According to Gliessman (2000), the Shannon index is an application of the theory of information, which claims that higher diversity corresponds to higher uncertainty when choosing an individual of a particular species randomly. The values of the analysis of the Shannon index are measured on a scale from 0 to 3, where 3 is the maximum value in the scale of diversity and 0 corresponds to a monocrop. Higher species diversity corresponds to higher probabilities of environmental services such as biological control of plagues and diseases, balance of biological regulators, and delivery of soil nutrients, among others.

The diversity indicator is a measurement of equity in a certain population and its niche. If any of the species represents most of the diversity and many others represent a small percentage of the total, there is a decisive factor to keep including the dominant species. The number of individuals per species needs to increase evenly for the diversity index to rise. This type of measurement can provide information about dominant species that can cause a lack of balance within the system – become monocrops owing to its prevalence.

Profitability

Indicator that defines the economic efficiency of products tradable in the market. The relation between raw profits and net profits results in a percentage of profitability that should be positive (Organización de las Naciones Unidas para la Alimentación y la Agricultura -FAO-, 2015). This indicator is closely related and depends at a large extent of the social organization, of which producers make part, since one of the functions of the organization is to allow the producer to sell at a fair price and minimize costs for the chain through economies of scale.

Social organization

Indicator that defines the associative capacity of producers to face their primary needs in the regional context. The success of the social organization is related to its capacity to respond to the real needs of its members or beneficiaries (Velásquez and Mata, 2008). Needs such as marketing, technical assistance, access to credit, among others, are essential factors for producers to respond with efficiency. These are base organizations that can lead and guide social and productive processes in the region under conditions of marginality and institutional neglect. All things considered; this type of organization defines social resilience in the territory.

RESULTS

In the analysis of three agroforestry parcels, the study resulted in four main measurement indicators for production systems, described as ***guiding indicators*** for the assessment of energy efficiency and productive sustainability from the agroecology field: 1) energy efficiency (energy cost and use) 2) diversity 3) profitability and 4) organizational capacity. However, each indicator has a differential value owing to its strategic weight inside the productive system, in agreement with the priorities in each parcel defined by the producers (Table 1).

Energy Efficiency

Parcel 22:

1. The energy balance for production in the Parcel 22 is ***High*** since the energy produced is more than the invested: per each megajoule (MJ) invested (force – work, supplies, biomass) 36 MJ are produced; relation 1:36. There are 36 times more energy produced than invested.
2. Productive performance is ***Average***: 9 tn/Ha are produced, whereas the average value in the region is 3 tn/Ha.
3. The number of people fed per hectare is ***very low;*** it is 3, whereas the world average ranges from 8 to 15 people per hectare (Funes, 2009).

Table 1. Weighting of indicators of agroecological production efficiency (EPA).

Component	Indicator	Referent for measurement	Interpretation		
			Level	**Value**	***Quality***
Efficiency and Energetic Use	Energetic cost	relation 1:6	1:3	1	Low
			1:6	3	Average
			Higher than 6	5	High
	Production	10 tn	1 to 5	1	Low
			6 to 8	3	Average
			Higher than 10	5	High
	Human Labor intensity	44 hours/week	Lower than 27.5 and more than 44 hours	1	Not acceptable
			between 27.5 to 44 hours	3	Acceptable
			44 hours	5	Optimum
	People fed/hectare	8 to 15 people/hectare	1 to 5	1	Low
			6 to 8	3	Average
			More than 8	5	High
	Animal and vegetable protein availability	25Kg/person/year	Lower than 25	1	Low
			Higher than 25	5	High
Production Diversity	Shannon index	0 to 3	Lower than 1	1	Low
			1 to 2	3	Average
			Higher than 2	5	High
Profitability	Economic	37%	1 to 25	1	Low
			26 to 37	3	Good
			Higher than 37	5	High
Social Organization	Associativity	Organizational Capacity	1 to 2	1	Low
			2 to 3	3	Average
			3 to 5	5	High

4. Another aspect that should be highlighted is the intensive human labor use in the parcel La Granja: 13 wages/ year/ Ha, which is very low and is expressed in the low levels of production (1.9 tn/Ha). This indicator could have been higher in terms of production increase given the number of inhabitants on the farm (2 adults, 2 youths). However, it is worth mentioning that this parcel is still under recovery process and soil deficiencies are still significant, which hinders higher productive increase. As parcels advance in the process, productivity rises.

Parcel 10:

1. The energy balance for production in the Parcel 10 is ***High*** since there is more input than output: per each megajoule (MJ) invested (force – work, supplies, biomass) 50 MJ are produced; relation 1:50. There is 50 times more energy produced than invested.
2. Productive performance is ***High***: 6 tn/Ha are produced, whereas the average value in the region is 3 tn/Ha.
3. The number of people fed by hectare is ***High;*** it is 10, whereas the world average ranges from 8 to 15 people per hectare (Funes, 2009).
4. Another aspect that should be highlighted is the intensive human labor use in the parcel La Granja: 14 wages/ year/ Ha, which is very low compared with the levels of production (6 tn/Ha). This indicator shows human labor efficiency and human effort cost compensated with productive levels.
5. Animal protein required for a proper daily diet for the family is ***Very Low.***

Parcel 5:

1. The energy balance for production in the Parcel 15 is ***High*** since there is more input than output: per each megajoule (MJ) invested (force – work, supplies, biomass) 10 MJ are produced; relation 1:10. There is 10 times more energy produced than invested.
2. However, other energy use indicators such as the productive performance, the number of people fed by energy and human labor intensity among other are **Very Low** and under the normal referents above mentioned.

DISCUSSION

Scientific studies related with the energy assessment in potato, tomato and lettuce crops showed the highest energy efficiency in the tomato crops where the relation between investment and production was 1:3.5, followed by potato 1:2.6; the lowest was lettuce 1:0.25 (Denoia and Montico, 2010). Likewise, Singh *et al*. (1996) analyzed the energy cost in 4 farms in India and as total result obtained 1:4 per hectare as relation between invested (inputs) and produced (output) energy expressed in food and biomass.

Under other production conditions, Campos and Naredo (1980) mention studies about energy costs carried out within the Naring community in New Guinea, which obtained energy relations of 1:18 for orchard fields located in the highest areas of the region and 1:20 for the ones in the lowest areas. These orchards supply food needs and only receive workforce or wages as input.

If intensive supply production systems show results of 1:3 and systems under highly natural conditions as the orchards in New Guinea resulted in 1:20, it could be suggested that the optimum relation, in terms of energy invested and food produced in a productive system under low production conditions, not linked to intensive market dynamics, would be 1:6. This is then an ideal referent for energy cost in small and medium-scale systems.

In the field of agroecology, biodiversity plays a determining role in production processes. Biodiversity plays a key role in regulating the functioning of ecosystems and directly influences the quality of human life. Biodiversity provides services both in the natural ecosystem (carbon capture, water conservation, among others) and agroecosystems (control and balance of pests and diseases, nitrogen capture, mobilization of minerals to the plant, microclimate, biomass for recycling of nutrients, among others). The term “functional groups” suggests the existence of a relationship between diversity and functional groups with the functioning of ecosystems and the services that they provide to agroecosystems (Moonen and Barberi, 2008), a concept that can be named as Functional Biodiversity.

When analyzing the biodiversity of the productive system, the biodiversity index considers an attribute relevant to functionality rather than the number of species. Likewise, the index must consider that when replacing a species with others or with similar functional traits, the sum of individuals must be equivalent to the number of individuals of the replaced species (Salmerón *et al.*, 2017). In this way, it can be understood that energy efficiency is directly related to the biodiversity index in terms of functionality. Thus, two great attributes are added: energy and functionality, two concepts that add to the efficiency of productive agroecological systems.

All things considered, it could be concluded that concerning Agroecological Productive Efficiency

(EPA), the parcel 22 is the most efficient, despite being the newest of the three, which means fewer energetic subsidies and ecosystem recovery.

Regarding the results in energy efficiency, the parcel 10 is the most efficient in terms of energy, production and food supply per hectare. Nevertheless, its diversity indicator makes its score lower against the others: even though there is a high number of species, the parcel 10 shows a lack of balance in the production system.

The sole indicator of energy efficiency comprises 4 important principles of agroecology: 1) recycling of nutrients -biomass produced- 2) natural resources use for agricultural production -synthetic chemical and organic input invested in production- 3) food security and 4) equity -workforce and surplus food for trade and sales. Such is the reason for defining the energy efficiency indicator as the main guiding indicator in the analysis of sustainable agricultural production.

The agroforestry parcels, as a successful experience of the ecological and social contribution of mining, constitute a conceptual and practical frame for a model in which alluvial mining could give way to integration and restoration in the regional context. However, increased participation by local and national institutional actors is required, to gather political instruments that enable overall sustainability and social strengthening in production sector.

It can be noticed that, from both the quantitative analysis of indicators and the qualification or factors, there is a highly fragile socio-ecological resilience inside the parcels, or in other words, the low capacity of producers to remain through time despite disruptions in the system. There is a lack of structured processes to strengthen the social organization, which are fundamental for participative decision-making, decentralized from institutional support – autonomy and self-management. Higher dependence of producers on institutional support corresponds to a higher lack of sustainability within the system. Besides, social interaction among producers needs to be consolidated to enable greater exchange of endogenous knowledge and group planning in the parcels, which are fundamental in the construction of Agroecological Beacons.

Devendra (2007) considers that energy efficiency planning is also economic efficiency planning and the key for both is an accurate location of plant, animal species and productive structure zone and sector – Agroecological design. Besides, both the production of certain items and its production system highly influence the results in terms of energy efficiency in an agricultural production unit.

Undoubtedly, and according to the results of our analysis, the agroforestry parcels represent a model of *successful experience* based on the results obtained in energy efficiency, which kept high scores in most of its indicators in the study of the parcels and that has been proven to be key in any small and medium scale production process. The agroforestry parcels could thus become a sustainable and resilient model called *Agroecological Beacons*. This is a concept that agroecology defines as a system of agricultural production regulated by agroecological principles, whose structure and functioning dynamics depend on sociocultural and historical factors, characterized by high levels of energy efficiency, adaptability to external phenomena – markets, social vulnerability, among others – as well as equity in the information networks inside the production system stakeholders. Also, it is based on principles of connectivity between the various subsystems and structures generated in every production process chain and the group of successful biotic, cultural and social processes – markets, organization, and institutions – that determine complexity in a sustainable system. However, for the agroforestry parcels to be acknowledged as Agroecological Beacons it is necessary to strengthen connectivity of the agroecosystem with its sociocultural surroundings (governance system, markets, social organization, and technological innovation, among others).

CONCLUSIONS

Agroecology is a science that allows us to analyze agroecosystems from a holistic perspective based on a complex vision of reality, that is, from environmental factors as well as from the social, political, economic and biological components. They are a set of connected processes, rather than the sum of separate activities.

The analysis of energy efficiency in agroforestry plots allowed the identification of multiple connections in the relationship between food production and the practices and models that are applied in the intervention of highly fragile ecosystems such as mining soils. In this sense, the variables of sustainability and resilience, when intervening in this type of ecosystem, are essential when seeking greater performance in terms of energy efficiency.

In this sense, the evaluation of energy efficiency in production systems must be oriented towards the identification of the multiple connections in the value chain, which allows the relationship between the stakeholders of the production process to be evidenced. In this way, each component of the production system, at each of its levels, and with each of its emergencies, in an integrated manner, will be able to contribute to the sustainability of the systems in its environment.

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Compliance with ethical standards: Informed consent was obtained from the owner of the agroforestry parcels, where free, spontaneous participation in the research was declared. Due to the characteristics of the information, opinions and observations, the anonymity was preserved.

Data availability: Data are available upon reasonable request with the corresponding author (leonardo.rios@udea.edu.co)

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