Scientific Paper

# Utilization index of renewable energy sources, associated to appropriate technologies in family farms in Cuba

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## Abstract

**Objective**: To conceive a measurement index of the utilization potential of renewable energy sources with appropriate technologies in 25 farms of Cuba.

**Materials and Methods**: A proposal was designed from the Delphi methodology, validated through Kendall's coefficient of concordance. The Utilization Index of Renewable Energy Sources was obtained, applied in the del Medio farm, in Sancti Spíritus province, Cuba, from a longitudinal study with three different stages (1995-2000; 2001-2006; 2007-2016).

**Results**: As consequence of the implementation of the Index, it was determined that the energy self-supply in this farm is 83,7 %. During 2016, other 24 representative farms, which stand out for their participation in processes of technological innovation and development of agroecology principles, were evaluated. The situation they show regarding the use of renewable energy sources was characterized. Their poor utilization (only 20 % in the best case scenario) was observed.

**Conclusions**: The analysis of the Utilization Index of Renewable Energy Sources in the del Medio farm showed that, from the use of appropriate technologies, the energy demand is supplied in 83,7 % with renewable energy sources.

**Keywords**: energy, agricultural farms, diversification, innovation

## Introduction

Historically, Cuban agriculture has stood out for depending on the imports of external inputs for agricultural production and overexploiting the soil and water resources, without valuing the optimum use of waste and cycle closing to increase the efficiency of processes. This has caused the degradation of 76 % of the agricultural soils (García *et al*., 2014), high production costs and loss of the feeding capacity in many communities, among other consequences.

However, in the Cuban agricultural model, family agriculture, with agroecological practices and diversification in its agricultural systems, produces more food per hectare than any other commercial farm of industrial agriculture. This modality generates most of the foodstuffs that are fundamental for the population: more than 75 of the food produced in Cuba (ONEI, 2017). In addition, it reaches yields per surface unit higher than those of conventional methods, with higher energy efficiency (Casimiro Rodríguez, 2016).

The different agroecological practices in these systems have preventive and multipurpose character. They are carried out with minimum dependence on agrochemicals, fossil fuels and energy subsidies, which leads to complex agricultural systems that autogenerate fertility and productivity (Nicholls *et al*., 2016). For such reason, agroecology is shown as the most viable option for agricultural production in the face of the current energy, climate and financial limitations (Nicholls *et al*., 2016; Gliessman, 2018). This type of alternative agriculture favors the small farmer's capacities, farmer knowledge and achievement of food, technological and energy sovereignty within a farm, territory or nation.

In this context, the use of renewable energy sources (RES) with appropriate technologies (AT) and contextualized in a socioecological system, is a key element to achieve the self-supply of foodstuffs with available local resources, and in turn contributes to the energy and productive efficiency on sustainable bases, to the decrease of costs and minimum dependence on external resources. These conditions

Received: July 11, 2019
Accepted: September 17, 2019

How to quote a paper: Rodríguez, Leidy Casimiro; Casimiro-González, J. A.; Suárez-Hernández, J.; Martín-Martín, G. J. & Rodríguez-Delgado, I. Utilization index of renewable energy sources, associated to appropriate technologies in family farms in Cuba. *Pastos y Forrajes*. 42 (4):237-245, 2019.

contribute directly to increase sociecological resilience and decrease the vulnerability of a farm to the effects of climate change or other events that can affect its capacity of permanence in time.

The objective of this research was to conceive an index to measure the utilization potential of renewable energy sources with appropriate technologies in 25 farms of Cuba.

## Materials and Methods

The proposal of measurement of the utilization Index of Renewable Energy Sources (UIRES) was stated in an assessment analysis in a panel of experts, constituted by 13 specialists on the topic. The Delphi methodology (Horrillo *et al*., 2016, figure 1) was used for this purpose. The first questionnaire was elaborated by the authors of the study and was evaluated by the panel. The criteria were processed through Kendall's coefficient of concordance (Medina *et al*., 2011). Once the index and its calculation form were defined, in order to gain experience the proposal was evaluated in the del Medio farm during three periods (1995-2000; 2001-2006 and 2007-2016). Afterwards, during 2016, it was implemented in 24 Cuban family farms, distributed in six provinces and 11 municipalities.

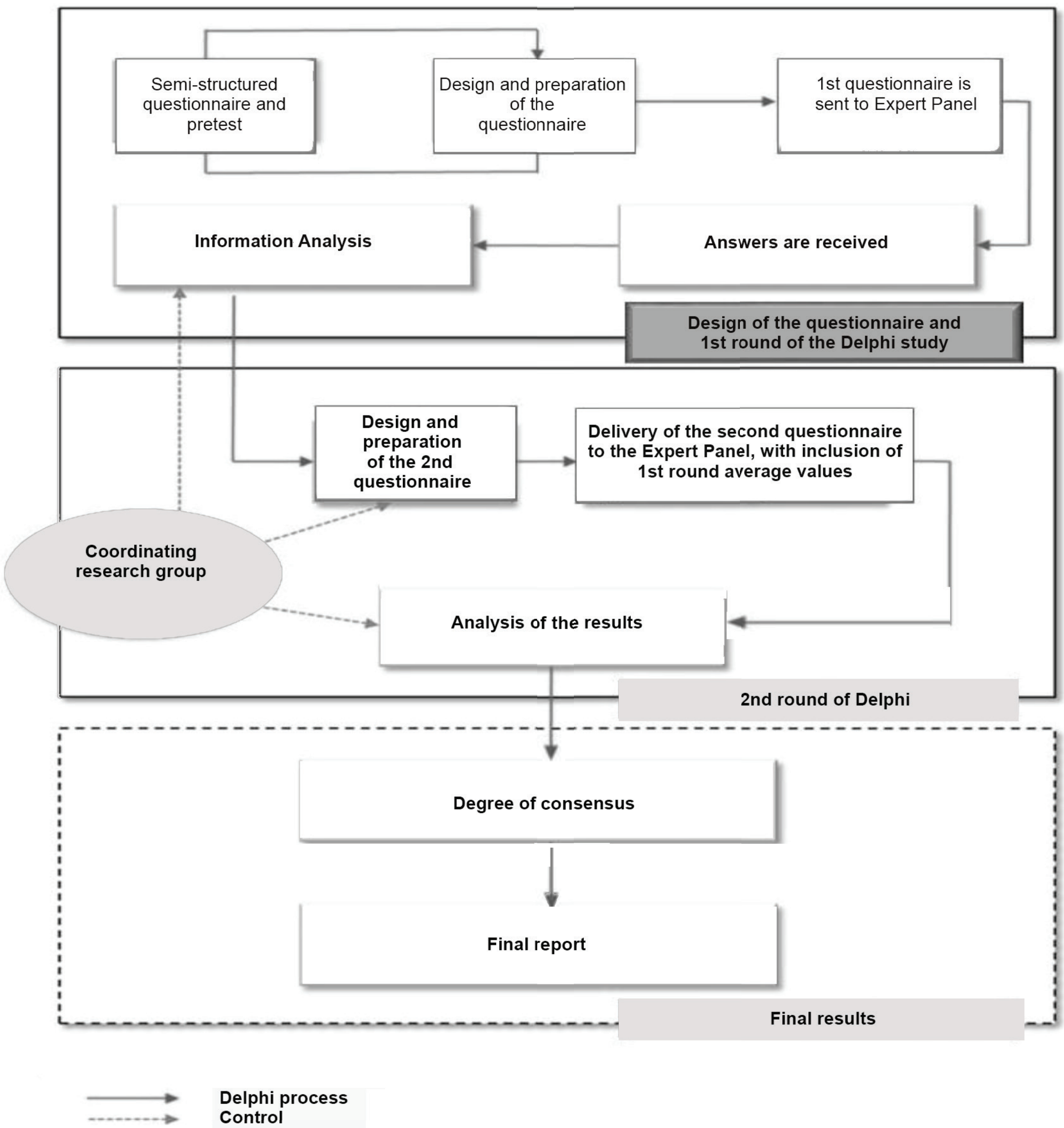


Figure 1. Delphi methodology
Source: Horrillo *et al*. (2016).

Through Kendall's method (Medina *et al*., 2011) the concordance among the opinions expressed by the panel of experts was verified. They were requested to emit their criterion with regards to the adequacy of the use of the index and thresholds, considered in their evaluation as very favorable and very little favorable.

The criterion for the selection of the 24 farms considered the outstanding community participation by each one of them in food production and the development of agroecological practices, articulated to the main local projects that were implemented in the last years in each territory.

In order to know the structure and functioning of the farms, the limits and surface (area) of the system, subsystems, their main interactions, as well as the inputs and outputs were described by using the information capture card proposed by Casimiro Rodríguez (2016).

The farms are in the Las Tunas, Holguín, Sancti Spíritus, Santa Clara, Matanzas and Mayabeque provinces. The selection criteria of the non-probabilistic sample (24 farms) were based on the representativeness of several provinces and municipalities, linked to the projects BIOMAS-CUBA[1] and PIAL[2]. They are farms under agroecological transition, with high heterogeneity among them, regarding the different diversity levels of crop, animal and forest species. Each farm represented a special case, because of its production purposes, market relations, management characteristics, soil and ownership types, among other aspects.

## Results and Discussion

After the experts' opinions, the notion of the importance of the utilization capacity of renewable energy sources (RES) from appropriate technologies, contextualized to a socioecological system, was reinforced.

Kendall's index of concordance was 0,59, for which there were coincident criteria among all the members that made up the panel. This allowed to consider the conducted study as reliable and to validate the proposal (Medina *et al*., 2011). Table 1 shows the assessment and calculation of the index.

UIRES is a new indicator, conditioned by the utilization potential of RES with technologies, *versus* the total energy demand of the system, expressed in kilowatts-hours. It is defined as the percentage of utilized energy in one year within the system with RES and the energy cost in kWh, which would lead to be equally supplied with this energy from electricity. The index is used as conceptual, methodological and practical basis for the proposal of technological alternatives, valid for each context, which allow the most efficient use of the available RES in each system.

The application of the index will permit, in the short term, to determine the utilization and use capacity of RES with AT, so that the identification of the critical points of the system design and management, as well as the establishment of strategic plans that improve the results in the future, is possible.

In the long term, and by means of periodical applications, the system progress and dynamics is shown. This will also contribute to develop effective processes in decision-making by farmers, who can adopt measures to improve the energy efficiency of renewable sources. Decision-makers will also have the possibility of elaborating agrarian policies that promote the use of appropriate technologies for the maximum utilization of solar, wind, water, photovoltaic and biomass energy, among others.

The agroecological transition process (1995 to 2015) in the del Medio farm, where the UIRES was first applied, allowed to observe three periods that were considerably differentiated, taking

Table 1. Utilization index of the renewable energy sources (UIRES), associated to appropriate technologies.

| | | | |
|---|---|---|---|
| Utilization indexes RES | Utilization potential of RES, associated to technologies, when considering the utilizable potential in the farm (%). | $UIRES=\frac{UPRES}{EDS} \times 100\ (\%)$<br>Where:<br>UPRES= Utilized potential of RES with appropriate technologies.<br>DES: Energy demand in the system. | Assessment scale♦<br>UIRES > 75 %; 5<br>75 % ≥ UIRES > 50 %;4<br>50 % ≥ UIRES >35 %; 3<br>35 % ≥ UIRES >20 %; 2<br>20 % ≥ UIRES =0; 1 |

♦Scale from 1 to 5, where 5 is the most favorable value and 1, the least favorable.

[1] International collaboration project funded by the Swiss Development and Cooperation Agency (SDC) and implemented in Cuba by the Pastures and Forages Research Station Indio Hatuey.

[2] Local Agricultural Innovation Program, Cuba, of the National Institute of Agricultural Sciences and funded by SDC.

into consideration the strategic projection of the farmer family and the design and management of the socioecological system. Thus, this study was focused on the transformation processes for each one of these periods:

- Period I (1995-2000): agricultural management based on practices and technological packages of conventional agriculture, use of agrochemicals, development of specialized monoculture, innovation and farmer experimentation processes throughout the longitudinal study.
- Period II (2001-2005): change of mentality, conception of agriculture focused on the introduction of agroecological practices, production diversification and use of organic fertilizers.
- Period III (2006-2016): agroecological management and design, use of appropriate technologies for the maximum utilization of RES and the available resources in the locality.

For the first two periods, in the UIRES evaluation, the minimum value (0) was obtained, because there were no ATs for the direct utilization of RES. Nevertheless, in the last stage, from the link with important research centers in Cuba, such as the Integrated Center of Appropriate Technologies (CITA, for its initials in Spanish) of Camagüey and the Pastures and Forages Research Station "Indio Hatuey", in addition to local development projects, new technologies that favored the use of RES (hydraulic rams, air pumps and biodigesters) were implemented and validated in the farm.

The UIRES, in the first two periods, showed the minimum values. However, it obtained in the third period 83,7 %, value that comes from the use of appropriate renewable energy sources. Table 2 shows the percentage of generated and utilized energy in the farm during one year. This number also shows the equivalent measurements in MJ and the energy cost (kWh) of supplying the farm with electrical energy from the national grid.

This analysis showed the effect of RES utilization on the saving of energy consumption and on minimizing the monetary costs. The contribution appropriate technologies can have in the development of agroecology with the use of locally available resources, was also proven.

During the process of experimentation, innovation and adoption of these technologies, the family observed in the local environment the absence of specialists in integral technological repair. This influenced the fact that its members became specialized in each one of these technologies, and that they obtained as a result 22 innovations in the system of hydraulic rams, besides contributing with CITA to the manufacturing of efficient equipment. In this period, studies related to the development of this technology in the region were also conducted. At the same time, with the air pumps a water capture system was obtained which improved the efficacy of the ram system. Additionally, new methods were implemented for the assembling and disassembling of air pumps with novel tools, which make these operations more rapid and efficient, and facilitate their maintenance in the case of storms, cyclones or strong winds. The improved designs for the construction of biodigesters and management of liquid and solid effluents are not excluded here.

The innovations showed the important function played by the processes of contextualization, adoption and improvement of scientific results. Likewise, they proved the importance of the links between the academic sector and this type of agriculture. The relevance of farmer innovation in its contribution to local rural development was also shown, which coincides with the report by Vázquez and Martínez (2015).

In the rainy season (May-October), the del Medio farm is supplied, as average, with 20 000 L per day of water, which are stored in deposits located in the high part of the farm through the utilization of hydraulic rams, placed in the dam, and an underground conduction system, which allows to carry the water to 400 m of distance and 18 meters high. This allows, later, with the use of the gravity force, to apply different irrigation techniques to the crops, supply the animals and guarantee domestic use, trying not to drag soil particles. It is important to emphasize that, if the gauge is performed in lower distances, the water availability is multiplied.

In the dry season (November-April), the water cycle is complemented in the farm with the two air pumps installed in artesian wells, which supply the system with 4 000 L per day, as average. The implementation of this infrastructure has allowed to generate a closed water cycle with designs carried out from the system itself. In the future, the use of other technologies, such as irrigation systems activated by photovoltaic cells and air pumps, is foreseen.

Constant water availability, although limited, favors optimum saving and utilization of the water resource, for which the culture of using it at the precise moment and in the required quantity is part of the socioecological design and management. In

Table 2. Generated and utilized energy in the farm in one year, with RES and the use of AT.

| Appropriate technology | Uses | Description | Expenses kWh /year | Equivalent in MJ |
|---|---|---|---|---|
| Efficient firewood cooker | Family food and feed cooking, fruit and spice dehydration, baking, water heating. | At a rate of 50 kWh per day | 18 250,0 | 65 700,0 |
| Biodigester | Production of biofertilizers and biogas for cooking, drying, dehydration, baking and refrigeration of food-stuffs, electricity generation and water heating. | Consumption of 6 m³ of biogas per day (1 m³ is approximately equivalent to 6 kWh). (Cepero *et al.*, 2012) | 13 140,0 | 47 304,0 |
| Hydraulic ram | Water supply | At a rate of 12 kWh per day for seven months of the year, during the 24 hours of day (June to December) | 2 568,0 | 9 244,8 |
| Air pump | Water supply | At a rate of 1 kWh per day for five months of the year, average four hours/day (January to May). | 151,0 | 543,6 |
| UPRES | Water supply, energy for cooking, food dehydration and baking, refrigeration and lighting, among others. | Utilized potential of the RES with appropriate technologies. | 34 109,0 (93,5 kWh /day) | 122 792,4 |
| Consumption of external energy | House electrification | It refers to energy imported in this phase, equivalent to the consumption for house electrification. | 6 660,000 (18,3 kWh /día) | 23 976,0 |
| EDS | UPRES+ Consumption of energy external to the system | Total energy demand in the system, considering the consumption (kilowatts) represented by supplying the farm from RES and AT (UPRES) and the consumption external to the system. | 40 769,0 | 146 768,4 |
| UIRES % | | UIRES=(UPRES/EDS)x100 | 83,7 | 83,7 |
| Equivalent in USD of UPRES | | The cost of 1 kWh delivered in Cuba is 0,211 USD (Cepero et al., 2012). | | 7 197,0 |

UIRES: Utilization index of the potential of renewable energy sources, RES: Renewable energy sources, UPRES: Utilized potential of RES with technologies, EDS: Energy demand of the system, AT: Appropriate technologies

addition, from a capture system, implemented on the roof of the houses, rainwater is utilized. This regime is part of the innovation processes generated by the family in their interaction with the agroecosystem.

The efficient cooker is a new technology designed in the farm (built and rebuilt 13 times, to take it to the maximum efficiency level). It has the capacity to perform several functions with little energy: food cooking, dehydration of fruits and spices, water heating and treatment for meat conservation, among others.

Two connected biodigesters propitiate the sufficient energy for the refrigeration, baking, cooking and dehydration of foodstuffs, with average consumption of 6 m³/day of biogas. These biodigesters produce biofertilizers from their effluents (650 kg/day), which are used in crop fertigation by gravity. This production of biofertilizers is complemented with 10 t of earthworm humus and 20 t of nutrient-rich sludge/year, which are extracted from the bottom of the dam in the dry season.

Biofertilizers are used for the nutrition of different crops through the fertilization of the agricultural areas of the farm, which allows to restore the soil natural fertility. In this farm, the farmer family applies the principle that for each kilogram off foodstuff obtained, 5 kg of organic fertilizer should be contributed.

In the evaluation carried out on 24 farms from other municipalities and provinces, high heterogeneity was observed: although some common traits stood out:

- The farmer family lives in the productive system and constitutes, fundamentally, the labor.
- The farmer family supplies themselves with foodstuffs in more than 75 %, as average.
- The farmer family is incorporated to different mass organizations and to the Cooperatives of Credits and Services (CCS)[3]
- Animal husbandry and agriculture are associated (to a higher or lower degree).
- The presence of AT for the utilization of FRES is scarce.
- The access to agricultural inputs is poor, due to their cost and the low offer. In the local environment there is absence of specialists in services of technological installation or repair.

Table 3 shows the characterization of the other farms, regarding the area, social object and evolution of the agroecological transition, in addition to the UIRES.

The utilization of RES was more efficient in the farms that have biodigesters and air pumps, which allows to use biogas for food cooking and refrigeration, and utilize the benefits of wind energy for water supply to the family and the animals. The most significant value in the utilization of RES was obtained by the Los Pinos farm. In the farms with zero value, the worst performance for this indicator was shown, which is due to the fact that the RES are not utilized with ATs.

In general, in all the farms the RES potential is wasted, to which the inexistence in the national market of appropriate technologies and resources for their installation, starting up and maintenance, contributes. This is in addition to the high acquisition cost of technologies that are commercialized in Cuba, which prevents the access by the farmer families.

In studies conducted by Casimiro (2016), it was determined that the family farms under agroecological transition have favorable indexes of innovation, technological change capacity and local articulation. This was shown in the field trips and interviews to the farmer families who have created their own technologies or made innovations in technologies from locally available resources. Her results have been presented in regional forums of science and technology, in experience exchange with the Farmer to Farmer methodology, led by the National Association of Small Farmers (ANAP). These farms also have links with local development projects and are acknowledged as agroecological beacons. They constitute spaces for carrying out practices and studies with different universities. These elements are fundamental to assimilate, by the families, new designs and technologies that contribute to the utilization of RES.

All the above-stated facts favor the empowerment of families and gender approach (Ravera *et al*., 2016). To this, such projects as BIOMAS-CUBA and PIAL contribute, reinforcing the effective link with research centers, universities and agreement spaces through the municipal platforms. This link allows capacity building and adoption of new technologies, among other processes that facilitate agroecological reconversion (Vázquez and Martínez, 2015), mainly due to the constant interaction in training and exchange processes, as well as to the access to new technologies from the support of national and international organisms. Efficiency evaluation, systematization of good practices, design and redesign of strategies in the farms to increase their resilience, are also included.

In the 24 farms the utilization of RES with appropriate technologies must be increased for the use of solar, hydraulic, wind and biomass utilization energies and thus decrease the entrance of external inputs, mainly conventional energy for crop irrigation. This would also contribute to increase the efficiency of family work and to add value to their productions, so that product diversity can be increased, the production processes in the farm are extended and, consequently, higher economic profits are obtained.

It is necessary to establish a redesign strategy in which the farmer families and the different actors

[3] CCSs constitute a cooperative form of agricultural management, formed by the farms of small farmers who are voluntarily associated and have the ownership or usufruct of their respective lands and other production means, as well as the production they obtain. It is an agrarian cooperation form through which the technical, financial and material assistance the State provides for small farmers' production and commercialization of their products, is arranged and made viable. It has its own juridical personality.

Table 3. Performance of the UIRES in the 24 evaluated family farms (year 2016).

| Province | Municipality | Name of the farm | Area, ha | Social object | Appropriate technologies vs RES | Evolution of the AT♦ | UIRES |
|---|---|---|---|---|---|---|---|
| Mayabeque | San José | El Mulato | 14,5 | Staple crops | - | 3 | 0 |
| Matanzas | Jovellanos | La Coincidencia | 23,0 | Staple crops | B, WM | 3 | 15 |
| | Perico | La Palma | 13,4 | Cattle | - | 3 | 0 |
| | Perico | Mercedita | 5,1 | Fruits | - | 3 | 0 |
| | Calimete | La Arboleda | 7,0 | Staple crops | WM | 3 | 5 |
| | Calimete | Godínez | 3,5 | Pigs | B | 2 | 15 |
| | Colón | Huerto Escolar | 13,4 | Cattle | - | 2 | 0 |
| | Colón | La Quinta | 33,0 | Cattle | B | 3 | 15 |
| | Colón | La Cantera | 3,0 | Staple crops | - | 4 | 0 |
| Santa Clara, Guamuhaya mountain range | Manicaragua | El Piñal | 0,6 | Coffee | - | 3 | 0 |
| | Manicaragua | Salvaremos el futuro | 17,0 | Coffee | - | 5 | 0 |
| | Manicaragua | El Girasol | 2,5 | Coffee | - | 4 | 0 |
| Sancti Spíritus | Cabaiguán | Flor del Cayo | 9,6 | Tobacco | B | 3 | 15 |
| | Cabaiguán | Las Dos Rosas | 12,4 | Tobacco | B | 3 | 15 |
| | Sancti Spíritus | San José | 9,2 | Tobacco | B | 4 | 15 |
| Sancti Spíritus Guamuhaya mountain range | Trinidad | La Cuba | 6,4 | Coffee | - | 3 | 0 |
| | Trinidad | La Providencia | 26,0 | Coffee | - | 3 | 0 |
| | Trinidad | El Manantial | 2,0 | Coffee | - | 4 | 0 |
| | Trinidad | Mangos Pelones | 8,3 | Coffee | - | 3 | 0 |
| | Trinidad | El Jengibre | 3,0 | Coffee | - | 3 | 0 |
| | Trinidad | Orlando García | 4,0 | Coffee | - | 3 | 0 |
| Holguín | Gibara | Santa Ana | 5,0 | Staple crops | B | 5 | 15 |
| Las Tunas | Manatí | Los Pinos | 19,1 | Staple crops | B, WM | 3 | 20 |
| | Las Tunas | Recompensa | 9,0 | Pigs | B | 2 | 15 |

UIRES: Utilization index of the potential of renewable energy sources, RES: Renewable energy sources, AT: Appropriate technologies, B=Biodigesters; WM=Wind mills.

♦Evolution of the AT: 1-Fully conventional agriculture; 2-Development of some agroecological practices; 3-Development of agroecological practices, combined with the use of agrochemicals and external concentrate feeds; 4-Agroecological design and management prevail, although they use some agrochemicals and external concentrate feeds; 5-Total agroecological management and design.

and decision-makers (local and national) participate around the development of energetically efficient agriculture, with the use of RES. This strategy will contribute to the substitution of imports, system resilience and to increase the economic and productive efficiency, by depending on energy that is always available. Likewise, it will establish the closing of cycles and functional interrelations with each agroecosystem component. Arguments like these coincide with the criteria expressed by Darnhofer (2014), Cruz and Cabrera (2015) and Darnhofer *et al*. (2016).

The farms that have biodigester should make an efficient use of the total produced biogas and of the liquid and solid effluents for fertilizing the different crops. In the farms where it is not fully used, the BIOMAS-CUBA project (Stage III) elaborates strategies for the development of biogas distribution networks that would benefit houses close to the farms. Likewise, it designs production models of organic fertilizers, aimed at the self-supply and commercialization of the surplus production.

The diverse actors of the Cuban institutions involved in this strategy must pay special attention to the promotion of the technologies that have incidence on the efficiency of agricultural farms in all their aspects (energy, economic, environmental, sociopolitical, and cultural). From this perspective, the country would stop granting subsidies for house electrification and use of fossil fuels in agricultural production, among other advantages. These resources could be used for the contextualization of several technologies in the farms, such as photovoltaic panels for electricity generation and irrigation, air pumps for the use of wind energy in water supply and the construction of biodigesters, among others. Such technologies would contribute to the total independence from conventional energy consumption in the farmers' houses and would increase electricity saving in Cuba.

These elements will allow family farmers to manage holistically, with valid technological options for each context, the resources they have in their environment, incorporating collective and participatory actions. However, to guarantee these results, improving the public policies that favor their progressive development is required, in agreement with the report by González-de-Molina (2013).

## Conclusions

The analysis of the Utilization Index of Renewable Energy Sources in the del Medio farm proved that, from the use of appropriate technologies, the energy demand is supplied in 83,7 % with RES.

The UIRES is a tool used to evaluate in a family farm the utilization potential of RES with technologies *versus* the total energy demand of the system, expressed in kilowatts-hours.

## Acknowledgements

The authors thank the international cooperation project BIOMAS-CUBA, of the Pastures and Forages Research Station "Indio Hatuey", which has benefitted a great part of the studied farms, providing them with biodigesters and air pumps, technologies that have increased the use and efficiency of energy sources and quality of life of the farmer families.

## Authors' contribution

- Leidy Casimiro Rodríguez: Contributed to the conception and design; to data analysis and interpretation and wrote and/or revised the paper.
- José Antonio Casimiro González: Contributed to the conception and design; to data analysis and interpretation and wrote and/or revised the paper.
- Jesús Suárez Hernández: Contributed to the conception and design; to data analysis and interpretation and wrote and/or revised the paper.
- Giraldo Jesús Martín Martín: Contributed to the conception and design; to data analysis and interpretation and wrote and/or revised the paper.
- Irán Rodríguez Delgado: Contributed to the conception and design; to data analysis and interpretation and wrote and/or revised the paper.

## Conflict of interests

The authors declare that there is no conflict of interests.

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