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Towards a More Sustainable Viticulture: Integration of Solar Photovoltaic Projects in Vineyards of Argentina, Chile, and South Africa

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Abstract. Grapevines in Argentina, Chile and South Africa are grown under high levels of solar radiation. The availability of this resource is an opportunity to implement agrivoltaics as a practice for climate change mitigation. This study was conducted during 2020-2021 to: i) compare the legal framework in these countries to promote photovoltaic (PV) technology, ii) analyze the integration of PV technology with viticulture, and iii) evaluate its social acceptance. To analyze the regulatory framework, national and regional laws to promote the integration of PV technology with viticulture were evaluated. The PV technology and viticulture practices adopted were evaluated through a survey in ten vineyards located in Argentina, Chile, and South Africa. Social acceptance of PV integration with viticulture was evaluated in a participative process. The main facilitators common to the three countries are the availability of the solar resource, the scenario of legislative transformation related to the production of renewable energies, and the reduction of production costs in the long term for wine companies. Although there have been advances in the regulatory frameworks, especially in Chile and Argentina, agrivoltaics is still not mentioned. This, coupled with limited local experience of agrivoltaics in vineyards, limits communication of the potential benefits in grape, wine, and energy production.

Keywords: Viticulture, Agrivoltaics, Irrigation

1. Introduction

In 2019, the viticultural area of Argentina (215,169 ha), Chile (210,008 ha) and South Africa (122,405 ha) represented 7.4 % of the world's viticultural area [1]. In the same year, wine production was 13, 11,9 and 9,7 million hectoliters in Argentina, Chile, and South Africa respectively and, together, represented 8% of the world's wine production. Regarding the volume of world wine exports, Chile is currently the fourth exporter, South Africa the eighth and Argentina the tenth [1].

In these countries, most of the vineyards are irrigated; thus, they require the use of energy for underground water pumping and pressurization of the irrigation systems. In addition, they are grown under high levels of solar radiation, which justify the adoption of photovoltaic systems as a practice for climate change adaptation and mitigation in the wine regions of these countries [2],[3].

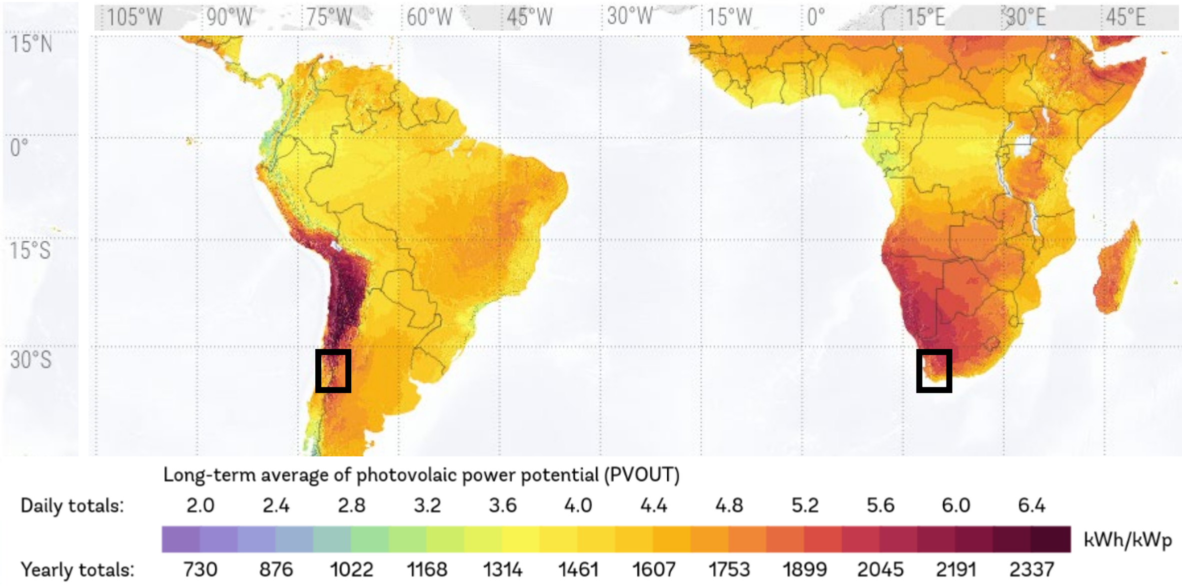

Figure 1. Photovoltaic power potential of the main wine-growing regions of Argentina, Chile, and South Africa.

This study is part of the south-south cooperation project “Irrigation and energy saving in the 30° southern latitude: solar energy in vineyards of Argentina, Chile, and South Africa”, and was conducted during 2020-2021, with the aims to: compare the legal framework in these countries to promote the incorporation of solar PV technology, analyze the integration of solar PV projects with viticulture, and evaluate the social acceptance of PV technology.

2. Materials and Methods

To analyze the regulatory framework, the following national and regional laws to promote the integration of PV projects with viticulture were evaluated: the Argentine National Law n° 27424/2017: Regime for the Promotion of Distributed Generation of Renewable Energy [4], the Chilean National Law n° 20571/2012 [5] and n° 21118/2018 [6] and the South African Renewable Energy Independent Power Producer Procurement Program (IPP PP) 2011 and Small Projects IPP PP 2013 [7].

For the evaluation of the integration of solar PV projects with viticulture, a study of cases was conducted in ten vineyards that have incorporated PV technology in the last few years. Two of the vineyards were located in Mendoza, Argentina, six in the Maule and O’Higgins Regions of Chile, and two in Stellenbosch, South Africa. To this end, a survey was answered by grape growers and consultants. The survey was structured in three parts: 1) process for the incorporation of PV technology, 2) integration of a PV project with viticulture and 3) SWOT analysis by country.

The social acceptance of PV technology was evaluated analyzing common motivations, obstacles, and facilitating factors to integrate PV projects with viticulture in three participative workshops. Participants included grape growers, researchers, extensionists, consultants, and PV system suppliers from Argentina, Chile, and South Africa. The participative workshops were on-line and conducted during the COVID-19 pandemic.

In the first workshop, the answers to the survey were presented and the main results of research on agrivoltaics systems in vineyards, i.e. combination of PV installations with crops on the same land [8], achieved by the French National Research Institute for Agriculture, Food and Environment (INRAE) were presented in a seminar. In the second workshop, the methodology to deepen the experience of participants for the implementation of PV systems was defined by country commissions. Finally, in the third workshop, the methodology to visualize joint strategies, to enhance facilitators and to identify elements for the construction of a joint future agenda was defined in a plenary session.

3. Results

3.1 Regulatory Frameworks: Review of the Renewable Energy Laws of Argentina, Chile and South Africa.

Argentina and Chile showed more advances than South Africa in their regulatory frameworks to promote the distributed energy and incorporation of PV technology (Table 1). However, Chile has more experience and history since it has a law that regulates the payment of electricity prices for end-user generators distributed energy since 2012, before Argentina where the law was established in 2017.

Table 1. Regulatory frameworks of Argentina, Chile, and South Africa.

Country	Regulatory frameworks	Sales of surplus	Reference to agrivoltaics	Limits
Argentina	Law n° 27424/2017	Yes	No	2 MW
Chile	Law n° 20571/2012 and n° 21118/2018	Yes	No	300 Kw
South Africa	Renewable Energy Independent Power Producer Procurement Program (REIPP PP), 2011. Small Projects IPP PP, 2013.	No	No	Independent Power Producer Procurement Program (IPP PP):1800 MW for tender. Small Project IPP PP: 1 and 5 MW.

None of these frameworks showed a distinction among end users (residential, industrial, or agricultural). In addition, they do not refer or have no section on agrivoltaics to promote it as an alternative PV system.

3.1.1. Argentina

Law nº 27424/2017 defines the policies and legal and contractual conditions for the generation of electricity from renewable sources by users of the distribution grid, for self-consumption, with an eventual injection of surpluses into the grid. The main conditions established by the law are that:

- every user of the distribution grid has the right to install equipment for the distributed generation of electricity from renewable sources up to a power equivalent to that contracted with the distributor (Art. 4) and, to generate electrical energy for self-consumption and to inject its electrical energy surplus into the distribution grid (Art. 5).

- the regulation of the law shall establish different categories of user-generators according to the contracted power and generation capacity (Art. 6).

- each distributor shall calculate the compensation for the energy injected into the grid under the net balance billing model based on the following guidelines (Art.12). On the one hand, the user-generator will receive a price for each kilowatt-hour injected into the distribution grid. This price will be established by regulation according to the seasonal price corresponding to each type of user that distributors must pay in the Wholesale Electricity Market (WEM). On the other hand, the distributor shall reflect in the invoicing the volume of energy consumed by the user-generator as well as that injected into the grid, and the prices corresponding to each one per kilowatt-hour. If the user-generator has a monetary surplus for the kilowatt-hours injected, this shall constitute a credit for the invoicing of the following periods.

- the law created the public trust fund for the “Distributed Generation of Renewable Energies (DGRE)” to promote the implementation of distributed generation systems from renewable sources. (Art. 16). For the fulfillment of its purpose, this fund may implement different instruments. Some of them are i) tax benefits and ii) finance dissemination, research, and development activities. (Art. 21).

3.1.2. Chile

Law nº 20571/2012 regulates the payment of electricity prices for end-user generators and law nº 21118/2018 incentivizes the development of end-user generators. These laws establish the main following conditions (modified Art. 149 bis):

- the end users who have electrical energy generation equipment by renewable sources or efficient cogeneration facilities for their own consumption, individually or collectively, shall have the right to inject the energy into the distribution grid. The installed capacity for each property or installation of end user may not exceed 300 kilowatts;

- the end users that are grouped must be connected to the grid of the same distribution service concessionaire and prove joint ownership of the electrical generation equipment;

- the energy injections shall be valued at the price of the regulated user generators of the public distribution service concessionaires. The valuation shall also include the lower electrical losses of the public distribution service concessionaire associated with the energy injections;

- the valued energy injections shall be discounted from the invoice. If there is a remainder in favor of the customer, it shall be charged and discounted in the subsequent invoice/s.

Also, in Chile, there are currently a series of national instruments that can be accessed by growers to help finance renewable energy facilities. There is also the Energy Service Companies (ESCO), a technical-financial business model, which allows a commercial relationship for the development of Energy Efficiency (EE) and Renewable Energy (RE) projects for self-consumption. It is offered by ESCO, where the initial investment is paid through the savings generated by the implementation of an EE or RE measure [9].

3.1.3. South Africa

The fundamental driver for renewable energy projects continues to be the Renewable Energy IP PPP, was launched in 2011. The Renewable Energy IP PPP is a competitive tender process designed to facilitate the investment of independent power producers (IPP) in grid-connected renewable energy generation. The Small Projects IPP PP was introduced in 2013 to be easier and less expensive for bidders to encourage the participation of small and medium enterprises, which are often unable to compete effectively with larger players. The Risk Mitigation IPP PP was launched in 2020 and designed to procure new generation capacity derived from different types of power generation projects that will enter power purchase agreements to stimulate the participation of independent power producers in the electricity supply industry.

The regulatory regime does not currently allow the sale of surplus energy generated into the grid and there are currently no significant tax incentives or other government-led programs to promote the growth of renewable sources. However, in 2019, South Africa introduced a carbon tax aimed to reduce the emission of greenhouse gases and thus, indirectly, promoting the incorporation of more renewable energy [7].

3.2 Study of Cases

In the cases studied, the most frequently mentioned reasons for the incorporation of PV technology were clean energy generation and resource efficiency/sustainability. The predominant PV systems were on-grid, associated with pumping and irrigation system, with reservoir (Figure 2).

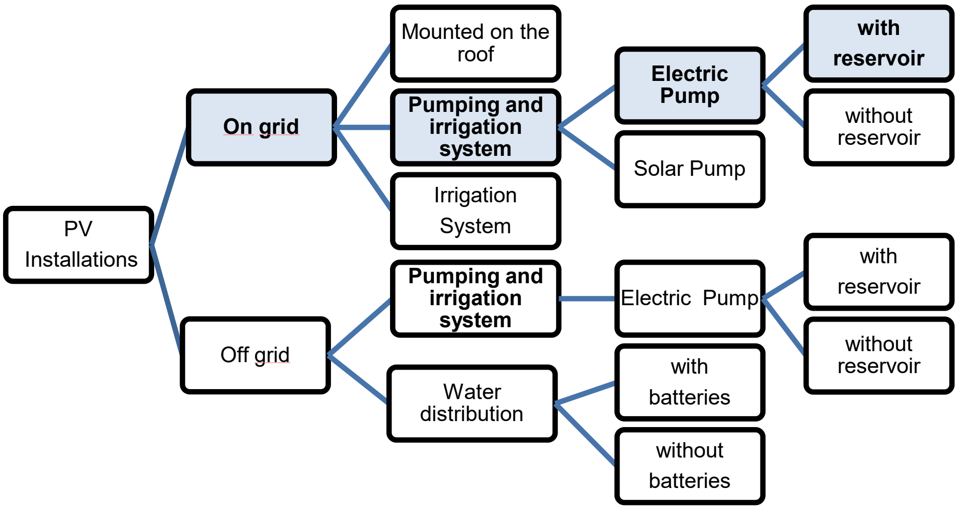

Figure 2. PV installations in vineyards (gray boxes show the most frequent system).

The results of the surveys showed that the PV systems integrated into the electricity grid include solar systems integrated into the pumping system (electric pump) with reservoir and without reservoir, a PV system integrated to a solar pump, a PV system without integration to pumping equipment and a PV system composed of a subsystem connected to the electrical grid and another one isolated. The remaining solar systems found were isolated, integrated to the pumping system, with and without reservoir. Among the PV systems surveyed, only two replaced the pumping equipment with the incorporation of solar technology. In one of them, the solar pump was incorporated. The panels installed were polycrystalline type and mounted on aluminum structures in the space available on the farm or on the roof in the case of the winery.

Isolated systems were found only in Chile, implemented in small-scale productive farms. The energy generated was used to distribute water for irrigation directly (one case) and to accumulate and distribute water from a dam (another case). In the remaining four cases of Chile, PV systems connected to the grid, its incorporation has been through the ESCO model and the solar energy generated was used to obtain and apply water for irrigation. In one of the companies, energy was also used in winery and tourist services.

The two cases surveyed in Argentina were large farms with an on-grid installation with the possibility of injecting the surplus energy generated into the grid. The energy generated was used for irrigation. They did not modify irrigation practices with the incorporation of the solar system.

The two cases surveyed in South Africa were vineyards with PV systems connected to the electricity grid without injection of surplus energy into the grid. One of them was a set of subsystems that also included an isolated system. The systems provided energy to buildings and offices and, in one of them, water for the nature reserve located next to the vineyard. Neither system was used for irrigation of the vineyards.

The vineyards included in the study frequently use precision technologies (such as drones, Scholander chambers, sensors, and agro-meteorological stations) to optimize the soil-water-plant relationship. The agricultural, irrigation and technological practices used in the vineyards included in the study did not change with the integration of the PV systems.

3.3 Social Acceptance of PV installations in Argentina, Chile and South Africa

Each country showed specific motivations, obstacles and facilitating factors that respond to their own socio-economic conditions (Table 2).

Table 2. Social acceptance of PV installations in vineyards in the countries studied.

Country	Motivations	Obstacles	Facilitating factors
Argentina	Business interest in sustainability. Sales of energy surplus. Public support. Solar radiation. Clean energies. Dissemination of these technologies and initiatives.	Economic-political instability. Lack of dissemination of these technologies and their cost-benefits.	Global trend, demand for sustainability. Resource availability. Wide range of suppliers and decreasing costs. National distributed generation law.
Chile	Good alternative when off the grid. Added value (leasing land, sales of surplus, and use of energy in other processes). Public support. Levels of radiation. Companies are environmentally responsible.	System design problems. Theft and vandalism. Problems related to maintenance. Cost in storage batteries.	Solar energy is stable. Laws. Interest of companies to invest in PV projects on agricultural land. Radiation is high, although it decreases in coastal areas.
South Africa	Reducing costs / saving on energy costs. Energy crisis in South Africa. Energy can be used in several farm facilities and activities	Limitations of the regulatory framework. Lack of public support. Monopoly in the energy generation market. Land use dispute discourages growers from making investments.	Energy supply problems. Rising energy costs make it increasingly convenient the solar energy. If Europe starts asking for carbon footprint

		High implementation costs and maintenance.	certifications, use of solar energy might be promoted.

Results from the workshops showed that common motivations and facilitating factors were closely related, with the latter contributing to the technological transition (Table 3).

Table 3. Common social acceptance of PV installations in farms with vineyards.

Motivations	Obstacles	Facilitating factors
Resource availability. Scarcity of water. Corporate image. Global market trends in sustainability. Add value.	Investment and maintenance costs. Lack of diffusion and knowledge. Possible negative impacts of shading (Agrivoltaics).	Resource availability. Changes in the national legislation. Reduction of production costs.

4. Conclusions

Under the regulatory frameworks of Argentina and Chile, grape growers that use energy for irrigation, when incorporating PV systems, consume clean energy and also have the possibility of injecting the surplus of energy into the grid. In Argentina, the power limit to install PV systems to the contracted power established in the law prevents the possibility that the energy activity competes with agricultural production. This discouragement to change land use contributes to sustainable territorial development. The creation of the trust fund for the DGRE may increase research and technology transfer practices such as agrivoltaics. In Chile, the contracts between groups of users represents an opportunity to increase the scale of projects since the installed capacity for end users may not exceed 300 kilowatts. In addition, the ESCO model avoids initial investment and maintenance and reduces energy costs for grape growers in a context of predictable prices. In South Africa, the organization of the generation market still limits the incentive for distributed generation. However, the recent introduction of the CO_2 emissions tax may encourage the replacement of non-renewable energy sources with renewable sources.

Regarding the study of cases, the integration of PV projects with viticulture aimed to improve irrigation distribution to reduce energy costs (Chile and Argentina); to add value to tourism products (Colchagua, Chile); and to contribute to the biodiversity as part of the values of the company (Stellenbosch, South Africa). Although the vineyards included the use precision technologies to optimize the soil-water-plant relationship, agrivoltaics was not mentioned or known practice.

The social acceptance of PV systems responds to the particular socio-economic dynamics of each country. In Argentina and Chile, the motivations are similar. In Chile, the added value that could be obtained from renting agricultural land appears as a distinctive motivation. In South Africa, the motivations are given by an energy crisis and the possibility of reducing costs. Regarding obstacles, the distinctive obstacles in Chile are aspects related to the limitations of technology, those in Argentina are related to the political-economic instability, and those in South Africa are related to the lack of a regulatory framework. Regarding the facilitating factors, the distinctive factor in Chile is the interest of the private sector in investing in these technologies. Finally, the main facilitators common to the three countries are the availability of the solar resource, the scenario of legislative transformation related to the production of renewable energies, and the reduction of production costs in the long term for wine companies.

Although there have been advances in the regulatory frameworks of the countries studied, agrivoltaics is still not mentioned. This, coupled with limited local experience in vineyards, limits communication of the potential benefits in grape, wine and energy production.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author, Jorge E. Perez Peña, upon reasonable request.

Author Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Gabriela L. Acosta, Natacha Pizzolon, Jorge E. Perez Peña and Lucia R. Palazzo. The first draft and final version of the manuscript were written by Lucia R. Palazzo. All authors contributed to the manuscript.

Competing Interests

The authors declare no competing interests.

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