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Review article

Commercial potential of linear Fresnel solar collectors in the industrial sector of Ecuador: preliminary assessment

Nathaly Cartuche Cojitambo[1], Margarita M. Redina[1], Jesus López Villada[2], Rafael Soria Peñafiel[2]

[1]Peoples' Friendship University of Russia (RUDN University)
8 Podolskoye shosse, bldg. 5, Moscow, 115093, Russian Federation
[2]The National Polytechnic School
Ladrón de Guevara Ave., E11-253, Quito, 170517, Republic of Ecuador

Abstract. One of the crucial challenges faced by industry has been finding approaches that meet its increasing energy demand and decreasing reliance on non-renewable sources. Ecuadorian policies promote the use of renewable sources of energy; nevertheless, there is limited research on concentrated solar energy in the country. Therefore, this review article presents an overview on previous research on the description of linear Fresnel collectors for solar heat for industrial processes, promising Ecuadorian industrial branches for its application, and the solar resource available for this purpose in Ecuador. As a result of existing literature analysis, the manufacturing industry may be a key sector for the application of this technology, which could reduce the use of conventional energy sources, especially in the food industry located in the Andean region. The outcomes will contribute to future thorough research on the topic.

Keywords: concentrated solar energy; linear Fresnel collectors; direct normal irradiance; solar heat for industrial processes; industry; Ecuador

Introduction

Industry consumes about one-third of the total energy utilised in the world [1; 2]. Heat is responsible for three-quarters of industrial energy demand, and fifty per cent of it is of low to medium temperature [3]. Current heating systems for industrial process heat depend on steam, as well as on hot water, produced basically in boilers, which predominantly uses fossil fuel or electricity [4]. Nevertheless, heat for common industrial requirements may be supplied by concentrated solar systems such as linear Fresnel collectors (LFCs) and parabolic trough collectors (PTCs) [5]. As a matter of fact, to expand the energy matrix based on renewable energies, and to enhance scientific research on this field are goals aligned with the Ecuadorian policies. However, there is limited investigation on concentrated solar energy in the country, and consequently, it has not been applied yet by industry.

This review article provides information on promising industrial sectors that could use linear Fresnel collectors for solar heat for industrial processes (SHIP) in the continental region of Ecuador. The outcomes will contribute to forthcoming techno-economic studies.

Existing literature on LFCs for SHIP was analysed, which has been carried out as well for the work developed by [6]. First of all, it was necessary to recognise the advantages and disadvantages of LFCs. Then, reliable sources of information such as the Global Solar Atlas [7] and the NSRDB Data Base [8] provided data on the solar resource in Ecuador. At the same time, the most incident industrial sectors of the country and their location were identified, through the review of available statistical reports [9; 10]. Finally, current Ecuadorian policies and legislation on renewable energy were underlined.

Linear Fresnel collectors

Table 1 shows the drawbacks and benefits of LFCs, in comparison with other concentrated solar technologies, discussed in articles and reports related to the topic.

Table 1

Disadvantages and advantages of LFCs [11–14]

Disadvantages	Advantages
The implementation of tracking devices increases financial and maintenance resources	Compared to other types of solar fields, this technology is simple, compact and cheap. It has a lower investment cost and a payback period
The direct normal irradiance depends, among other factors, on the geographical location	Efficiency in the available land use, for its implementation. It offers a multiple land use too; for example, agriculture could make use of the semi-shaded space under the LFCs
The mirror rows shade each other at high transversal incidence angles	Absorber tubes and collectors can be very long, which reduces pressure losses, the number of loops and tube connections
Optical losses may induce a partial decline in the total cost-effectiveness	The use of solar radiation presents lower thermal losses thanks to the secondary concentrator in the receiver
If it is necessary to reach higher temperatures, then HTFs such as molten salt, oil, and other materials must be added	Fresnel for a direct steam generation does not need any HTF in between
Cleaning is often needed to reduce dust accumulation. However, it is simpler for LFCs than for PTCs	The tracking system of LFC needs lower forces to move the mirrors than PTC
Research on advance material to avoid ultraviolet degradation is required	Once its useful life is over, most of its components could be recycled. The remaining ones can be incinerated or sent to landfill

LFC is a line-focus system that belongs to concentrating direct normal irradiance (DNI) technologies, which can reach temperatures of about 400 °C [15] depending on the heat transfer fluid employed. An LFC is divided into numerous long rows of almost flat mirrors, which rotate individually along one axis to focus solar radiation onto a linear fixed receiver [12; 13]. This technology has been developed mainly by industrial enterprises from Germany, Spain, United States, Italy, France, and others [16; 17]. LFC has not been adopted yet in Ecuador due to a lack of studies showing its technical and economic potential.

Industrial sector in Ecuador

One of the multiple applications of LFCs is the direct steam generation for SHIP. Key industrial sectors suitable for the adoption of solar thermal systems may differ between countries. For the most part, they are generally food, beverage, transport equipment, machinery, textile, and pulp and paper industries, because approximately 60% of the heating requirements can be supplied at less than 250 °C [18].

According to [19], the agro-food industry has stood out with more than 50% of manufacturing gross domestic product (GDP) in Ecuador. In 2014, the industrial sector accounted for 19,4% of the total energy consumption of the country, which increased by more than 50% from 2006 to 2014. Manufacturing industrial subsector mostly contributed to this increase. Then, in May 2018, the manufacture of food products was by far one of the most incident sectors in Ecuador regarding the manufacturing production index [9]. Accordingly, it may be a key sector for the use of solar thermal systems in the country. Diesel and electricity have been the main sources of energy for the Ecuadorian industry [19], which indicates that they could be reduced or replaced by LFCs.

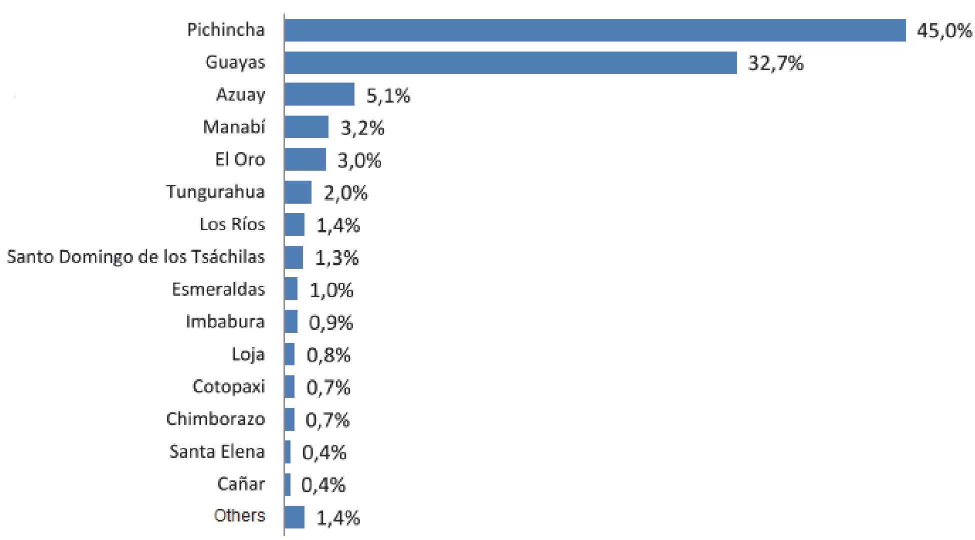

Figure 1. Share in sales of companies with manufacturing activities by province in 2016

Source: Adapted from [10].

It is worth to mention that, as depicted in Figure 1, in 2016, more than 75% of total sales were made by enterprises located in Pichincha and Guayas provinces. In contrast, firms from the Amazon and Insular regions had the lowest percentage of about 1% of the total sales.

Solar resource in the continental region of Ecuador

The direct normal irradiance is the resource used by concentrated solar technologies for SHIP [20]. Its implementation takes place with higher economic feasibility in areas where DNI is abundant (>5 kWh/m^2/day) [19], which are usually located in subtropical latitudes (dry and hot regions with clear skies). Nevertheless, DNI is remarkably higher at higher elevations, where absorption and scattering of sun's rays owing to aerosols can be much lower [21]. However, values between 4 and 6 kWh/m^2/day may be still considered economically feasible [22].

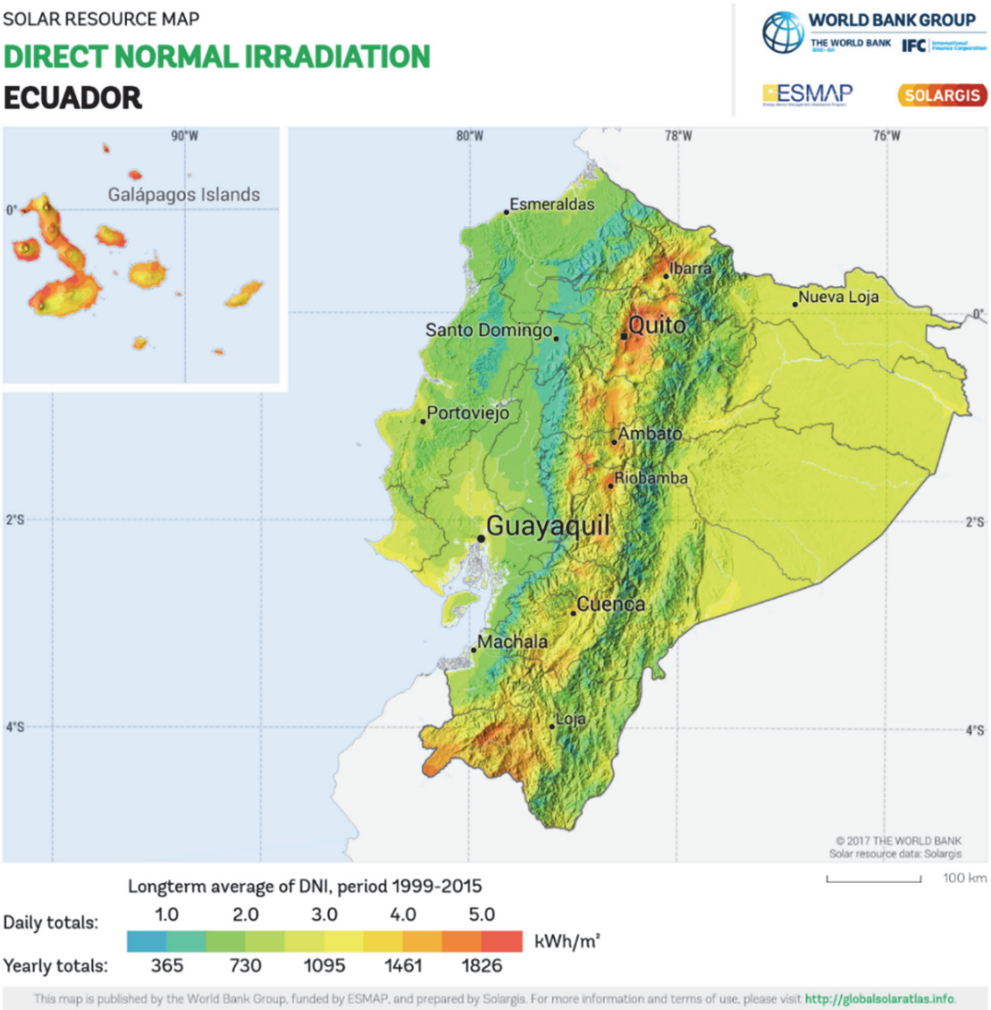

Figure 2. Direct normal irradiation map of Ecuador

Source: Global Solar Atlas [7].

Ecuador has a relatively abundant solar resource that reaches a value of approximately 4,6 kWh/m^2/day [19]; with attention to its Andean region, where the DNI is higher. As evidence, Figure 2 [7] illustrates the long-term average of DNI from 1999 to 2015. Conversely, despite Ecuador's important solar potential, the participation of this energy in the energy matrix is minimal. In agreement with Vaca [23], one of the reasons is originated in the limited number of studies to quantify the solar resource in the localities of Ecuador.

Ecuadorian policies and regulations on renewable energy

Not only Ecuador was the first country worldwide to grant rights to Nature or *'Pacha Mama'* in its 2008 constitution, but also it has a relevant number of policies and regulations for environmental management. They include mechanisms of promotion and economic incentives that encourage an efficient and sustainable use of natural resources. Table 2 is only an example of Ecuadorian regulations that cite renewable energies, and international agreements on the topic that the country has ratified.

Table 2

Ecuadorian legal framework and international agreements on renewable energy

Name	Year
National Constitution of Ecuador [24]	2008
Rio Declaration on Environment and Development [25]	1992
Kyoto Protocol, second period [26]	2013–2020
2030 Agenda for Sustainable Development [27]	2015
'Toda una vida' National Development Plan 2017–2021 [28]	2017–2021
National Energy Efficiency Plan '*PLANEE*' 2016–2035 [29]	2016–2035
Organic Code of the Environment [30]	2017
Organic Law of Energy Efficiency [31]	2019
Organic Law of the Public Service of Electric Power [32]	2015
Institutional Framework for Environmental Incentives. Ministerial Agreement No. 140 [33]	2015

Preliminary conclusions

Ecuador promotes the use of renewable sources of energy and energy efficiency through its legal framework: National Constitution of Ecuador, *'Toda una vida'* National Development Plan 2017–2021, Organic Code of the Environment, Organic Law of Energy Efficiency, the Organic Law of the Public Service of Electric Power, and so on. Moreover, the country has ratified international commitments on this regard: Kyoto Protocol, Rio Declaration on Environment and Development, 2030 Agenda for Sustainable Development.

LFC is a simple, compact and reasonable technology, with techno-commercial challenges. It is geographically restricted to areas with high DNI, like the Ecuadorian Andes, but fortunately, leading industrial companies are located in many provinces of this region.

In spite of having good solar resource and supportive laws, Ecuador has insufficient research on LFC for SHIP. This technology has not been adopted yet by the industrial sector.

The implementation of LFCs in the manufacturing sector of Ecuador could reduce the use of conventional sources of energy, especially in the food industry.

All these points considered suggest that there is a feasible market for linear Fresnel technology in the country. Nevertheless, this conclusion must be confirmed or denied by means of further research.

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Bio notes:

Nathaly Cartuche Cojitambo – master's student, Department of Applied Ecology, Ecological Faculty, Peoples' Friendship University of Russia (RUDN University). *Contact information:* e-mail: nathalycartuche@gmail.com

Margarita M. Redina – Doctor of Economic Sciences, Associate Professor, Dean of the Faculty of Ecology, Head of the Department of Applied Ecology, Peoples' Friendship University of Russia (RUDN University). *Contact information:* e-mail: redina-mm@rudn.ru

Jesus López Villada – Doctor of Mechanical Engineering in HVAC (Heating, Ventilation and Air Aconditioning) Technologies and Energy Efficiency in Buildings, Department of Mechanical Engineering, The National Polytechnic School. *Contact information:* e-mail: jesus.lopez@epn.edu.ec

Rafael Soria Peñafiel – Doctor of Science in Energy Planning, Department of Mechanical Engineering, The National Polytechnic School. *Contact information:* e-mail: rafael.soria01@epn.edu.ec

Обзорная статья

Коммерческий потенциал линейных солнечных коллекторов Френеля в промышленном секторе Эквадора: предварительная оценка

Н. Картуче Кохитамбо[1], М.М. Редина[1], Х. Лопес Вильяда[2], Р. Сория Пеньяфьель[2]

[1]Российский университет дружбы народов
Российская Федерация, 115093, Москва, Подольское шоссе, д. 8, корп. 5
[2]Национальная политехническая школа
Республика Эквадор, 170517, Кито, пр-т Ладрон де Гевара, E11-253

Аннотация. Одной из важнейших задач, стоящих перед промышленным сектором, является поиск подходов, которые удовлетворяют растущий спрос на энергию и уменьшают зависимость от невозобновляемых источников энергии. Эквадорская политика поощряет использование возобновляемых источников энергии; тем не менее исследования по концентрированной солнечной энергии в стране малочисленны. В статье представлен обзор предыдущих исследований, посвященных описанию линейных солнечных коллекторов Френеля и их использованию в промышленных процессах, перспективных для их внедрения отраслей промышленности, а также имеющихся для этой цели в Эквадоре солнечных ресурсов. По итогам анализа существующей литературы было выявлено, что обрабатывающая промышленность может стать ключевым сектором для применения данной технологии, что может сократить использование традиционных источников энергии, особенно в пищевой промышленности Андского региона. Результаты будут способствовать будущим тщательным исследованиям по этой теме.

Ключевые слова: концентрированная солнечная энергия; линейные коллекторы Френеля; прямое нормальное излучение; солнечная энергия для промышленных процессов; промышленность; Эквадор

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Сведения об авторах:
Картуче Кохитамбо Натали – магистрант кафедры прикладной экологии, экологический факультет, Российский университет дружбы народов. *Контактная информация:* e-mail: nathalycartuche@gmail.com

Редина Маргарита Михайловна – доктор экономических наук, доцент, декан экологического факультета, заведующая кафедрой прикладной экологии, Российский университет дружбы народов. *Контактная информация:* e-mail: redina-mm@rudn.ru

Лопес Вильяда Хесус – доктор технических наук по технологиям ОВКВ (отопление, вентиляция и кондиционирование воздуха) и энергоэффективности зданий, кафедра машиностроения, Национальная политехническая школа. *Контактная информация:* e-mail: jesus.lopez@epn.edu.ec

Сория Пеньяфьель Рафаэль – доктор технических наук в области энергетического планирования, кафедра машиностроения, Национальная политехническая школа. *Контактная информация:* e-mail: rafael.soria01@epn.edu.ec