Using renewable energy sustainably - Industrial Symbiosis Potential

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Abstract

Solar energy has become one of the biggest drivers in the quest of reducing our reliance on fossil fuels and, subsequently, fight against climate change. However, some concerns have been raised regarding its installation given the amount of land required and the impact on biodiversity from its structures. This introduces the concept of industrial symbiosis, one of the subfields of circular economy and industrial ecology. This concept aims at a collaborative and mutually beneficial approach between different industries or companies exchanging resources with each other in order to improve their performance and efficiency. The central objective of this dissertation was to develop a methodology to help identify and evaluate possible industrial symbioses and apply it to the solar parks that Start Campus will construct. First, the methodology identified the stakeholders involved in similar projects. Then, based on similar case studies, the potential symbioses were identified. Finally, we proceeded to analyze them in two steps, in which the first consisted of evaluating the benefits and drawbacks of each alternative followed by the drivers and barriers they may encounter in establishing them. The application of the methodology presented three possible symbioses for the Start Campus project. The findings were quite promising as they clearly demonstrate how communities and/or industries can be involved in solar projects. The research also showed that is possible to offset the high initial investment costs with further benefits.

Keywords: Solar energy; Industrial Symbiosis; Start Campus; Sustainability; Stakeholders;

1. Introduction

Over the past century, the energy sector has been one of the most important drivers of the global economy, supporting economic and social progress, improving quality of life, and bringing prosperity to people all over the world. Since the Stone Age, energy has been a part of people's lives in many forms, starting with fire and progressing to a vast range of energy forms (coal, oil, natural gas, and renewable energies, such as solar, wind, hydropower, etc.) in contemporary days. The emergence of all these sources of energy over time, as well as their widespread application in everyday life, resulted in a massive dependency upon energy by the world's population, particularly in developed countries.

According to International Energy Agency (IEA) statistics, the world's total final consumption of energy was 194 EJ in 1973 and 418 EJ in 2019, reflecting a change of roughly 115% over 46 years. IEA further adds that this consumption will continue to grow as global energy demand is expected to increase 47% over the next 30 years. Unfortunately, resources are not all unlimited, therefore we will need to carefully plan how we will respond to the demand, as other major concerns arise, namely climate change.

The biggest driver of climate change is carbon dioxide (CO_2) emissions, which is the most dominant greenhouse gas (GHG) produced by fossil fuel burning (87%), land use change (9%), and industrial production (4%) according to Our World in Data. It is urgent to stabilize the global climate as serious consequences can emerge (severe storms, rising ocean, poverty, etc.), hence society must commit to making a significant change to drastically reduce GHG emissions.

At the heart of this discussion lies the fossil fuels which continue to be the primary energy sources, as reported by IEA, with oil accounting for 30.9%, coal for 26,8%, and natural gas for 23.2% from the 606 EJ produced in 2019. (Butturi et al., 2019) state that the industry sector is one of the main contributors to the release of CO_2 direct and indirect emissions, which originate from "fuel combustion and industrial processes (direct) and energy production, such as electricity and heat (indirect)". Now in order to reduce these GHG emissions, a rapid world transition to renewable energy sources (RES) must occur.

The most suitable RES for industrial applications is solar radiation, either photovoltaics (PV) or thermal, biomass and wind. Among these RES, Solar PV presents itself as one of the most technically feasible and environmentally sustainable solutions to address the abovementioned concerns. As per Our World in Data, solar energy is currently the third largest generated renewable energy, only behind hydropower and wind, but is expected to lead the way in transforming the energy sector in the next 10 to 20 years.

Typical solar energy projects are ground-mounted solar parks, which consist of solar panels installed on metal supports on the ground. Yet, despite being considered a sustainable energy source, given its exponential growth in the last decade, possible implications on the ecosystem might have been overlooked. Impacts on land use and the local environment and communities are currently relatively unknown and need to be explored otherwise it will offset the benefits that this RES brings to climate change mitigation. For example, land use change can alter or degrade habitats affecting some species and leading to habitat loss, which constitutes a direct threat to biodiversity (Blaydes et al., 2021). In the local environment, concerns related to the changes in the microclimate, soils, or vegetation arise and for local communities, visual pollution starts to become a problem.

To prevent further escalations, the solar energy sector will need to look out for solutions that counterbalance these concerns. In this sense, the solar energy generating companies could promote resource exchanges to create mutually beneficial relationships between them and other organizations that could mitigate some problems that have been raised with the solar parks' implementation.

One concept that reflects such relationships is industrial symbiosis, which aims to create synergies between different organizations to develop a system with resource exchange, e.g., materials, energy, or by-products. Its goals include using and sharing economic and natural resources increasing economic performance, reducing the environmental impact, and creating benefits for local communities (Al-Karkhi & Fadhel, 2020). IS networks can also lower inputs, increase resource productivity, and decrease the environmental impact while increasing economic growth and employment prospects.

Despite all the potential, the concept is still not widespread among companies and industries. Yet, to our knowledge, few assessments have explored these problems or the integration possibilities of IS and solar energy generation, particularly in Portugal. A major motivation for this study is that year after year, the installed solar capacity and, subsequently, the PV production has been breaking records, and by February 2022, Portugal had produced for the first time more than 1 gigawatt per day (Expresso, 2022). One of the big projects that will contribute to the installed capacity in Portugal already in 2023 will be the Sines 4.0 project, led by Start Campus. This project will create a mega data center in Sines that will be supplied by PV power generation of about 1GW. This installed capacity will require several solar parks, which resurrect the aforementioned issues.

Hence, this master's thesis will aim to investigate viable possible symbioses of solar park/farm projects with other industries or local communities to share mutually advantageous opportunities. The main specific objectives of the study are:
- How will it be possible to involve the community and industries with respect to solar energy production?
- How can the high costs of investment and the appropriate infrastructure development associated with solar energy production be balanced?

2. Methodology

The methodology will be applied to a real case study, namely to the Sines 4.0 project, which is run by Start Campus (SC). The project will be to build a Hyperscale Data Centre campus of up to 495MW, however, our focus will be on the solar parks that will be constructed to provide energy to the data centers.

2.1. Research Design

The methodology attempts to conceptualize a step-by-step plan to investigate potential symbioses for these solar parks. This plan was conceptualized by taking several research and analyses of industrial symbioses. By crossing all this research, we were able to innovate in this dissertation by creating a new research design.

2.2. Project Planning

First, the project must start by assembling partners and defining the site where the symbiosis will take place. It might be a city, a municipality, an industrial park, or any type of area. Next, it is necessary to identify and engage the stakeholders and gather the necessary resources to fund the project.

2.2.1. Case Study Description

The case study's description will allow us to discover some key points and concepts about the project, so that, we can apply the proposed methodology. Some main topics that we will mention are the Sines 4.0 project, the project responsible organization SC and some key data, which will be highly valuable for our study.

2.2.2. Stakeholders

In summary, it is possible to conclude that stakeholders play a crucial role in developing an implementation plan as they may have experience, information, or insights to define its success. Furthermore, and most importantly, they are often in a position to support or block the strategy implementation according to their interest, demonstrating their true value. To understand how they are satisfied and what are their expectations, a stakeholder analysis must take place to identify them and comprehend their role in these types of projects as it will unveil how important and influential, they will be to the symbiosis.

Stakeholder analysis is "an approach for understanding a system, and changes in it, by identifying key actors or stakeholders and assessing their respective interests in that system" (Maguire et al., 2012). The author also outlines the steps to deliver such an analysis:

1) Identify and group the stakeholders, which influence the system
2) Determine the stakeholder's roles in the project
3) Identify the relations between each other
4) Understand the possible conflicts that could threaten the system

Starting with stakeholder identification, it is crucial to determine the project's stakeholders and consequently, to manage the expectations of all parties involved in a project. The research of Aviso et al. (2022) provides a background of which stakeholders are involved actively in symbioses and their according roles. This research will serve as inspiration to apply to our case study which will contemplate potential symbioses with solar parks. After this identification, it is necessary to understand the relationships between each stakeholder and how they are connected. In this stage, we will utilize a visual representation to determine whether the stakeholders have an impact on both the symbiosis and the organizations that take part in it, which logically implies that they also have an impact on the symbiosis indirectly. The last step will determine whether there might be possible conflicts between stakeholders in the future.

2.3. Identification of potential symbioses

To identify the possible symbioses, we cross-referenced a set of alternatives provided by SC with the literature review. SC provided possible applications for PV integration into various parts of the human environment – buildings, lakes, traffic routes, agriculture, etc. Nevertheless, based on our case study, some applications are not compatible with the solar parks that SC wants to implement, for example, Vehicle-Integrated PV. The purpose is to create symbioses with the solar parks thus we will resort to the literature review, which presented different types of solutions in line with our objective.

2.4. Analysis of the potential symbioses

Finally, we will conduct a two-step analysis of the previously discovered symbioses. The first step consists of outlining the benefits and drawbacks from each party's perspective. At last, we will discuss some intervening factors, such as potential drivers and barriers that may be encountered.

2.4.1. Benefits and Drawbacks

The content presented here will mostly be based on best practices and lessons learned from previously implemented symbioses. In addition, we will do thorough research on similar examples implemented throughout the world.

2.4.2. Drivers and Barriers

To develop a symbiosis, it is essential to understand the driving forces and barriers of this model. Understanding the drivers will assist society to perceive the advantages that symbioses can leverage, making them models of best practices. On the other hand, studying the barriers will allow the involved organizations to understand what they will face when it comes to implementation, thus avoiding unpleasant surprises. Different papers not only support this theory but also add that these are primarily related to four aspects (Al-Karkhi & Fadhel, 2020; Azevedo et al., 2021):

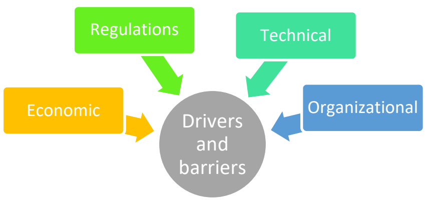

Figure 1: Main drivers and barriers to the IS implementation

3. Application to the Sines Data Center

3.1. Case study description

The case study in question is an hyperscale data center, part of the Sines 4.0 project, which is being developed by Start Campus, the project's management company. Start Campus, started in April 2022 the construction of the campus's first building called NEST (New & Emerging Sustainable Technologies), which will be completed in the first quarter of 2023 having a total capacity of 15 MW (ECO, 2022).

The Sines 4.0 project will be located on the southwest coast of Portugal in the Sines Industrial and Logistics Zone (SILZ), which is inserted in the District of Setúbal. Even more important than the general location of the project is where the dissertation's applicability will be, meaning the location of the solar parks that will supply the data center. After collecting the information provided by SC, we were able to pinpoint the first lands purchased and ready to be licensed. These lands are all adjacent to SILZ, except for one that is already existing inside the area. The 5 locations' total size is equal to roughly 750 hectares. However, the company has already purchased around 1500 ha, meaning that these five lands only represent 50%.

3.2. Stakeholders

All stakeholders found are applicable to any of the alternatives that we will present in the next section. The only exception will be the stakeholder defined as the "Target organization". This stakeholder is the second organization part of the symbiosis besides Start Campus and will be presented more carefully when it is introduced.

Start Campus - Entity that will directly participate in the established symbiosis and will mainly assume the role of energy and land use supplier.
Target Organization - Second participating entity will receive what Start Campus has to offer. As a mutually beneficial process, this organization will also bring something to the table, which has to please Start Campus fill one of its gaps.
Ministry of Environment - Government department in charge of the Environment and Climate Action area and offers support for policymaking, manages and allocates funding programs within the same area.
Sines City Hall - The city hall is the executive body of the municipality of Sines. The entity is responsible for the approval of any construction projects, meaning all the necessary licenses for the construction of solar parks will have to go through this entity.
Solar panel development company - This stakeholder is not yet defined by Start Campus. Is responsible for providing and installing solar panels on the land purchased by the company.
Redes Energéticas Nacionais (REN) - REN operates the national energy transport network which connects producers to consumption centers.
Local/Adjacent Communities - Communities of the municipality of Sines and/or adjacent locations where solar farms may be developed. They represent a powerful stakeholder since they can directly affect or be affected by the establishment of these farms
C6 Coalition - A group constituted of 6 NGOs intending to defend the preservation and promotion of nature and biodiversity before civil society and public and/or governmental institutions.
Since the stakeholders have already been identified, we can now determine the relationships between them in light of any potential symbiosis that might be formed.

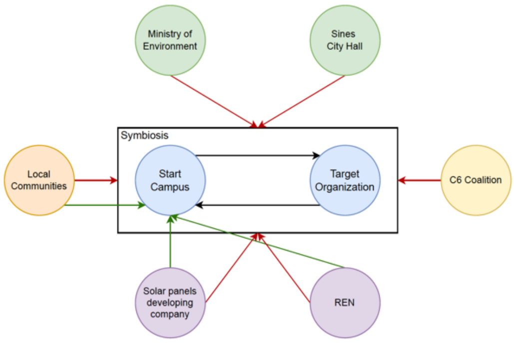

Figure 2: Stakeholders' interconnection

3.3. Potential Symbioses

Start Campus started by providing 6 possible applications for PV integration with its data center. A brief description of each application is provided below:
Vehicle-Integrated PV – Solar panels installed in an electric car's roof. The main target is to provide extra mileage to the electric car and the energy generated is not fit for other purposes.
Building-Integrated PV – Solar panels are integrated into the building's envelope and are part of the building's components such as roofs or windows.
Agrivoltaics - Simultaneous use of land areas for photovoltaic solar energy generation and agriculture.
Road-Integrated PV - Incorporation of solar panels into and near land areas reserved for transportation.
Floating PV – Set of solar panels mounted on a water-floating structure.
Urban PV – Construction of solar modules in urban landscapes such as public squares or recreation areas.

Focusing on the case study at hand, before analyzing which application would be matching, it is important to point out what SC is looking for or what it is offering to form such symbioses. By developing these solar farms, SC will be trying to fill two gaps:
- Land use required to construct a solar park of this magnitude
- The energy produced during the hottest hours of the day typically exceeds the constant supply needed by the service, in this case, the data center.

Considering that a symbiosis requires mutually beneficial inputs and outputs and the previously described applications, one of them stands out and has been previously mentioned in this dissertation, which is agrivoltaics. The agriculture industries are willing to receive these types of inputs/explore these opportunities and can produce benefits for the Start Campus with their outputs, thus promoting sustainable development (Toledo & Scognamiglio, 2021). Despite not being mentioned in the applications, the adjacent communities could also have something to contribute. Community solar projects could satisfy the needs of Start Campus and would guarantee the company a powerful ally.

Although these organizations are eager to receive electricity or land as a perk, they must also demonstrate how they would add value to Start Campus, so that they can be chosen as the best alternative. Before we analyze the benefits and drawbacks that each organization can provide to the Start Campus and vice versa, we must understand how the symbioses can be established.

3.3.1. Ground-mounted solar panels with sheep farming

The first symbiosis involves letting animals graze the ground beneath the installed solar panels. Not only do the panels have to be cleaned, because obstructions, such as dust, can negatively impact the panels' performance, but also the land underneath them. Therefore, having animals graze the area where the solar farms are located will be very advantageous for the farms' upkeep because it will also result in a decrease in expenses. This will also provide the opportunity for the sheep herders to acquire fresh and expansive grazing territory for their flocks.

Applying this to our case study, Start Campus has two options to implement this symbiosis:
- The first option will be to inquire the adjacent communities about the presence of shepherds and their corresponding sheep flocks. If so, SC will need to assess how many sheep it will need to graze its land and determine whether the supply matches its demand.
- The second option will only come into question if the supply from the neighboring areas does not match the required demand. In this situation, SC will need to track down and get in touch with sheep producers to create partnerships. SC will have to evaluate this option's economic viability as it will require a specific area to rest the flock and the according shepherds to walk them, meaning it will demand the construction of a farm nearby.

3.3.2. High-mounted panels with berries production

The second possible symbiosis is high-mounted panels to cultivate specific crops. These panels create a large area of shaded land since they are raised to a certain height, between 2-5 meters, which greatly impacts the type of agricultural product it can be grown. This type of installation has been widely used for berry crops since these trees have a medium height.

In this situation, SC may search for a berry-producing company that is willing to try this innovative technique. For instance, Lusomorango, the largest national producer organization in the fruit and vegetable sector. This company has a lot of potential for several reasons: 1) Sines is located in the ideal region for the production of these products, as mentioned in the previous paragraph; 2) Lusomorango is strongly committed to the environment and innovation. The company is focused on generating the minimum waste, so it has allocated considerable resources to the acquisition of various equipment that allows the use of water resources in an optimized way.

3.3.3. Community solar projects

The last symbiosis involves providing energy to the adjacent communities. In this situation, we could be talking about on-site or off-site community solar projects. On-site would mean that the communities have the panels installed on their properties, whether on the roofs or owned land. Off-site is the most common practice since the communities can still have a piece of the energy generated even when they don't own a home or have a suitable roof to install.

Keeping in mind that Start Campus will have a hyper-scale data center to supply, the only way to accommodate such projects is to distribute the excess solar power it generates to them. On an on-site project, if there are few panels installed, the solar excess could be directly supplied to the property where they are located. On an off-site project, the surplus would be injected into the grid for everyone to benefit from it and each receiving its share.

Important is that data centers will function around the clock, therefore there needs to be storage to ensure not only uninterrupted operation at night but also potential peaks during the day. Apart from that, the data center will consume a constant value of electricity, which will always be less than the peak production of solar farms, representing an excess in production in some intervals. In this case and without compromising the supply to their data center, these solar community projects can be examined and formed so that Start Campus can sell energy at a reduced price to prevent wastage of excess.

3.4. Symbioses analysis

This analysis will be unbiased and conducted by considering both the donor's and the receiver's perspectives. We will compare each alternative's advantages and disadvantages in the presented order in the previous section.

3.4.1. Benefits & Drawbacks

Ground-mounted panels with sheep farming
→ Perspective – Start Campus
Benefits:
- One of the major maintenance expenses is controlling the growth of grass and plants surrounding the solar panels, which requires labor, machinery, and products like herbicides. Allowing lamb grazing on these fields will slow down or even prevent plant growth leading to a significant reduction in the maintenance costs for SC.
- SC can promote environmental sustainability since they are reducing or even replacing the use of lawnmowers that run on fossil fuels. This action would mean a GHG emission reduction since the machinery would be replaced by sheep. Additionally, this system would have a positive overall impact on the ecosystem in fields such as "animal science, soil carbon sequestration, vegetation biodiversity, and pollinator habitats" (Wang, 2022).
- Sheep farming can generate stronger ties with local communities, making the infrastructures more attractive and easier to install, due to social acceptance.

Drawbacks:
- "On average, to keep plant growth under control, one to five sheep per acre are needed." (Bay Journal, 2022). For the current 1500 ha that Start Campus possesses, 9375 sheep would be needed to graze the grounds. This being said, it is difficult to estimate whether Sines or nearby farmers have enough herds to meet the company´s needs. For the aforementioned number of sheep, equivalent shepherds would be needed.

→Perspective – Shepherds/ Sheep farming companies
Benefits:
- Lamb welfare is improved by solar panels since the shade provided helps the animals to preserve energy (Clean Energy Regulator, 2022).
- With the protection during periods of high temperatures and during rain and hail in the lambing season, it was observed that the sheep "were slightly lighter stocked than the average in the district but were cutting an amazing amount of wool with higher quality" (Jose & Calver, 2022)
- If Start Campus ends up renting the shepherd's land to install their panels, it will be an extra income for these pastors. This is highly valuable for these shepherds, as they are struggling most of the time due to low wages, thus it would increase the rural community's livelihood and financial viability.

Drawbacks:
- Sheep farming companies have a hard time finding shepherds as normally is shown as a family business. For this, the sheep farming company or communities would have to ensure that there are enough shepherds and consequently pay their wages.

High-mounted panels with berries production
→ Perspective – Start Campus
Benefits:
- The land use for the solar park would be fully explored. By establishing this symbiosis, the Start Campus could still generate its solar energy while also making better use of the area by encouraging an agricultural company to exploit the land. In addition, this would relieve the pressure on ecosystems and biodiversity as these are affected when cultivated areas are expanded.
- Land maintenance would also be assured by the berries production company, since having good soil health would be fundamental for its fruits to bloom. Hence, healthy soil will guarantee that the installation of the panels will be easier and more resilient.,
- Environmentally speaking, berries such as raspberries or strawberries contribute to the reduction of GHG emissions since their carbon footprint is pretty low and allows them to collect a significant amount of CO_2 emissions.

Drawbacks:
- Installing such systems will represent a considerably higher cost than just installing ground-mounted panels, meaning a higher cost per kilowatt-hour generated due to larger capital expenditures.
- The support mechanisms for these types of projects are almost non-existent, meaning Start Campus would have to import these technologies and the necessary knowledge to implement them from other places, translating into a much higher cost.

→ Perspective – Berries production companies
Benefits:
- The agricultural business could purchase electricity at a set price from Start Campus in case of surplus output to run its irrigation systems or machinery.

- Improvements to the farmers' health who often harvest crops in extremely hot conditions, could result in serious health issues. Thus, this technique enhances their work conditions by providing shade while harvesting.
- Fruit production's quality is 2 to 3 times better under solar panels and it requires about 50% less water than without this protection.

Drawbacks:
- Like all fruits, berries require sunlight to grow, therefore the panels will partially reduce their energy yield and might harm their production.
- Moving the crops to another location may be a difficult task, as there are many factors involving this relocation such as economic and productivity aspects. Berries may not do well where the solar parks are located due to the climate and these companies should not expect any compensation, meaning the relocation costs will be on the companies.

Community solar projects
→ Perspective – Start Campus
Benefits:
- Start Campus can use this opportunity to increase its acceptance rate within local communities. This would present an opportunity not only to save money but also to boost the local economy and create job possibilities. Such projects require engineers, contractors, electricians, etc., so even if locals do not end up taking these positions, it will already increase the activity in the surrounding areas.

Drawbacks:
- As previously mentioned, Start Campus already purchased 1500 ha to construct its solar farm and is still looking for additional land to enhance it even further. Lots of space is needed, meaning land clearing will probably be required before installation can take place. This could have unforeseen environmental effects like habitat loss and deforestation. Start Campus will have to take this into account and demonstrate sustainable land-use practices to gain support from local communities and most importantly.

→ Perspective – Communities
Benefits:
- Local communities will have access to this energy that would be directly fed into the grid by Start Campus at reduced prices, meaning very close to the production cost, representing a considerable gain for the locals. It is anticipated that subscribers will save between 20-30% on their monthly electricity bills by choosing this alternative (Silva, 2021)
- Considering the energy crisis, where electricity prices have been rising constantly, this synergy can represent an opportunity for local communities to fight this increase and have some protection against price volatility by having access to this cheap supply.

Drawbacks:
- Communities should be ready and consider this synergy as a temporary rather than a permanent benefit. Due to the high investment, SC might have the incentive to, in the future with a solid customer base, increase prices to cover the initial investment. Not only that but they could find more advantageous, viable, or profitable ways in the future to supply energy, stripping the communities of this privilege.

3.4.2. Drivers & Barriers

This evaluation can reinforce some of the already highlighted benefits since there may be drivers pointing in this direction or have the opposite effect, which will present various barriers making the alternative more challenging to implement or adopt.

Ground-mounted panels with sheep farming

The biggest driver for Start Campus will be the reduced O&M costs of this alternative and possibly some minor reduction in the initial costs. Start Campus will be able to cut back on some labor expenditures by using sheep to keep the fields healthy since they partially do the worker's job.

For shepherds, the principal economic driver is the additional revenue both directly and indirectly. Directly, they will collect a certain wage established in the contracts with Start Campus to graze their sheep in the solar park. Indirectly, the protection of the panels throughout the different seasons will improve lamb welfare and the quality of the wool harvested, raising the shepherds' income.

One problem that may arise is if the flocks have to be relocated, as the farms may not be directly adjacent to the solar parks, involving extra costs and efforts to flock owners. To overcome this problem the owners could request additional funding in the contracts for both, increased sheep production and relocation, which will be advantageous to both parties.

Moving on to the regulatory parameter, a newspaper article in Expresso by Prada (2022), reports that the government accepted the legislative solution found by the Ministry of the Environment to speed up the installation of new photovoltaic capacity in Portugal, ensuring faster licensing, but also financial compensation for municipalities. Municipalities will be entitled to receive a fixed compensation of 13,500 euros for each MW installed in their territory.

However, there has recently been some disagreement in Portugal over the installation of photovoltaic plants. According to Dinheiro Vivo (2021), the C6 coalition has asked the parliament to legislate on solar photovoltaic plants to prevent their locations in critical areas in the country. C6 believes that the installation of these plants is jeopardizing the natural heritage, namely the fertile soils and ecosystems.

Since it is the municipal councils that approve or reject the projects, they are the ones who will be the biggest obstacle, as they will be in charge of protecting and preserving their natural areas. In this case study, this task will be dealt with by the Sines city hall, which can invalidate some locations. Nonetheless, SC will always be recognized for its status and the promised benefits to the local communities, which will help in social acceptance before such governmental agencies.

This symbiosis, at the technological level, may have as a driver's new techniques of movement and herd management within the lands, which can push this symbiosis to a new level. Yet, innovations that favor more organizations individually might emerge more quickly. For Start Campus, as there is this symbiosis, there can be other technological breakthroughs, which can present themselves as more viable at all levels. In the same way that for sheep farmers and breeders it may no longer make sense to graze their flocks on these parks if they find more fertile soil or if they find new technologies that improve their wool production.

High-mounted panels with berries production

Installing high-mounted solar panels represents a very high upfront cost for SC, which consequently means a high barrier to the formation of this symbiosis. Even if the chosen agricultural firm were to cover all the land maintenance costs and would pay a fixed amount in order to have a percentage of produced electricity to power their necessary systems, it would never be enough to offset the high initial costs that SC would incur, or at least on a short to medium term.

Furthermore, since this is an innovative project and a recent concept to be implemented in Portugal, it implies a project with many risks and uncertainties associated. These two factors combined result in a difficulty increase to obtain funding whether this comes from banks or investors. Not only that but looking at the project as a whole, a large workforce will be needed to coordinate a project of this magnitude, which results in additional costs.

On the other hand, the chosen berries production company will be economically driven to force this symbiosis because it can significantly improve its revenue and savings. The aforementioned benefits state that the quality of the food produced is 2 to 3 times better, which can directly translate into a higher volume of sales or prices, thus increasing its revenue. In terms of savings, the agricultural company can save on water consumption for the maintenance of its crops. However, the agricultural industry will always have to keep in mind the initial entry cost such as relocation investment or new crops to be planted and compare with the benefits after the symbiosis has been established.

In this symbiosis, regulation, and policies besides being linked to the governmental agencies are also highly correlated with social and community acceptance. Involving the communities in the project development would reflect local values and positive attitudes toward the project. Taking into account that some regulations and policies are started by the local communities' dissatisfaction and unhappiness, with their approval of this symbiosis, we would be one step closer to the governmental agencies ruling in its favor. However, we must always take into account the significant influence that communities have over the government, allowing them to apply pressure and prevent such a symbiosis.

At last, the technology factor is of great importance in this symbiosis. Such APV projects are complex to pull off, which generates a lot of concerns for all stakeholders involved, specifically for SC. Focusing on the technical specifics, some concerns are the complexity associated with the integration of dual usage beneath the solar panels, the impact of non-optimal angles for electricity generation, and the technological know-how to implement the solution.

On the other side, this complexity could be seen as a potential driver. If capital is no subject here, this innovative system could generate growth in multiple aspects. This symbiosis may be one of Portugal's pilot initiatives, and with the learning curve, we'd be able to eliminate some drawbacks and reduce some risks in the event of success. As modern technology is advancing so quickly, new technologies could be adopted both for the construction of the SC structures and for the maintenance of the crops by the agricultural company. To implement a such system, a large workforce would be required, so there would be a significant increase in job creation in Sines leading to an increase in local income which in turn leads to a greater local demand for goods and services generating a cycle of growth.

Community solar projects

Remember that there can be on-site or off-site projects, and both have different economic effects, either for the SC or for the participating communities. In this case, SC will not have much incentive to establish this symbiosis except for 2 drivers: 1) SC will be able to obtain some additional revenue with the sold electricity. Even though the company will not be able to sell it at market price, it is surplus sold, which normally would be traded at production cost; 2) In the case of on-site projects, it would allow some savings in the land acquisition, installing costs, and O&M costs.

The story changes when it comes to the community's perspective. Being part of such projects, communities would have access to lower-cost energy and additional lease revenue, which consequently would increase the likelihood of this symbiosis being established. Given the low-income households in the area, these savings are expected to have a major impact by lowering the energy burden for local communities.

At the regulatory level, this symbiosis is well supported by regulators. The Ministry of Environment with the Environmental Fund has created a program of support for the implementation of Renewable Energy Communities (REC). This program aims to finance initiatives that promote the production of electricity from renewable sources under REC. Specifically, it is intended to lead to a 30% reduction in primary energy consumption, on average. Both residential customers and companies will be eligible for this funding, therefore in this instance, SC and communities can seek to participate in this program.

This project will have no technological barriers, only if some properties have particularly uneven and rough ground or cannot sustain such infrastructure, or if the houses/buildings are not suitable for the installation of solar panels on their roofs. So, technologically, it can only result in advancements in either increased panel efficiency, which enhances electricity generation, or new techniques for installing panels allowing faster installation and less environmental impact.

At last, the organizational parameter is transversal to all the alternatives and is essentially linked to the good relationship that the stakeholders will require as they will determine whether or not to start a symbiosis. In this case, some best practices are: full engagement of the respective stakeholders in the phases that concern them; good and effective communication between all parties; and above all transparency. All these will drive and accelerate the realization and implementation of any alternative.

Or else, various barriers can be formed as frequently there is a lack of openness, willingness, and trust (Bacudio et al., 2016; Park et al., 2018), which could hinder the start of this kind of collaboration for several reasons. An example is if one of the participating organizations realizes that they are not benefiting from the agreement as much as Start Campus or are being undermined. In such scenario, one strategy to overcome this barrier will be to introduce facilitating entities that act as intermediaries in the negotiations as they will act impartially. Yet, above all that, there should be trust and honesty between the participating entities, as this is the basic principle of any symbiotic relationship.

4. Discussion

From the stakeholders' analysis, we highlight the Sines City Hall, which is in charge of approving the upcoming projects for SC, since all solar parks so far are located in the Sines municipality. Encouraging a good relationship with the city hall will be in the best interest of the company in the short and long term, to guarantee a faster-licensing approval, or else, the project's deadlines might be delayed and jeopardize other stages. Second, the company responsible for developing the solar panels and for mounting all structures according to the SC's guidelines. This choice has to be thoughtful and meticulous since a large portion of the capital cost will be applied here. Therefore, the expectations and quality standards of the product supplied will be very high, as it represents the foundation of the whole project. At last, the local communities exert a great deal of power over the project's social acceptance. Conflicts with this stakeholder will likely lead to disagreement and possible demonstrations that could damage the project's reputation and, in extreme cases could result in the project's termination.

Afterward, three possible symbioses to be formed with solar parks were found, namely: Ground-mounted panels with sheep farming; High-mounted panels with berries production; and Community solar projects. After these findings, all symbioses were submitted to a benefit vs. drawbacks and drivers vs. barriers evaluation.

Starting with the first option, ground-mounted panels with sheep farming show interesting results. Without a doubt, the biggest advantage and driver for SC will be the significant reduction in O&M costs. Sheep grazing the land not only replaces the machinery and herbicides required for land maintenance but also ensures that weeds and plants do not grow large enough to block the panels, which would lead to less sun exposure and less electricity generated. As a result of not requiring fossil fuel-powered machinery, this symbiosis reduces GHG emissions and promotes a positive impact on biodiversity, vegetation, and soil sequestration. It is vital to perform a deeper evaluation of this impact since it deeply concerns society in light of the exponential growth in solar parks' construction as research shows that land use change can cause much habitat loss.

Economically speaking, the shepherds will certainly also be pleased given the additional revenue this symbiosis can generate for them. It can be either by receiving a direct fee for grazing sheep on the fields or supplied with energy generated meaning a decrease in their electricity bills or even indirectly where sheep generate higher wool quality thus originating higher prices. However, the big question that remains is whether the local communities have enough flocks and human resources to match the 1500+ ha that SC will need to care for.

Moving on to the second identified symbiosis, high-mounted panels with berries production, it was possible to conclude that it is a complex system but with potential. Financially it will be way more expensive than our last referred option, ground-mounted panels, as the structure is a new technology with high implementation complexity with less than a dozen cases in Portugal. Even with the benefits brought by the agricultural industry, namely maximization of land use efficiency, control and cost assurance over land maintenance, and carbon footprint reduction, SC will still be reluctant due to the high costs since they are not in business to lose money. In addition, the technological barrier will bring difficulties since the technological and human know-how has to be imported from successful pilot cases abroad.

To overcome these drawbacks and barriers, at an early stage, SC could recur to governmental institutions, such as the Ministry of Environment, to provide incentives and funds to support the establishment of these new systems full of potential. Afterward, economies of scale could appear leading the solar panels' production price to decrease, which has been happening for all types in the last decade. This way, SC would have the initial leverage needed to start this project which would greatly help communities by stimulating job creation, and consequently, the local economy. With this proper incentive, the berries production companies could then apply to these projects taking advantage of perks such as power supply for irrigation systems or the machinery responsible for crop maintenance.

Finally, the last symbiosis refers to community solar projects, which have grown in popularity in Portugal. The biggest driver for SC to move forward with this project will be the increase in its social acceptance rate within the communities and country. Involving the local communities will only make some of Start Campus' problems, such as the large land use needed, be overlooked given the benefits generated to locals, for example, the possibility to have a 20% - 30% electricity bills reduction, which makes a significant impact on certain families due to the global energy crisis we currently face.

Looking to governmental agencies and their policies, these projects will have their support and incentives like the Environmental fund, rather than becoming a barrier as this symbiosis will only promote sustainability and stimulate the Sines local economy. Nevertheless, local communities will have to be careful and establish well-defined contracts bearing in mind that this could be a temporary project. It is important not to forget the main purpose for the creation of these solar parks, which is the power supply to the data centers. Only after assuring this, can SC start providing the energy excess to the transmission grid for other purposes.

Based on the results obtained, all three symbioses seem to have a lot of potential. Comparing all symbioses in general, the most viable economic option for SC would be sheep grazing in its solar parks, as they would continue to construct the most used structures on the market, ground-mounted panels, and would save on maintenance costs.

As for sustainability, all alternatives promote good practices, however establishing a connection with a berries production company stands out due to its major benefit of guaranteeing maximum land efficiency. In terms of regulations and policies, Portugal is currently offering many incentives towards solar energy production and if it can provide further benefits to the communities and nation even better, making all symbioses viable initiatives. As for the technological factor, the most innovative is undoubtedly the high-mounted panels over agricultural crops, yet also the most complex and difficult to implement. In the social aspect, developing community solar projects will be the most appealing symbiosis given the direct benefits it generated in the face of this energy crisis. Last but not least, the organizational aspect will be the key to establishing any of these symbioses as all stakeholders need their concerns to be heard and interests to be taken into consideration, to achieve a successful project.

All this is purely a theoretical analysis, so it is recommendable that SC evaluates the initial costs and the possible environmental impact to be able to draw more concrete conclusions. Additionally, most information obtained is based on case studies in other countries, so it is recommended to understand the major differences to implement such projects in Portugal.

5. Conclusion and Recommendation

Nowadays, even though companies are more aware of the circular economy and industrial ecology, it is necessary to develop strategies and techniques to promote this new economic model. This dissertation explores one of the associated strategies within these two concepts: industrial symbiosis. This concept promotes the resource exchange between firms in industrial processes, where a company's outputs can be the inputs of other organizations or vice-versa. The main objective of this exchange is to provide mutual benefits and opportunities for the participating organizations.

Hence, the concept served as an inspiration to achieve this dissertation's aim of investigating viable possible symbioses of solar park projects with other industries or local communities. To this end, the case study methodology was adopted for a specific case – Start Campus' solar parks. The main purpose of these solar parks will be to supply energy to the data centers, however, there are opportunities to explore, namely the amount of necessary land to implement these structures and the excess energy that can be produced.

In the application of the methodology, we were able to identify the stakeholders with the greatest influence in a possible symbiosis with solar energy production, beyond the participating entities – Sines City Hall, the future solar panel developing company, and the local communities. The application also allowed us to identify three possible symbioses, two with the agricultural industry – ground-mounted panels with sheep farming and high-mounted panels with berries production; and one with local communities – community solar projects. This identification was based on other case studies of IS with solar parks that have been applied and implemented around the world.

Afterward, an analysis of benefits and drawbacks was performed on each alternative individually, which allowed us to accurately identify what the target organization has to offer to SC and vice versa. From this analysis, we highlight the main benefits and drawbacks of each symbiosis:

Solar parks with sheep farming – Reduction in land maintenance costs and GHG emissions for SC; Extra income for shepherds; Higher lamb welfare and wool quality; Land misuse; Possible sheep and manpower shortage for the amount of land

Solar parks with berries production – Maximization of total land use; Positive impact on biodiversity; Reduction in electricity and water bills; Higher fruit quality; Very high initial costs for SC; High structure complexity; Relocation difficulties for target companies.

Community solar projects – Full engagement with local communities; Best use of the excess energy produced; Reduction in electricity bills; Less reliance on fossil fuels, thus reducing carbon footprint; Land misuse; Possibility of being just a temporary project

Finally, we performed an analysis of the major drivers and barriers according to four parameters – economic, regulatory, social, and organizational to understand if these symbioses can be promoted or if too many obstacles hinder their implementation. Main drivers that stood out: contribution to sustainable development, contribution to an improved company image, reduction in consumption of natural resources, financial incentives, and funds, process innovation; job creation; higher social acceptance rate; local economy stimulation. In terms of barriers, the following caught our eye: high investment costs, high complexity projects, lack of investment in innovative projects, concern about the impact on biodiversity, lack of human and technological know-how, lack of communication and information exchange, and lack of cooperation and trust.

Combining all these results, we can conclude that it is possible to involve communities and/or industries in the implementation of solar parks. Also, important to mention that these are only three of the many different possible symbioses that can be established with the solar energy industry, as the existing research is lagging. One last conclusion is that, despite the high costs that the solar panel structures possess, it is possible to obtain several benefits that can contribute to a higher cause, meaning stimulation of society and the country's economy.

Note that the study has some limitations, for example, the lack of identification of stakeholders influencing the target organization since it can lead to the introduction of new key players that can generate other benefits or conflicts. Another limitation of this case study is the analysis of benefits, drawbacks, drivers, and barriers, which was based on other international projects and only had one value judgment – the author that can cause biased results.

As a recommendation for Start Campus, it is proposed to assess the real investment necessary to implement any of these alternatives and a life cycle assessment to understand the real impact on the ecosystem. After this evaluation, the next step could be to resort to a multiple-criteria decision analysis with the most important criteria and corresponding weighing to the company, to identify the best alternative for them.

As a suggestion for future research, it is advised to expand the practice of industrial symbiosis to other activity sectors, through the exploration of new case studies. These should involve materials, products, energy, or by-products from other industries and different applications should be explored for their commercialization in other areas.

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