ISSN 2310-340X RNPS 2349 -- COODES Vol. 8 No. 2 (May-August)
Alonso Vázquez, A.C., Benítez Odio, M., Iriban Díaz, C.A, Vázquez Fleitas, A. "Economic-environmental contributions of a dairy agro-ecosystem" p. 250-262
Available at: http://coodes.upr.edu.cu/index.php/coodes/article/view/302

2020

Economic-environmental contributions of a dairy agro-ecosystem

Aportes económicos-ambientales de un agroecosistema lechero

Contribuições económicas-ambientais de um agroecossistema leiteiro

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Received: March 6th, 2020.
Accepted: June 10th, 2020.

ABSTRACT

According to the Theory of the Total Economic Value of the Ecosystem, the techniques of economic-environmental valuation allow us to identify the main environmental functions that are directly or indirectly reflected in the market, which makes them one of the most widely used techniques for the economic valuation of the environment. This research was carried out with the aim of estimating the environmental costs and benefits generated in a dairy agro-ecosystem and with the application of economic-environmental valuation methods. To this end, the general functions of support or load, joint production, habitat and regulation at the end of 2018 were studied, applying the dialectical-materialistic method, as the guiding method of the research, in addition to empirical methods based on scientific observation and documentary analysis and the measurement method to describe and analyze the behavior of the functions studied. For the economic-environmental valuation analyses, items such as gross benefit, direct costs and avoided costs were calculated. It was found that the goods and services existing in the dairy ecosystem contribute to the total economic value a very favorable economic benefit, which is supported by a correct management of them, standing out in the contributions made by the functions of joint production, support or load and habitat. The integral analysis of the functions that make up the total economic value of any livestock

ecosystem offers the possibility of deepening its efficient management and what this activity contributes in a sustainable manner in Cuba.

Keywords: livestock agro-ecosystems; environmental functions; dairy; total economic value

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RESUMEN

Según conviene la Teoría del valor económico total del ecosistema, las técnicas de valoración económica-ambiental permiten identificar funciones ambientales principales que tienen reflejo directo o indirecto en el mercado, lo que las convierten en una de las más utilizadas para valorar económicamente el medioambiente. Con el objetivo de estimar los costos y beneficios ambientales generados en un agroecosistema lechero y con la aplicación de métodos de valoración económica-ambiental, se desarrolló la presente investigación. Para ello, se estudiaron las funciones generales de soporte o carga, de producción conjunta, de *hábitat* y de regulación al cierre del año 2018, aplicando el método dialéctico-materialista, como método rector de la investigación, además de métodos empíricos basados en la observación científica y el análisis documental y el método de medición para describir y analizar el comportamiento de las funciones estudiadas. Para los análisis de valoración económica-ambiental, se calcularon partidas como: beneficio bruto, costos directos y costos evitados. Se constató que los bienes y servicios existentes en el ecosistema lechero aportan al valor económico total un beneficio económico muy favorable, lo que está sustentado por una correcta gestión de los mismos, sobresaliendo en las aportaciones realizadas las funciones de producción conjunta, de soporte o carga y la de *hábitat.* El análisis integral de las funciones que conforman el valor económico total de cualquier ecosistema ganadero ofrece la posibilidad de profundizar en su manejo eficiente y en lo que aporta de manera sostenible esta actividad en Cuba.

Palabras clave: agroecosistemas ganaderos; funciones ambientales; lechería; valor económico total

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RESUMO

De acordo com a Teoria do Valor Económico Total do Ecossistema, as técnicas de avaliação económico-ambiental permitem-nos identificar as principais funções ambientais que se refletem direta ou indiretamente no mercado, o que as torna uma das técnicas mais utilizadas para a avaliação económica do ambiente. Esta investigação foi realizada com o objetivo de estimar os custos e benefícios ambientais gerados num agroecossistema leiteiro e com a aplicação de métodos de avaliação económico-ambiental. Para tal, foram estudadas as funções gerais de apoio ou carga, produção conjunta, habitat e regulação no final de 2018, aplicando o método dialético-materialista, como método orientador da investigação, para além dos métodos empíricos baseados na observação científica e análise documental e o método de medição para descrever e analisar o comportamento das funções estudadas. Para as análises de avaliação económico-ambiental, foram calculados itens como o benefício bruto, os custos diretos e os custos evitados. Verificou-se que os bens e serviços existentes no

ecossistema leiteiro contribuem para o valor económico total um benefício económico muito favorável, que é apoiado por uma gestão correta dos mesmos, destacando-se nas contribuições feitas pelas funções de produção conjunta, apoio ou carga e habitat. A análise integral das funções que compõem o valor económico total de qualquer ecossistema pecuário oferece a possibilidade de aprofundar a sua gestão eficiente e o que esta atividade contribui de forma sustentável em Cuba.

Palavras-chave: agroecossistemas pecuários; funções ambientais; lacticínios; valor económico total

INTRODUCTION

In most livestock farms, only the final production reached and marketed (milk or meat) is given weight, while the variety of environmental functions and resources present in each production base, which add economic value to the rubles reached, are neglected.

According to Armenteras, González, Vergara, Luque, Rodríguez and Bonilla (2016), over the last few decades, the concept of ecosystem has been treated with great force in decision-making, in terms of resource planning; hence the economic valuation of ecosystem goods and services, as an element of Environmental Economics, contributes significantly to the economic and environmental decision-making process (Portela Peñalver et al, 2019); in addition to improving the management of natural resources in order to mitigate the risk of climatic disasters and the effects of climate change.

Researches carried out in Cuba to economically value the environment has shown progress in recent years, with a greater number of studies focusing on tourism or sectors with high landscape value, forest massifs and protected areas (Rodríguez Córdova et al., 2017; Zequeira Álvarez et al., 2016), while for the livestock sector they are less numerous and only a few studies have been recorded, such as those of Miranda, Machado, Machado y Duquesne (2007) and Báez (2018).

In the opinion of Ferro, Gómez, and Herrera (2016), environmental functions, together with the environmental products and services generated by ecosystems, have taken off in recent years with the application of the Theory of Total Economic Value (VET in Spanish), which states that any ecosystem is composed of several attributes, some of which are tangible and easily measurable, while others may be more difficult to quantify, although no less important.

In this sense, it is vitally important to study the economic-environmental contributions generated by any natural context and, even more so, in livestock contexts, due to the amount of environmental goods that concur in their processes. The economic-environmental valuation is a tool that allows to measure effectively the economic contributions generated by the natural environment, under a correct conduction and application of economically effective policies in the sustainable management of the species and the environment, in function of an effective management that strengthens the resilience and durability of the ecosystems.

Based on the above, the central objective of the work is defined as: to estimate the environmental costs and benefits generated in a dairy agro-ecosystem, applying economic-environmental valuation methods.

MATERIALS AND METHODS

For the development of the research, the dialectic-materialistic method was applied as a guiding method, the Marxist approach was assumed in the realization of the evaluation of the environmental goods and services, derived from the productive livestock management, which contribute to conform the total economic value of a dairy ecosystem.

The historical-logical method was used to determine the theoretical-methodological background related to the Theory of Total Economic Value, its evolution and relationship with livestock ecosystems, which made it possible to confirm the progress made in research carried out in this sector in Cuba and worldwide.

Empirical research methods were also used, based on scientific observation and documentary analysis, which made it possible to characterize the current situation of the environmental functions existing in the milk production unit, case study.

At the same time, for the application of the Theory of Total Economic Value (Dixon & Pagiola, 1998), the measurement method was used to describe and analyze the behavior of the general functions described by Jiménez (1996) that allowed calculating the contributions generated by environmental products and services present in the case study ecosystem. In addition, consultations with secondary information sources were used to obtain elements that contributed to the functions that generated the TEV of the ecosystem.

RESULTS AND DISCUSSION

The study was carried out in the typical dairy (Vaquería 101), belonging to the Unidad Empresarial de Base (UEB) "La Barbarita", of the Empresa Pecuaria Genética "Camilo Cienfuegos", in the westernmost province of Cuba (Pinar del Río) in the period from December 2017 to December 2018.

The unit is located approximately in the 22º 45' of North longitude and the 83º 15' of West latitude, at 306 m. over the sea level; it has a territorial extension of 105.15 ha, which are dedicated to the milk production. On its soils, grasses such as: *Pannicum maximum* (Guinea likoni), *Cynodon nlfluencis* (Pasto estrella) and *Pennisetum purpureum vc* Cuba CT - 115 grow, as well as, protein shrubs such as *Morus alba* (Morera) and *Tithonia diversifolia (Hemsl*) A. Gray (Botón de oro) and a small forest heritage where *Eucalyptus melliodora* and *Acacia magium* predominate, scattered in the border areas and in others not intended for grazing.

This unit also has a 30 m^3 biogas to perform different functions from the methane gas produced by the anaerobic decomposition of bovine waste, to which other renewable energy sources (FER in Spanish) are added, such as photovoltaic panels that feed a submersible pump for the extraction of groundwater, a system of electric fences to maintain the unit's quartering, fed by the same source of generation, together with a solar heater that uses its water for sanitation of the mechanized milking equipment and other functions.

According to Dixon and Pagiola (1998), the VET of environmental assets (Fig. 1) is composed of the value of use plus the value of non-use, while Azqueta (1994) summarizes it in the following equation:

VET = use values (VUD + VUI + VO) + non-use values (VE + VL)

Where:

VUD = Direct Use Value

VUI = Indirect use Value

VO = Option value

VE = Existence value

VL = Bequest value

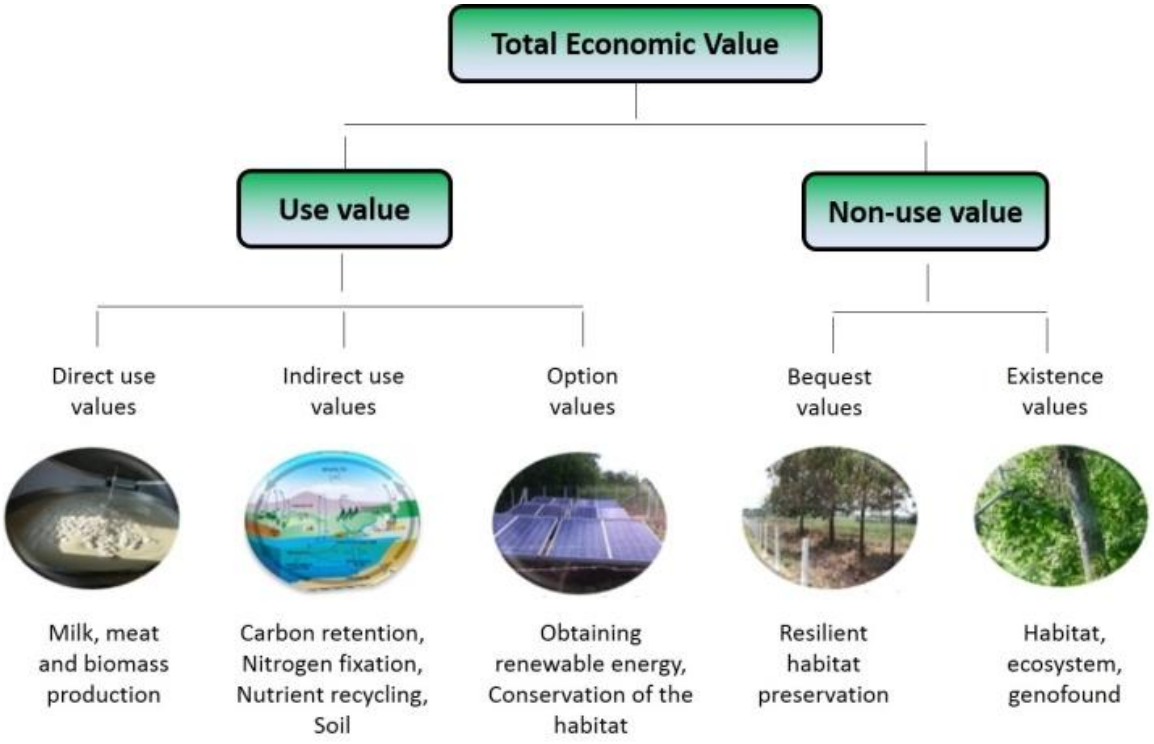


Fig. 1 - Total economic value of environmental assets
Source: Own elaboration based on Dixon and Pagiola (1998)

In accordance with the classification described in figure 1, within the use value, different elements were identified in the unit under study related to direct use values (milk production), indirect use values (benefits derived from the functioning of the ecosystem) and option values (inputs generated by FER).

Meanwhile, for the non-use value, the legacy value took into account the existing resources that allowed the resilience of the ecosystem under study and its perpetuity for future generations, while the existence value took into account those resources that make up the genofund and habitat as an environmental asset; considered of high value for these studies in correspondence with the arguments of Ferro et al. (2016).

The determination of the VET of the ecosystem under study was also based on some of the general functions described by Jiménez (1996), among which are: Support or load functions (1), Co-production functions (2), Habitat functions (3) and Regulation functions (4), where the environment plays an active role although human decisions predominate. Each of these functions brings together specific functions such as those described below (and which were considered in the study):

- Space and substrate reservoir functions (1): The method used by Miranda et al. (2007) was applied to estimate the carbon retained in the soil based on area, bulk density, sampling depth and organic matter contained in the soil. The economic value was estimated directly from market prices per ton of carbon as reported by Alatorre, Caballero, Ferrer and Galindo (2019).
- Agricultural production functions (2): The biodiversity of the agro-ecosystem was used to calculate, in addition to calculating the necessary wages used to control weeds in the area studied and the cost of labor, taking as a reference what was described by Miranda et al (2008).
- Intensive and extensive functions of animal production (2): The technique of gross profit was used (Rangel Cura et al., 2013), of milk production; technical data registered in the dairy, from the period of closing of 2017 to closing of 2018 were used.
- Functions for the development of species and ecosystems (3): The calculation of biodiversity was made and the Shannon (H) index from the methodology indicated by Shannon and Weaver (1949) was taken into account.
- Waste disposal functions (1) and containment functions (4): The avoided costs attributable to the use of the excrements and their reuse in the 30 m3 biogas were evaluated, which made it possible to determine the monthly energy produced by the biogas and the energy generated by the existing photovoltaic park, using the indexes described by Ponce, Ponce, Ramos, Díaz and Valles (2016).

The space and substrate reservoir functions showed carbon sequestration values between 26 and 35 t C ha^{-1} at a depth of up to 14 cm, which represents an estimated economic value in that function for the 105.15 ha of arable land of the dairy under study, of $ 22 450.00 USD to the total economic value (1 USD=1 CUC and 1 CUC=25 CUP). This value was lower than that reported by Portela et al. (2019) when taking as a price, for that element, the average in USD fixed in the international market (between 5 and 10 USD according to Ferro et al., (2016)).

The evaluation of carbon retention in the dairy agroecosystem, case study, only represents a small part of what could actually exist as potential, since the carbon stored in the aerial and necrotic biomass is not taken into account.

The agricultural production functions recognized in the areas of protein plants (*Tithonia diversifolia (Hemsl.) A. Gray and Morus alba L.*), pastures and biomass banks (*Pennisetum purpureum vc Cuba CT - 115*) existing in the livestock unit, an important heritage that pays tribute to the total economic value, as it is part of the tropical pastures and forages that form the food base that allows covering the nutritional requirements of the cows in production.

The *Tithonia diversifolia (Hemsl.)* A. Gray, also contributes to other important ecosystem benefits among which are recognized the high levels of phosphorus it provides and its large root volume, which gives it a special ability to recover the scarce nutrients from the soil, in addition, it has a high concentration of nitrogen in its leaves that allow it to provide up to 33% of raw protein, contents similar to those presented by any legume (Rodriguez Garcia, 2017). This makes it an essential fodder material in cattle feed, given the high protein content they provide.

Another element of the forest, which contributes to the regeneration of the unit's soils, is the small forest heritage composed of one hectare of *Eucalyptus melliodora* and *Acacia magium* which, in addition to this function, help to counteract the erosion processes that could be generated as part of their use in livestock activities.

The value of the forest cover adopted was the unit price $ 4 129.70 CUC/ha, described by Rangel et al. (2013), according to the replacement cost technique. This amount was much lower than that reported by Portela et al. (2019) when studying mountain forest ecosystems.

The number of days dedicated to weed control per hectare per year was reduced to less than 10; this allowed an average wage saving per day of approximately $ 0.58 USD per worker, which generated an annual contribution to the biodiversity function in the dairy, case study, valued at $ 213.60 USD.

On the other hand, the joint production function (milk production) contributed an annual average of $745,200.00 USD by the end of 2018, which is considered an acceptable value considering that, out of 141 cows in the dairy, 57.4% of the herd contributed 165,600.0 litres of milk during the year.

The biological diversity index (H) of grassland vegetation assessed within the developmental functions of species and ecosystems averaged 1.19. This indicated that the silvopastoral system-maintained stability in the soil-grass system, which was evidenced by the high density of the base grass, the decrease in weeds and the gradual increase in soil fertility. This behavior produced a decrease in the diversity of the vegetation as a result of the correct management, which managed to maintain the gramine-protein association in similar proportions (20:80) to those referred to by Galindo, Rodríguez, González, García and Herrera (2018), together with the existing protein and pasture banks that guarantee the productivity, efficiency and persistence of the system.

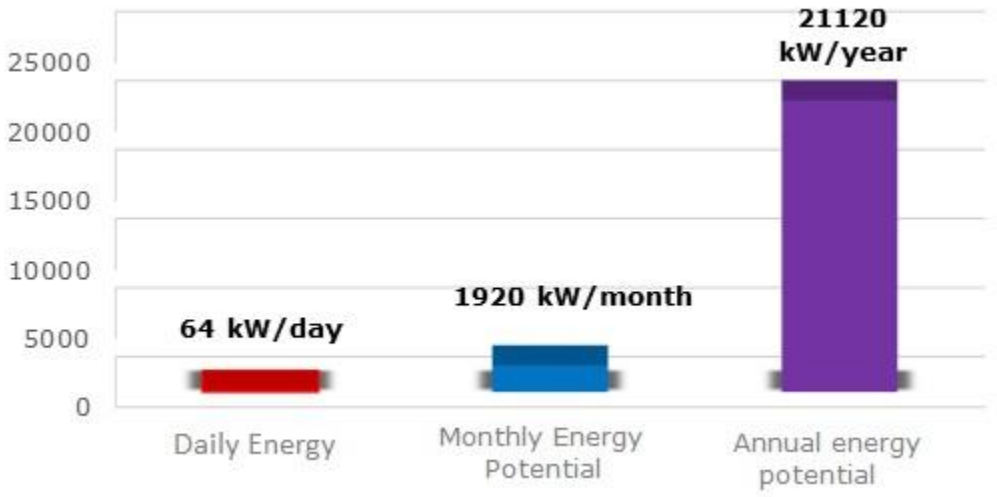
The case study unit has 141 dairy cows of the Cuban Siboney breed with an average live weight of 450 kg. The cows are kept in the shade houses for 10 to 12 hours a day, and the volume of excreta deposited per cow in the facility is calculated at around 10 kg per day, which represents a total of approximately 1,410 kg of excreta per day, a volume that is considered the basis for biogas generation.

Bovine enteric fermentation is considered to be one of the main sources of greenhouse gas emissions in the world, and therefore the correct management of manure and urine produced by these animals can counteract the negative effects they have on ecosystems, which corresponds to the ideas of Wilkes, Reisinger, Wollenberg, and van Dijk (2017).

As an effective solution to the management of these residues, it is found the use of biogas, which allows us to convert most of the carbon in the bovine excrement into gas and obtain important volumes of solid matter, with concentrations of nutrients that are used as natural fertilizer, as well as its liquid residues. The construction of biogas in livestock entities constitutes a solution that allows minimizing the pollutant load generated, at the same time that it favors obtaining energy capable of self-supplying the consumption of the productive unit.

The support or loading functions found that from the approximately 1410 kg. of excreta per day, which are generated in the shade houses, about 45 % of them can be recovered. From the 141 heads that exist in the cow shed, it is estimated that approximately 634.5 kg. per day will be collected, equivalent to 231,592 kg. per year, which is enough to feed the biogas in the unit and use other volumes after decomposition as organic fertilizer for the grazing areas, which raises the quality of the substrate and substantially improves the efficiency of the established pastures and forages.

By determining the energy potential in kWh/day, month and year, produced by the 30 m3 biogas (Graph 1) in terms of monthly energy, it could be seen that it is capable of producing a daily energy equivalent equal to 64 kW/day. This energy equivalent is capable of covering the calculated demands for the livestock activities that consume electrical energy in the study dairy, since, according to the Basic Electrical Organization of the municipality, the consumption for carrying out all daily activities of this productive unit is calculated at around 31.5 kW/day, an annual consumption of 11.34 MW at a cost price of $ 160 USD per MW.



Graph 1 - Energy potential in kWh/day, month and year produced by 30 m^3 biogas
Source: Own elaboration

The use in the FER unit (biogas, solar heater, submersible water pump and electric fence system for quartering that are fed by photovoltaic panels) under conservationist principles that mitigate the emission of greenhouse gases, allows the annual replacement of about 6969 liters of gas / oil for the generation of electricity and the non-emission into the atmosphere of about 316 tons of CO2 from the use of biogas, contributing to the total economic value estimated at $ 2 536.00 USD.

In addition to the energy obtained from biogas, approximately 10 kg/day of solid organic fertilizer of the highest quality and more than 190 kg/day of liquid fertilizer are extracted, values similar to those reported by Núñez (2016), which are tangible and translate into avoided costs for the purchase and application of fertilizers that are applied to the forage areas of the unit. According to studies carried out by Núñez (2016), despite being considered an investment of a certain amount, the recovery period is considered short, together with the economic benefits that will subsequently be generated by the sale of energy to the national electro-energy system.

On the other hand, the contributions of organic matter obtained from the biogas process when applied as fertilizer in the pastures improve the water retention capacity of the soil and promote better development of the plant roots and the absorption of nutrients from the pastures and protein plants existing in the unit, aspects that correspond to what was proposed by Beltrán, Álvarez, García and Castro (2017).

The total economic value contributed by the livestock ecosystem was $774,529.30 USD (Table 1). The integrative analysis of the dairy farm made it possible to manage the livestock activity from a multidimensional point of view. It shows the potential of silvopastoral systems and the use of renewable energy sources in livestock activity to generate environmental goods and services and the different economic benefits that can be obtained from them.

Table 1 - Total Economic Value of Dairy 101 by Environmental Function

Functions	Studied variables	Total economic value (USD/ha/year)	Total economic value (USD/year)
Support or load	Carbon production	$ 213,50	$ 22 450,00
Joint production	Milk production	$ 7 087,01	$ 745 200,00
Habitat	Biodiversity and forest cover	$ 4 131,70	$ 4 343,30
Regulation	Use of renewable energy sources	$ 24,11	$ 2 536,00
Total		$ 11 456,32	$ 774 529,30

Source: Own elaboration

Environmental economic valuation is an instrument that allows an integral analysis of elements that are sometimes dismissed by economic accounting systems. The integral analysis of the functions that make up the total economic value of any ecosystem offers the possibility of deepening the efficient management of the ecosystem and what it contributes in a sustainable manner. In the case of the livestock sector, it not only allows the impact generated by this activity to be assessed from a negative point of view, but also the great variety of environmental goods and services derived from its productive management.

Hence, Báez (2018) advocates the need to promote the implementation of effective, economically efficient policies for the sustainable management of environmental goods present in livestock ecosystems.

Although a system of payments for environmental services generated by livestock activity has not yet been established in Cuba, the research carried out by different authors on the subject could serve as a reference for laying the foundations and putting them into effect, thus encouraging this sector to contribute to the sustainable management of its processes.

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Conflict of interest:

Authors declare not to have any conflict of interest.

Authors' contribution:

The authors have participated in the writing of the paper and the analysis of the documents.