Energy transition for rural development: A preliminary case study in Colombia for improving artisanal fishing

Transición energética para el desarrollo rural: Un caso de estudio preliminar en Colombia para mejorar la pesca artesanal

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***Abstract*— According to the Food and Agriculture Organization of the United Nations (FAO), artisanal fishing involves the use of small fishing vessels for short fishing trips aimed at capturing fish for consumption and local marketing. This process requires energy at various stages, from boat navigation to refrigeration for storage. The energy used in this process typically comes from fossil fuels, which has environmental impacts due to the carbon footprint of the boats. Additionally, the lack of economic resources to purchase the necessary fuel for the engines hampers the daily work of fishermen. The International Renewable Energy Agency (IRENA) defines energy transition as the pathway towards transforming the global energy sector from fossil-based to zero-carbon by the second half of this century. The energy transition aims to decarbonize the economy and offers opportunities to reduce dependence on fossil fuels. This paper reviews essential concepts for understanding the process of reducing fossil fuel consumption in fishing operations from the perspective of energy transition. Technological, environmental, and socio-economic factors are considered to promote responsible fishing in rural coastal areas of Colombia. A case study in the municipality of Guapi (province of Cauca, Colombia) is examined.**

***Index Terms*— Artisanal fishing, Decarbonization, Energy Transition, Renewable energy.**

***Resumen*— Según la Organización de las Naciones Unidas para la Agricultura y la Alimentación, la pesca artesanal se relaciona con el uso de pequeñas embarcaciones pesqueras para viajes cortos de pesca dedicados a capturar pescado para su consumo y también para la comercialización local. Se trata de un proceso que requiere el uso de energía en sus diferentes fases, desde el barco para la navegación hasta el centro de refrigeración para el almacenamiento. La energía utilizada para este proceso normalmente proviene de combustibles fósiles, lo que genera un impacto desde el punto de vista ambiental por la huella dejada por las embarcaciones, sumado a la falta de recursos económicos para la compra de combustible requerido por los motores, obstaculizando el trabajo diario de los pescadores. La Agencia Internacional de Energías Renovables define la transición energética como el camino hacia la transformación del sector energético mundial de base fósil a cero carbono para la segunda mitad de este siglo. La transición energética busca la descarbonización de la economía y ofrece oportunidades para reducir la dependencia de los combustibles fósiles. Este artículo revisa algunos conceptos básicos necesarios para entender el proceso de reducción del consumo de combustibles fósiles en las operaciones pesqueras desde la perspectiva de la transición energética. Se consideran factores tecnológicos, ambientales y socioeconómicos para promover la pesca responsable en las zonas costeras rurales de Colombia. Es considerado un caso de estudio en el municipio de Guapi (departamento del Cauca, Colombia).**

***Palabras claves*—Pesca artesanal, descarbonización, transición energética, energía renovable.**

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I. INTRODUCTION

IN recent years, rural areas have become significant problems in terms of productivity and social wellbeing. There is a large technological gap between rural and urban areas and this has challenged the development of regions where social indicators are low [1],[2]. One of the main social and productive activities in rural areas in Colombia is artisanal fishing. Many people depend on this sector but unfortunately they do not have sufficient means to optimize the process of capturing and marketing fish. This activity continues to be a process that relies heavily on the use of fossil fuels in different stages, from the mobility of the small vessels that require an internal combustion engine up to the fish storage in local refrigeration centers [3].

According to the Food and Agriculture Organization of the United Nations (FAO), the artisanal fishing can be defined as the traditional activity involving fishing households using relatively small amount of capital and energy, relatively small fishing vessels, making short fishing trips, close to shore, and devoting their capture mainly for local consumption [4]. The main obstacle for achieving carbon neutrality in fishing process is that some of the energy end-uses of industrial and transportation sectors cannot easily be achieved through electrification or the use of renewable energies. Renewable resources available on rivers and oceans, such as wind, waves and solar energy, can be used to improve transport technology and make it clean, ecological and sustainable [5]. Since the energy produced by these sources is not constant at all times due to the climatic conditions of the zone, they can be incorporated together to have a reliable hybrid system operating within the set values [6], [7]. The vast majority of solutions are monoenergetic. For example, in Cauca Department vessels are used mainly for maritime and river mobility being a key part for rural transportation and developing economic activities such as traditional fishing. However, the use of fossil fuels for propulsion, leads to problems such as depletion of natural resources, environmental damage due to poor maintenance of these vessels and the lack of resources for improving the boats [8]. Based on the above, some solutions have been implemented using clean energy sources that replace conventional ones without affecting the efficiency, economy, and safety of people using these means of transportation [9].

A hybrid generation system based on non-conventional energy sources for marine and river electric mobility, is characterized by the manner it keeps its frequency under fluctuations in the power generated load demands, and also guarantees the coverage of demand [10],[11]. Hybrid generation systems are generally built in such a way that the benefits of individual sources can be exploited [12]. This creates the need to use a good electrical energy storage system in order to contribute significantly to the stability and reliability of the system [13].

In a hybrid system, it is essential to manage the flow of energy between the different components, a strategy is needed to control the system's power exchanges and also to regulate the loading and unloading process of the storage unit [14]. A marine hybrid energy system consisting of a diesel generator, solar energy, a battery and a supercapacitor is proposed in [15], and a mathematical model of solar power generation in oceanic conditions is established. The performance characteristics of the solar output power and the optimum capacity of the supercapacitor are analyzed. For the design of the generation system in [16] a detailed proposal was presented making use of solar energy and thermal energy as a means of propulsion, taking into account safe installations for passengers. Some of the disadvantages in hybrid generation systems based on non-convention energy sources for the development of vessels are due to the influence of the movement of the vessel, which leads to fluctuations in the power of the system, in addition to those already caused by climatic factors due to the stochastic nature of these sources. Another disadvantage of hybrid generation systems is their low sustainability, which is even more noticeable when these types of systems are handled directly by people who do not have minimal technical knowledge about the characteristics of these devices, although this condition can be solved by a proper monitored training [1]. It is under these circumstances that multicriterate analysis takes importance and it is necessary to consider elements such as the maturity of the technology, ease of use, operating and maintenance costs, among other elements that do not only depend on the availability of the primary resource.

Energy transition is increasingly regarded as a promising opportunity for the economic development of rural areas and becomes an alternative to lower costs and increase the productivity of Marine Small-Scale Fisheries, Food Security and Poverty Alleviation. Renewable energy and energy efficiency measures can potentially achieve 90% of the required carbon reductions [17]. This paper proposes a strategy based on the concept of energy transition to reduce the use of fossil fuels in the development of artisanal fishing, in dialogue with fishermen local knowledge.

II. Renewable Energy and rural development

In recent years, Colombia has been increasingly installing its capacity of using renewable energies in different sectors. In 2018, Colombia had only two renewable energy parks: a solar farm in the municipality of Yumbo in Department of Valle del Cauca, and a wind farm in the Department of Guajira in the north of Colombia. These two parks produce no more than 30 MW. Since the implementation of the Law 1715 issued in 2014, some modifications have been made that include tax incentives and regulatory adjustments to promote the use of non-conventional energy sources, which led the country to install more than 10 solar farms by 2020, with projects totaling about 225 MW [18],[19]. This promising scenario generates a great expectation for the decarbonization of the economy, universal access to energy, and promoting social development in regions where there is no permanent access to energy [20].

A. *Potentiality of Renewable Energy Sources (RES)*

Colombia presents a high energy potential that is usable when government agencies provide the different instruments that allow the development of different technologies such as wind, solar, geothermal, biomass, among others [21]. The participation of these energy sources does not contribute significantly to the National Interconnected System (NIS). At the end of 2019, the effective capacity of NIS was 17,462.34 MW, where 30.75% is generated by non-renewable energy sources and 69.25% by renewable energy sources, of which only 1% corresponds to non-conventional renewable energy sources, with 0.11% biomass, 0.80% wind and 0.10% solar [22]. In Colombia in 2018, the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM) published the new version of the Climatological Atlas, Radiation and

Wind with a history of information from 1981 to 2010, an official document where the values of the country's energy resources are saved. The solar irradiation in Colombia has an average of 4.5 kWh/m^2 per day, a value that exceeds the estimated world average of 3.9 kWh/m^2 per day, in addition to localized winds with average speeds of about 9 m/s at 80 m height [23]. However, the Atlas also shows the lack of particular and detailed data for large areas of the country, which represent most of the non-interconnected zones [24]. Colombia's strategic geographical position in the southern hemisphere allows the country to have broad coasts on the Atlantic and Pacific oceans, whose line extension is about 3,531 km, and Colombian maritime areas represent 45% of the national territory. From this perspective, Colombia has a great potential for the exploitation of the primary resource from the oceans. According to the UPME, a potential for the coasts of 30 GW is estimated with respect to the energy of the waves and a potential for tidal energy in the Colombian Pacific of 500 MW.

B. Energy Poverty in Colombia

Although the political constitution of Colombia in the article 365 defines the obligation of the state to ensure the efficient delivery of public services to all inhabitants of the national territory, in Colombia approximately 52% of the territory corresponds to non-interconnected zones (NIZ), which characterized by not having permanent access to energy. In order to cover the needs and supply energy, the NIZ has generation sources with a total operational capacity of 288.206,62KW (271,866.62 KW of diesel capacity and 16,340 KW of renewable energy capacity). In this sense, it is noticeable that conventional energy sources represent the highest percentage of operational capacity of NIZs, which requires a solution that provides reliable, consistent, quality and environmentally sustainable service; this involves assessing the feasibility of increasing the installed capacity of renewable energy sources by ensuring that generation costs are affordable to users in those areas.

On the other hand, the result of the last Electricity Coverage Index 2018 (ICEE), which takes as its main source of information the National Census of Population and Housing 2018 (CNPV) of the National Administrative Department of Statistics (DANE), showed that the percentage of ICEE for Colombia is 96.44%, representing 505,981 non-energy housing units, of which 53,461 are in urban areas and 452,520 in rural areas, with rural coverage being 12 percentage points lower than urban coverage. Fig. 1 presents the distribution of ICEE in Colombia.

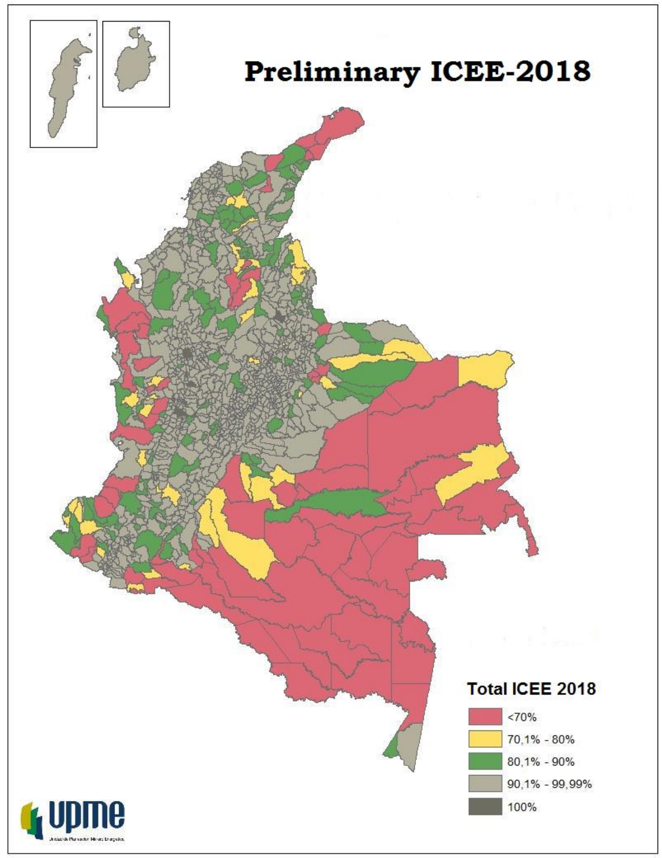

Fig. 1. Map of the preliminary total ICEE 2018 at the municipality level [25].

The limited access of energy in NIZs have affected negatively the quality of life of the inhabitants and has highlighted the existence of energy poverty. The Human Development Index (HDI) is related to energy consumption [26], and together with the ICEE, it is essential for government-led actions to reach the Sustainable Development Goals (SDGs).

Considering the above, the national energy plan 2020-2050, established as the first objective ``to allow universal access to reliable, quality-standard, and affordable energy solutions” by proposing as an indicator of follow-up to that objective the Energy Equity Index of the Energy Trilemma of the World Energy Council. The trilemma seeks to qualify countries in their ability to provide sustainable energy in three aspects: Energy security, energy equity and environmental sustainability, Colombia is ranking in the position number 36 out of a total of 101 countries.

C. Transportation sector energy consumption in Colombia

The Colombian Energy Balance describes that by 2018 the final energy consumption of the country was 1,308 PJ, where the transport sector was the main energy consumer representing 40% (524 PJ) of total consumption, 22% (293 PJ) the industrial sector, 20% (263 PJ) in the residential sector, 6% (71 PJ) in the commercial and public sector and other sectors with 12% (157 PJ) [27].

The main source used in the transport sector is fossil fuels with a 91% share, with ACPM and gasoline being the most important source of energy in the sector; natural gas and biofuels with a share of 3% and 6% respectively, while electricity consumption has the lowest share (0.07%).

The transport sector, having a greater participation in the final energy consumption, also represents greater potential for improving energy efficiency, since according to the results of the Balance of Useful Energy (BUE), only 24% of the energy consumed in this sector is really useful energy. The potential for efficiency improvement for this sector, by adopting the best technologies available in Colombia, would be around 50%, representing a saving potential of $3,426 billion per year. While adopting the best available technologies internationally, the potential for efficiency improvement would be around 75%, representing savings potential in the order of $5,997 billion per year [28].

III. Energy in the fishing sector

The fishing community states that the main cost of operating their work is the acquisition of gasoline. To improve this, the replacement of the energy source is proposed to propel vessels, where their new source is renewable and cheaper, as well as implementing safety systems at sea and improving ergonomics in their fishing journeys. Currently, the small vessels used in fishing operations in Colombia depend 100% on fossil fuels and it is common to see small vessels like the ones shown in Fig. 2. In addition, it is considered essential to study and analyze the value chain of fishing to seek improvements opportunities in it.

Fig. 2. View of the port of Guapi, august 2021

The fisheries sector in Colombia makes a small contribution to the country's Gross Domestic Product (GDP), and a decreasing trend in its contribution has been shown, since 2009 had a share of 0.18% of total GDP and 2.66% of agricultural GDP, in 2018, its share of national economic growth was 0.17%, and in the sector, 2.68% [3]. This sector generates employment, income and food in rural areas where economic opportunities are scarce. In the area of employment, according to the 2019-2020 accounting report of the Ministry of Agriculture and Rural Development, the fisheries and aquaculture sector provides approximately 423,135 jobs, including artisanal fishermen, direct employment generated in the other fishing activities, as well as indirect employment of persons involved in the processing, transformation, marketing of products, construction, repair and maintenance of vessels [29],[30]. This data has not changed significantly since 2011, demonstrating a critical lack of data to understand the sector's contribution to employment, value generation, poverty reduction, and food security [31].

According to data taken from the DANE household survey in 2013, the population related to the fisheries and aquaculture sector was 1,439,778, of which 89% are male and 11.2% female; of this total, 68% live in the rural sector and 32% live in urban areas. More than half (52.7%) of those engaged in fishing, fish production in fish farms and fish farms, and fishing-related service activities are considered to reach only the primary level of basic education, while 17.8% are illiterate. However, the sector plays an important role in the local economy of the poor coastal and rural regions of the country, requiring greater investment, export diversification and implementation of projects that boost productivity and competitiveness [31],[32].

A. *Socioeconomic description*

In this paper, it is considered a particular case in the municipality of Guapi, located at the pacific coast in Cauca province. The main economic activities, in terms of employment generation, income and energizing local economies, are currently fishing, mining-traditional, coconut, artisanal sectors and basic local commerce and services.

Around 80% of the families of the municipality depend on fishing and agriculture, because their income depends on the work they do daily, but they do not have logistic, financial or services support [33]. The municipality of Guapi was added to the National Interconnected System in 2018, thanks to the “All We Are Peace Plan”, also known as Plan Pazifico, of the national government. Although this project has changed the lives of the Guapi’s people as they have a constant energy supply during the day, months after the project was delivered, intermittency problems began to occur in the connection network between Popayán and Guapi, and the response time to solve the faults has been too slow because the length of the electrical network (a little more than 200 km) and the difficulty of accessing the area. The Fishing technology is based on traditional local knowledge and methods such as manual techniques.

B. *Fishing organization and infrastructure*

Servipesca, Renacer progresista guapireño and Asociación

Nueva Bella vista, are integrated by a total of 46 people, from which 16 are women and 30 men. Fishing activities are male mainly, however women are integrated in the whole value chain, supporting fishing journeys by assuming housing roles while their partners are absenting. Furthermore, this type of organization is based on kinship. Although the project is focused on three pilot organizations, others will be benefited from the results. Participating organizations are described in Table I.

TABLE I
PARTICIPATING FISHING ORGANIZATIONS IN GUAPI

Organization's name	Women	Men	Total
Servipesca	9	11	20
Renacer progresista guapireño	2	9	11
Asociación Nueva Bella Vista	5	10	15
Total	16	30	46

The fishing performed are handmade and manual. The craft consists of the use of "chinchorros" meshes, lightning rods and hooks. The manual method is done with "catanga" and crab trap. The Nueva Bella Vista is integrated by indigenous group Eperara siapidara and their crafts for fishing is different from the other two integrated by afrodescendants and creole people. The boats they use are made of wood and fiberglass, with an outboard motor and powered by rowing and small engines of 15 HP (Horse power). Fishing can go from one to five days. According to information gathered in the field by the social team of the University of Cauca, the costs of the fishing operations are identified. These data were obtained according to a fishing journey ("faena") that corresponds to a 4-day trip at sea for fishing. It can be seen in Fig. 3 that the cost of greater incidence (62%) on the entire fishing operation is fuel consumption. It is important to note that the price of fuel in Guapi is 16% higher compared to most areas of the country, this is because the municipality of Guapi does not have access roads and therefore must be by sea from the port of Buenaventura in the Province of Valle del Cauca.

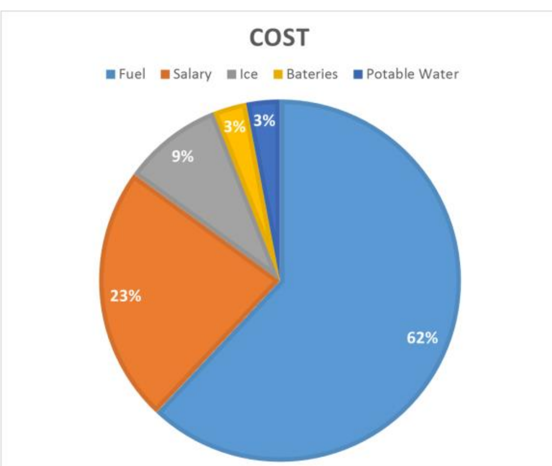

Fig. 3. Fishing cost, Source: Econavipesca Project, 2020

IV. RESULTS

Based on the fieldwork and the information provided by the community, the combustion of gasoline generates approximately 2.3 kg of C02 per liter consumed. On average, according to fishermen, about 10 gallons of gasoline are consumed daily per boat. To determine the number of boats, present in the municipality of Guapi and their frequency of operation, a detailed study is required, but it is estimated that about 100 vessels are mobilized per day, which would generate about 8705 kg of CO2 daily emitted to the environment. Additionally, as a result of localized but permanent discharges of fuel in storage and handling, soils and water sources are affected. After analyzing the information presented and considering the concept of energy transition, the following solutions are proposed to implement which will be executed within the ``Pacific Econavipesca project: Ecosystem for sustainable fishing navigation in the municipality of Guapi, Cauca".

- Fuel: To substitute partially or completely the use of fossil fuels due to its negative impact on the environment. Also, since the use of gasoline is the main factor that affects the low profitability of the fishing business for this purpose, energy from Renewable sources is considered to replace fossil fuel.
- Telecommunications: To implement a communication system between the vessel and the continent in order to strengthen the safety conditions that occur in fishing operations.
- Lighting: Installation of a lighting system on the boat that allows to increase safety at nighttime on the sea.
- Ice storage: Improving the efficiency of ice storage systems inside the vessel, replacing the purchase of ice that increases costs in fishing operations.
- Water desalination: To evaluate the implementation of a water desalination plant for the consumption of the crew during their stay at sea, thus avoiding the purchase of fresh water bottles.
- Operation conditions: To diagnose and analyze the operating conditions to which the vessels will be subjected to complement the design of the new solutions. The conditions to which this item refers correspond to the study of the sea and the river (currents, waves, temperature, etc.) and the solar potential of the area (solar peak hours, radiation by area).

It is important to highlight that the boat should be designed under reliability-based design methodologies since they should mitigate to the maximum or ideally eliminate any risk present in fishing conditions. And finally, an asset management must be delivered over time and its study of profitability over time, since the community must be able to multiply this model without relying on external institutions.

A. Technology

The propulsion system of the boat is proposed by using renewable energy sources with the aim of improving the profitability of the fishing business and reducing the environmental impact generated by the current fossil fuel system, and the implementation of a telecommunication system to improve safety during the deep sea fishing journeys. In parallel, it is equally important in this proposal to generate empowerment strategies of the participating artisanal fishermen organizations with respect to the model and management of the fishing business, developing a mindset of self-efficacy and productive entrepreneurship in the local community.

B. Finance-Funding

Another factor that can be mitigated is the cost of acquiring ice (9%) for fish storage. It is estimated that after four "faenas" per month, the owner of the vessel has $350,000 COP (Colombian pesos) in utility. They pay $210,000 COP to each crew member. If the owner of the boat is a fisherman, he will have a monthly income of $560,000 COP, which corresponds to 68% of the Colombian legal minimum wage in force for the year 2019. With this income one can check the reason for the low quality of life and conditions of poverty of the community of Guapi. So, one key contribution of the project will be the reduction of costs per fishing journey, an activity which is highly hazardous.

C. Interdisciplinary and cooperative research

Given the complexities of this initiative, it demands a cross cultural interaction amongst different disciplines and local people. Ensuring a cooperative, comprehensive and intercultural dialogue is a key factor to reach main objectives. An intercultural experience where scientific and local knowledge encounter will provide a better condition for appropriating and making sustainable the outcomes.

V. CONCLUSIONS

In this paper, a set of solutions aimed at reducing the use of fossil fuels for the mobility of artisanal fishing vessels have been presented. Technical, social, environmental, and economic factors have been considered so that the proposal is more feasible. The proposed strategies are a preliminary solution that will be validated with a set of three local organizations under actual operating conditions.

Different definitions can be found about the concept of the energy transition, and what they all agree on is basically that a path must be drawn toward the transformation of the energy sector to reduce the use of fossil fuels to a level of zero emissions for energy production, and they are set as a target the second half of this century. In Colombia, the outlook is that, by 2030, 25% of the energy matrix would be based on non-conventional energies reducing CO2 emissions in 22.5%. To achieve this, all economic sectors must be involved and seek the feasibility of the proposed alternatives. At the same time, a collective effort between researchers (interdisciplinarity) and local communities is needed. Valuing local knowledge in dialogue with science is a precondition to reach the main objectives of the projects in using local resources for improving traditional fishering.

Finally, it is appropriate to link the issue of energy transition in Colombia to reducing energy poverty, how the use of new technologies eliminates dependence on fossil fuels in isolated areas where the cost is higher and the impact of not having quality service and continuous energy decreases the progress of the regions.

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