Renewable Energy at Chilean Universities: Is it Possible?

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Abstract. The concept of sustainable universities has gained increasing relevance and momentum in the recent decades. This has led Higher Education Institutions to incorporate the conceptualisation of sustainability in their teaching, research, campus operations and outreach realms. In such a way, that innovative projects regarding sustainable initiatives and clean technologies have arisen in many universities worldwide. In operational terms at Chilean Higher Education Institutions, it is possible to find endeavours related to renewable energy, greenhouse gas emissions, water management, energy efficiency, recycling systems, among others. In the present work, the case study of on grid solar photovoltaic projects at the University of Magallanes in Patagonia, and at the Faculty of Physical and Mathematical Sciences of the University of Chile in Santiago are described, in their conception and operation stages respectively. Additionally, these developments are analysed in light of context-based variables, considering latitude, funding and business models, technologies, and the corresponding electric systems characteristics.

1. Introduction

Universities have continuously been change agents in society [1], and the sustainability pursue has found a fruitful space in Higher Education Institutions (HEIs) curricula and campuses worldwide. Universities and academics play a key role in shaping a sustainable forthcoming, as they instruct professionals who manage in our civilization [2]. Furthermore, they can represent models for the public [3]. A wide range of endeavors have arisen in different backgrounds, including the integration of sustainability in vision pronouncements and emissions decline agendas [4]. Likewise, global declarations have been created in order to direct HEIs in the incorporation of sustainable development [5].

Typically, sustainability transformational processes at universities focus on four fundamental aspects:

- curricula modifications,
- strengthening sustainability research,
- greening campuses, and
- further committing with outreach.
In operational terms in Chile, it is possible to find undertakings related to renewable energy, greenhouse gas emissions, water management, recycling systems, among others. A milestone which allowed significant progress to be accomplished was the Cleaner Production Agreement for universities, with the certification of 14 HEIs [6]. This commitment required the completion of eleven goals, such as: having a sustainability policy, training 20% of students and professors in sustainability matters, and implementing a recycling system on campus.

Hence, given this increasing sustainability inertia and the eventual availability of proper mechanisms in place, innovative projects regarding clean technologies and renewable energies, can arise at the university level. Within the HEIs realm, this brings co-benefits such as senior management, professors and students’ awareness, education and research related to the systems, as well as community commitment and showcase opportunities.

The present work focuses on solar photovoltaics projects at HEIs. In this regard, the matter of finding feasible business models for universities solar photovoltaics systems is studied by [7], through the examination of technical and financial viability of five prospective sites at the Illinois State University campus in the United Stated. The authors affirm that solar energy clearly has economic, ecological, and learning benefits, but that it is problematic for public universities to get funding for these initiatives.

In this paper, the case study on grid solar photovoltaic projects at the University of Magallanes (UMAG for its acronym in Spanish) in Patagonia, and at the Faculty of Physical and Mathematical Sciences of the University of Chile (FCFM for its acronym in Spanish) in Santiago are presented, through a critical perspective, in their conception and operation stages respectively.

UMAG is a state HEI located in Punta Arenas founded in 1961. It has 6 Faculties: engineering, education and social sciences, health, economic sciences, science, and Institute of Patagonia. UMAG activities focus mainly on teaching, and it has 213 full time professors and 4,380 students. Its electricity consumption on the main campus was approximately 1 GWh in 2018.

The University of Chile is the eldest public university in Chile (created in 1842), with a nationwide public profile, and it is research-oriented. FCFM has around 425 lecturers and 5,960 students, while the engineering training takes six years for completion. Its consumption on the entire site was around 11 GWh in 2018.

In order to gain further insight, section 2 provides facts regarding solar photovoltaic deployment in university campuses, chapter 3 describes the UMAG and FCFM experiences, section 4 discusses critical variables involved, and chapter 5 concludes with final remarks.

2. Solar photovoltaic implementation in university campuses
The global and national current condition is worth exploring as a preliminary context. This sheds light on solar photovoltaic deployment in HEIs, regarding issues such as their location, capacity installed, and year of implementation.

2.1. International experience
The international higher education community is well aware of the affordable and clean energy for all notion given by the United Nations 2030 Agenda for Sustainable Development. Likewise, well-known global sustainability rankings exist, such as The Sustainability Tracking, Assessment & Rating System and the UI GreenMetric World University Rankings, both methodologically containing energy considerations.

The latter for instance, has an Energy and Climate Change (CC) indicator, including variables of number of renewable energy sources on campus and the ratio of renewable energy produced towards energy usage [8]. Considering 2018 results, University of Alcalá in Spain ranks number one in the Energy and CC category, with all the energy consumed coming from renewable energy sources [9]. Among others, low enthalpy geothermal energy is utilised.

Another noteworthy example is the case of Freie Universität Berlin in Germany (ranked number 5) which since 2011 has nine solar photovoltaic plants with a capacity of 675 kW; the annual production
is 600,000 kWh approximately [10]. The university informs that these installations are typically operated by investors and that they lease the roofs and purchase the electricity produced.

Systemic research on the topic is fairly limited. However, two singles case studies are found. First, Strathmore University in Kenya connected in the year 2014 2,400 solar photovoltaic panels on six buildings roofs, with a total power of 600 kW, thus becoming zero-carbon footprint [11]. The location of the country is privileged in terms of insolation, the installation generates more electricity than internally required, and it was economically supported by the French Administration. Second, Florida Atlantic University in the United States installed in 2008 192 panels totalising power of 26 kW [12]. Monetary resources came from donations, university funds, among others.

The work by [13] develops comparative research concerning renewable energy and energy efficiency at universities. To this end, participants of the Inter-University Sustainable Development Research Programme were surveyed, obtaining a sample of 50 HEIs worldwide. Results show that 72% replied that renewable energy is utilised in their campuses, 80% being deployed after 2010, 70% informed that the technology installed is solar/photovoltaic, and that in most cases renewable energy generation is a small percentage of university consumption.

2.2. National experience
The Chilean scenario regarding solar photovoltaic projects in university campuses is shown in Table 1. This particular section does not intend to represent a comprehensive information gathering process, but rather to consist of a referential framework.

| University | Campus | Region/Zone | Type   | Power  | Starting Year | Ref. |
|------------|--------|-------------|--------|--------|---------------|------|
| Universidad Andrés Bello | Casona de Las Condes | Metropolitana/Central Zone | Private | 18.0 kW | 2012 | [14] |
| Universidad Católica | San Joaquín | Metropolitana/Central Zone | Private | 9.0 kWp | 2013 | [15] |
| Universidad de Antofagasta | Coloso | Antofagasta/North Zone | Public | 21.2 kWp | 2013 | [16] |
| Universidad Andrés Bello | Casona de Las Condes | Metropolitana/Central Zone | Private | 80.0 kW | 2014 | [17] |
| Universidad de Chile | Edificio Beauchef | Metropolitana/Central Zone | Public | 15.0 kW | 2016 | [18] |
| Universidad Técnica Federico Santa María (UTFSM) | Casa Central Valparaíso – San Joaquín – Vitacura – Viña del Mar | Valparaíso/Central Zone | Private | 992.0 kWp | 2018 | [19] |
3. The UMAG and FCFM case studies

Subsequently, in order to present the UMAG and FCFM undertakings, both the initial setting and the technical aspects are described. The first project is currently in its conception stage, whereas the FCFM endeavour is in its full operation.

3.1. UMAG

The idea of installing a solar photovoltaic system at UMAG started with the isolated motivation of a professor of the GAIA Antarctic Research Centre. A few months later, the university committed to become carbon neutral by 2040. This is expected to bring additional momentum to the project, which is currently in the fundraising phase. Technical specifications are described below:

**General information**
- Place: Punta Arenas, Chile
- Latitude: -53.15
- Power: 94.1 kWp
- Type of system: on grid, with north orientation

**Photovoltaic panels**
- Technology: polycrystalline
- Manufacturer: Hanwha Q Cells
- Model: Q.PLUS L-G4.1 330
- Number: 285
- Unit power: 330 Wp

**Energy and investment**
- Annual electricity production: 103,400 kWh
- Investment: USD 140,000 – without the connection between the solar installation and the electrical facilities.

**Space use and contribution**
- Area: 1,485 m2
- Fraction of annual electricity contribution: 10%

3.2. FCFM

The second case study originated as an instruction from the authorities to the Sustainability Chief, with the aim of strengthening the sustainability of a LEED Gold building of around 50,000 m2. Thus, a 15 kW solar photovoltaic plant was implemented in May 2016, utilizing Building Integrated Photovoltaics technology, combining electricity generation and architectural design. The technical characteristics are the following [20]:

**General information**
- Place: Santiago, Chile
- Latitude: -33.4
- Type of system: on grid
- Engineering, supply and assembly: STC SUNBELT.
- Financial aid: SUNEDISON.
- Nominal power: 15 kW
- Installation in the form of an open gable roof, with east-west orientation.

**Photovoltaic panels**
- Technology: Amorphous silicon
- Manufacturer: Nexpower
- Model: Nexpower Lucid Plus NB-130AP
Number: 124
Unit power: 130 Wp
Transparency: 10%

Energy and investment
- Annual electricity production (first year of operation): 23,754 kWh
- Investment: USD 139,000

Space use and contribution
- Area: 200 m² approximately
- Fraction of annual electricity contribution: 0.5% of the building and 0.2% of the campus

4. Results
At the present moment, it is only possible to expose results corresponding to the FCFM system. The 2019’s energy production (until July) is shown in Figure 1, while in Figures 2 and 3 it is possible to compare the power generated in January and August 2019.

Figure 1. Monthly electricity generation in kWh for the year 2019 at the FCFM facility, total generation of 10,889 kWh.

Figure 2. Daily power in January the 10th 2019.

Figure 3. Daily power in August the 1st 2019.
5. Discussion
In the present chapter, the UMAG and FCFM case studies are analysed and discussed in light of context-based variables.

5.1. Latitude, temperatures, radiation, and technologies
Certain characteristics of the region where the system is installed directly affect its design and performance. For instance, the latitude of Punta Arenas and Santiago define the tilt of the solar panels.

Similarly, the panel temperature disturbs its efficiency due to current and voltage changes, which is determined by factors such as the ambient temperature, the nominal operating cell temperature, and the irradiance [21]. It stands out that for Punta Arenas the annual average temperature is 6.9 °C, while for Santiago it is 15.2 °C [22].

Likewise, incident radiation, which produces the electricity transformation, depends on variables as weather conditions, the inclination of the surface compared to the horizontal plane, and the presence of reflective surface [23] [24]. Figure 4 shows the incident solar radiation in Chile. In Santiago average radiation moves from 4.5 to 6.0 kWh/m²/day, while in Punta Arenas it is 3.0 – 4.5 kWh/m²/day. Also, accumulated dust, humidity, cloudiness, wind velocity, and other phenomena will affect energy production [21]. For instance, the frequent wind in Patagonia helps avoiding particle embedding and freshens the panels when necessary, and in Santiago smog diminishes the systems outputs.

As an estimate resulting from the Chilean Solar Explorer tool, a 1 kW photovoltaic system in Santiago (latitude -33.3, longitude -70.7) produces approximately 1,600 kWh/year with a capacity utilization factor (CUF) of 18%, but in Punta Arenas (latitude -53.2, longitude -70.9), the same system produces around 1,060 kWh/year (CUF of 12%). These approximations vary according to the technology utilized and system’s design.

![Figure 4. Incident solar radiation throughout Chile [25].](image)

The type of panels more widely employed are: i) monocrystalline (high cost and efficiency), ii) polycrystalline (medium cost and efficiency), and iii) amorphous (low cost and efficiency) [26] [27]. Their specific behavior differs when exposed to conditions such as high temperatures, particles accumulation, and relative humidity [27]. Accordingly, the UMAG and FCFM installations consider dissimilar technologies to optimize each system’s output and objectives.
5.2. Electric systems
The Chilean electric market has three sections: the national, Aysén and Magallanes structures. The interconnected system of the national zone possesses a higher renewable energy contribution (48%), in contrast to the Magallanes situation where 98% comes from fossil fuels [28]. Thus, energy, power, and net billing prices are not the same in each system, which similarly affects the project’s design and economic assessment.

5.3. Investment, funding, and business models
Regarding investment per kW, the UMAG preliminary estimations indicate that it will cost around 1,500 USD/kW and for the FCFM it was 9,200 USD/kW, the latter given the fact that it is an elevated system, small scale, with an expensive panel selection. Broadly speaking, 1 kW installed in Santiago costs around USD 1,250, whereas in Punta Arenas it increases to USD 1,900 (for on grid systems).

In terms of funding, the FCFM system was partially financed by the donation of a private company (50%) and the other half was covered by the university. It is worth-mentioning that the economic situation of the FCFM is considerably more stable and ameliorated when contrasted with the one of a significantly smaller and geographically isolated institution as UMAG.

The payback period for the solar photovoltaic systems for each case study are the following: UMAG with 100% university funding of 16 years; UMAG with 50% university funding and 50% subvention of 8 years; and FCFM with the real scenario 50% university funding and 50% donations of 31 years.

5.4. General aspects
In Chile, a total of merely 6 facilities within 5 universities are found out of 61 HEIs, with installed power ranging from 9 kWp to 992 kWp. The first system was installed in 2012, showing that these endeavours are recent at the university realm in Chile. It is important to draw attention to the difference of the projects funding. Some universities had their own resources, others mixed internal and external contributions, while others applied for international financing. For instance, UTFSM obtained economic aid through the Global Environment Center Foundation of Japan.

A consequence for UMAG of being established in a remote setting as it is Patagonia, is the fact that given the lower degree of industrialisation the amount of locally placed companies which may possibly be interested in supporting these type of sustainability-oriented endeavours through economic contributions, is significantly inferior. The same notion applies for the availability of properly trained technicians, professionals, and firms occupied in the renewable energy sector. Additionally, there is the local perception of a low feasibility of implementing solar projects in such distant locations. Interestingly, Hamburg’s latitude - in the north - is very similar than in Punta Arenas.

These type of projects typically require the collaboration between various actors who would contribute from their expertise: legal aspects, structural engineering, mechanical and/or electrical engineering, architecture, administrative tasks, among others. Thus, internal cooperation between the stakeholder constellations has been identified as key to facilitate the viability of such initiatives within the complex structures and dynamics at HEIs.

6. Conclusions
The international experience demonstrates that large scale solar photovoltaic facilities are feasible to build and operate at the university level, however most of the installations seem to represent a small percentage of university consumption. The national situation shows that deployment of this technology is scarce, concentrated in the central zone of the country, and not necessarily significant in terms of energy contribution. It is also observed that project implementation is recent both internationally and in Chile.

Aspects such as lack of resources and a sustainability culture are observed in the UMAG experience when conceiving a solar photovoltaic project. The FCFM has been successful mainly due to authorities’ engagement and the corresponding economic support.
Certain differences exist between the previously described initiatives such as the projects' scale. While the FCFM system can be considered a pilot project, the UMAG system aims at more vastly contributing to the university’s electricity consumption, which is facilitated due to space availability in a significantly larger campus. The population density and campus size difference between FCFM and UMAG, become relevant variables when designing renewable energy systems in HEIs.

The present work has explored how environmental conditions are decisive features on the installation of solar photovoltaic systems in campuses located in Santiago or Punta Arenas. This similarly occurs with systems payback, funding opportunities of each organisation, and internal engagement with sustainability and CC values and principles.

It is worth-mentioning that the FCFM has recently begun calculating the maximum installation potential within the campus roofs, while for the UMAG case study funding is the key issue at the moment.

Consequently, in order to conclude regarding the initially proposed question, it is conceivable to argue that solar photovoltaic at Chilean universities is expected to become ever more possible given several global and local factors. Some of these are the SDGs global agenda inertia [13], the IPCC special report about Global Warming of 1.5 °C which communicates a sense of urgency in tackling CC, the positioning of Chile as a privileged country for investment in solar energy, the COP25 event which has brought increasing awareness and action, a CC law in Chile which is currently under evaluation and commits with 2050 carbon neutrality, as well as a collective movement of HEIs worldwide which are declaring climate emergency.

Ultimately, this is an undergoing cultural change, where the local authorities’ paradigms are crucial, that could eventually open the doors for a more sustainable future for all.

Acknowledgments
The authors gratefully acknowledge financial support from CONICYT PIA/BASAL AFB180003.

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