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Renewable Electric Energy Generation in Argentina: Solar Thermal Pavement as a Clean and Affordable Alternative

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***Abstract*— Argentina has an area of 2.8 million square kilometers and an extensive network of paved roads and streets, with 640,000 kilometers in total. With this vast infrastructure, the country has the potential to advance technologies that take advantage of its available space, particularly in renewable energy sources such as solar thermal power. This project aims to explore a method of capturing solar thermal radiation through smart pavements, which accumulate heat in the asphalt and convert it into electrical energy. The purpose of this paper is to analyze a system that could position Argentina as a leader in clean and affordable energy, contributing to reducing dependence on non-renewable sources and promoting environmental sustainability. The study addresses the current energy problem in Argentina, compares it with other countries and presents the methodology of solar thermal pavement, evaluating the benefits and challenges of its application on national routes. This paper is expected to contribute to the analysis of alternatives to implement renewable energy generation strategies in Argentina.**

Keywords: **Renewable energy - Solar thermal energy - Intelligent asphalt.**

***Resumen*— Argentina tiene una superficie de 2,8 millones de kilómetros cuadrados y una extensa red de caminos y calles pavimentadas, con 640.000 kilómetros en total. Con esta vasta infraestructura, el país tiene potencial para avanzar en tecnologías que aprovechen su espacio disponible, particularmente en fuentes de energía renovables como la energía solar térmica. Este proyecto tiene por objeto explorar un método de captura de la radiación solar térmica a través de pavimentos inteligentes, que acumulan calor en el asfalto y lo convierten en energía eléctrica. El objetivo es analizar un sistema que pueda posicionar a Argentina como líder en energía limpia y asequible, contribuyendo a reducir la dependencia de fuentes no renovables y promoviendo la sostenibilidad ambiental. El estudio aborda el problema energético actual en Argentina, lo compara con otros países y presenta la metodología del pavimento solar térmico, evaluando los beneficios y desafíos de su aplicación en rutas nacionales. Se espera que este trabajo contribuya al análisis de alternativas de implementación de generación de energía renovable en la Argentina.**

Palabras clave: **Energía renovable - Energía termosolar - Asfalto inteligente.**

I. INTRODUCTION

Argentina is one of the largest countries in the world and the second largest in South America. The area of the country is approximately 2.8 million square kilometers and the country has a population of 46 million, representing one inhabitant each 60,000 square meters according to the last census in the year 2022. The country is not only extensive in its area, but also has a large extension in terms of roads, routes and paved streets. It has approximately 640,000 kilometers of national roads and freeways, provincial routes and municipal streets, but only 92,3% of this is paved, as mentioned in [1].

Taking into account these factors, Argentina possesses the necessary space to advance technologies that depend on such spatial availability. This initiative emphasizes the progression of renewable energy sources, with a particular emphasis on solar thermal energy. By harnessing this form of energy, it is possible to establish an innovative energy source that positions Argentina as a nation with a heightened commitment to renewable energy. Sustainable Development Goal (SDG) number 7 of the United Nations' 2030 agenda [2] refers to the importance of securing access to energy that is clean, economical, and sustainable for the forthcoming years, which is a goal that this purpose is aligned with.

This project aims to explore a methodology for harnessing the solar thermal radiation that impacts the land of Argentina, examining the potential applications and efficiencies of this abundant natural resource. This method consists in the use of an intelligent pavement that is able to capture the heat that accumulates in this asphalt [3]. The concept under consideration is associated with diverse studies in solar thermal energy and its implementation in asphalt technology, aiming to convert this energy into electrical power.

The purpose of this project is to analyze an existing system that would position Argentina as a key player in affordable and clean energy. This project aims to critically evaluate an innovative and sustainable method currently being employed in other countries for generating renewable energy within Argentina. This analysis will explore how this method leverages existing infrastructure, contributes to reducing dependence on non-renewable energy sources, promotes environmental sustainability and potentially impacts energy costs.

To this purpose, firstly, the current energy problem in Argentina in relation to renewable energy, and the comparison with other countries in the world are going to be discussed. Then, a method of generating electrical energy through solar thermal pavement is going to be presented. Finally, there is going to be an analysis of the benefits and challenges that may arise when applying these methods on national routes and streets. This paper is expected to contribute to the study of implementing strategies for renewable energy generation in Argentina.

II. ENERGY GENERATION IN ARGENTINA

Before focusing on the implementation of smart asphalt on the country's roads, it is important to be able to understand the problem of energy that currently affects Argentina and the reason why it is necessary to solve it. In the following paragraphs, the Argentine situation is going to be described in relation to the types of energy generated in the country, and the importance of advancing in the implementation of renewable energy sources.

A. Types of Energy Generated in Argentina

The foremost energy issue to address in Argentina is the low percentage of renewable energy generated. Argentina is a country that, over the years, has made progress in the development of renewable energy. It is such that in recent times increases of more than ten percent have been seen in a period of ten years [4]. Despite this progress, in Argentina, approximately 12.3 percent of the total energy generated in the country is energy from renewable sources [4].

In Fig. 1, the percentage of the distribution of energy generation sources is illustrated. Thermal energy ranks first, accounting for 63.5% of the total energy. Hydraulic energy follows in second place, contributing 17%, while various renewable energies collectively represent only 12.3% of the total energy produced in Argentina. Finally, nuclear energy occupies the last place with a percentage of 7%.

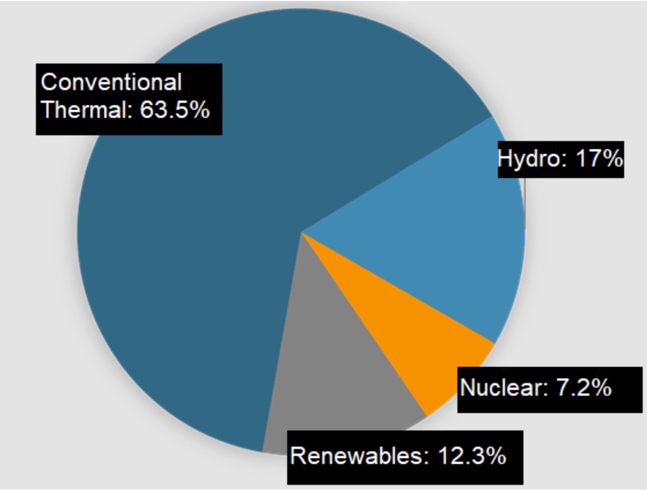

Fig 1. Percentage contribution of each type of energy [4]

The vast majority of energy generation comes from thermal generation. This category of energy generation is made up of different types of generators powered by or that use fossil fuels. As Fig. 1 shows, more than half of the country's energy is generated by different non-renewable methods. In these generators, gases or fuels are used to heat water and generate steam or move turbines. These types of energies are very harmful to the environment, particularly due to the emissions associated with fossil fuel-based energy, which will be discussed in the following section.

B. Fossil Fuel-Based Energy and its Emissions

The generation of energy from fossil fuels (coal, oil, and natural gas) in Argentina, as in the rest of the world, contributes significantly to greenhouse gas emissions. According to the International Energy Agency (IEA) [5], energy production globally accounts for over three-quarters of greenhouse gas (GHG) emissions, primarily due to carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions from fuel combustion. This global context is particularly relevant to Argentina, where fossil fuel-based electricity generation plays a similar role. Fig. 2 from the IEA illustrates the annual emissions of these gases from fossil fuel-based electricity generation worldwide, highlighting the impact over recent decades and providing a reference point for understanding Argentina's own emissions.

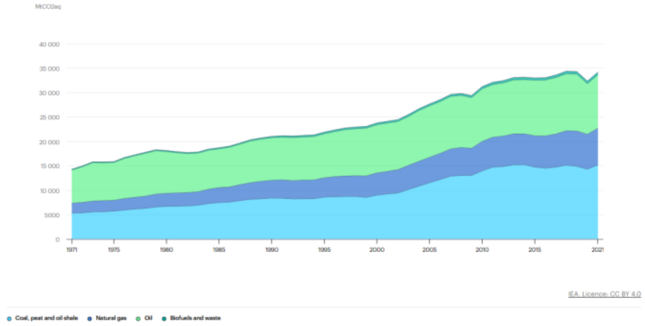

Fig 3. Total GHG emissions from fuel combustion per product [5]

C. Comparison of Renewable Energy Production Percentages Worldwide

In comparison with other countries, the percentage of renewable energy generated in Argentina is not really small. As shown in Fig. 3, it is possible to differentiate areas, such as the European continent, where the countries have an average value close to 14 percent of the total energy generated. In addition, influential countries in the world in terms of renewable energy generation, namely, the United States, China and Russia, have percentages of 11.6, 16.1 and 6.3, respectively [6]. In other words, Argentina is not widely surpassed, in terms of percentages, by the vast majority of developed countries in the world.

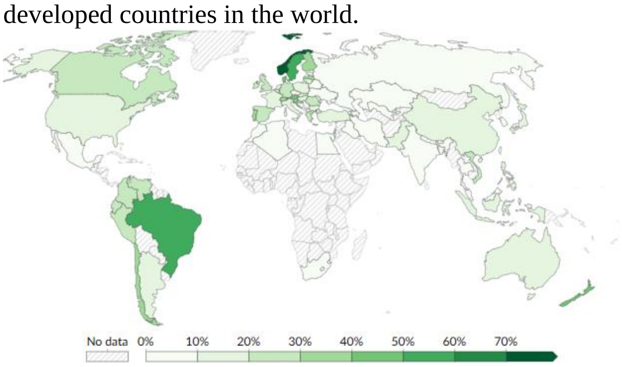

Fig 3. Primary energy generation from Renewable Sources [6]

However, it is also possible to highlight another aspect of the graph which is the difference between the percentage generated in Argentina and the other countries of South America, which exceeds 25 percent, shown in Fig 4. In other words, Argentina is still far from its limit in terms of renewable energy generation. It is for this reason that this project places great emphasis on the solar thermal energy captured by the pavements in order to take advantage of a sustainable method that has not been exploited in the country, and that it has the ideal qualities to be developed.

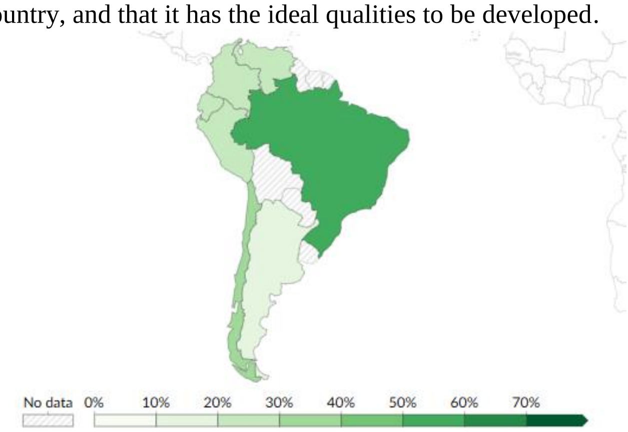

Fig. 4. Primary energy generation from renewable sources in South America [6].

III. SOLAR THERMAL ENERGY THROUGH INTELLIGENT ASPHALT SYSTEMS IN ARGENTINA

In Argentina, only 13% of the 12.3% of renewable energy comes from solar sources [4]. To address this challenge and promote the use of thermosolar energy in the country, this project aims to develop an intelligent asphalt system for Argentina's streets. The country has an extensive network of 640,000 km of national routes, which presents a significant opportunity for the implementation of this innovative technology.

The intelligent asphalt system involves utilizing solar irradiation to heat water circulating through tubes installed beneath the asphalt. This heat is then used to generate energy. The technology leverages the asphalt's capacity to absorb heat, acting as a solar collector [3]. The project would consist of two main stages. The first stage involves capturing solar irradiation through the heat absorbed by the asphalt. In the second stage, the heat transferred to the water in the tubes would be used to generate electrical energy.

This approach not only offers an innovative solution to increase the proportion of solar energy in Argentina's energy matrix but also maximizes the efficient and sustainable use of existing infrastructure. Additionally, implementing this technology could positively impact reducing greenhouse gas emissions and advancing the country's energy self-sufficiency.

A. *Solar Thermal Energy Capture*

Capturing solar thermal energy involves the use of solar collectors, such as flat plate collectors or vacuum tube collectors, to absorb and concentrate sunlight. Solar energy is converted into thermal energy by these collectors, which is then transferred to a working fluid, typically water. The heated fluid can be used in different ways. It can be used for both space heating and water heating, as well as industrial processes, or for producing steam that drives turbines for electricity generation [3]. The efficiency of this process is influenced by factors such as collector design, solar insolation level, and overall system configuration.

In an innovative approach, thermosolar energy can also be captured from asphalt pavements, which naturally absorb and retain solar heat. As stated in [3], this method involves embedding a network of pipes beneath the asphalt surface, through which a fluid circulates. The asphalt acts as a solar absorber, heating the fluid as it passes through the pipes. This heated fluid can then be used for various applications, such as heating buildings or generating electricity. According to studies, the efficiency of energy capture from asphalt surfaces can be significant, especially in regions with high solar radiation.

B. *Production of Electricity from Solar Thermal Energy*

Absorption of solar radiation is the first step in incorporating solar-heated asphalt into energy systems. This transmits heat to the water in the pipes, which increases the efficiency of the Rankine regenerative cycle, a mechanism that will be explained in the following paragraphs. The asphalt, which acts as an absorbent surface, first receives direct solar radiation. The temperature of asphalt increases significantly during daylight hours due to its high capacity to absorb and retain heat. Pipes under the asphalt receive this temperature increase by convection and conduction.

The absorbed heat is transmitted to water through these pipes that were built to contain water. This raises the water temperature to a level suitable for thermal use [7].

Water is transported through a system of insulated pipes from the asphalt pipes to the power plant once it reaches an appropriate temperature. This hot water is integrated into the plant's Rankine regeneration cycle. The Rankine cycle is a thermodynamic process that converts thermal energy into mechanical work by transferring heat to a working fluid which expands in a turbine to generate electricity [7].

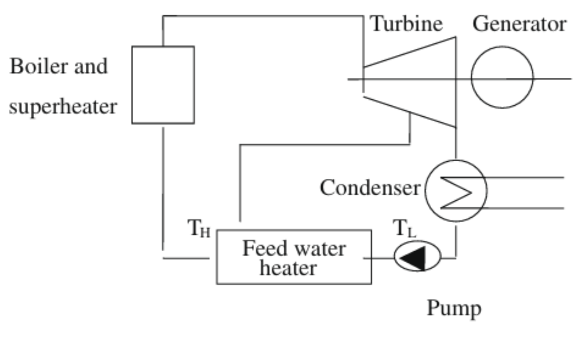

Fig. 5. Single-stage regenerative Rankine cycle with open feedwater heater [7]

Hot water from asphalt is used to preheat the feed water of the Rankine cycle, as explained in [7]. In a heat exchanger, the heat from the hot water is transmitted to the feed water before it enters the boiler, this preheating occurs. The boiler needs less energy to convert feed water into steam due to this thermal optimization. As a result, the amount of fossil energy required is reduced, which improves overall process efficiency and helps to reduce greenhouse gas emissions.

Finally, the preheating water enters the boiler where it is transformed into high pressure steam. The steam is moved to the turbine responsible for performing mechanical functions, this is where the steam expands, generating electricity. Then, in the next step the steam is condensed into water in a condenser and the cycle is repeated, as shown in Fig. 6. The use of solar heat captured in asphalt in this thermodynamic cycle is an important step because the water to generate that steam does not start from ambient temperature but has a higher initial temperature. This would help the environment of energy resources and improve the efficiency of power plants [7].

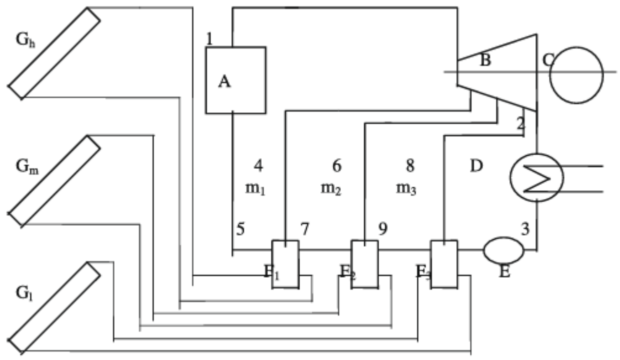

Fig. 6. Three-stage regenerative condensing-steam Rankine cycle [7].

IV. Benefits of Solar Thermal Energy in Asphalt Applications

The integration of solar thermal energy into asphalt applications represents a promising avenue for enhancing Argentina's renewable energy capacity. By leveraging the extensive network of roads and highways, this innovative approach not only seeks to harness solar energy but also offers a sustainable use of existing infrastructure. As Argentina looks for alternatives to reduce its dependence on non-renewable energy sources, it is important to consider both the potential benefits and challenges of implementing such a system. The following subheadings will address these topics and show a detailed analysis of the effects of the implementation of solar thermal technology in asphalt applications.

A. Advantages of Solar Thermal Asphalt Systems

Using existing infrastructure, such as roads and motorways, to generate renewable energy is one of the main advantages of asphalt thermosolar systems. By using this type of infrastructure, public investment is maximized not only as a transport route but also as a source of clean energy. In addition, the abundance of asphalt-covered surfaces in Argentina, particularly in regions with high levels of solar radiation, has a significant potential for energy generation.

Another important benefit is the reduction of greenhouse gas emissions. By integrating solar thermal energy into the country’s mix of different types of energy production, dependence on fossil fuels, which are the main source of carbon emissions, is reduced [8]. The United Nations' Sustainable Development Goals (SDG 7) for affordable and clean energy [2] are met by Argentina as a result of this change which contributes to its commitments to international climate agreements. Moreover, utilizing solar thermal energy can result in lower energy costs in the long run, resulting in both economic and environmental benefits.

B. Limitations of Solar Thermal Asphalt Systems

Despite the promise of solar asphalt thermal systems, there are numerous challenges and limitations to be considered. The initial cost of applying this technology is a major concern. Installation of the required infrastructure, such as the network of subgrade pipelines and heat transfer systems, may require a large capital investment. This could prevent people from investing, especially in areas with limited financial resources or where existing energy infrastructure is heavily dependent on non-renewable sources [9].

In addition, a variety of factors such as weather conditions and the quality of asphalt used can affect energy capture efficiency. The amount of energy captured may not be sufficient to justify costs in areas with less solar insolation or during periods of reduced sunlight. Since thermal expansion and contraction caused by temperature fluctuations can cause maintenance problems, which could increase system costs in the long run, it is important to consider the durability of asphalt and embedded pipes.

V. Conclusion

In conclusion, the integration of solar thermal energy through intelligent asphalt systems presents a solution capable of increasing renewable energy production in the country. Although the adoption of this technology offers important economic and environmental benefits, such as reduced greenhouse gas emissions and optimal use of existing infrastructure, it also requires substantial initial investment and careful assessment of climate factors and related constraints. Even so, to carry out this work further research, development, and financial support are necessary to fully utilize the potential of thermal solar pavements. The goal of this initiative is to align Argentina with global sustainability goals, particularly United Nations' SDG 7, which will lead to a more sustainable and energy-independent future.

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The present manuscript is part of the research activities in the Inglés II lesson at Universidad Tecnológica Nacional, Facultad Regional Paraná. Students are asked to research into a topic so as to shed light on a topic of their interest within the National Academy of Engineering's Grand Challenges or the United Nations' Sustainable Development Goals frameworks. If sources have not been well paraphrased or credited, it might be due to students' developing intercultural communicative competence rather than a conscious intention to plagiarize a text. Should the reader have any questions regarding this work, please contact Graciela Yugdar Tófalo, Senior Lecturer, at gyugdar@frp.utn.edu.ar