Agrivoltaic in Chile – Integrative solution to use efficiently land for food and energy production and generating potential synergy effects shown by a pilot plant in Metropolitan region

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Abstract

In Chile, one of the most vulnerable productive sectors, in the context of climate change, is agriculture. The country faces the risk of losing high-quality soil surface mainly by desertification, erosion, contamination and inappropriate agriculture practices. Risk of agricultural land losses constantly rises due to the increasing food and energy demand, as well as the use of land for human dwellings and industrial operations.

In addition, the rapid growth of the energy sector is highlighted, where Chile has ambitious goals on expanding non-conventional renewable energies. Here, solar photovoltaics (PV) present high potential due to the high irradiation levels especially in the northern region of Chile. This, added to decreasing PV system costs, allow solar PV installations going south closer to the energy consumption poles.

In the context of both trends, a system to combine agriculture with photovoltaics (APV) is presented as an inter-sectorial solution for food and energy production using the same land benefit from synergy effects like reduction of water evaporation and protection for crops, especially in arid/semi-arid zones. Additionally, first results of an APV pilot plant near Santiago of Chile are presented. Finally, conclusions are developed in addition to an outlook in order to provide a baseline of information for the usefulness of the concept in the country.

Key Words: agrivoltaic, photovoltaic, agriculture, efficient land use, synergy effects, potential in Chile

1. General Introduction

1.1 Context in Chile

Chile commits to reduce GHG emissions by 30 % per unit of gross domestic product (GDP) until 2030 compared to 2007, not considering land use, land-use change, and forestry (MMA, 2018). Here, the energy sector shows the highest contribution with 78% of the country's total emissions in 2016 (MMA, 2018). In 2018 the total installed capacity for electric generation reached 23.3 GW, distributed among 53% thermoelectricity, 26% conventional hydroelectricity and 21% non-conventional renewable energy (NCRE) which mainly includes solar, wind and hydraulic plants less than 20 MW (CNE, 2018). Among the different NCRE, solar PV technology represents the biggest share of electricity injection with 44% in 2018 (CNE, 2018) facilitated by unique climate conditions and high solar resource, especially in the north, allowing Chile to be one of the very few countries, where several PV projects have been developed without government subsidies (Nasirov et al., 2018). In recent years, Chile has significantly increased its NCRE participation mainly due to technology decreasing costs, increasing energy consumption, high energy dependency from external sources and its price variability, increasing GHG emissions and the failure of large energy projects due to environmental concerns (Nasirov et al., 2018). The previous has been boosted by different laws and regulations implemented in recent years wherein with a share of 16.2% in electric generation in 2018, energetic goals have been already surpassed (7% according to 20.257 law) (CNE, 2018). Beyond this development, Chile’s renewable energy target is at least 70% of the electricity generation by 2050 (MMA, 2018).

However, high-penetration scenarios bring new challenges, which concern socio-environmental impacts. This is where especially potential land use conflicts between urbanization, industrial activities and agriculture arise, which are intensified by limited cultivable land due to the particularity of Chile’s geography and climate. Although Chile has a total continental surface of 75.6 million hectares (ha) its geography is recognizable due to its narrow strip shape with more than 4 200 km long and a width from 90 to 375 km including two great mountain ranges (the Coastal Range reaching up to 3 000 m and the Andes reaching up to 7 000 m) making flat terrain scarce (Odepa, 2017). On the other hand, Chile presents diverse longitudinal and latitudinal climate zones from the arid

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and semi-arid zones in the north, over temperate climates with winter rains in the central zone, to the mildly cold and rainy zones in the extreme south (Odepa, 2017). This and due to economic factors, cultivated land area is only 2.1 million ha, distributed between annual and permanent crops (61%), sown pastures (19%), and lie fallow (20%) (Odepa, 2017). Regarding to crops location, 38% of all farms are concentrated in the intermediate depression and the intermediate depressions´ drylands between the two mountain ranges, almost 28% on both slopes of the coastal mountain range, followed by the Andean foothills, the transversal valleys, the Andean Range, Chiloe Islands and the drylands of Near North (Odepa, 2017). Nevertheless, the agriculture, livestock and forestry sector in Chile is one of the most important economic activities in terms of employment generation particularly in rural areas which accounted 9% of all employment in Chile in 2018 (INE, 2019). On the other hand it generated only 3% of the sectorial GDP in 2018 (BANCO CENTRAL DE CHILE, 2019).

As a consequence, innovative solutions like the APV concept (see next sub-chapter) are proposed in order to avoid land use conflicts, develop new business models based on the usage of solar energy in agriculture, reduce GHG emissions and adapt to climate change. Land use and potential losses of agricultural land will be demonstrated in chapter 2 in order to generate understanding for the usefulness of combining the PV market with the agricultural market.

1.2 APV Concept

In some countries like Germany and Italy, the installation of PV plants on agricultural land has been prohibited due to increasing land-use conflicts between energy and food production. This is where the concept of agrophotovoltaic ((Beck et al., 2013), also known as agrivoltaic (Dupraz et al., 2011) is proposed, which allows the production of food and electricity simultaneously (Figure 3). In order to measure the land-use efficiency, the Land Equivalent Ratio (LER) is used, which is the sum of the ratio of crop yield and electricity yield with and without APV. Based on simulation (Beck et al., 2013) obtained land-use efficiencies between 1.35 to 1.73 (Germany) and (Dupraz et al., 2011) between 1.6 to 1.7 (France).

Since PV plants create intermittent shading on the ground level and reducing, therefore, the available sunlight for crops, studies are needed to understand the requirements of different crops in order to design an APV plant. The module slope and row spacing of conventional PV plants are often optimized for collecting radiation close to the winter solstice, which allows radiation to enter at ground level in-between PV module rows. Here, (Beck et al., 2013) studied vegetation below existing PV plants in Germany, concluding that there is abundant natural vegetation under and between modules which could be also food crops. Thereby, (Beck et al., 2013) determined three categories for agricultural crops in temperate latitudes based on their shade tolerance: 1) crops that benefit from some shading (potatoes, all kind of lettuces, spinach), 2) crops that are not much influenced (rapeseed, rye, oats) and 3) crops that depend on maximum irradiation and are not suitable for APV (corn, wheat, horticulture). In addition, simulations of global radiation at ground level between module rows, showed that south orientation leads to persistent shade behind the module rows during summer, which is relatively independent to PV module´s elevation and row spacing. Hence, to achieve more uniform radiation on the ground level, a southeast or southwest orientation is recommended. Furthermore, the amount and homogeneity of radiation at ground level can be designed within certain boundaries by the choice of PV module technology, the PV system technology (fixed mounted, single-axis trackers or double-axis trackers) and by the PV plant layout (Dupraz et al., 2011). (Marrou et al., 2013) carried out studies on the microclimate below two APV systems with different densities during three-cycle crops (winter, spring, and summer) in France with lettuce, cucumber, and wheat. This study pointed out that small APV systems can be handled as open-field production systems, and they recommend confirming these results under larger systems wherein temperature and wind speed profiles could be different.

Moreover, in high irradiation regions, APV could provide protection to sensitive crops and could even allow cultivating crops that would normally not grow in these regions (Beck et al., 2013), (Dinesh & Pearce, 2016), (Yano et al., 2014). CEZA (Centro de Estudios de Zonas Áridas) is studying impacts on crops by partial shading in the Coquimbo region in Chile with the objective to use water efficiently considering that water consumption of crops is directly related to the amount of radiation caught by them (CEZA, n.d.).

In 2017 Fraunhofer Chile Research has installed the first three APV pilot plants in South America near Santiago de Chile, each with a capacity of 12.48 kWp. First results related to the PV design and its impact to the shadow profile on the ground level as well as on atmospheric micro-climate and electrical generation in the Metropolitan region are shared in the 3rd chapter which allows to identify challenges but also opportunities given by the concept. Derived from the results and also by gathered experiences during the technology transfer project, the potential of APV and outlook in Chile will be given in chapter 4. The aim of this paper is to give a baseline information of the usefulness of APV in Chile and the importance of future R&D activities related to the quantification of synergy effects encompassed by the concept, facilitating techno-economical feasible solutions.

2. Land use and potential losses of agricultural land

2.1 Climate Change

Chile has announced to be highly vulnerable to the adverse impacts of climate change and it exhibits seven out of nine characteristics described by the United Nations Framework Convention on Climate Change (UNFCCC), which are: small island countries; countries with low-lying coastal areas; countries with arid and semi-arid areas, forested areas and areas liable to forest decay; countries with areas prone to natural disasters; countries with areas liable to drought and desertification; countries with areas of high urban atmospheric pollution and countries with areas with fragile ecosystems, including mountainous ecosystems (Ministerio de Agricultura, 2013).

By its nature, the agroforestry sector is one of the human socio-economic systems with the greatest links to climatic conditions making it one of the most vulnerable to climate change. The environmental status in Chile is described in more detail by (Universidad de Chile, 2016) and climate change projection and impacts on Chilean's economy by (CEPAL, 2012). In summary, a gradual trend to higher average temperatures and lower rainfalls is noticeable and together with anthrophonic activities decreasing water availability especially in the northern and central zone of Chile in addition to increasing soil degradation mainly by processes of desertification, erosion and contamination will produce a shift of agricultural activities to the south.

2.2 Urbanization and industrial land

Figure 1 shows the development of the urban and industrial land as well as the agricultural, livestock and forestry land from 1997 to 2017 (INE, 2018b), where the agricultural land has been decreasing in the last couple of decades (annual decrease of 66 699 ha/year assuming linear decrease) while on the other hand urban and industrial land has been increasing (annual increase of 26 752 ha/year assuming linear increase). According to (INE, n.d.) Chilean population reached 17.6 million in 2017 (32% increase from 1992) and is expected to reach 20.7 million by 2030. Although, the country does not have a high population density (0.23 people/ha) people are concentrated in urban areas (88%) with 40% of them in Metropolitan region (RM) (INE, 2018b). In addition, population growth rate in Chile is expected to increase in the near future (2002-2017: 1.12%; 2017-2030: 1.38%) (INE, n.d.) in contrast to the world (2002-2017: 1.32%; 2017-2030: 1.02%) (Worldometer, n.d.). Land-use changes and replacement of agricultural land in RM-Santiago has been discussed in more detail in (Odepa, 2012) and (Poduje, 2006).

The growing population is not only demanding more land by human dwellings but also by land uses for food and energy production. The growth of the electricity market with a focus on PV will be discussed in the next chapter.

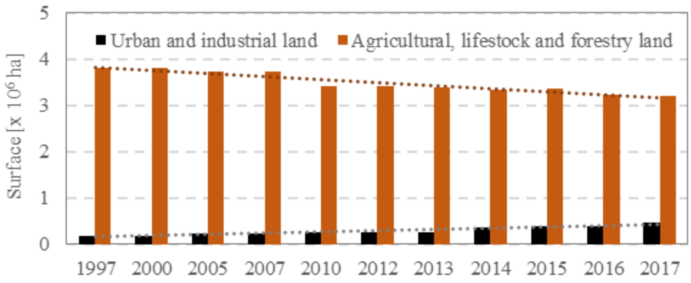

Figure 1 Change of urban and industrial land as well as agricultural, livestock and forestry land in Chile from 1997 to 2017 (own elaboration based on (INE, 2018b))

2.3 Electricity market growth with a focus on the PV market development

According to (CNE, 2018) an increase of 32% of electricity demand to 92 559 GWh until 2030 compared to 2019 is projected. With the expansion of the electricity market, the land demand for energy projects will increase. This is intensified by the increasing implementation of renewable energies projects, which have lower capacity factors (eia, n.d.) caused by the fluctuation of its primary energetic resource and higher land-use requirements compared to conventional energy sources like nuclear, coal and gas (Fritsche, 2017). According to (Jiménez-Estévez et al., 2015) PV plants in Chile can reach capacity factors beyond 20% and first results show capacity weighted land use requirements of 3.69 ha/MW for PV projects.

Figure 2 shows in the left the installed PV capacity by region from 2012 to 2018. The regions have been clustered in the North (Arica and Parinacota, Tarapacá, Antofagasta, Atacama and Coquimbo Region), Center (Valparaíso and RM region) and Near South (O'Higgins, Maule, Ñuble and Bío-Bío Region). In the more southern regions, PV installations larger than 3 MW have not been installed yet. Furthermore, the graph on the right shows PV projects under construction and projects, which entered the environmental impact assessment system SEIA (Sistema de Evaluación de Impacto Ambiental). As it can be seen in the graph the PV industry has experienced rapid growth from only 3 MW in 2012 to 2.3 GW in 2018 with the majority of the installation in the North. However, the trend can be seen, that over the last couple of years PV plants have been increasingly installed in the Center and the Near South of Chile. While PV installations in the North demonstrate a share higher than 98% until 2016, within only two years PV installation in the Center and the Near South reached already a share of 18% end of 2018. Furthermore, a significant rise of PV installation in the future can be expected considering PV plants under construction, approved PV projects and under evaluation. Assuming, that all currently approved projects will be implemented and all projects under evaluation will be accepted a total PV capacity of 21 GW could be achieved, which would represent an increase of 813% compared to 2018 (CNE, n.d.), (Energía Abierta, n.d.). This could lead to a land use requirement of 77 424 ha in total (based on 3.69 ha/MW), distributed to 88% in the North, 5% in the Center and 7% in the Near South.

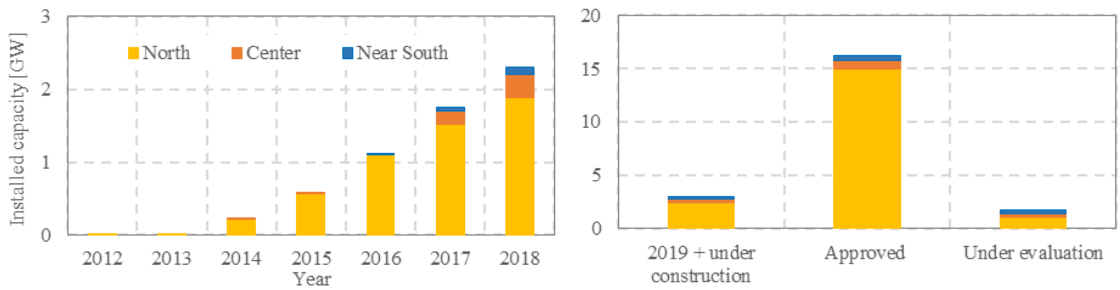

Figure 2 Installed PV capacity (PV plants larger than 3 MW) from 2012 to 2018 (left) and PV projects under construction, approved and under evaluation SEIA (right) in the three clustered zones: North (Arica and Parinacota, Tarapacá, Antofagasta, Atacama and Coquimbo Region), Center (Valparaíso and RM region) and Near South (O'Higgins, Maule, Ñuble and Bío-Bío Region) (own elaboration based on (CNE, n.d.), (Energía Abierta, n.d.))

In summary, decreasing PV system costs combined with sufficient solar resources enabled PV plants installation not only in the north but also closer to the major poles of electricity consumption in the center-south of Chile. In conclusion, due to the increasing energy demand and especially the trend of increasing NCRE, which have lower capacity factors and higher land-use requirements, the demand for more land for energy production will increase in Chile, especially in locations close to electric consumption considering RM the densest regions.

2.4 Summary and Discussion

The previous chapters are based on literature research, wherein some of the statistically available data are not updated and/or inconsistent, definitions and methodologies are sometimes unclear, or simply, there are no existing measurement data public available. Despite this, some trends with adverse impacts on the agricultural sector and agricultural land availability are pointed out:

- Projected movement of climatic zones towards the south, with, decreasing water and high-quality soil availability are expected
- Increasing land demand due to population growth and urbanization processes, especially in RM region
- Increasing land demand for electricity generation, wherein particular PV market dynamics indicate installations are going south closer to the poles of electrical consumption

Since soil is not only the base of agricultural development but also ecological sustainability, clear regulations are required. Projects with a certain size that involve soil loss or its capacity to sustain biodiversity due to degradation, erosion, waterproofing, compaction or presence of pollutants must be submitted to SEIA, based on the law 18.755 from 1989. The characterization of the affected soil is described by (SAG, 2011) and projects that generate significant adverse effects on the soil, must present measures of mitigation, restoration or recovery and/or compensation action (SAG, 2019). This is also crucial for the planning of PV projects above 3 MW.

Nevertheless, one solution in order to preserve high qualitative soil for agricultural activities, avoiding replacement by urbanization and industrialization processes, and simultaneously producing electricity could be the concept of APV, like described before and results will be shown in the following chapter.

3. APV pilot plant in RM

3.1 Approach Pilot plants in RM, Chile

In this publication, the first results of one of the three APV pilot plants installed within the competitiveness innovation fund FIC (Fondo de Innovación para la Competitividad) of the RM region in 2017 will be presented. The pilot plant with a power capacity of 12.48 kWp (48 poly-crystalline modules) has been integrated into the vegetable fields of an agricultural farm (azimuth of 295° NW) close to Curacaví. The PV modules are fixed mounted with an inclination of 27°. Moreover, the PV plant is connected to the electrical grid under the 20.571 law using 3x 2.5 kWp and 1x 5 kWp single-phase inverters in order to increase the number of beneficed people. The PV plant elevation and row spacing has been optimized based on electricity production and light management under the given scope of the project and the support of Fraunhofer ISE, Freiburg, Germany. The total area is 256 m^2 including row spacing after the last PV row, which represents a module/surface ratio of 27%. The mounting structure for the elevated PV system is made with galvanized metal posts based on concrete with adapted posts distance and elevation to allow agricultural activities as it can be seen in Figure 3.

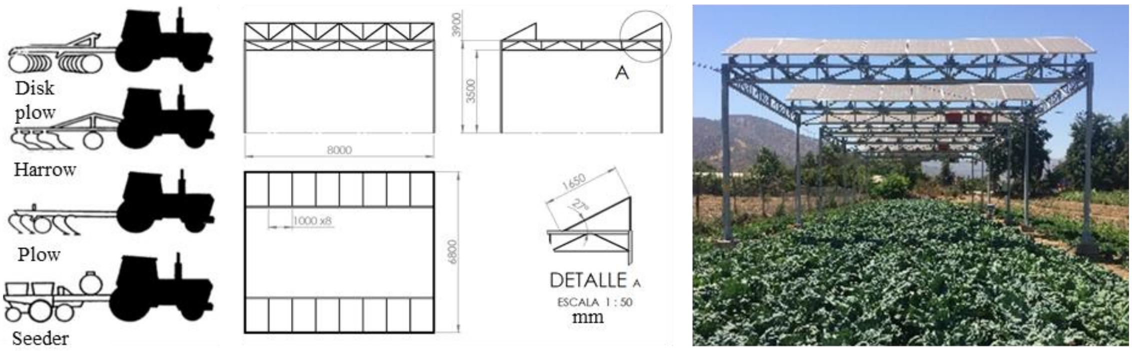

Figure 3 Characterization of different agricultural types of machinery as input for APV design (left); Technical drawing of the modular APV plant (middle); Photography of the 12.48 kWp APV pilot plant in Curacaví with cauliflower (azimuth 295° NW, inclination 27°) (right)

In addition, electrical output parameters of the PV plant (current and voltage on AC and DC side) have been registered by the integrated monitoring systems of SMA inverters with a sampling rate of five minutes and meteorological data by Campbell CR310 datalogger with a sampling rate of 10 seconds (global horizontal irradiance (GHI) by Apogee SP-110 silicon-cell pyranometer, air temperature (T_{air}) and relative humidity (RH_{air}) by DECAGON Devices VP-4, soil temperature (T_{soil}) and volumetric water content (H_{soil}) measurement by DECAGON Devices 5TM. The reference station has been installed outside the APV plant in the same crop field and the station below the APV plant has been installed in a representative location considering edge effects due to the small size of the pilot plant as can be seen in Figure 4. The measurement was performed for cauliflower crop (Brassicaceae, var. Skywalker), during Chilean summer (December 2018 to the middle of March 2019) where the analysis and results of the agricultural sector are not addressed in this publication. Relevant measurement for this study includes reference measurement (T_{air}, RH_{air}, GHI and GHI in the Plane of Array (POA) installed next to the PV modules) and APV measurement (T_{air}, RH_{air}, and GHI). Shadow profile simulation has been performed with SketchUp.

The objective of the analysis and ongoing studies is to estimate the effect of partial shading produced by the PV system on the growth and yield of vegetable crops in order to derive land-use efficiency considering electrical (kWh/ha/year) and agricultural (kg/ha/year) production.

3.2 Results

The increased row spacing of the APV pilot implies 50% less electricity production in comparison to a conventional PV plant with row spacing avoiding shade on the winter solstice at north orientation. Furthermore, electricity production losses generated by the sub-optimized orientation to the northwest, in order to increase homogeneity ground shadowing and allow the alignment of the APV plant to the agricultural field, are 7.5%. Further electrical losses observed during operation can be seen by a decreasing monthly performance ratio (PR) from 71% in December, over 67% in January to 58% in February.

Performed shadow profile simulation of the affected zone on ground level by the intermittent shadow generated by the APV plant can be seen in Figure 4 for the first and last day of the cultivation period at different times (UTC-3): in the morning (9 o´clock), at noon (13 o´clock) and in the evening (17 o´clock). As can be seen, the intermittent shadow moves from the upper left corner to the lower right corner with decreasing impact below the APV plant during the measurement period. The zone below the APV plant is capturing more irradiation in the cultivation rows on the right in the morning and in the lower part with GHI values up to 500 W/m^2 and more radiation in the afternoon on the left cultivation rows and in the upper part with GHI values up to 700 W/m^2.

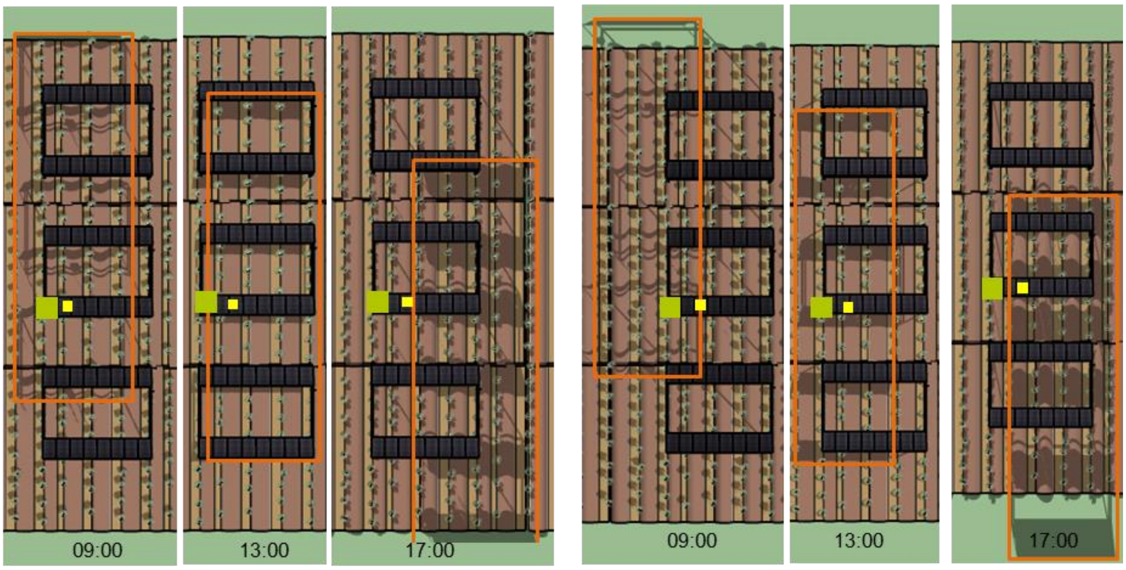

Figure 4 Intermittent shadow profile generated by the APV plant (orange rectangle) at 9, 13 and 17 o´clock (UTC-3) at the beginning (left) and at the end of cultivation (right); the location of the APV measurement of GHI, T_{air} + RH_{air} is represented by the green box and soil temperature and humidity is represented by the yellow box

The GHI profile below and outside the APV plant can be seen on the upper left in Figure 5 exemplary for sunny days at the beginning and at the end of the cultivation period. This profile under the APV plant represents a reduction of 19.7% up to 25.2% in the monthly sum of irradiation in comparison to the reference measurement. Furthermore, the graph shows on the upper right an exemplary profile of the air temperature and relative humidity below and outside the APV plant and on the bottom the development of the averaged minimum and maximum air temperature and relative humidity. In this context, the monthly average of the minimum temperatures shows slightly higher temperatures up to 0.6°C, and maximum values present similar or slightly lower temperatures. Furthermore, average minimum values of the relative humidity have been up to 3% higher below the APV plant. Average maximum air humidity values show at the beginning of the measurement period slightly lower values and then slightly higher values in the middle and the end of the measurement period in comparison to the reference measurement.

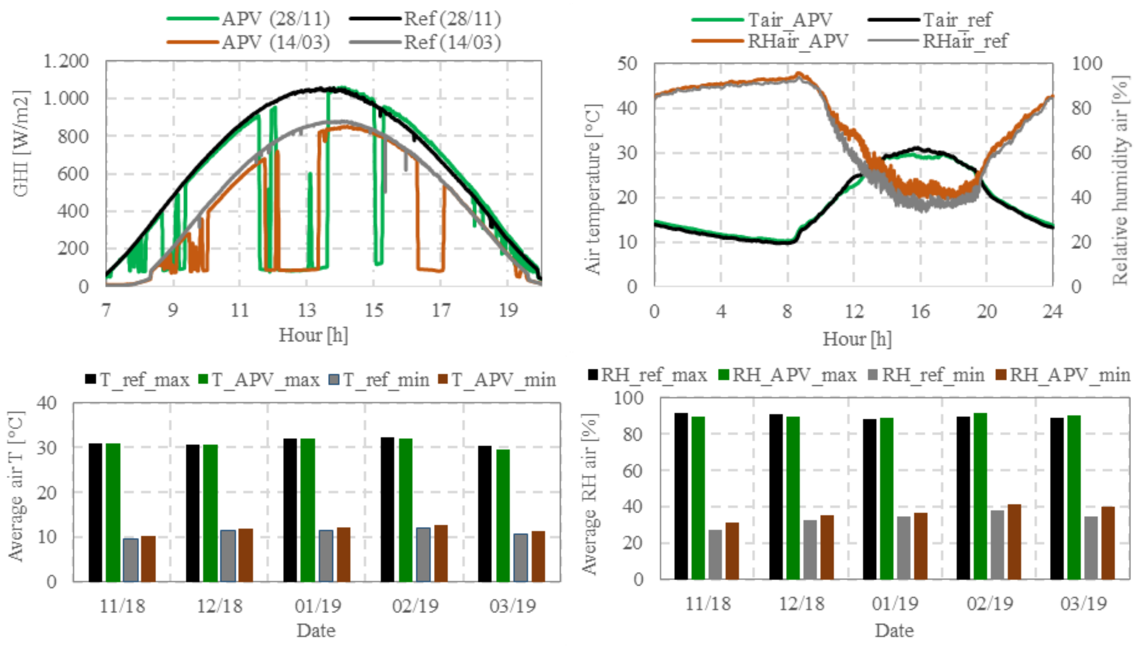

Figure 5 GHI below and outside the APV plant exemplary beginning and at the end of the cultivation period (upper left); Exemplary profile of T_{air} and RH_{air} below and outside the APV plant (upper right); Averaged minimum and maximum T_{air} (bottom left) and RH_{air} (bottom right) below and outside the APV during the measurement period

3.3 Summary and Discussion

Related to the PV design electrical generation losses, this can be reduced by further optimization considering location, micro-climate and kind of crops. Related to the operational electrical generation losses, the PR includes all electrical production losses (maintenance activities, blackouts, etc.). However, the gradual decrease of PR can be explained by the increasing impact of soiling during the measurement period. In this time, no cleaning activities have been performed and no rain with significant impact on the PV output has been registered. Considering the low occurrence of rain in RM, this is where an installation of a cleaning system is recommended in order to maintain a high electricity output. Here, one solution could be an automatized system that allows the use of water for cleaning the PV modules and its re-utilization for irrigation in order to save water.

In terms of air temperature and relative humidity, measurements have been conducted in the row between the posts in order to protect sensors against agricultural activities, and for maintaining equally setup test conditions for various cultivation periods. In this sense, they do not exactly have the same treatment as the crops. However, based on this it can be expected that relative humidity could be even higher and maximum temperatures lower if measurement would have been conducted in-between the cauliflowers. Nonetheless, it is possible to conclude that air temperature is less extreme below the APV plant (higher minimum air temperatures and lower/similar maximum air temperatures) and air humidity is higher.

Related to the chosen design (27% module/surface ratio), a reduction in the monthly sum of irradiation on the ground level of 19.7% up to 25.2% during Chilean summer has been registered. However, as mentioned before, the shadow simulation performed shows edge effects due to the small size of the pilot plant (width: 8 m; length: 23 m from the first to the last PV row) making a representative micro-climate and crop yield analysis challenging.

4. Summary and Outlook

4.1 Summary

The agroforestry sector is one of the human socio-economic systems with the greatest links to climatic conditions, making this activity one of the most vulnerable to climate change. In particular, the following main trends in Chile have been identified as risks for agricultural land-uses: expected movement of climatic zones to the south, in particular, less availability of water and high qualitative soil throughout Chile; increasing land demand by population growth and urbanization processes especially in RM region; increasing land demand for electricity generation, in particular, PV installation going south closer to the poles of electricity consumption.

This is where APV is proposed as an inter-sectorial solution for simultaneous electricity and food production to increase the overall land-use efficiency. Furthermore, the following synergy effects with high potential in the Chilean context have been identified: avoidance of losses of high productive soil; improve competitiveness of farmers due to usage of solar energy in agriculture; protection for crops against high solar radiation and thermal stress as well as reducing water consumption especially in arid and semi-arid zones; reducing GHG emissions; potential to avoid further land-use changes, and providing secured energy supply in rural areas.

Based on the APV pilot plant results and the literature research, the intermittent shadow profile on ground level generated by the PV system can be homogenized by the PV system design under certain boundaries. A southwest and/or southeast orientation should be chosen, if a persistent shade behind the module rows wants to be avoided. First approaches for the specifications of crop requirements have been done in the form of classification of the crops in positive, neutral and negative groups in respect to their shade tolerance. Literature and in addition to the results of this study show that advanced APV designs allow to control under certain limits not only light but also air temperature and humidity which can be used to optimize growing parameters for crops especially in semi-arid/arid climate zones.

4.2 Outlook

If APV would be only combined with shade-tolerant crops (e.g. potato and lettuce) expected future electricity demand could already be covered without losing further land for electricity production (Table 1).

Table 1 APV potential in Chile based on 644 kWp/ha and 1532 kWh/kWp PV output (CNE, 2018), (INE, 2018a)

Parameter	Surface [ha]	PV capacity [GWp]	Electrical energy [GWh/year]
Additional demand in 2030	-	-	*22,292*
Lettuce	6,237	4	6,128
Potatoes	41,268	27	41,364

As mentioned before, further research is needed in order to determine crop requirements regarding environmental parameters and especially solar radiation for different crops in different climatic zones in order to optimize techno-economically APV plants for electricity and crop production.

In this publication, economical consideration has not been included. APV concept makes a PV project more expensive mainly due to the elevation of PV modules. However, APV allows to develop new kind of business models not only considering incomes by electricity and food production, but also savings in land costs due to efficient land use, less usage of water, protection of crops and the opportunity to improve farmers' competitiveness by the development of aggregated-value agricultural activities based on solar energy. However, this phenomenon must be studied under different PV plant scopes and considering the current national regulation, which are:

- Self-consumption: 20.571 “Net-Billing” law for PV plants smaller than 300 kW
- Commercialization of energy (Watts Casimis & Pérez Odeh, 2018):
    - PMG/PMGD (Pequeños Medios de Generación / Pequeños Medios de Generación Distribuida): The 244 Supreme Decree allows the development of distributed generation projects up to 9 MW and access to stabilized prices
    - Larger PV plants are regulated by the general law of electric services and commercialize their electrical production in the energy spot market
    - In addition, exist the option to close forward positions in public and private tenders through bilateral power purchase agreements (PPAs)

In conclusion, the economic considerations for the quantitative value of synergy effects should be addressed in further research work, wherein the development of long-term sustainable solutions could be strongly supported in the context of taxes and incentives policies for controlling the consumption of natural resources (soil, water, air) and its externalities. Finally, the aim of this publication is to raise awareness and the necessity for developing inter-sectoral solutions that consider synergy effects, and its implementation under a circular-use strategy for natural resources.

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