IRENA
International Renewable Energy Agency

EL SALVADOR

RENEWABLE ENERGY TECHNOLOGY PLAN AND MITIGATION ANALYSIS IN THE AGRO-INDUSTRIAL SECTOR

Technology and infrastructure

CLIMATE ACTION SUPPORT

About IRENA

The International Renewable Energy Agency (IRENA) is an intergovernmental organisation that supports countries in their transition to a sustainable energy future and serves as the principal platform for international co-operation, a centre of excellence, and a repository of policy, technology, resource and financial knowledge on renewable energy. IRENA promotes the widespread adoption and sustainable use of all forms of renewable energy, including bioenergy, geothermal, hydropower, ocean, solar and wind energy, in the pursuit of sustainable development, energy access, energy security and low-carbon economic growth and prosperity. **www.irena.org**

About this document

This technical report summarises the key outcomes and findings of the mitigation analysis in the agro-industry subsector, including a detailed case study of the food processing industry in El Salvador, and assesses the potential for greenhouse gas emissions reductions through the implementation of various energy sector measures to inform the Nationally Determined Contribution update.

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ACRONYMS AND ABBREVIATIONS

AC	alternating current
BECCS	bioenergy with carbon capture and storage
BESS	battery energy storage solutions
c-Si	crystalline silicon
CAPEX	capital expenditure
CCS	carbon capture and storage
CCU	carbon capture and utilisation
CEL	Executive Hydroelectric Commission of the Lempa River (Comisión Ejecutiva Hidroeléctrica del Río Lempa)
CNE	National Energy Council (Consejo Nacional de Energía)
CO_2	carbon dioxide
COP 26	26^{th} Conference of the Parties
COSMO	Coronal Solar Magnetism Observatory
CSP	concentrated solar power
DC	direct current
DHI	diffuse horizontal irradiance
DNI	direct normal irradiance
DoD	depth of discharge
EU TAF	European Union Technical Assistance Facility
FAO	Food and Agriculture Organization
GHG	greenhouse gases
GHI	global horizontal irradiance
$GtCO_2$	gigatonne of carbon dioxide
GW	gigawatt
GWh_{th}	gigawatt hour thermal
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
km	kilometre
kW	kilowatt
kW_e	kilowatt electrical
kWh	kilowatt hour
kWh_e	Kilowatt hour electrical
kWp	kilowatt peak
kW_{th}	Kilowatt hour thermal
LPG	liquefied petroleum gas

m^2	square metres
m^3	cubic metres
MAG	Ministry of Agriculture and Livestock (Ministerio de Agricultura y Ganadería)
MARN	Ministry of Environment and Natural Resources (Ministerio de Medio Ambiente y Recursos Naturales)
MW	megawatt
MW_{th}	megawatt thermal
MWh	megawatt hour
MWh_e	megawatt hour electrical
MWp	megawatt peak
MWh_{th}	megawatt hour thermal
NASA-SSE	National Aeronautics and Space Administration's Surface Meteorology and Solar Energy
NDC	Nationally Determined Contribution
NREL	National Renewable Energy Laboratory
NSRDB	National Solar Radiation Database
OPEX	operational expenditure
PEt	Price of Energy to be Transferred to Tariff (Precio de la Energía a Trasladar a Tarifa)
PTC	parabolic trough collector
PV	photovoltaic
PVGIS	Photovoltaic Geographical Information System
RRA	Renewables Readiness Assessment
SAM	System Advisor Model
SARAH	Surface Solar Radiation Data Set – Heliosat
Si	silicon
STC	standard test conditions
tCO_2	tonne of carbon dioxide
TJ	terajoule
TMY	typical meteorological year
TRL	technology readiness level
TWh	terawatt hour
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollar

EXECUTIVE SUMMARY

The Central American country El Salvador has placed a premium on renewable energy development to reduce its reliance on imported fossil fuels and thus enhance its energy security. The country has placed a special emphasis on the power sector, increasing renewable energy penetration and improving energy efficiency throughout the energy supply chain. Indeed, since 2013, El Salvador has not added any new fossil fuel-fired power plants (IRENA, 2020b). The present study demonstrates that it is feasible and economically advantageous to extend beyond the power sector by setting targets for renewable energy technologies in end-use sectors such as the agro-industry subsector, for example, by promoting direct use of renewables for heat processes. The industrial sector's transition to renewable energy will require the country to develop a long-term energy strategy, emphasising the critical nature of reducing the country's reliance on fossil fuels for industrial power and heat demand. Apart from potential emissions reductions, this transition would undoubtedly benefit local economies by stimulating growth in the agricultural sector, increasing resilience and food security, and attracting foreign investment to stimulate the economy. Given that countries developed enhanced Nationally Determined Contributions (NDCs) in advance of the 26th Conference of the Parties (COP 26), El Salvador demonstrated its willingness to initiate a national industrial transition through the promotion and use of renewable energies through its updated NDC (more information in Box 1 – "El Salvador's second Nationally Determined Contribution").

As a party to the Paris Agreement, the country submitted in 2017 its first NDC to the United Nations Framework Convention on Climate Change secretariat. It is expected that it will resubmit an enhanced NDC in 2021 ahead of COP 26.

The Republic of El Salvador is the smallest country in Central America, being located on the west coast, bordered by the Pacific Ocean, Honduras and Guatemala. El Salvador has a total land area of 21 000 square kilometres (km^2), and its capital and largest city is San Salvador. As of 2021, the country had a population of approximately 6.8 million habitants.

In this regard El Salvador presented a number of contributions in order to establish a legislative and institutional framework that can guide economic and social development towards low emissions and adaptation to climate change. In terms of specific mitigation options for the energy sector, the country set a 46% greenhouse gas (GHG) emissions reduction target with respect to growth without concrete mitigation actions or "business as

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usual" by 2025. An additional 15% could be achieved, conditional on financial support for the development of an additional 92 megawatts (MW) from geothermal generation.

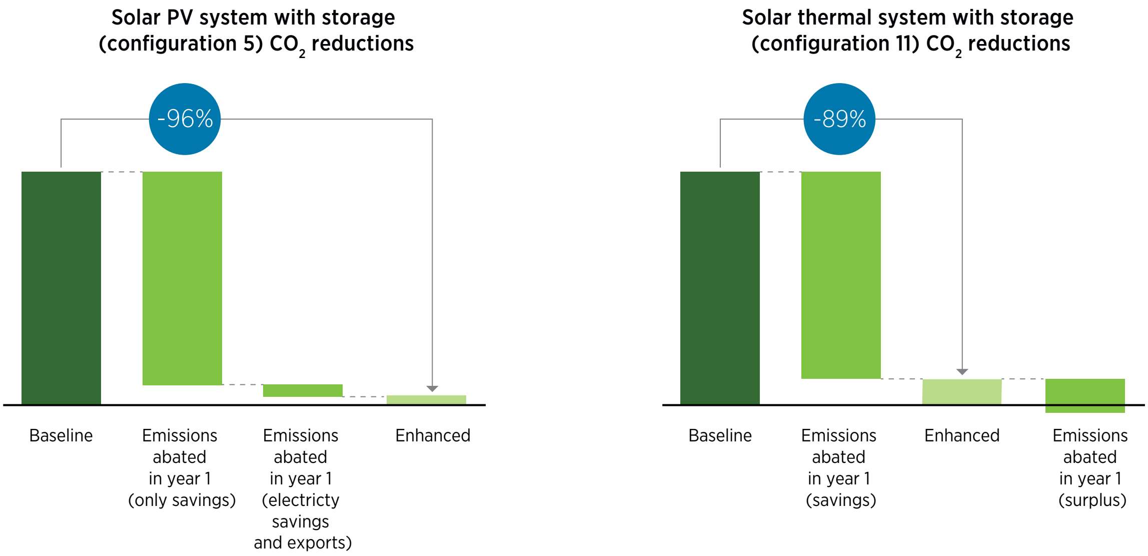
El Salvador has commissioned the International Renewable Energy Agency (IRENA) to conduct a technology and mitigation analysis, with a particular emphasis on the agro-industry sector. This technical report summarises the assessment's major findings and conclusions and assesses the potential for GHG emissions reductions through the implementation of various technology options, with a particular emphasis on solar energy technologies. The purpose of this study is to inform the update of the NDC and to make recommendations for power and thermal supply options based on renewable energy sources that are appropriate for the national industrial sector. The analysis is based on a real-world case study involving a national dairy facility.

Food availability is a critical component of food security, as it is largely determined by a country's agro-industry sector's capacity to provide safe and nutritious food to its population. According to the Food and Agriculture Organization (FAO), food production is already being impacted. Renewable energy can make a significant contribution to both climate change mitigation and adaptation, as well as provide opportunities for innovative climate change practices. The analysis used established methodologies and was based on national data. To ensure their validity in light of national climate action plans, the recommendations were validated with country officials. The steps in the analysis included the following:

- having a national consultation process in order to address and learn from the national context
- using data from a national agro-industry facility to build a viable case study
- evaluating the viability of renewable energy technology alternatives in order to develop a solution that meets the sector's unique power and thermal demand requirements
- analysing the mitigation potentials associated with the implementation of the identified technology options, both in the context of the case study at hand and in the context of their possible expansion to the entire national dairy sector.

The case study's technology options were implemented using solar technologies. Solar photovoltaic (PV) technology was chosen to provide electricity for the facility, while concentrated solar power was chosen to provide heat for the facility. Both technical solutions incorporate storage to compensate for the solar resource's transient nature. The percentages of annual GHG emissions avoided by the case study facility's solar technology solutions in their first year of operation are depicted in Figure 1. As illustrated in the figure, the adoption of the proposed renewable technology solutions would almost eliminate the facility's carbon dioxide (CO_2) emissions and significantly increase its energy resilience by self-supplying the majority of its energy needs with economically viable options.

Figure 1: Annual GHG emissions abatement for the first year of operation of solar PV and thermal solutions (%)



Attempting to reduce industry-related GHG emissions is critical if the world is to meet the Paris Agreement's targets. To avoid this, an extensive transition of industry to a low-carbon path is required. Renewable energy-based adaptation solutions simultaneously promote mitigation and reinforce adaptation efforts across multiple sectors. Numerous countries recognise renewable energy as a synergistic mitigation-adaptation measure and include it in their Paris Agreement-compliant NDCs and long-term development strategies. By the end of 2020, 64 (34%) of the 190 countries that had submitted NDCs had included renewable energy in their adaptation component.

The purpose of this study was to illustrate the mitigation potentials associated with incorporating renewable energy technologies into the agro-industry sector. Additionally, mitigation's co-benefits such as energy resilience, food security and renewables non-energy services have been discussed. The inclusion of the agro-industry subsector in El Salvador's revised NDC would demonstrate the sector's national significance from a mitigation and adaptation perspective, enhancing the previous submitted NDC while also serving as a tool to facilitate and promote foreign direct investment in a sustainable, green and resilient national industry.

When it comes to industrial transition planning, it is proposed that the following considerations be considered:

- **Encourage the diffusion of innovative renewable energy technologies** that support the transformation and adaptation of a modern energy system to a constantly changing and increasingly competitive environment. Developing policy tools, initiatives and strategies is critical for assisting regions in diversifying their economy. Increase employment and move up the value chain.
- **Incentivise the direct use of renewable energy sources** with renewable energy policies that support the deployment of renewable energy for heating, cooling and transport. This may include regulatory measures that establish a market for these technologies, as well as fiscal and financial incentives, such as the elimination of fossil fuel subsidies, that facilitate adoption and make renewable energy more equitable for all types of users. Policy makers must build focused, transparent and long-term frameworks for the development of solar thermal energy solutions. These frameworks might take the form of roadmaps, industrial strategies and specific objectives.
- **Avoid a fossil fuel lock-in**. The detrimental long-term and global implications of fossil fuels such as natural gas may outweigh their supposed benefits. Investing today in natural gas infrastructure may slow the transition to zero-carbon systems and hinder long-term emissions reduction efforts.
- **Increase consumer and citizen awareness**. Consumer and public engagement is critical for integrating the complex dynamics of social systems into the energy transition. Consumers may drive governments and businesses to accelerate their decarbonisation efforts.
- **Create a long-term plan for industrial transition**. Accelerating and maximising the advantages of the energy transition requires an integrated energy planning approach that incorporates targets and active commitments alongside holistic and long-term plans. A comprehensive long-term plan should be prepared in collaboration with other ministries.

Table 1 illustrates some examples of how countries plan to cut emissions to support low-carbon industrial transitions in their NDCs they have submitted under the Paris Agreement.

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Table 1: Specific mitigation measures targeting industry in NDCs

COUNTRY	MEASURE TYPE	NDC	MEASURE
Uruguay	Mitigation and adaptation	1st NDC	"Use of solar collectors for domestic hot water in large users, industrial and residential users: 50 MW_{th} of installed capacity for 2025".
Costa Rica	Mitigation	1st NDC (updated)	"Costa Rica's commitment for the industrial thematic area is focused on its transformation through efficient and sustainable processes and technologies that use energy from renewable or other zero-emission sources. "By 2030, the area of industry and services will have innovative production models or with a circular economy approach in the main agro-industry productive chains of agro-industry, services, construction, and the creative and cultural economy, among others".
Panama	Mitigation	1st NDC (updated)	"By the year 2030, the solar thermal evolution is expected to be: 247 904 m^2 solar thermal DHW and industry. Including incentives".
Paraguay	Mitigation	1st NDC (updated)	"Promote the use of solar thermal energy through the use of solar water heaters".
Honduras	Mitigation	1st NDC (updated)	"Integration of renewable energies in the national electricity grid and the processes of industrial air conditioning".
Morocco	Mitigation	1st NDC	Implementation of a pilot project for energy recovery from air compressors in 250 industrial companies (conditional).
Jamaica	Mitigation	1st NDC (updated)	"The country is also undertaking a range of pilot projects to explore biodiesel from cooking oil, the production of biogas using animal waste and increasing the use of biodigestors".

Notes: MW_{th} = megawatts thermal; m^2 = square metres; DHW = domestic hot water.

Box 1: El Salvador's second Nationally Determined Contribution

El Salvador submitted its second Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change in January 2022, in accordance with its Paris Agreement commitments.

In terms of its contribution to global climate change mitigation, El Salvador commits to have an annual emissions reduction (by 2030 and with respect to a baseline scenario [business-as-usual] from 2019) of 640 kilotonnes of carbon dioxide equivalent (kt CO_2-eq) from fossil fuel burning activities in the energy sector and up to an annual emissions reduction of 819 kt CO_2-eq in the same activities and sector, if during the period up to those years the technological models, financing structures, regulatory frameworks and massive capacity-building processes are installed with international support.

The NDC outlines the support needed to significantly accelerate the implementation of the NDC's measures, which is divided into three categories: financial support, support for technology development and transfer, and support that has enabled the promotion and strengthening of national capacities.

The NDC outlines the necessary means of implementation, which refer to the instruments and support mechanisms required to achieve the country's goal of contributing to adaptation and mitigation actions and priorities in accordance with the Paris Agreement's commitments. A key element in this context is the availability of international assistance in the form of funding, technology development and transfer, and/or capacity-building assistance.

Based on a technology assessment and case study developed with the support of the International Renewable Energy Agency (IRENA) and the European Commission through the EU Technical Assistance Facility (EU TAF) with the goal of promoting emissions reduction targets in El Salvador's energy sector, the second NDC detailed the need for support for the development and application of a feasibility study, as well as financial resources for the implementation of a pilot project in the agro-industrial dairy sector of El Salvador.

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1. INTRODUCTION

El Salvador submitted its first Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) in 2017. NDCs are national climate action plans and serve as the backbone of the Paris Agreement, which was adopted by 197 member states of the UNFCCC in 2015, and thereby committing to pursue the necessary efforts to keep global warming at 1.5°C. NDCs include mitigation actions, and in most cases, adaptation actions that a country takes to stay in line with the goals of the Paris Agreement. A key principle of the Paris Agreement is that NDCs are to be revised, updated and enhanced every five years. Numerous countries updated and submitted their NDCs to the UNFCCC prior to the 26th Conference of the Parties (COP 26) in November 2021 in Glasgow.

A mitigation analysis can assist countries in identifying, evaluating the potential for, and selecting green and clean technologies that will inform their path towards decarbonising the energy sector. Thus, such analysis can be used to inform the development of the NDC, the NDC implementation plan and long-term sectoral plans. Additionally, it can aid in the development of renewable energy, increased access to energy and increased private-sector involvement.

This technical analysis is undertaken by the International Renewable Energy Agency (IRENA) with support from the EU Global Technical Assistance Facility for Sustainable Energy (EU TAF) as an effort to support El Salvador in the process of revising and updating its NDC.

Mitigation analyses with a focus on technology plans can be used to determine the viability of a new concept, idea or solution; they determine whether a proposed plan is technically feasible and worth the investment, or in other words, whether it can be converted into a working system. A technology plan evaluates an idea or solution, which makes it an ideal tool for both technology validation and long-term planning. These assessments provide insight into the potential, capability and scale of climate-smart technologies for adaptation or mitigation, and they can play a critical role in the formulation, enhancement and implementation of NDCs. Typically, innovative technology plans serve as a test bed for reducing perceived risk associated with specific technologies and thus promoting future investment. Technology plans also promote the growth and development of a given technology in a particular country or region by increasing its technology

Photo: Soliterm / www.solarthermalworld.org/news/rush-industrial-solar-heat-germany.

readiness level (TRL), which is widely regarded as an effective indicator of a technology's development stage. Additionally, demonstration solutions aid in anticipating and avoiding potential technological and system pitfalls, as well as in increasing technology awareness among relevant stakeholders and the general public.

This mitigation analysis for the agro-industry subsector in El Salvador is intended to serve as a guide for addressing the early stages of implementing a renewable energy technology solution, including resource assessment, technology feasibility analysis, and appropriate infrastructure and equipment requirements. The analysis must be tailored to the country's specific needs and make economic sense. As a result, initial costs and investment requirements are also included. The analysis details how the technology could be integrated into the existing energy sector, thereby paving the way for a larger-scale implementation in the future. Due to the activity's support for the revision of El Salvador's NDC, it is necessary to assess cross-cutting mitigation, adaptation and resilience issues.

The technology plan can serve as a foundation for establishing new mitigation and co-adaptation targets for greenhouse gas (GHG) emissions reductions that will inform the revision of the NDC. The findings of the analysis will provide critical information for technology identification, cost estimation and quantification of potential emissions abatement. The analysis can be incorporated into the NDC and its implementation, assisting decision makers in developing sectoral plans for the energy and agriculture sectors, and establishing a path for the country's energy sector to transition from fossil-based to zero carbon, with the need to reduce energy-related carbon dioxide emissions to limit climate change at its core. The National Energy Council (CNE – Consejo Nacional de Energía) in collaboration with other key national stakeholders, such as the Ministry of Environment and Natural Resources (MARN) and the Ministry of Agriculture and Livestock (MAG), will decide whether the mitigation technologies presented in this analysis will be included in El Salvador's updated climate action pledge. The purpose of this document is to provide the information necessary to assist in that decision-making process.

The report is structured as follows:

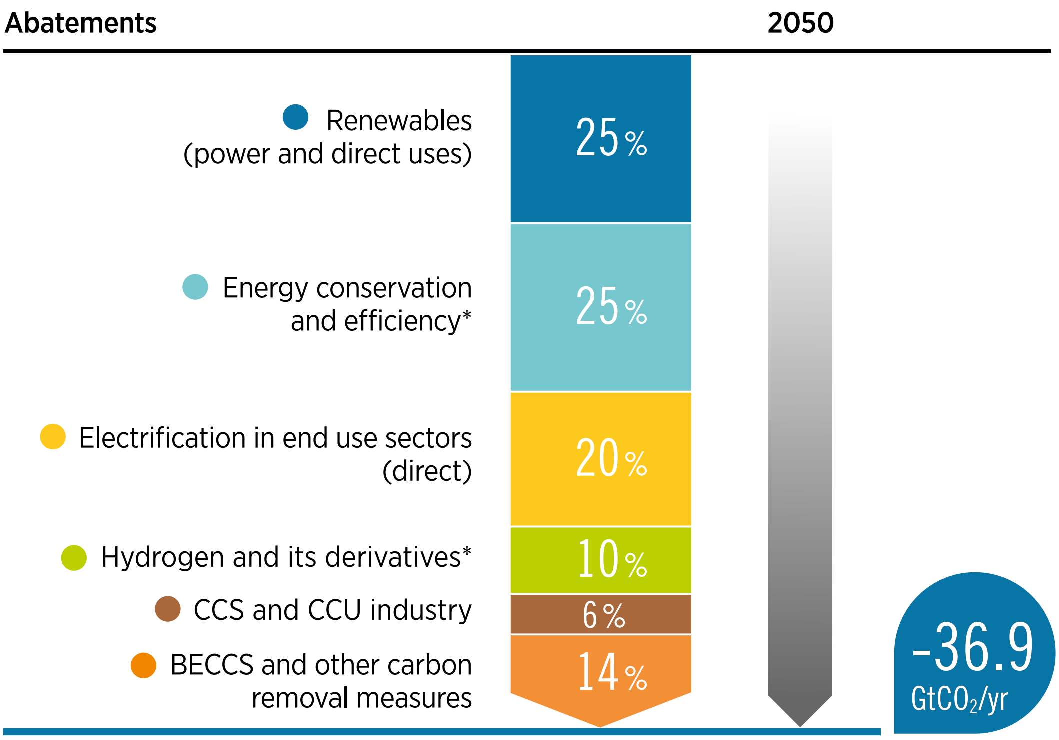
- **Chapter 1** introduces the analysis and establishes the report's structure.
- **Chapter 2** contextualises the technical analysis, which is based on IRENA's *World Energy Transitions Outlook*, which lays out a path forward for the world to meet the Paris Agreement's goals and slow the rate of climate change through a transformation of the global energy sector. Additionally, it compares the country's current climate targets to the Intended Nationally Determined Contribution submitted.
- **Chapter 3** details the methodological approaches, datasets and assumptions that were used in each step of the methodology process. Chapter 3 describes the consultation process developed in collaboration with CNE to identify the case study that will serve as the foundation for the demonstration solution's technology plan. Chapter 3.2 details the process of developing the technology solution for the identified case study's electrical and thermal systems, while Chapter 3.3 details the analysis of the selected technology solutions' GHG reduction potential.
- **Chapter 4** summarises the modelling findings for each technology solution. The outcomes and their implications are discussed in detail. The first two sections discuss the energy yield assessment for electrical and thermal solutions, as well as the economic analysis for both. The potential for GHG reductions associated with the various mitigation strategies considered are presented. Following that, a third section examines the combined mitigation potentials of the solutions.
- **Chapter 5** examines the scalability of the case study presented in Chapter 3 for both solar photovoltaic and solar thermal technology solutions in El Salvador's entire dairy industry sector.
- **Chapter 6** provides some context and recommendations for the process of revising and implementing the NDC. The mitigation options recommended for the NDC update are summarised.

2. BACKGROUND

2.1 *WORLD ENERGY TRANSITIONS OUTLOOK*

The increasing number of countries committing to net-zero carbon strategies indicates a significant shift in global climate discourse. Similar trends can be found at all levels of government and in the private sector, including in the hard-to-abate and oil and gas sectors. As much of the world deals with the effects of the economic downturn due to the pandemic, investments in the energy transition can help align short-term priorities with medium- and long-term development and climate goals. Indeed, several countries have made significant commitments to dedicate public funds to these purposes and to support solutions such as electric mobility and clean hydrogen. More than 80% of the world's population lives in countries that are net importers of fossil fuels. In contrast, every country has some renewable potential that can be used to increase energy security and independence at a lower cost. The IRENA *World Energy Transitions Outlook* outlines how carbon dioxide (CO_2) emissions abatements would be allocated across energy sources, practices, and uses Figure 2 under the 1.5°C Scenario compatible with the Paris Agreement (IRENA, 2021a).

Figure 2: Carbon emissions abatements under the IRENA 1.5°C Scenario (%)



Note: Abatement estimates include energy and process-related CO_2 emissions along with emissions from non-energy use. Renewables include renewable electricity generation sources and direct use of renewable heat and biomass. Energy efficiency includes measures related to reduced demand and efficiency improvements. Structural changes (e.g. relocation of steel production with direct reduced iron) and circular economy practices are part of energy efficiency. Electrification includes direct use of clean electricity in transport and heat applications. Hydrogen and its derivatives include synthetic fuels and feedstocks. CCS describes carbon capture and storage from point-source fossil-fuel-based and other emitting processes, mainly in industry. BECCS and other carbon removal measures include bioenergy coupled with CCS in electricity, heat generation, and industry.

CCS = carbon capture and storage; CCU = carbon capture and utilisation; BECCS = bioenergy with carbon capture and storage; Gt CO_2 = gigatonnes of carbon dioxide.

Source: IRENA (2021a).

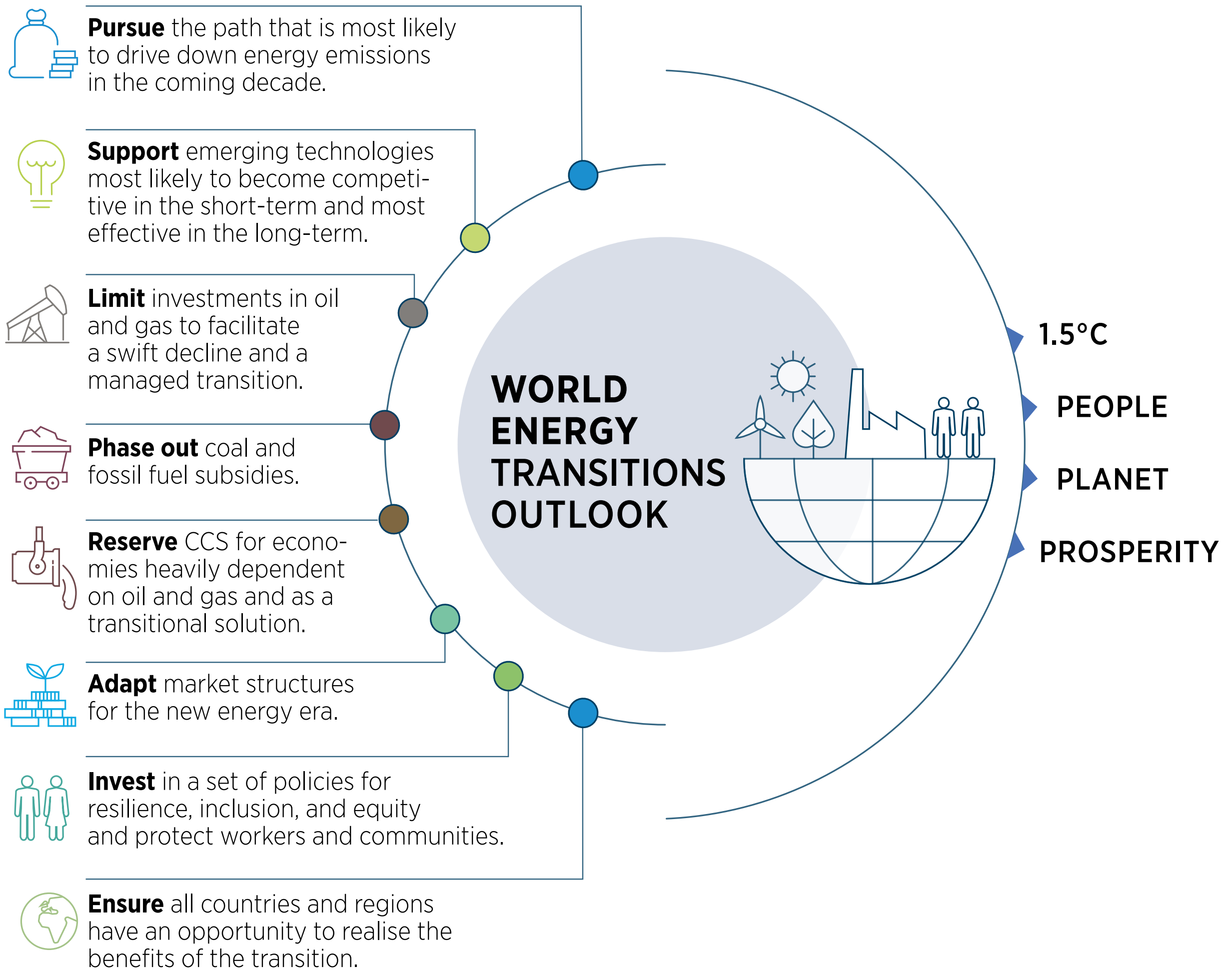
A global energy system transformation aligned with the 1.5°C climate goal has the potential to be a great equaliser in a world that needs to become more resilient, just and inclusive. A resilient energy system necessitates rapid development and deployment of resilient technologies, as well as investments in people and institutions. Significant progress has been made, but it has been uneven across geographies and communities. The greatest progress has been made in a few countries and regions. In other areas, widespread energy poverty continues to stymie economic and social progress. In 2020, Europe, the United States and China accounted for the majority of new renewable capacity, while Africa accounted for only 1% of global new renewable capacity. This is despite the fact that Africa has the greatest need for expanded access to modern forms of energy and a renewable potential that far exceeds projected needs. Despite being a major avenue for expanding access, only USD 1 billion was invested in off-grid renewables between 2008 and 2019 in Africa. Uneven deployment patterns are also reflected in the concentration of jobs and industries, leaving large parts of the world behind. Current plans fall far short of the 1.5°C target. Based on existing government energy plans and targets, including the first round of NDCs under the Paris Agreement, the policies in place will do nothing more than stabilise global emissions, with a slight drop as 2050 approaches. Despite clear evidence of human-caused climate change, widespread support for the Paris Agreement and the prevalence of clean, affordable and sustainable energy options, annual energy-related carbon dioxide (CO_2) emissions increased by 1.3% on average between 2014 and 2019. Time is of the essence, and a rapid reduction in emissions must begin immediately in order to maintain a fighting chance of staying within 1.5°C. Coal and oil should have peaked by now, according to the Intergovernmental Panel on Climate Change (IPCC) report on limiting global warming to 1.5°C by 2050, with natural gas peaking in 2025. The resources and technologies required to accelerate the energy transition are now readily available. In line with the IPCC's schedule, the International Renewable Energy Agency (IRENA) plots a steep and continuous downward trajectory towards a 45% reduction in CO_2 emissions from 2010 levels by 2030, and net zero by 2050.

The *World Energy Transitions Outlook* from IRENA is a 1.5°C-compatible pathway that also examines full socio-economic and policy implications and provides insights on structural changes and finance. Rapid decarbonisation technologies are becoming more available, but thinking about the energy transition should not be limited to the energy sector. Realising the transition's far-reaching potential necessitates systemic innovation that considers both technologies and enabling frameworks. Renewable energy systems will bring about profound changes that will reverberate throughout economies and societies. Only by comprehending these deep currents will we be able to achieve the best results from the transition process. The *World Energy Transitions Outlook* draws on IRENA's extensive knowledge to make this possible, by providing policy makers with insights, tools and advice to help them chart the way forward.

Box 2: Renewables and COVID-19 recovery

The COVID-19 outbreak has led countries around the world to an unprecedented economic, health and social crisis. The International Monetary Fund (IMF) estimates a resultant contraction of the economies in Central America of around 3.5% average during 2020. These new regional conditions are undermining the economic growth of El Salvador; however, the new National Energy Policy 2020-2050 and the ongoing efforts towards the revision of the NDCs by the country are creating an opportunity to centrally position the Salvadorian energy sector at the core of the post-COVID recovery, focusing its efforts to achieve a green recovery. Renewable energy serves as an opportunity to increase energy security, attract investment to the country and develop into a long-term source of jobs for its inhabitants. Additionally, investing in domestic renewable energy infrastructure offers the potential to boost health capacity and build climate resilience. It can also greatly strengthen El Salvador's post-COVID recovery efforts (IRENA, 2020b).

Figure 3: Guiding framework of World Energy Transitions Outlook theory of change



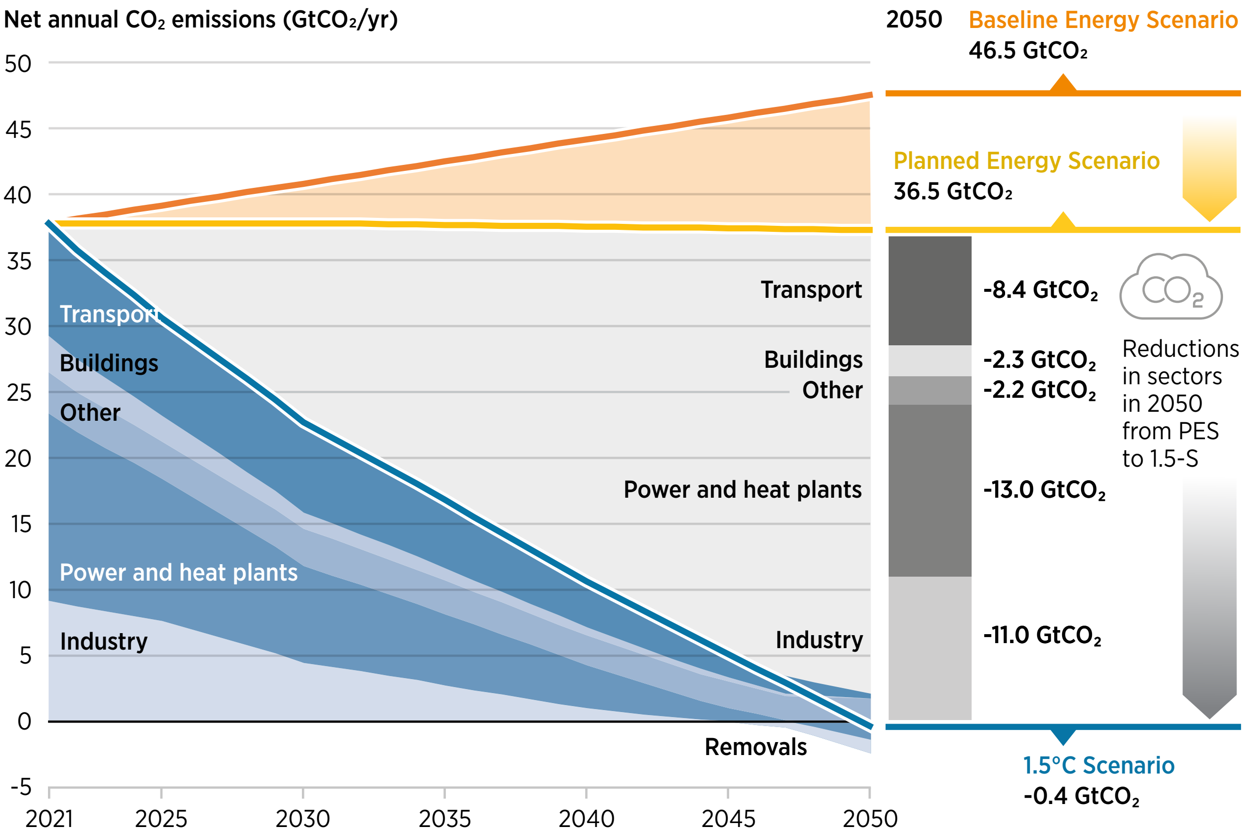
Source: IRENA (2021a).

2.2 THE ROLE OF RENEWABLE ENERGY TECHNOLOGIES TOWARDS ACHIEVING NET ZERO BY 2050

The share of modern renewable energy in global final energy consumption has increased only slightly since 2010, staying around a threshold of about 10%. In simple terms, while renewables are increasing, so is energy demand. It should be noted that modern renewable energy excludes traditional uses of bioenergy, which if included in this share would bring the share of all renewable energy in total final energy to 18% (IRENA, 2020a). Electricity costs from renewables have fallen sharply over the past decade (2010-19), driven by improving technologies, economies of scale, increasingly competitive supply chains and growing developer experience. As a result, renewable power generation technologies have become the least-cost option for new capacity in almost all parts of the world. This new reality has been increasingly reflected in deployment, with 2020 seeing renewables account for 82% of all new capacity additions worldwide (IRENA, 2021c).

Energy is used in a wide range of sectors and areas of human activity, including for power generation, heating and cooling, and in industry, transport and buildings. Figure 4 summarises current global shares of greenhouse gas (GHG) emissions associated with energy use in these sectors. The analysis developed by IRENA outlines what is required for a global energy transition shift and presents an energy pathway that is consistent with limiting global temperature rises to 1.5°C – a pathway IRENA calls the 1.5°C Scenario. The IRENA analysis starts with the goal of reducing global CO_2 emissions following a steep and continuous downward trajectory from now on and reaching net zero by 2050. The energy sector is responsible for around 80% of anthropogenic CO_2 emissions and has a central role in delivering the decarbonisation required. To reach net zero by 2050, CO_2 emissions must decline 3.5% year-on-year, on average. The 1.5°C Scenario shows that this is achievable but extremely challenging, requiring urgent action on multiple fronts. In the Planned Energy Scenario (scenario on energy system developments based on governments' current energy plans and other planned targets and policies [as of 2019], including NDCs under the Paris Agreement) annual emissions reach 36.5 Gt CO_2 in 2050. For the 1.5°C Scenario, emissions need to drop to net zero. All sectors need to reach almost net zero. Further efforts in sectors such as power, heat and industry are needed, with negative emissions delivering the necessary additional carbon reductions. Renewable energy plays a key role in the decarbonisation effort. Over 90% of the solutions in 2050 involve renewable energy through direct supply, electrification, energy efficiency, green hydrogen and BECCS (IRENA, 2021a).

Figure 4: For the 1.5°C climate target, global CO_2 emissions need to drop to net zero by 2050



Notes: PES = Planned Energy Scenario; 1.5-S = 1.5°C Scenario.
Source: IRENA (2021a).

There are plenty of opportunities for renewable energy technologies throughout the entire energy sector. Focus is currently on decarbonising the power sector. Renewables for power generation have gained prominence due to cost reductions in technology, which both encourages and is driven by increased uptake. For example, the global average levelised cost of electricity from utility-scale solar photovoltaic (PV) fell by

82% between 2010 and 2019 (IRENA, 2020c) and by 7% between 2019 and 2020 (IRENA, 2021b). By 2050, electricity generation triples compared with the 2018 level, and renewables supply 90% of total electricity by 2050, up from 25% in 2018 (IRENA, 2021a). Therefore, the decarbonisation of electricity generation will continue to be a key focus.

With the ever-increasing deployment of renewable energy in the power sector, the shift from energy use to electricity in other sectors, including transport, buildings (heating and cooling) and industry, could make a significant contribution to decarbonisation. In transport, the sustained growth of electric vehicle adoption, supported by the international roll-out of infrastructure support, offers an opportunity to decarbonise the sector. However, the increase in demand for electricity may be a challenge for the power sector, becoming a key issue to be analysed by local experts.

For a more in-depth analysis of the IRENA *World Energy Transitions Outlook* and its vision of the transition of the world's energy landscape aligned with the Paris Agreement goals, please refer to IRENA's report *World Energy Transitions Outlook: 1.5°C Pathway* (IRENA, 2021a).

Box 3: Renewables Readiness Assessment El Salvador

IRENA has developed its Renewables Readiness Assessment (RRA) as a tool for carrying out a comprehensive evaluation of the conditions for renewable energy deployment in a given country. The RRA is a country-led consultative process, providing a venue for multi-stakeholder dialogue in identifying challenges in renewable energy deployment. The assessment then tries to come up with solutions to existing barriers.

For the Republic of El Salvador, the RRA process has been led by the Executive Hydroelectric Commission of the Lempa River (CEL – Comisión Ejecutiva Hidroeléctrica del Río Lempa), in co-ordination with the National Energy Council (CNE – Consejo Nacional de Energía) and with technical support from IRENA. The process incorporated extensive consultations with a large group of public and private energy stakeholders, including the ministries, the regulator, generation companies, transmission and distribution utilities, project developers, energy market operators, financial institutions, development partners, regional organisations, civil society, and academia, among others.

In December 2020, IRENA launched the RRA report for El Salvador highlighting the following five key action areas to accelerate the country's uptake of renewables: i) enhance long-term planning and policy for the renewable energy sector; ii) create enabling conditions for geothermal energy development; iii) establish clear institutional frameworks and co-ordination; iv) assess the implementation of distributed power generation; and v) foster project development and financing for renewables. Furthermore, 14 short- and mid-term actions were identified towards implementation of the outcomes from the RRA consultative process.

With the launching of the report, the post-RRA process has been initiated, aiming to bring the identified actions to reality. This process is led by the country and benefits from the close collaboration with all national and regional stakeholders from the private and public sectors. Additionally, the RRA has provided important inputs to the NDC revision process of El Salvador, specifically for the energy component, touching upon important aspects such as the promotion of direct use of renewable energy sources, development of clean energy scenarios, and applications of renewables in the industrial and agri-food sectors, among others. The RRA and associated actions are expected to pave the way for energy transition and associated climate action in El Salvador.

2.3 NATIONAL CONTEXT

The Republic of El Salvador is the smallest country in Central America, being located on the west coast, bordered by the Pacific Ocean, Honduras and Guatemala. El Salvador has a total land area of 21 000 km², and its capital and largest city is San Salvador. As of 2021, the country had a population of approximately 6.8 million habitants. El Salvador is crossed to the west by two parallel mountain ranges, with a central plateau in between and a narrow coastal plain hugging the Pacific. The country is divided into two physiographic regions by these physical features. The interior highlands, which cover 85% of the land, are made up of mountain ranges and a central plateau. The Pacific lowlands refer to the remaining coastal plains.

Figure 5: Geographical location of El Salvador

Source: wikipedia.org.

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Figure 6: San Salvador capital city, El Salvador

Photo: Henryk Sadura / Shutterstock.com.

Regarding Sustainable Development Goal 7, ensuring access to affordable, reliable, sustainable and modern energy for all, El Salvador has made impressive progress. The country's access to electricity rate reached around 97% in 2018, compared with 95.4% in 2015 (ACAPS, 2019).

2.4 EL SALVADOR'S FIRST NDC

El Salvador submitted in 2017 its first National Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC) secretariat. In this regard El Salvador presented a number of contributions in order to establish a legislative and institutional framework that can guide economic and social development towards low emissions and adaptation to climate change. El Salvador provided information about its planned actions in the following areas: institutional development; legal systems; infrastructure; water resources; agriculture, livestock and forestry; energy and health care, social welfare and transportation.

In terms of specific mitigation options for the energy sector, the country set a 46% GHG emissions reduction target with respect to growth without concrete mitigation actions or "business as usual" by 2025. An additional 15% could be achieved, conditional on financial support for the development of an additional 92 MW from geothermal generation.

In addition, the NDC detailed that the power generation sector will define and commit to a target increase of renewable energy by 2025 of no less than 12% of the total electricity generated in the country in 2014. The proposal will present implementation resource needs beyond the reach of national finances.

Figure 7: Rooftop solar PV installation

Photo: Bilanol / Shutterstock.com.

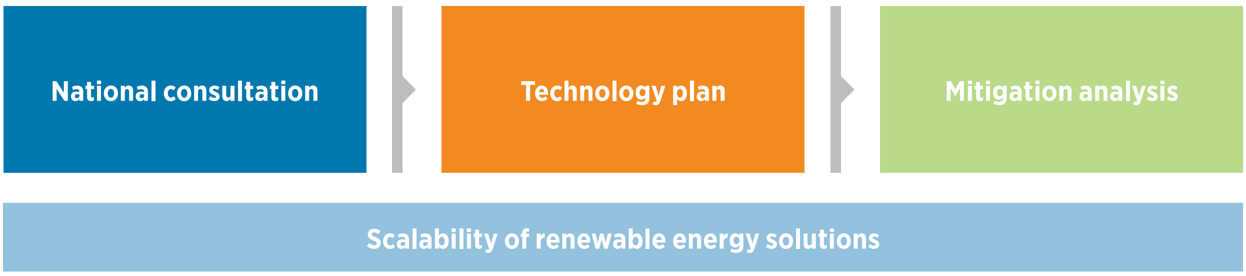
3. METHODOLOGY

The mitigation analysis for the agro-industry subsector in El Salvador is being developed as a guideline for addressing the early stages of implementing a renewable energy technology solution with specific aspects such as resource assessment, technology feasibility study, appropriate infrastructure and equipment requirements, and economic assessment. The analysis sheds light on how the technology could be integrated into the existing energy sector, thereby paving the way for future large-scale implementation. The activity will contribute to the revision of El Salvador's Nationally Determined Contribution (NDC) by conducting a preliminary analysis of how solar technologies could be integrated into the agro-industry subsector. Additionally, it will address transversal issues such as mitigation, adaptation and resilience. As illustrated in Figure 8, a step-by-step process is used to implement the mitigation analysis in the agro-industry subsector:

- **national consultation**: bringing together energy and climate stakeholders to identify relevant solutions and industry subsector to be analysed
- **technology analysis**: technical and economic feasibility analysis based on a selected case study
- **mitigation analysis**: exploring the subsector's scalability potential (electric and thermal).

This chapter discusses the methodologies used, the datasets used and the assumptions made at each stage of the methodology process. Section 3. 1 details the national consultation process developed in collaboration with the National Energy Council (CNE – Consejo Nacional de Energía) to identify the case study that will serve as the foundation for the technology plan as a demonstration solution. Section 3. 2 details the process of developing a technology solution for both electrical and thermal systems for the identified case study. Section 3. 3 details the mitigation analysis from the chosen technology solution for both electrical and thermal systems.

Figure 8: Methodology for developing the technical analysis



3.1 NATIONAL CONSULTATION

This section describes the methodology, data and justification used to identify the selected case study for the technology plan, which served as the starting point for the analysis.

National consultation process

The International Renewable Energy Agency (IRENA) implemented a national consultation process through an online survey to support and inform the identification of the case study for developing the technology plan. The online survey served as a participatory process for engaging and collecting inputs and technical insights from key national stakeholders, such as the CNE, the Ministry of Environment and Natural Resources (MARN – Ministerio de Medio Ambiente y Recursos Naturales), and others. The CNE provided support to IRENA in identifying the national organisations and key stakeholders to involve in the exercise. Detailed questions on the survey can be found in the Appendix.

Survey participant profile

There were 31 key national stakeholders from the list shared by the CNE who responded to the survey. The group of participants included a high percentage of government officials (65%), mainly CNE and MARN officials. The participation of the National Centre for Agricultural and Forestry Technology, Enrique Álvarez Córdova (CENTA – Centro Nacional de Tecnología Agropecuaria y Forestal), and academia was also high, at 13% for CENTA and 19.4% for academia. Overall, the survey brought together participants with a diverse distribution from 12 different backgrounds. Detailed results on the participant profile are shown in Figure 9 and Figure 10.

Figure 9: Participant profile: Share of organisation distribution

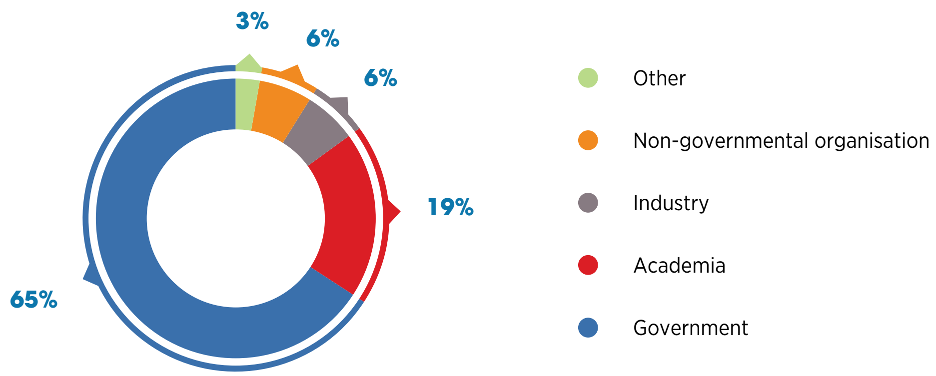


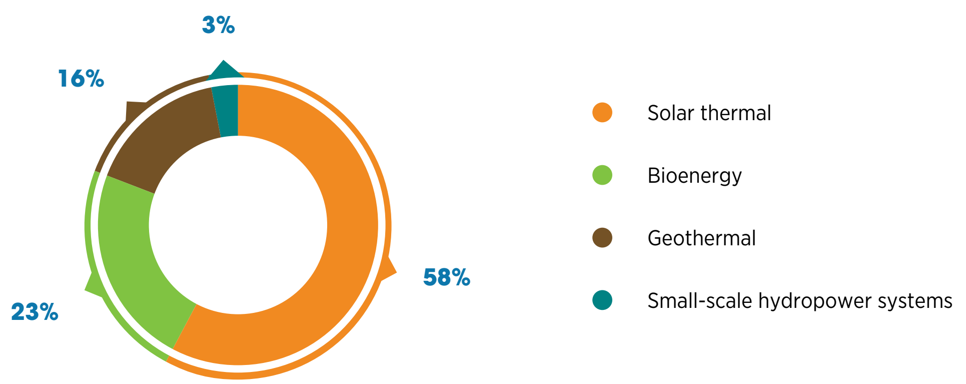
Figure 10: Participant profile: Organisation distribution count

Survey overall findings

Participants were asked to provide feedback through an online survey by answering multiple-choice questions and one open question. Participants were surveyed on the interaction between renewable energy and the agro-industry sector, national capacities, renewable energy technologies, and other criteria. Overall, the findings show that El Salvador places a high value on the link between clean and green technologies and the agricultural sector. Additionally, the survey revealed that respondents believe renewable energy is associated with national resilience, food security and poverty reduction. Another noteworthy feature is that it is thought that the country lacks national regulations that would encourage national self-consumption of renewable energy.

Participants were asked in terms of the utilisation of solar thermal technologies to meet the energy requirements of agro-industry heat processes. The assessment was based on availability of resources, social acceptance of technology and potential barriers to implementation. The proportion of respondents who agreed and disagreed with the statement that the combined availability of high-quality solar resources and land at agro-industry locations was roughly equal. With regard to the social acceptance of solar thermal technologies for productive agricultural use, the results show a critical possibility that the technology may not be well understood and addressed at the national level, resulting in a potential land-use conflict. Therefore, there is a clear need for improving social acceptance, as it is crucial for successful project implementation. It is key to assess and address potential social conflicts, such as public opposition, which are generally due to lack of awareness of technology and climate change topics. In this line, there is typically a correlation between people's awareness of climate change and its impacts and their willingness to act against it. In addition, a strong agreement could be seen from the participants that there are currently barriers to development, such as sectoral, technological, policy and/or regulatory ones. Finally, the results show a high agreement among participants, reaching 80%, on finding solar thermal technology that is generally well suited for productive agricultural use in the country. As illustrated in Figure 11, there was widespread agreement on the use of solar technologies for the case study, as evidenced by both governmental and non-governmental responses. In this context, the technology plan will aim to address issues raised during the consultation process, with solar technologies being used to conduct the analysis.

Figure 11: Technology identification for pilot plan



Justification of the selected case study

The CNE is currently developing its long-term National Energy Policy 2020-2050. This aims to reduce the electricity tariff through added renewable power generation, facilitating the removal of electricity subsidies towards the end of the policy period. This new strategy goes beyond the power sector, too, stipulating targets for clean energy technologies in end-use sectors and energy efficiency, as well as promoting pilot projects for direct use of renewables in the industrial and agri-food sectors (IRENA, 2020b). The agro-industry Los Quesos de Oriente was chosen as the case study for the development of the technology plan in this context.

Los Quesos de Oriente is a Sonsonate-based dairy company that was founded in 1986. Since its beginning, the dairy producer has been regarded as a cheese boutique. After 30 years in business, and with a desire to serve the food service channel and introduce new product lines, the company invested in facility expansion and technology acquisition, transitioning from an artisanal to an industrial plant. In this vein, new product lines such as yogurts and gelatos were introduced in 2008. The company, which has established itself as one of the best dairy plants in the country, now offers a complete line of products for sale to supermarket chains, allowing it to increase production and sales volume. In addition, the business started exporting its goods to countries in the region.

The Chamber of Commerce and Industry of El Salvador awarded Los Quesos de Oriente La Palmera Dorada, the highest award given to Salvadoran industries that have left their mark on the country's economic, social and cultural development, on the verge of celebrating 20 years as a company and in recognition of its contribution to Sonsonate's development. Additionally, in 2019, consumers voted the company as the best dairy products in the country, for which they won first place in the Universidad Tecnologica de El Salvador Top Brand Award in the cheese category. Los Quesos de Oriente today employs more than 200 people in El Salvador, with more than 10 dairy boutiques, a corporate customer base, nationwide distribution, social contributions to non-profit organisations and a portfolio of corporate clients. The industry national background and its more than 30 years of market experience, combined with the continuing growth of its production levels and technological level of its industrial processes, presented a good opportunity for CNE and IRENA to choose Los Quesos de Oriente as the case study for the technology plan.

Figure 12: Industrial processing plant of Los Quesos de Oriente

Photo: www.losquesosdeoriente.com.

3.2 TECHNOLOGY ANALYSIS

This section examines a technology solution for Los Quesos de Oriente, specifically the dairy facility chosen for the project. The analysis is being developed as a guide for addressing the early stages of implementing a renewable energy solution that includes specific technology aspects, such as resource assessment, technology feasibility study, appropriate infrastructure and equipment requirements, and economic analysis. The analysis demonstrates how the technology can be integrated into the existing dairy production system, laying the groundwork for future large-scale implementation.

The location of the industrial facility is described in the first section. Following that, the facility's electric and heat demand profiles are evaluated in the second section, allowing for the selection of appropriate technology and system configuration. Following that, a third section will look at site characteristics such as weather conditions and solar resource. Finally, Chapter 0 delves into the identified technology solutions by the national consultation process, namely solar photovoltaic (PV) and thermal, providing an overview of their maturity and state of the art, as well as the methodology used to choose the best technology solutions for the case study of the agro-industrial facility Los Quesos de Oriente.

Industrial facility location

The facility of Los Quesos de Oriente is located in the south-west of El Salvador (Figure 13), 4 kilometres (km) from the coastal town of Acajutla, specifically in the latitude and longitude co-ordinates 13.61/-89.80. The footprint of the dairy facility is illustrated in Figure 14. The site is located in a predominantly rural area, with a number of dwellings in the west and pastures and agricultural land in the south, east and north of the site.

Figure 13: Location of Los Quesos de Oriente dairy site in El Salvador (yellow pin)

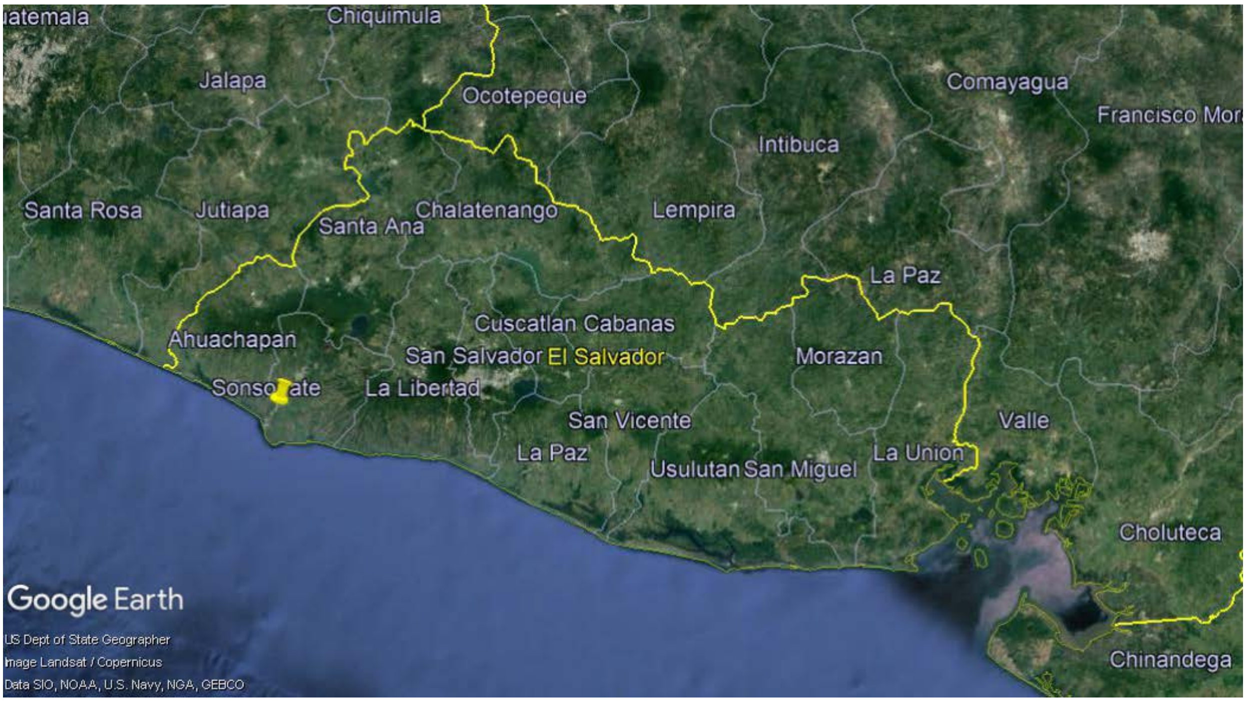


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Figure 14: Facility of Los Quesos de Oriente dairy site (yellow pin)

Survey of electric and heat demand

The assessment of the facility's electric and heat demand profiles is the first step in developing the case study. On a monthly basis, real datasets on consumption data, particularly for thermal analysis, were available. This section describes the process used to generate the hourly demand profiles, as detailed modelling requires a higher resolution (hourly values). Synthetic electric and thermal hourly demand profiles have been generated in this context, based on the operational characteristics and equipment available in Los Quesos de Oriente's dairy facility. The CNE compiled the datasets and information and shared them with IRENA.

Electrical demand profile

Two dataset inputs were used to generate the hourly electrical demand profile for a year: the total monthly electricity consumption from 2020, as well as a one-day hourly profile of a typical production day at the facility (17 April 2021).

Figure 15 depicts the annual electricity demand in 2020, demonstrating that consumption remains relatively constant throughout the year, with an average monthly demand of 55.257 kilowatt hours (kWh) and a total annual electricity demand of 664 megawatt hours (MWh). The daily demand profile is depicted in Figure 16, with a clear consumption peak between 09:00 and 13:00.

Figure 15: Monthly electricity demand in 2020 (kWh)

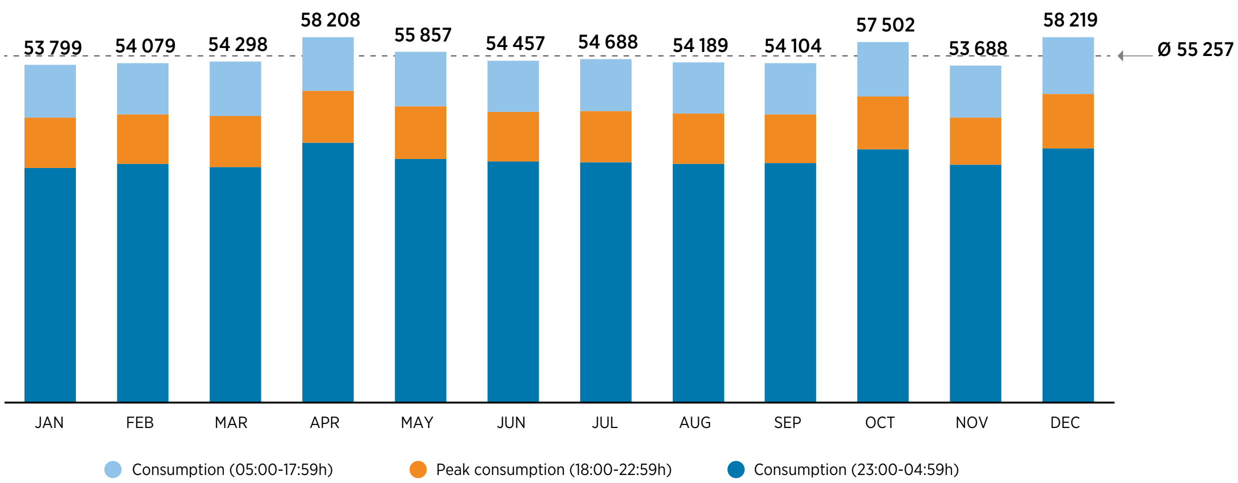
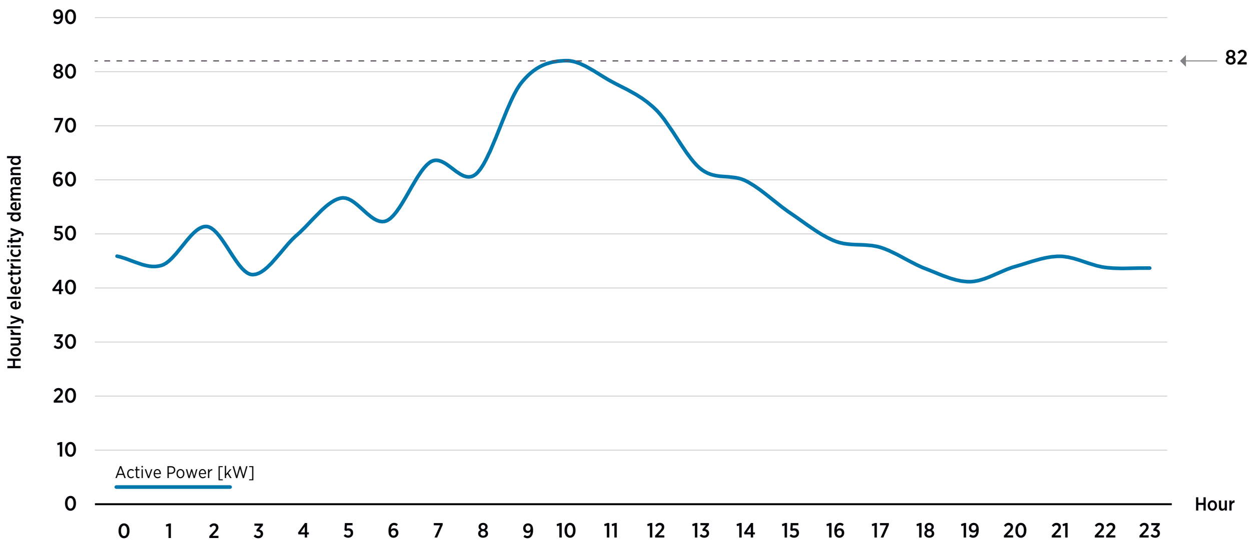


Figure 16: Hourly electricity demand on a typical day (17 April 2021)



Note: kW = kilowatt.

Following the analysis of both datasets, an open-source tool[1] developed by IRENA was used to create an annual hourly electrical demand profile. To generate the complete year hourly time series, the tool combined the characteristics of the annual demand with the typical day profile. The resulting electrical demand characteristics are shown in Table 2.

1 https://navigator.irena.org/pages/Home.aspx.

Table 2: Electric demand profile's main characteristics for Los Quesos de Oriente facility

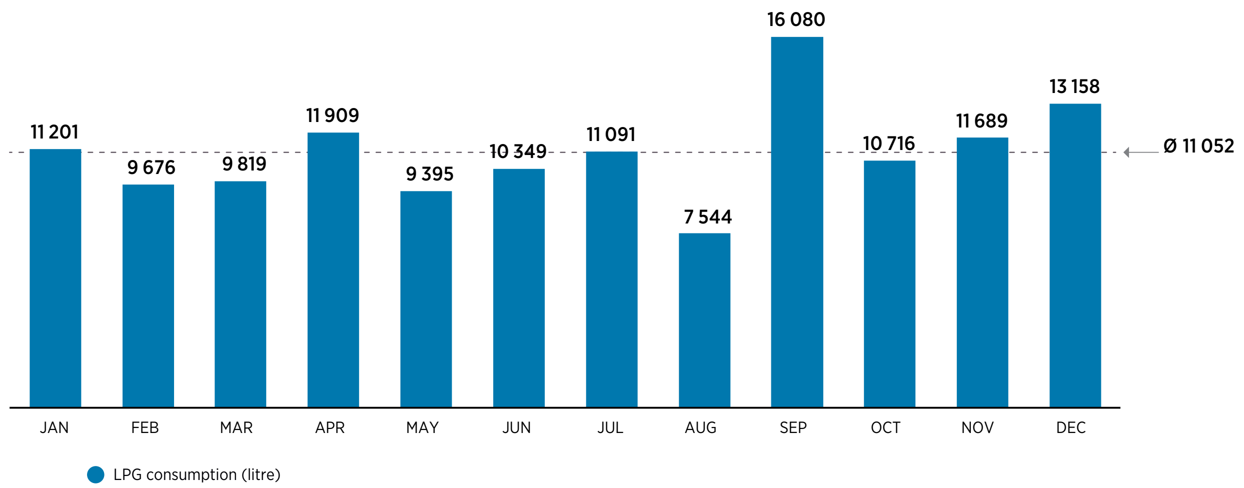
ELECTRIC DEMAND PROFILE	
Average electric power demand (kilowatt electrical [kW_e])	77
Maximum electric power demand (kW_e)	124*
Minimum electric power demand (kW_e)	55
Total annual electricity demand (megawatt hour electrical [MWh_e])	674

* The peak demand of 124 kW_e is greater than the one depicted in Figure 16 because the corresponding date is a Saturday and industry activity is assumed to be lower than during the weekdays. 124 kW_e corresponds to 10 a.m. on 1 April 2021.

Thermal demand profile

The facility shared the total annual fossil fuel consumption of the boiler in 2020, which is used for all heat processes, in order to generate the hourly thermal demand profile for one year. The fuel consumption in the year 2020 is depicted in Figure 17. Liquefied petroleum gas (LPG) is the fuel used at the facility, with an average monthly consumption of 11 052 litres in 2020.

Figure 17: Monthly LPG demand in 2020 (litres)



Following the analysis of the electrical demand profile, an open-source tool[2] developed by IRENA was used to generate the annual hourly thermal demand profile. Due to a lack of data on the hourly heat demand profile, and after consulting with national stakeholders, it was decided to combine the characteristics of the annual demand and correlate them with the typical hourly electrical profile in order to generate the complete year hourly time series for the thermal side. Figure 18 and Figure 19 depict the resulting heat demand profile at the facility on a typical production day in January and September 2020, respectively. The graphs show how the synthetic profiles correlate with LPG consumption on a monthly basis in the year 2020. A typical day in January has a peak heat load of 140 kW, whereas a typical day in September has a peak load of around 220 kW.

Figure 18: Hourly thermal demand on a typical day (January)

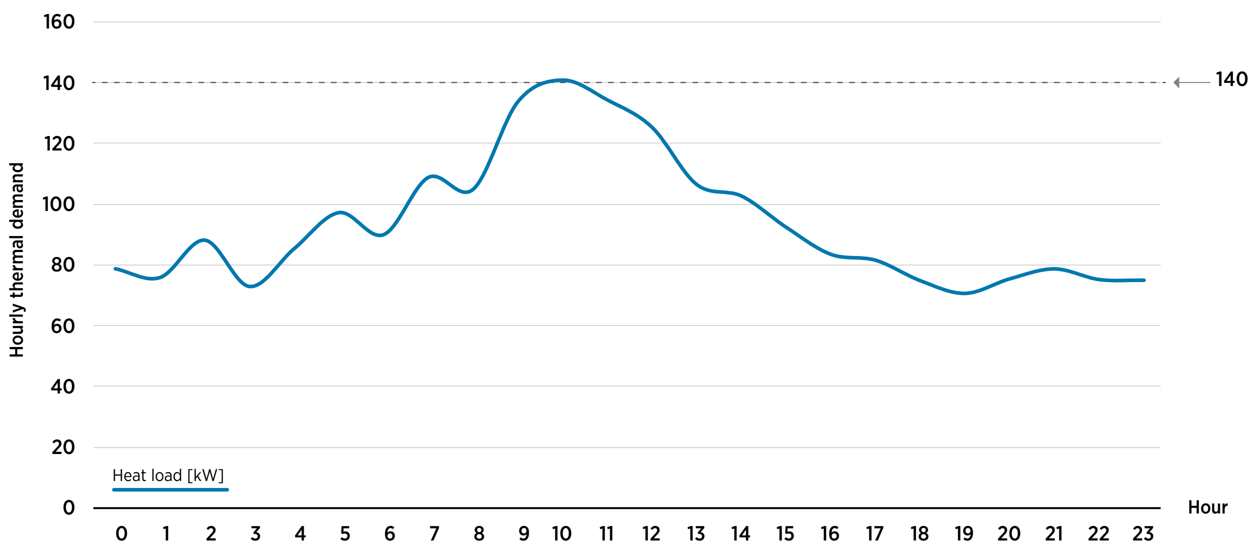
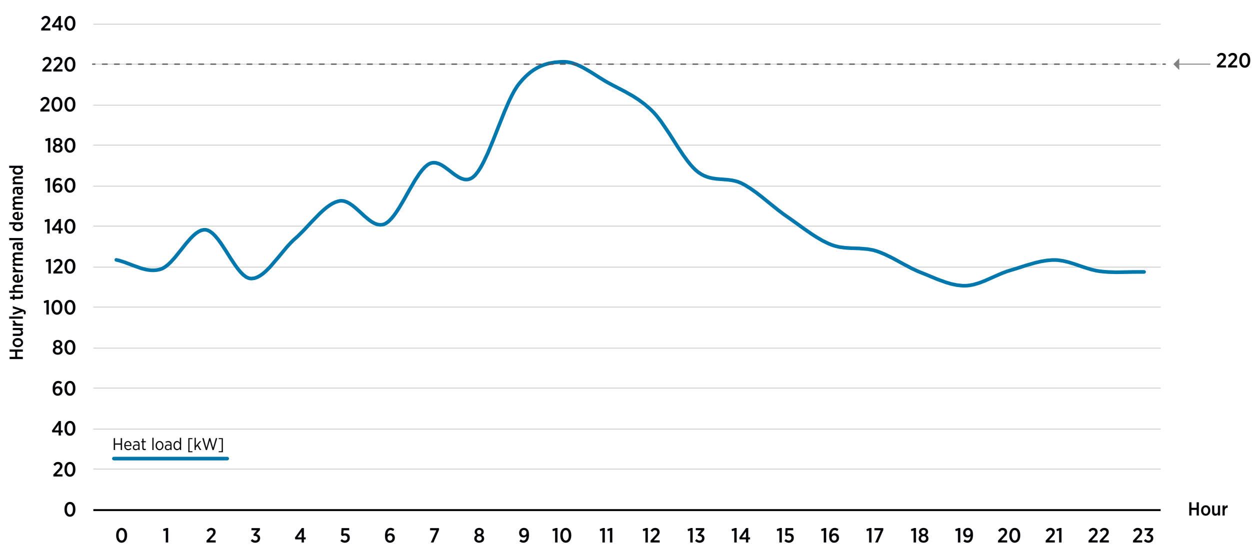


Figure 19: Hourly thermal demand on a typical day (September)



2 https://navigator.irena.org/pages/Home.aspx

Table 3 depicts the resulting thermal demand characteristics. The complete datasets can be found in the Appendix.

Table 3: Thermal demand profile's main characteristics for Quesos del Oriente facility

HEAT DEMAND PROFILE	
Average heat demand (kilowatt thermal [kW_{th}])	126
Maximum heat demand (kW_{th})	291
Minimum heat demand (kW_{th})	45
Total annual heat demand (megawatt hour thermal [MWh_{th}])	1105

Solar resource assessment and weather characteristics

Due to the unavailability of long-term solar irradiance data at the site, the solar resource assessment has been performed based on data available from a number of sources commonly used in the solar industry. These sources generate accurate and representative typical years for any place on earth based on satellite and ground-based weather station data. The following sources have been consulted for the solar resource assessment:

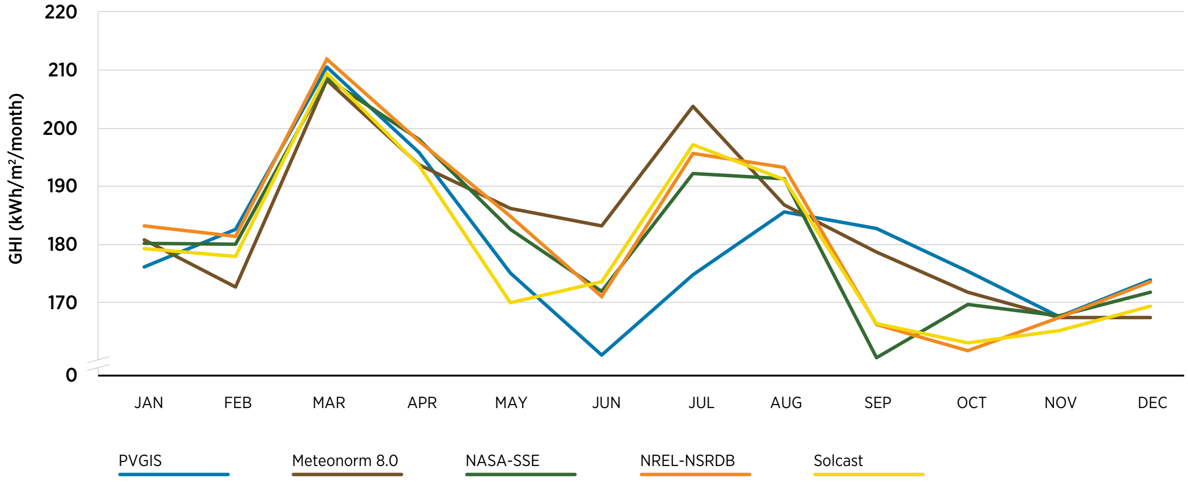
- Photovoltaic Geographical Information System (PVGIS). Generates a typical meteorological year (TMY) based on solar databases Surface Solar Radiation Data Set – Heliosat (SARAH), the Coronal Solar Magnetism Observatory (COSMO) or the National Solar Radiation Database (NSRDB) (Huld, Müller and Gambardella, 2012).
- Meteonorm. Uses satellite and ground-based weather station data between 2000 and 2009 (Meteotest, 2021).
- National Aeronautics and Space Administration's Surface Meteorology and Solar Energy (NASA-SSE). Uses satellite data between 1983 and 2005, with a spatial resolution of 1 degree x 1 degree (NASA Langley Research Center, 2021).
- National Renewable Energy Laboratory (NREL) NSRDB. The NSRDB is derived from satellite measurements based on the physical solar model version 3 (PSM-v3) with a resolution of 4 km x 4 km (US DOE/NREL/ALLIANCE, 2021).
- Solcast. Satellite-derived global TMY and historical solar data with a resolution 0.01 degree x 0.01 degree (approximately 1 km^2) (Solcast, 2021).

Three climate parameters have been collected from the above listed sources to characterise the climatic conditions at the site: global horizontal irradiance (GHI), diffuse horizontal irradiance (DHI) and ambient temperature. Table 29 and Table 30 present the site's monthly figures of GHI and DHI respectively from the different sources consulted. The tables can be found in the Appendix section.

Figure 20 plots the monthly GHI profile for the site characterised by the five sources consulted. There is good correlation between the sources assessed between January and April. For the rest of the year, there is good convergence between NREL-NSRDB, Solcast and NASA-SSE, while there are some discrepancies with the datasets obtained from PVGIS and Meteonorm. Correlation between NREL-NSRDB and Solcast is very good in all months except for the month of May. In May, the GHI from NREL-NSRDB is in line with that from Meteonorm and NASA-SSE.

Based on the above considerations and the good resolution provided by the NREL-NSRDB, this is the data source selected to characterise the solar resource at the site when modelling the solar PV and solar thermal systems.

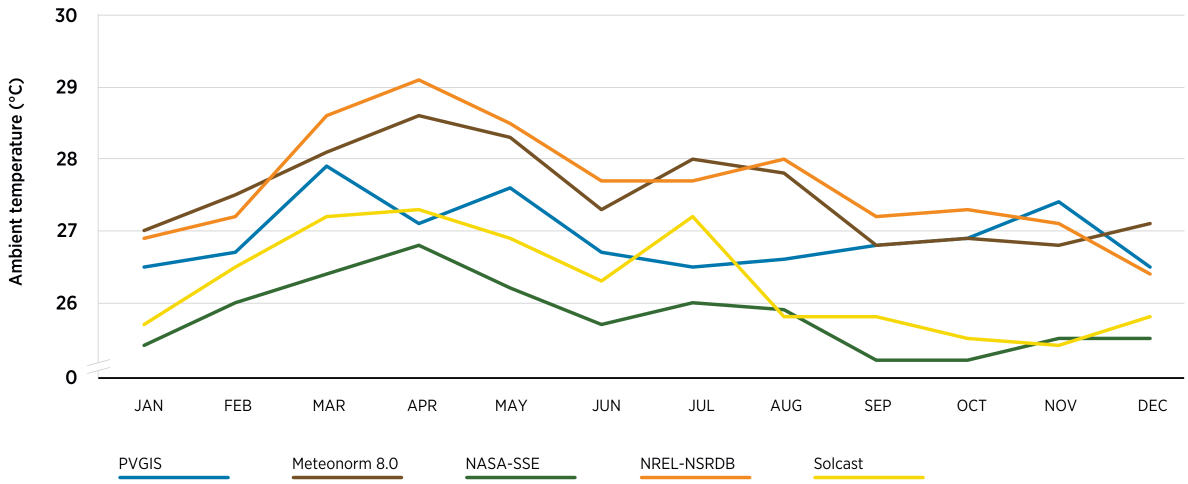
Figure 20: Monthly GHIs for the sources consulted



Note: m² = metre squared.

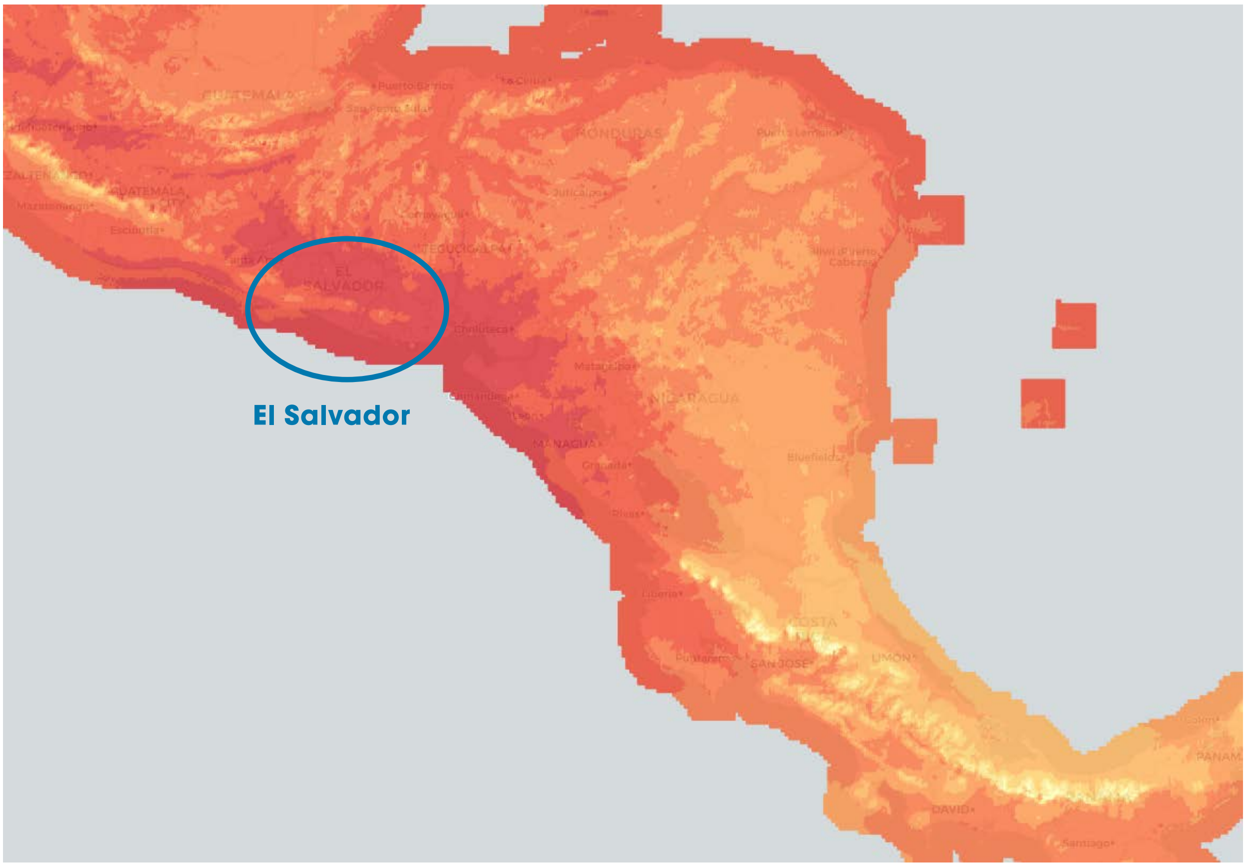
Figure 21 Illustrates the monthly average ambient temperatures at the site for the five databases consulted. Taking into consideration that the selected solar irradiance database is the NREL-NSRDB, for this database the average annual ambient temperature is 27.6°C. April is the hottest month with a monthly average ambient temperature of 29.1°C and December is the least hot month with 26.4°C. Table 31 depicts the datasets of the monthly average ambient temperatures at the site for the five databases consulted. The table can be found in the Appendix section.

Figure 21: Monthly average ambient temperature data at the site



According to the NREL-NSRDB database, based on satellite data with a resolution of 4 km, the annual global horizontal irradiance is 2 187.6 kWh/m^2. For this data source, at a 95% confidence interval, the validations of the solar predictions at seven ground-based solar measurement locations revealed the overall uncertainty in the annual GHI estimates ranges between 5% and 10%, while for hourly GHI estimates this ranges between 12% and 24% (Sengupta et al., 2018). Figure 22 depicts the general good solar resource overall throughout the country.

Figure 22: Global horizontal irradiance NSRDB data viewer: Central America



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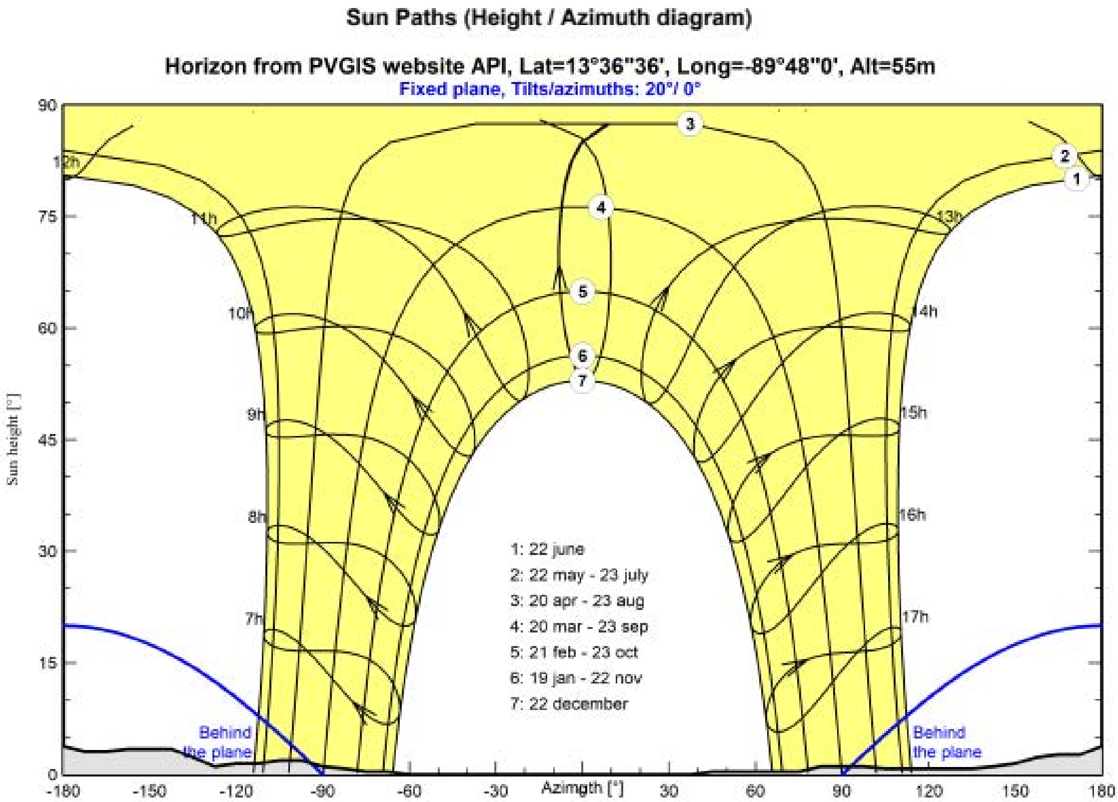
The topographic conditions combined with the high global irradiance regime of the area make the chosen site an ideal location for the use of this type of resource. Additionally, the surroundings of the site are predominantly flat. The sun paths and solar horizon at the site were plotted using PVsyst in Figure 23, indicating that there are no significant obstacles (e.g. mountain, hill) that could result in significant generation losses.

Figure 23: Sun paths and horizon at the site (PVsyst)



Technology solution for the facility's electrical demand

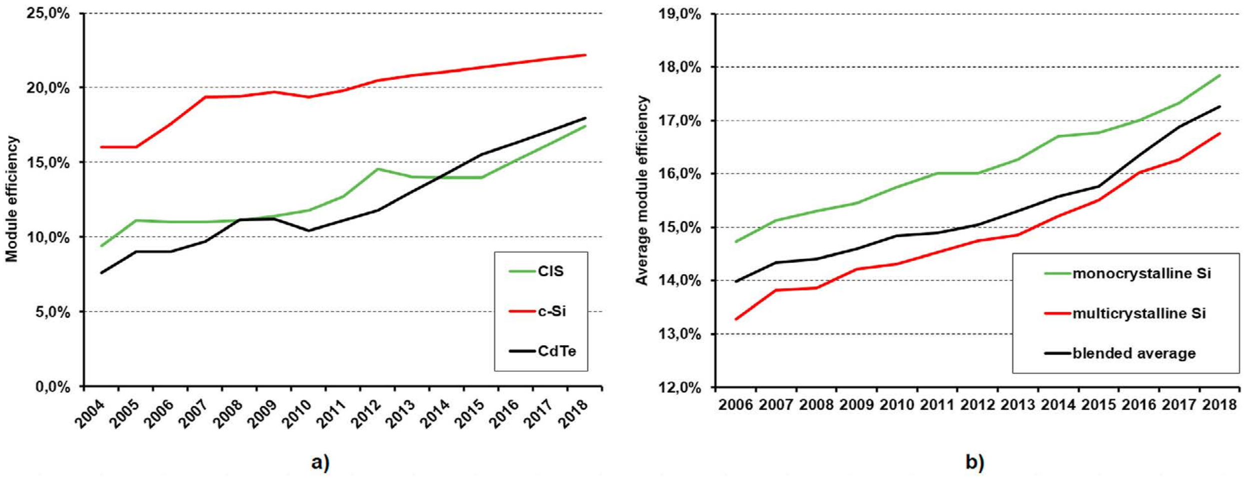
Solar PV technology was chosen to meet the electricity demand at Los Quesos de Oriente's production facility. To address the solar resource's intermittency, and with the aim to minimise both grid imports and exports, the technical solution includes storage equipment, namely battery energy storage solutions (BESS). The renewable energy system was designed with the goal of covering as much of the electricity demand as possible with renewable energy. The facility is connected to the grid, allowing for electricity imports to balance supply and demand. Excess electricity generated can be fed and sold into the grid.

Solar PV systems – Technology state of the art

By the end of 2020, over 707 gigawatts (GW) of solar PV systems had been installed worldwide. This represented more than 16-fold growth for the technology since 2010. About 127 GW of newly installed systems was commissioned during 2020 alone. These new capacity additions were the highest among all renewable energy technologies that year. The downward trend in solar PV module costs has been an important driver of improved competitiveness historically – and this trend continued during 2020. Between December 2009 and December 2020, crystalline silicon (c-Si) module prices declined between 89% and 95% for modules sold in Europe, depending on the type (IRENA, 2021b).

Currently, for non-concentrating solar PV module technology, the market is dominated by c-Si cell (mono- and polycrystalline) technologies which commonly have an efficiency higher than 14% and a service life greater than 15 years. The efficiency of crystalline silicon modules has experienced a constant increase in the past 15 years as shown in Figure 24, and at present they have an efficiency between 16% and 22%.

Figure 24: Solar PV module efficiency evolution of the top (a) and average (b) products on the market



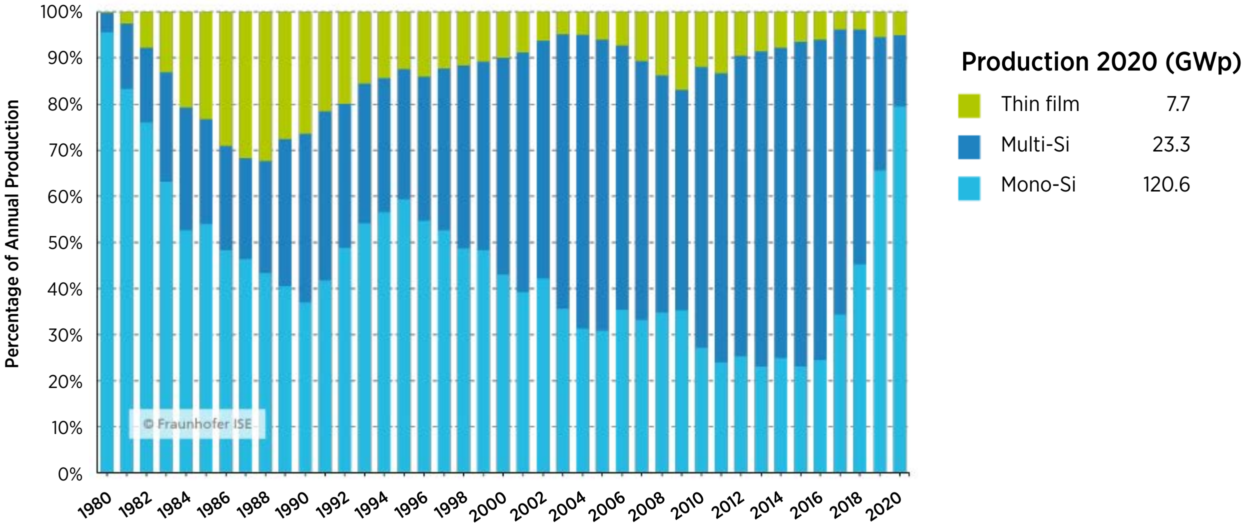
Notes: CdTe = cadmium-telluride; c-SI = crystalline silicon; CIS = copper indium diselenide

Source: Benda and Černá (2020).

Crystalline silicon modules present lower costs than other modules from other materials. Unprecedented solar module cost reductions have been driven by high levels of production volumes (i.e. learning curve). In April 2020, updated average module prices were USD 0.177 per watt peak (Wp) for multi-crystalline silicon (Si), USD 0.200/Wp for monocrystalline Si and USD 0.221/Wp for thin film (Benda and Černá, 2020).

Figure 25 illustrates the PV production by technology as a percentage of global annual production depicting a shift in the market share between 2015 and 2020 (Fraunhofer ISE, 2021).

Figure 25: PV production by technology 1980-2020



Notes: Mono-Si = monocrystalline silicon; Multi-Si = multi-crystalline silicon.

Source: Fraunhofer ISE (2021).

The service life of the solar PV modules depends on the materials and technologies used to laminate the modules. Service life of glass and plastic sheet-based modules can reach 30-40 years and 25 years respectively. Glass modules perform better in high temperatures, humidity and UV conditions, and present better mechanical stability (Benda and Černá, 2020).

Table 4 includes a list with the ten most efficient solar PV modules in 2021 (Svarc, 2021c).

Table 4: List of most efficient solar PV modules in 2021

MANUFACTURER	MODEL	POWER (WP)	EFFICIENCY (%)
SunPower	Maxeon 3	400	22.6
LG	Neon R	380	22.0
REC	Alpha	380	21.7
FuturaSun	FU M Zebra	360	21.3
Panasonic	EverVolt	370	21.2
Trina Solar	Vertex S	405	21.1
Jinko Solar	Tiger Pro 6RI3	390	20.7
Q cells	Q.Peak DUO G9	360	20.6
Winaico	WST-375MG	375	20.6
Longi Solar	Hi-Mo 4	375	20.6

In terms of the other elements that are part of a solar PV system, current inverters present typically an efficiency greater than 98%. Some examples of commercial inverter manufacturers in the range of 30 kW to 100 kW are SMA, FIMER (ABB), Sungrow, Huawei and SolarEdge (Svarc, 2021b). Batteries integrated in solar PV systems have evolved from the lead-acid type used in past years to the lithium-based batteries, driven by the reduction in cost of the latest. Some examples of solar battery manufacturers are Sungrow, LG Chem, BYD, Tesla, Powerplus and Redback (Svarc, 2021a).

Solar PV has a technology readiness level (TRL) of 9, with full commercial applications and where technology is ready for deployment at a large production rate and can be integrated with other supporting technologies (Rose et al., 2017).

At the end of 2020, the total installed capacity of solar PV worldwide exceeded 700 GW, with more than half of that capacity deployed in Asia, and about 2.4 GW installed in Central America and the Caribbean, of which 429 megawatts (MW) are installed in El Salvador according to IRENA's estimates (IRENA, 2021c).

Solar PV is becoming the lowest-cost option for electricity generation in most of the world, which is expected to propel investment in the coming years. In 2019, more than 100 GW of solar PV were installed worldwide, of which 66 GW were utility-scale, 26 GW commercial/industrial and 16 GW residential (IEA, 2020). Solar PV generation increased a record 156 terawatt hours (TWh) (23%) in 2020 to reach 821 TWh. It demonstrated the second-largest absolute generation growth of all renewable technologies in 2020, slightly behind wind and ahead of hydropower. Overall, a record 133 GW of solar PV was installed globally in 2020 (IEA, 2021).

Analysis of different solar PV configurations

The design of the solar PV system has been made based on the electric load profile described in the first section. The analysis focused on minimising both electricity imports and exports (surplus generation) from and to the grid in order to make the dairy facilities as renewable as possible without converting their activity focus to selling energy surpluses. Hence, the sizing exercise of the solar PV system has focused on two items: solar PV collection field, defined by the direct current (DC) rated capacity in kilowatt peak (kWp); and the accumulation capacity of the battery storage system, characterised as the 80% of the depth of discharge (DoD) in kWh_e.

Table 6 lists the ten solar PV system design configurations modelled. The average load demand has been used as the set parameter to determine the size of the solar PV collection field (system configuration number x average load demand) and accumulation capacity (4 x system configuration number x average load demand). An accumulation capacity of four times the size of the solar PV collection field is generally used to design off-grid systems, which is suitable in this case where the aim is to minimise both grid imports and exports. The solar PV system is dynamically simulated with one-hour time steps using the commercial software PVsyst 7.2 (PVsyst SA, 2021), based on the solar irradiance and ambient temperature conditions. The different losses in the PV system are defined based on the current practice in the industry and are listed in Table 5.

Table 5: Losses considered in the PVsyst model of the solar PV system

ELEMENT	PARAMETER	VALUE
Solar PV module	Thermal loss factor (watts per square metre, per degree Kelvin [W/m^2K])	29
	Efficiency loss (%)	-0.8
	Light-induced degradation (%)	-2
	Solar module mismatch losses (%)	-1
	Incidence angle modifier ASHRAE bo (-)	0.05
	Solar module annual average degradation factor (%)	-0.4
System	DC ohmic loss fraction at standard test conditions (STC) (%)	-1.5
	Alternating current (AC) ohmic loss fraction at STC (%)	-3.79
	Voltage mismatch in strings (%)	-0.1
	Yearly soiling factor (%)	-3
	Unavailability time fraction of the system (%)	-2

For each solar PV system design configuration, depicted in Table 6, the model is run for a whole year and the following annual parameters are computed: electricity consumption from grid; solar PV electricity stored and used within the facility; solar PV electricity directly used within the facility; and electricity exported to the grid.

Table 6: Solar PV rated capacity and battery storage for the ten system configurations assessed, and computed annual parameters

SYSTEM CONFIGURATION NUMBER	SOLAR PV RATED CAPACITY (kWp)	BATTERY STORAGE CAPACITY 80% DOD (kWh_e)	ELECTRICITY CONSUMPTION FROM GRID (MWh_e)	SOLAR PV ELECTRICITY STORED & USED (MWh_e)	SOLAR PV ELECTRICITY DIRECTLY USED (MWh_e)	ELECTRICITY EXPORTED TO GRID (MWh_e)
1	77	308	536	0	138	0
2	154	616	402	14	258	0
3	231	924	275	106	293	0
4	308	1 232	153	217	304	0
5	385	1 540	61	287	326	33
6	462	1 848	18	286	370	131
7	539	2 156	12	250	412	258
8	616	2 464	10	220	444	385
9	693	2 772	8	196	470	518
10	770	3 080	7	176	491	654

Based on the results in Table 6, the configuration chosen for the facility Los Quesos de Oriente is number 5, in which grid electricity is reduced to around 10% of the facility's consumption, and exported electricity accounts for about 5% of the facility's total electricity demand. To reduce grid electricity consumption to zero while maintaining a significant surplus of electricity generation, it is necessary to oversize storage capacity while also increasing solar PV capacity. Apart from greening its energy demand, the latter could be beneficial to the facility because it would gain complete autonomy, reducing its vulnerability to potential power grid outages and thus increasing its energy resilience.

The hourly dispatch for 13 March and 3 October, which represent two different representative types of days in terms of solar irradiance profiles, are illustrated in the following figures. The depicted parameters are: load, energy injected into the grid, energy consumed from the grid, battery charging energy and battery discharging energy. These parameters are analysed for the different solar PV system configurations. The hourly dispatch was calculated for both typical days for configurations number 1, 3, 5, 7 and 10.

Figure 27 and Figure 26 illustrate the case for configuration number 5 while the rest of the illustration charts can be found in the Appendix.

Figure 26: Hourly profiles on 13 March for configuration 5 of the solar PV system

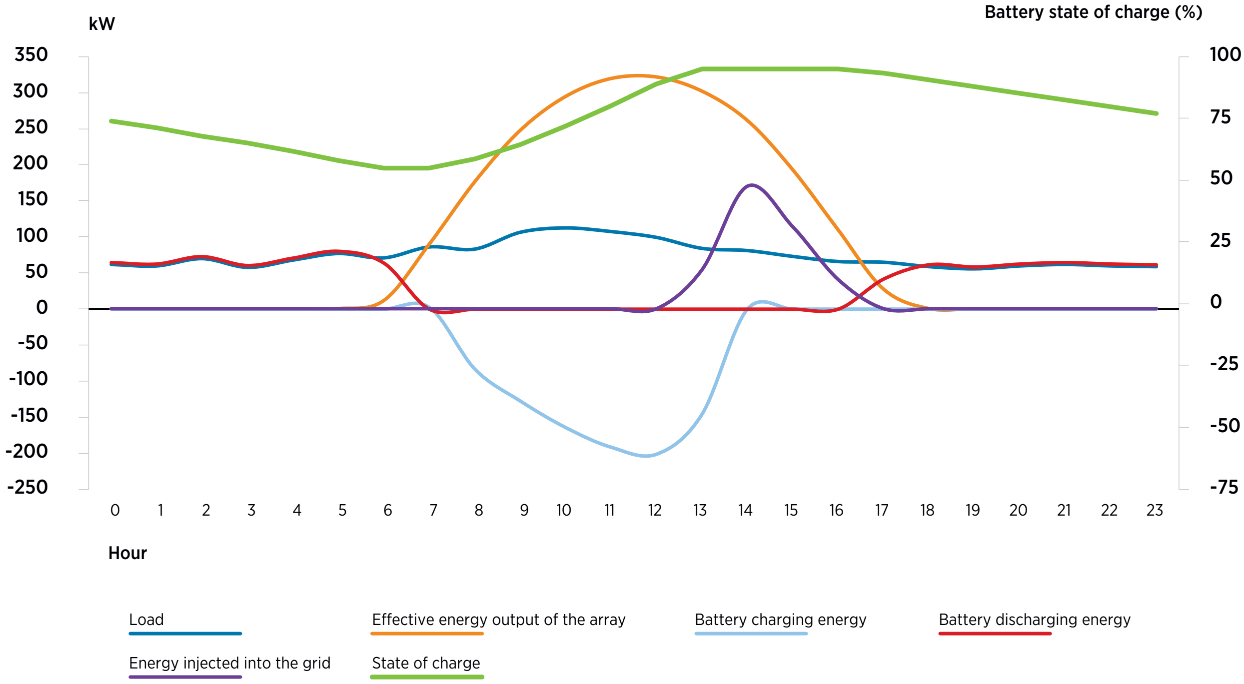
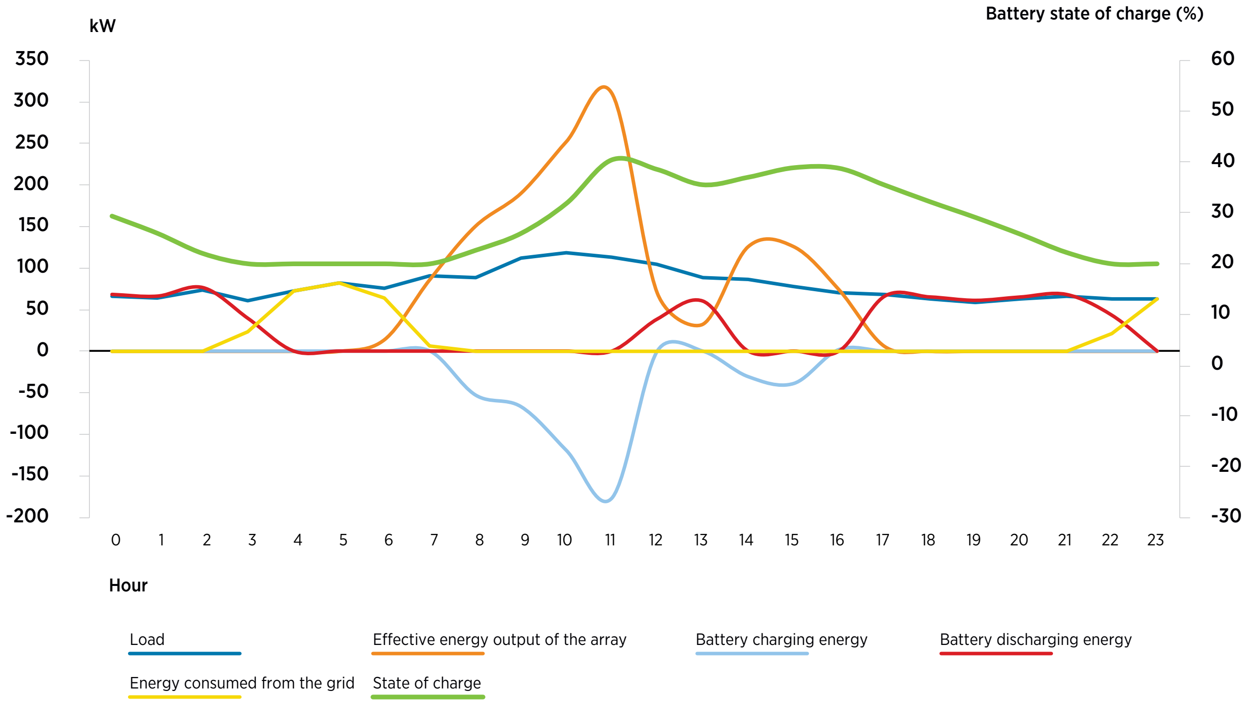


Figure 27: Hourly profiles on 3 October for configuration 5 of the solar PV system

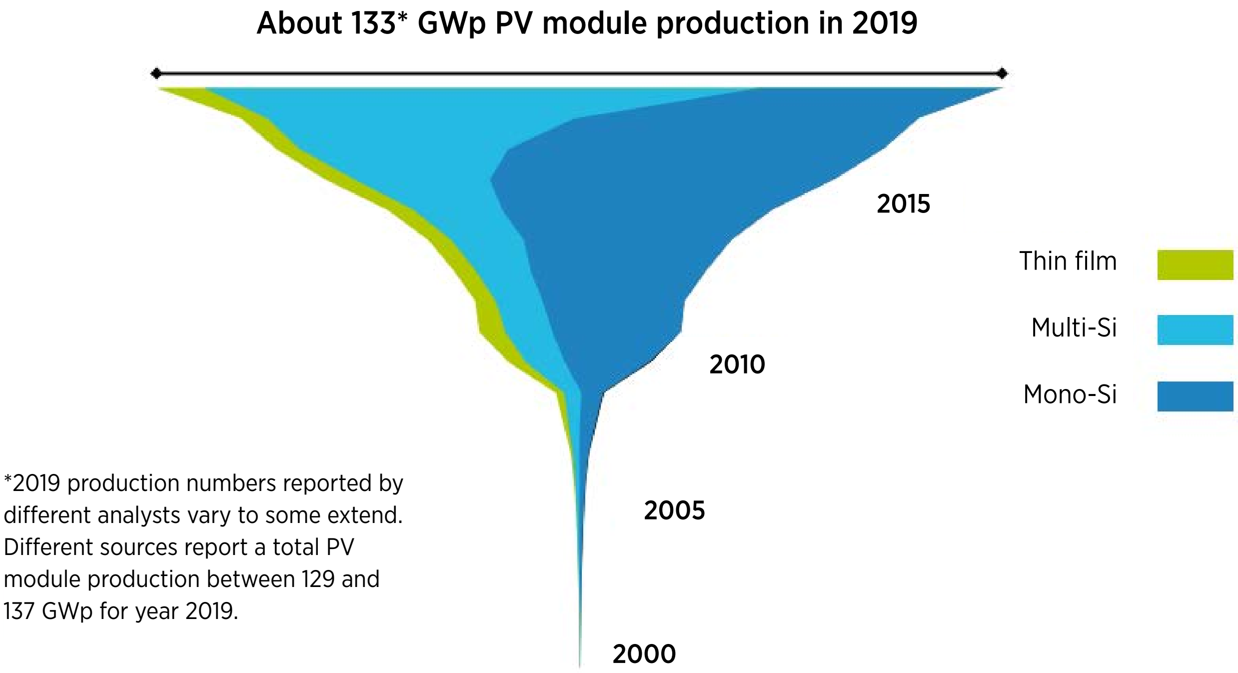


It is possible to observe how configurations with lower solar PV rated capacity and battery storage than configuration number 5 present difficulties to charge the battery storage system, as generation from the solar PV system is predominantly used to cover the facility's load, imports from the grid are required to meet the demand, and there is no surplus generation to feed in the grid. On the opposite side, configurations with higher solar PV rated capacity and battery storage capacities than configuration number 5 show that electricity demand is well covered with the solar and battery storage system without the need for imports from the grid. For configurations 7 and 10, the observed low fluctuation in the state of charge of the battery storage system reveals that the accumulation capacity may be oversized.

Components and technical characteristics for the selected solar PV solution

In this section, the components and technical characteristics for configuration number 5 for the solar PV system are detailed. Solar PV modules represent the main component of a solar PV system and occupy the largest area of the plant. These modules convert solar irradiance into electric current, causing it to flow due to the voltage difference set up in the module. For non-concentrating solar PV module technology, the market is dominated by c-Si cell (mono- and polycrystalline) technologies. Figure 28 illustrates the global annual PV production by technology until 2019.

Figure 28: Global annual PV production by technology, 2019



Note: GWp = gigawatt peak.

Source: Fraunhofer ISE (2021).

The balance of system typically refers to all equipment other than solar PV modules that transmits and regulates DC electricity produced in the array and converts it to AC electricity to be offtaken to the grid. Table 7, Table 8 and Table 9 include the technical characteristics of the solar PV modules, inverters and batteries respectively. The technical characteristics have been assessed from manufacturer's data sheets, taken for purely illustrative purposes. Considered manufacturer's data sheets can be found in the Appendix.

Table 7: Technical characteristics of the system solar PV modules

Solar PV module manufacturer	Jinkosolar (or equivalent)
Solar PV module model	JKM380M-72-V
Rated power at STC* (watt peak [Wp])	380
Module efficiency at STC (%)	19.16
Cell type	Monocrystalline
Number of cells	72
Dimensions (mm x mm x mm)	1 979 x 1 002 x 40

* STC: irradiance, 1 000 W/m²; cell temperature, 25°C; and mass of the air (AM), 1.5.

Table 8: Technical characteristics of the system inverters

Inverter manufacturer	SMA (or equivalent)
Inverter model	Sunny Highpower Peak1
Rated power DC (kW_e)	76.5
Rated power AC (kW_e)	75
Euro efficiency (%)	98.2

Table 9: Technical characteristics of the system batteries

Battery manufacturer	Tesla (or equivalent)
Battery model	Powerwall 2
Voltage (V)	50.4
Capacity (amp hours)	268
Stored energy at 80% DOD (kWh_e)	11
Nominal stored energy (kWh_e)	13.8
Battery input charger euro efficiency (%)	95
Battery to grid inverter euro efficiency (%)	95

Finally, Table 10 summarises the technical configuration of the solar PV system considered. The system has a DC nominal power of 383 kWp with a total of 1 008 solar PV modules; the AC output of the system set by the inverters is 375 kW; and the battery storage capacity is 1 556 kWh_e at 80% DoD, with 144 battery modules.

Table 10: Technical summary of the selected solar PV and storage system configuration

ELEMENT	PARAMETER	VALUE
Solar PV	DC rated power (kWp)	383
	Number of solar modules	1 008
	Module azimuth (degrees)	0
	Module tilt (degrees)	20
	Layout modules	Landscape
	Number of modules in height	2
	Pitch (m)	6
	Total land area required (hectare)	0.55
Inverter	Solar PV AC rated power (kW_e)	375
	Number of inverters	5
	DC/AC ratio	1.02
Battery	Storage capacity 80% DoD (kWh_e)	1 556
	Nominal storage capacity (kWh_e)	1 952
	Number of battery modules	144

Technology solution for the facility's heat demand

Industrial process heat refers to the thermal energy used in manufacturing processes for material transformation and chemical reactions. In the case of the dairy facility of Los Quesos de Oriente, the main production processes which require heat are pasteurisation and cheese melting. Both processes require a temperature of around 90°C. In this context, there is a significant potential for direct and indirect renewable heat use, which are crucial to reduce carbon dioxide (CO_2) emissions and adapt to climate change.

Solar thermal technology was selected to cover the heat demand at the dairy's facilities. The technology solution has incorporated storage equipment to address the variability of the solar resource. The renewable energy system has been designed to maximise the fraction of electricity and heat demand covered with renewable energy. To fill any gaps between the heat generated and the heat demanded, the facility's current available boiler would be used as back-up system.

Figure 29: Industrial heat solar parabolic trough system in Mexico

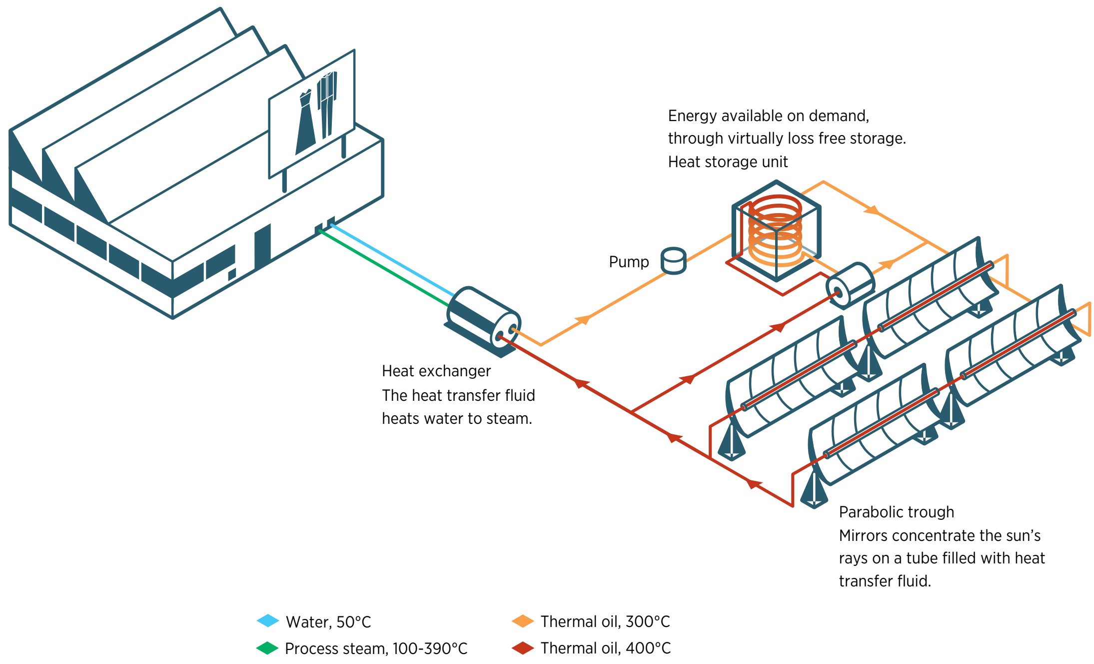
Photo: Inventive Power, https://inventivepower.com.mx/solucion-en-energia-solar/.

Concentrated solar thermal systems – Technology state of the art

Concentrating solar systems work in areas with high direct normal irradiance by concentrating the sun's rays using mirrors to create heat. In most systems today, the heat created from concentrating the sun's energy is transferred to a heat transfer medium, typically a thermal oil or molten salt. Many concentrated solar power (CSP) plants include low-cost thermal storage systems to decouple generation from the sun. It is possible to classify CSP systems according to the mechanism by which solar collectors concentrate solar irradiance, either "line concentrating" or "point concentrating" varieties. These terms refer to the arrangement of the concentrating mirrors.

Typically, single parabolic trough collectors (PTCs) consist of a holding structure with an individual line-focusing curved mirrors, a heat receiver tube and a foundation with pylons. The collectors concentrate the solar radiation along the heat receiver tube (also known as the absorber), a thermally efficient component placed in the collector's focal line. Various PTCs are traditionally connected in "loops" through which the heat transfer medium circulates to achieve scale. Line concentrating systems rely on single-axis trackers to maintain energy absorption across the day increasing the yield by generating favourable incidence angles of the sun's rays on the aperture area of the collector. Specific PTC configurations must account for the solar resources at the location and the technical characteristics of the concentrators and heat transfer fluid (IRENA, 2021b). Figure 30 illustrates the working principle of a concentrated solar thermal system.

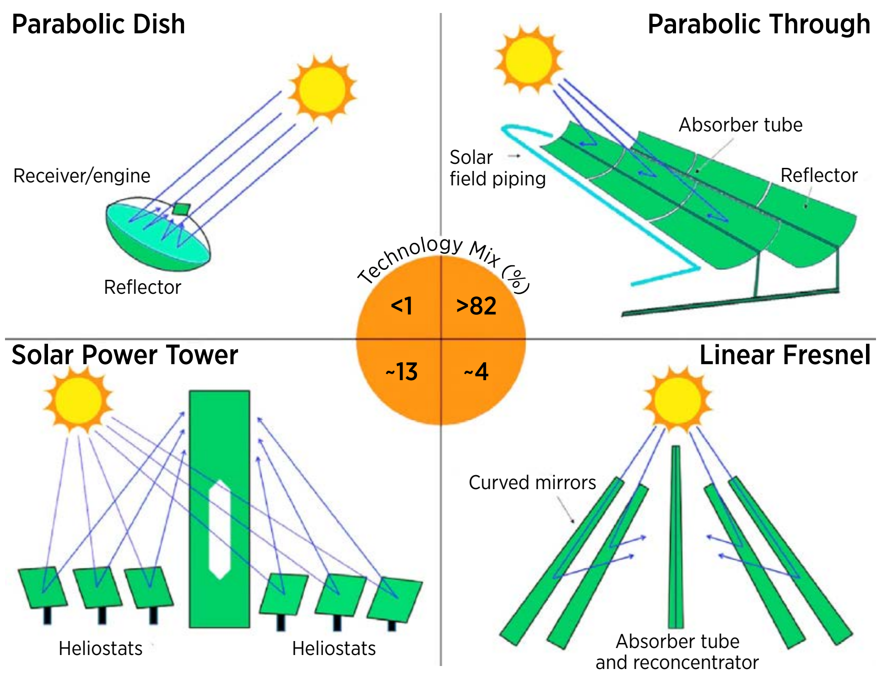
Figure 30: Working principle of a concentrating solar thermal system



Source: https://protarget-ag.com.

For concentrated solar power, there are four different types of technologies (Figure 31): parabolic dish, parabolic trough, solar power tower and linear Fresnel. The focus is on the parabolic trough class as this is the one used in the case study. Linear concentrated systems present the most mature options among the concentrated solar power technologies and, like the other concentrated solar power systems, it requires a yearly direct normal irradiance at the site larger than 1 800 kWh/m^2 (Islam et al., 2018).

Figure 31: Types of concentrated solar power technologies



Source: Islam et al. (2018)

The global weighted average levelised cost of energy of CSP plants (concentrated solar power together with an electricity generation component) decreased by 68% between 2010 and 2020 from USD 0.34/kWh to USD 0.108/kWh (IRENA, 2021b).

Typical concentrated solar power collectors have a TRL of 9,[3] where all systems and components are ready for full operation production and commercial application, and several plants are installed all over the world (Rose et al., 2017). Concentrated solar for heat dispatch and steam generation follows the same operating principle as the concentrated solar power, although the latest presents an additional component for power generation. The concentrated solar power installed capacity worldwide reached almost 6.5 GW at the end of 2020. About 2.3 GW are installed in Spain, and North America has 1772 MW and South America has 100 MW.

Analysis of different solar thermal configurations

Following the approach used for the design of the solar PV system, the solar thermal system was sized based on the heat demand of the dairy facility previously calculated in the first section, maximising the heat demand covered by the solar thermal system and minimising the heat surplus as this cannot be used elsewhere.

The target temperature for the heat generated with the solar system is set to 90°C. At these operating temperature conditions, concentrated solar thermal technology is a good fit. The solar thermal parabolic trough technology is used in the analysis, as this technology has effectively been implemented in the region with an important number of industrial applications in the southwest from Mexico (AEE INTEC, 2021). The solar thermal system is considered to generate exclusively heat, and no power generation component is considered.

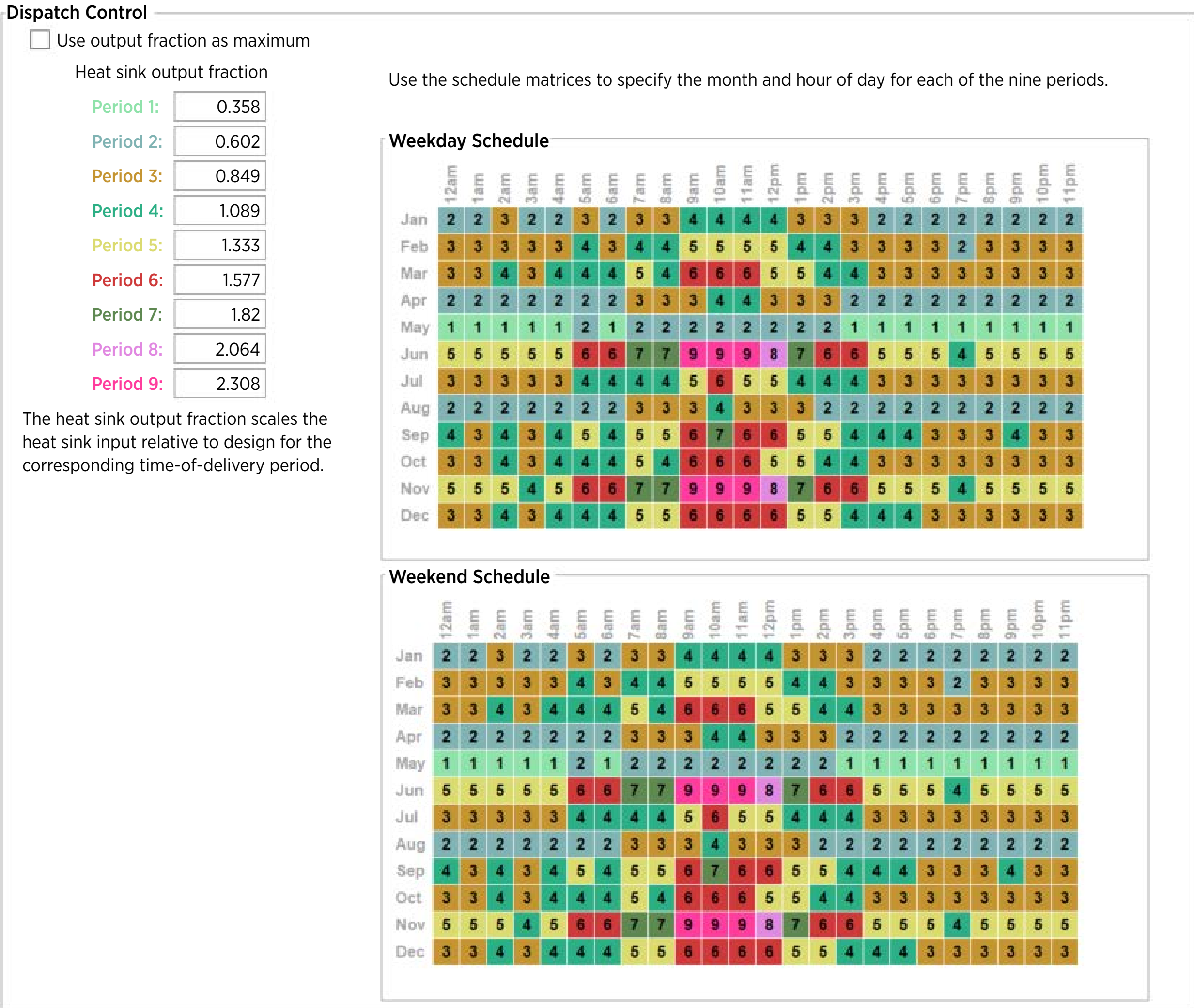
The solar parabolic trough system is modelled in System Advisor Model v.2020.11.29 (SAM), an open-source software developed by NREL (NREL, 2020). The solar thermal system is complemented with a thermal accumulator, which provides a set number of hours of operation of the system.

The solar thermal system is simulated with one-hour time steps, based on the solar irradiance and temperature conditions. The solar collector field is modelled including a single east-west axis tracking system, and pressurised water is used as the heat transfer fluid. Model parameters are defined based on current industry practice. System losses, such as thermal and optical, among others, as well as system availability are presented in the Appendix.

SAM does not incorporate a functionality to import a thermal load profile, but rather heat dispatch is set in a maximum of nine different periods as a fraction of the heat sink output (Figure 32). A dispatch period is assigned to a specific hour, and hourly weekday and weekend schedules can be defined for each month of the year. The facility's heat demand profile was adapted to accommodate these dispatch periods using the nearest-neighbour interpolation methodology. This process of load profile reshape leads to a coarser load profile resolution, which will inevitably lead to certain discrepancies between the modelled solar thermal system output and the actual demand.

3 The TRL index is a globally accepted benchmarking tool for tracking progress and supporting in the development of a specific technology from basic technology research (TRL1) to actual system demonstration under all expected conditions (TRL9). For more details, refer to Annex 1.

Figure 32: Heat dispatch control in SAM defined in nine periods. Periods are assigned to every hour of weekdays and weekends for a set month



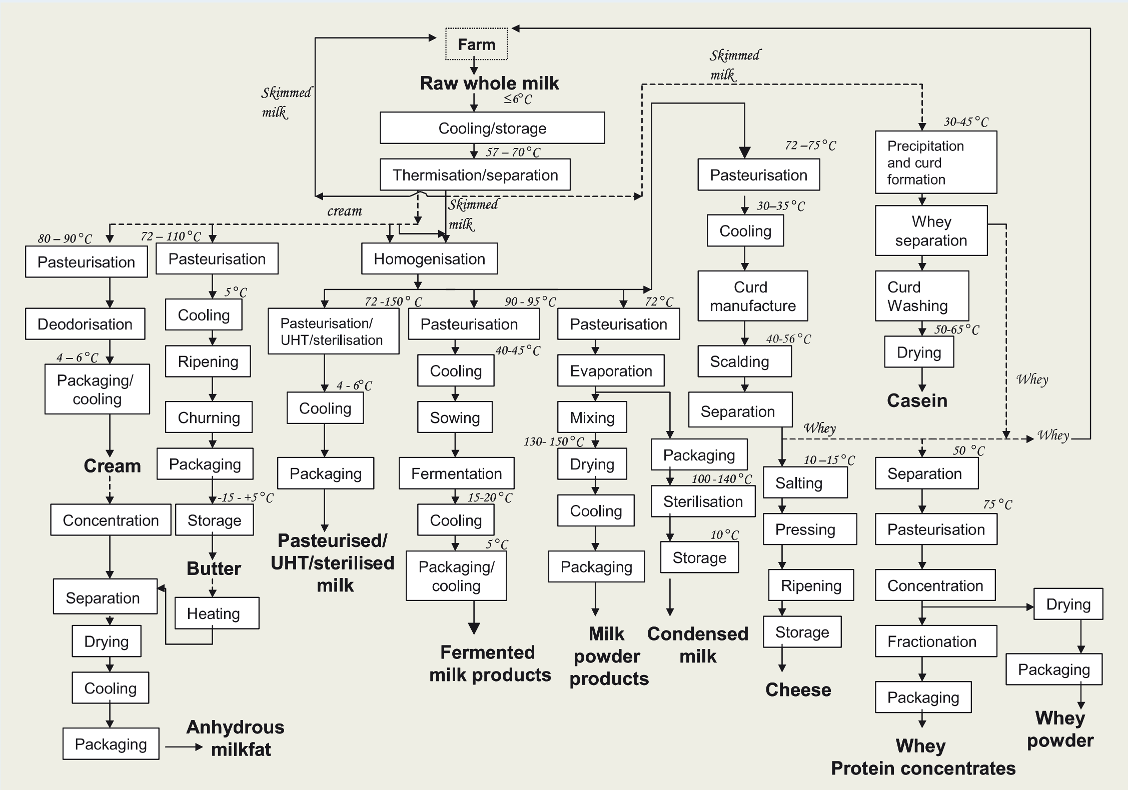
A set of 12 different solar thermal heat sink and storage capacities have been assessed (Table 11). Three heat delivery capacities are considered based on maximum heat demand, average heat demand and a midpoint demand between the two. Four different heat storage capacities are considered (3, 6, 12 and 18 hours), defined as the number of hours that the storage system can provide energy at the design point (i.e. full load). The sizing of the heat storage is based on the typical storage design of concentrated solar thermal systems, with the additional consideration that a high degree of self-sufficiency is investigated, hence the inclusion of storage capacities of 12 hours and 18 hours. For each system configuration, the model is run for a whole year, resulting in the following annual parameters: thermal energy output; thermal energy savings; percentage of heat demand covered; thermal energy surplus; and heat surplus as percentage of the demand. From the results presented in Table 11, the selected system configuration is number 11 as it covers about 89% of the annual heat demand at the facility, while limiting the excessive heat to about 14% of that generated in a year. For configuration number 11, Table 12 shows the correspondent nine heat sink output fraction periods set up in the dispatch control in SAM.

Heat demand could almost be completely covered employing configurations 4 or 12, but where resulting heat surplus will exceed 20% of the demand in configuration 4 and an oversized storage will be required for configuration 12. In the case of configuration number 4, unless this excess in heat generated can be used elsewhere or stored, this configuration is considered unattractive.

Box 4: Major heat processes from raw whole milk to milk products

Thermal treatment of milk is the key task. Pasteurisation is the most common first step where chilled milk is heated to kill any bacteria and micro-organisms and is then cooled. Most commonly whole milk is heated to 55-65°C in the pasteuriser before being separated. Following separation, the cream is standardised at a preset fat content and subsequently, the calculated amount of cream intended for bottled milk, cheese, butter etc. is separated, then remixed with an adequate amount of skimmed milk. In the production of milk powder, evaporation takes place under vacuum pressure, sometimes at temperatures as low as 40°C.

Figure 33: Major processes of raw whole milk from the farm to produce a range of milk products.



Source: FAO and USAID (2015).

Table 11: Defined heat sink power capacity and heat storage capacity for the 12 solar thermal system configurations assessed, and computed annual parameters

SYSTEM CONFIGURATION NUMBER	HEAT SINK POWER CAPACITY (kW_{th})	HEAT STORAGE CAPACITY (HOURS)	THERMAL ENERGY OUTPUT (MWh_{th})	THERMAL ENERGY SAVINGS (MWh_{th})	PERCENTAGE OF HEAT DEMAND COVERED (%)	THERMAL ENERGY SURPLUS (MWh_{th})	HEAT SURPLUS AS PERCENTAGE OF DEMAND (%)
1	291	3	1082	783	70.9	299	27.0
2	291	6	1213	944	85.4	269	24.3
3	291	12	1255	1000	90.6	254	23.0
4	291	18	1263	1015	91.9	248	22.4
5	126	3	565	528	47.8	37	3.3
6	126	6	690	649	58.7	42	3.8
7	126	12	784	737	66.8	47	4.3
8	126	18	793	746	67.6	47	4.2
9	209	3	867	703	63.7	164	14.8
10	209	6	1021	867	78.5	154	14.0
11	209	12	1137	983	89.0	153	13.9
12	209	18	1157	1006	91.1	151	13.7

Table 12: Heat sink output fraction periods set up in the dispatch control in SAM v.2020.11.29 for configuration number 11

PERIOD	HEAT SINK OUTPUT FRACTION
1	0.216
2	0.364
3	0.511
4	0.658
5	0.806
6	0.953
7	1.101
8	1.248
9	1.395

Components and technical characteristics for the selected solar PV solution

The components and technical characteristics of configuration number 11 are detailed in this Chapter. Table 13, Table 14 and Table 15 summarise the major technical characteristics of solar thermal system collectors, receivers and storage.

Table 13: Technical characteristics of the solar thermal collectors

Reflective aperture area (m^2)	656
Aperture width (m)	6
Length of collector assembly (m)	115
Number of modules per assembly	8

Table 14: Technical characteristics of the solar thermal receivers

Absorber tube inner diameter (m)	0.076
Absorber tube outer diameter (m)	0.08
Glass envelope inner diameter (m)	0.115
Glass envelope outer diameter (m)	0.12
Heat loss at design (W/m)	190

Source: Burkholder and Kutscher (2009).

Table 15: Technical characteristics of the solar thermal system storage

Tank height (m)	15
Tank diameter (m)	2.6
Wetted loss coefficient (W/m^2K)	0.3
Estimated heat loss (MW_{th})	0.03

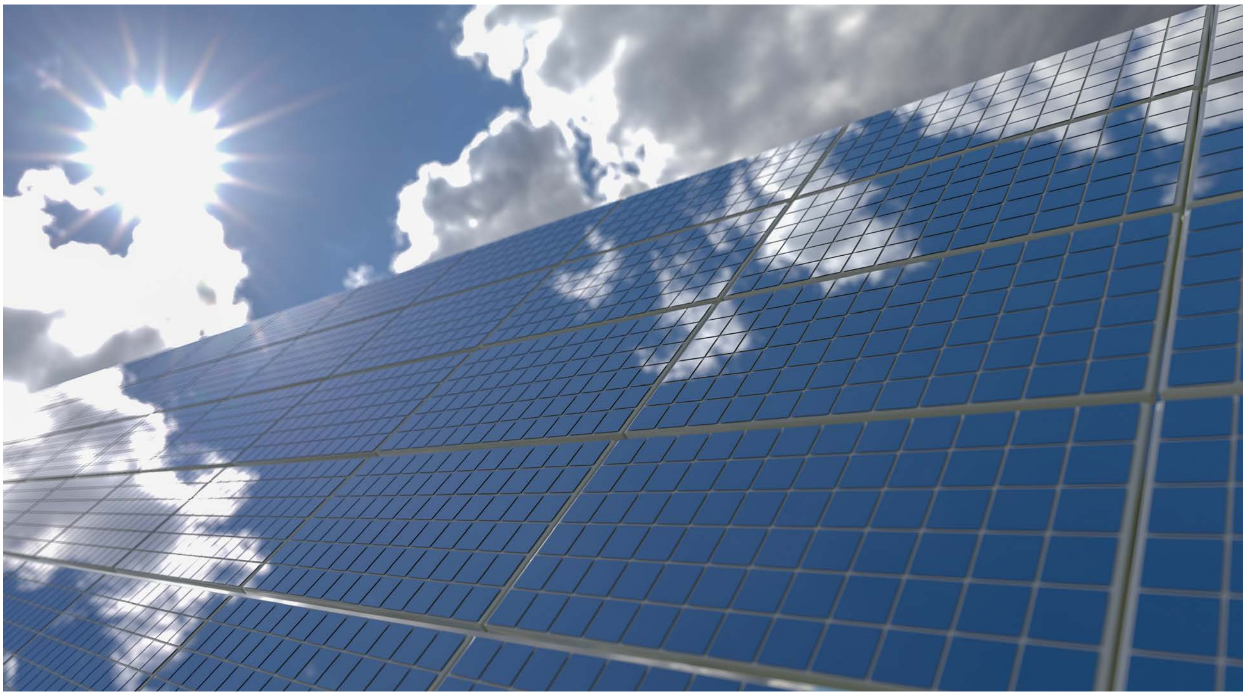


Photo: kwarkot / Shutterstock.com.

Table 16 presents the technical characteristics of the solar thermal system configuration number 11. In this case, the solar field has a total aperture reflective area of 1 312 m^2 which translates into a thermal output of 0.87 MW_{th}; the power capacity of the heat sink is about 0.21 MW_{th}; and the thermal storage capacity is 2.5 MWh_{th} with a storage volume of 77 cubic metres.

Table 16: Technical summary of the selected solar thermal system configuration

ELEMENT	PARAMETER	VALUE
Solar field	Inlet heat transfer fluid temperature (°C)	60
	Outlet heat transfer fluid temperature (°C)	90
	Collector tilt (degrees)	0
	Collector azimuth	0
	Total aperture reflective area (m^2)	1 312
	Pitch (m)	15
	Total land area required (hectare)	0.3
	Actual field thermal output (MW_{th})	0.87
Heat sink	Heat sink power capacity (kW_{th})	209
Thermal energy storage	Hours of storage at design point (hour)	12
	Thermal capacity (MWh_{th})	2.5
	Storage tank volume (m^3)	77

3.3 MITIGATION ANALYSIS

After analysing the technology solution for both electric and thermal systems, as previously defined, it is critical to assess their potential for the abatement potential. This section discusses the methodologies and assumptions that were used to conduct the mitigation analysis, which included determining the potential for greenhouse gas (GHG) reductions associated with each technology solution.

Emission factors of El Salvador

The abatement potential of GHG emissions for the solar PV system is evaluated based on the 2019 grid emission factor for displacement of generation, which was 0.5943 tonnes of carbon dioxide (t CO_2) per MWh. The installation of the chosen solar PV and storage system is taken into account when calculating the amount of emissions avoided in a given year. Additionally, the abatement of GHG emissions for the solar thermal system is evaluated based on the emission factor of LPG. Similarly, the installation of the chosen solar concentrated system is taken into account when calculating the amount of emissions avoided in a given year. The resulting GHG abatement potential is computed based on LPG savings and does not take into account the possible usage of the surplus heat generated by the system.

As regards the methodology, GHG emissions are calculated for the mitigation option by multiplying the emission factor by the respective renewable electricity or thermal production. The emission factors applied are presented in Table 17. Emissions associated with manufacturing, installation, operation and decommissioning of the solar PV and thermal projects have not been considered, and it is therefore assumed that they present zero emissions. The emissions have been calculated on an annual basis based on the estimated abatement potential.

Table 17: Emission factors for each fuel type considered

FUEL	EMISSION FACTOR	SOURCE
Renewable energy generation technologies	0 t CO_2/MWh	Own assumption
Grid emission factor– El Salvador	0.5943 t CO_2/MWh	CNE[4]
LPG	6.1 kilograms of CO_2/gallon	IPCC, 2006

4 El Salvador's National Energy Council provided the data.

4. FINDINGS

This chapter summarises the key findings from the modelling of each technology solution. The findings and conclusions are detailed, with key figures and charts demonstrating how Los Quesos de Oriente, as a demonstration technology system, can help the energy sector meet ambitious renewable energy generation targets by 2030.

The first two sections discuss the energy yield assessment for electrical and thermal solutions, as well as the economic analysis for both. The potential for GHG reductions associated with the various mitigation strategies are presented. Following that, a third section will examine the combined mitigation potentials of the solutions.

4.1 ENERGY YIELD ASSESSMENT

This section includes the results of the energy yield assessment of the solar PV and thermal systems.

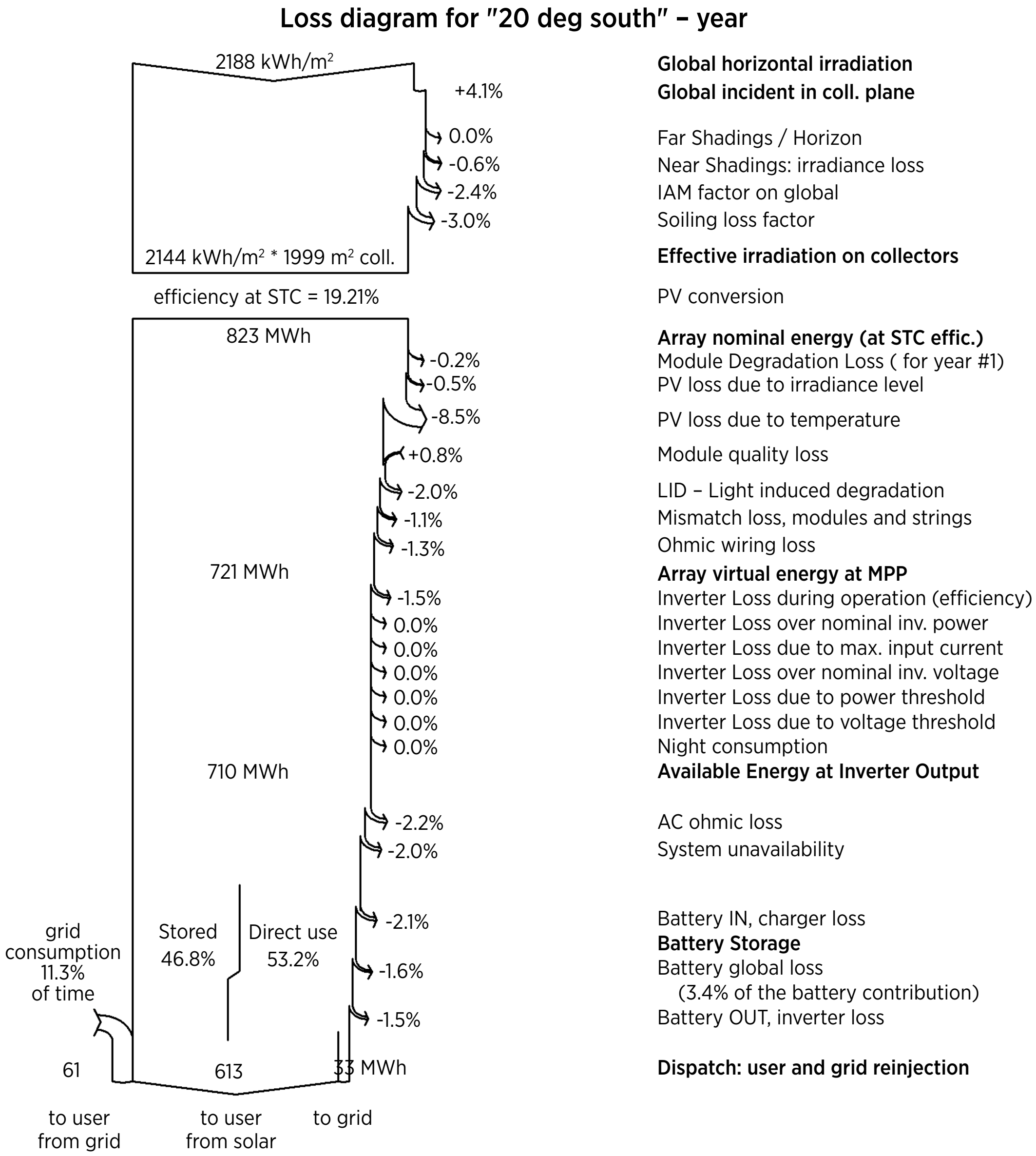
Solar PV system

Figure 34 shows the resulting Sankey diagram for the selected configuration for the first year of operation. The Sankey diagram shows the losses and gains in the system. Gains are associated with the increase in irradiance due to the solar photovoltaic (PV) module tilt compared with the global horizontal irradiance, as well as to the module quality loss. The quality loss is defined by the solar PV module tolerance, which in this case is between 0 and +3%, and PVsyst considers a quarter of this value, that is +0.75%. Many factors lead to losses in the PV system, including near and far shadings, soiling, temperature of modules, module degradation, wiring losses, and inverter and battery operation associated losses.

The results show that 613 megawatt hours electrical (MWh_e) of the electricity generated by the PV system in a year will be used to cover the electricity demand of the facility. Of these 613 MWh_e, 287 MWh_e are stored in the battery storage and used, and 326 MWh_e are fed directly to cover the demand of the facility. The facility must import 61 MWh_e from the grid, and exports to the grid (or has a generation surplus of) a total of 33 MWh_e.

Photo: Thinnapob Proongsak / Shutterstock.com

Figure 34: Sankey diagram for the solar PV and storage system



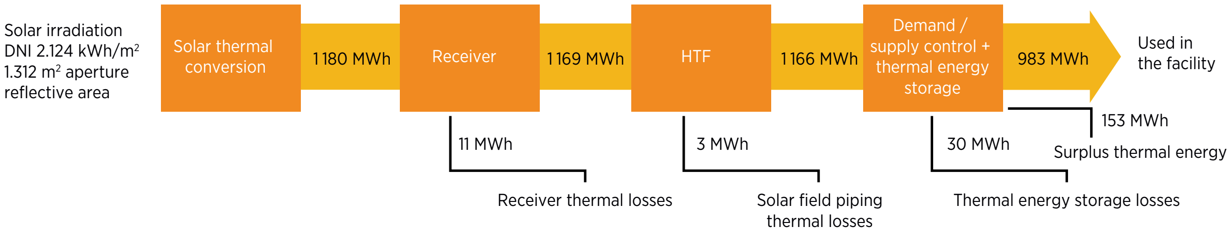
Notes: kWh = kilowatt hours; m² = square metre; STC = standard test conditions; MWh = megawatt hours; AC = alternating current; IAM = incidence angle modifier; MPP = maximum power point; coll. Plane = collector plane.

Solar thermal system

The energy yield assessment of the solar thermal system configuration number 11 with 207 kilowatts thermal of heat sink and 2.5 megawatt hours thermal (MWh_{th}) of storage capacity reveals a total annual thermal output of 1 137 MWh_{th}. Note: DNI = direct normal irradiance; HTF = heat transfer fluid.

Figure 35 presents the Sankey diagram corresponding to the first year of operation of the concentrated solar thermal system. The thermal output of the selected concentrated solar thermal configuration leads to 983 MWh_{th} in savings to the facility, covering almost 89% of the total annual heat demand. This solar thermal configuration yields a thermal energy surplus of 153 MWh_{th} per year, which is about 13.9% of the facility's heat demand. This excessive heat could be used for preheating processes within the facility or, if technically feasible, to feed a nearby heat demand.

Figure 35: Sankey diagram for the solar thermal system



Note: DNI = direct normal irradiance; HTF = heat transfer fluid.

The operation of the solar thermal system has an associated electricity consumption (i.e. balance of plant and auxiliaries), which in this case is estimated to be about 6.3 kilowatt hours electrical (kWh_e) per MWh_t, totalling an annual electricity consumption of 7 105 kWh_e. This additional electricity consumption is assumed to be supplied by the grid.

4.2 ECONOMIC ANALYSIS

This section presents the results from the economic analysis performed for the solar PV and thermal systems.

Solar PV system

Table 18 presents the data used to carry out the economic analysis, which is built on a number of cost assumptions and solar module degradation (typically around 0.4%), which are in line with the technical characteristics of the designed and selected solar PV system configuration number 5. The results from the energy yield assessment included in Chapter 4.1 also feed the economic analysis.

Table 18: Summary of data employed in the economic analysis of the solar PV system

ELEMENT	PARAMETER	VALUE	REFERENCE
CAPEX	Solar PV (USD/kWp)	850	CNE, Datos Quesos de Oriente
	Battery storage (USD/kWh_e)	313	Cole and Frazier, 2019
OPEX	Solar PV + battery storage (% of CAPEX)	2	Own assumption
Solar module degradation	Annual degradation (%)	0.4	Own assumption
Electricity	Exported to grid in year 1 (MWh_e)	33	Results from model
	Electricity saved in year 1 (MWh_e)	613	Results from model
	Cost of electricity (USD/MWh_e)	144	CNE, Datos Quesos de Oriente
	Annual increase of cost of electricity (%)	2.5	Own assumption
	Electricity sale price PEt (USD/MWh_e)	107	CNE, Datos Quesos de Oriente
Other	Inflation (%)	1	Own assumption

Notes: CAPEX = capital expenditure; OPEX = operational expenditure; PEt = Price of Energy to be Transferred to Tariff (Precio de la Energía a Trasladar a Tarifa); CNE = National Energy Council (Consejo Nacional de Energía); kWp = kilowatt peak.

Figure 36 shows the annual variation in accumulated cash flow for the solar PV system configuration 5 during a period of 30 years. It is possible to observe that positive accumulated cash flow is not reached until year 12, resulting in a 12-year payback period for the solar PV system configuration number 5.

The selected configuration number 5 focuses on the minimisation of grid imports and self-sufficiency of the dairy facility. Nevertheless, another variable to consider in the assessment is the payback of the solar PV system. For that, an additional analysis is performed based on configuration numbers 4 and 5.

The possibility to export to the grid the excess electricity generated based on the "renewable producer user" (Usuario Productor Renovable [UPR]) legislation approved in 2017 (SIGET, 2017) has been assessed. UPR provides a compensation, referred to as PEt, to those renewable energy facilities with or without energy storage for the electricity they export to the grid. Those renewable energy facilities with energy storage have to comply with the following conditions:

- There is no limit on the power rated capacity of the renewable energy system in relation to the peak demand of the facility they deliver the electricity to.
- The monthly averaged electricity produced by the generating unit has to be lower than 90% of the average electricity consumption of the facility the deliver the electricity to.

For configuration number 5, the monthly averaged electricity generated, about 60 MWh, exceeds the 90% of the monthly averaged consumption, about 50 MWh, of the dairy facility and thus, according to UPR regulation, this configuration cannot get rewarded from the electricity fed to the grid.

Nevertheless, configuration number 4 monthly averaged electricity generation is estimated to be around 48 MWh, which complies with the UPR legislation (i.e. <90% monthly averaged consumption) to be rewarded with the PEt for the exported electricity. In this context, six additional solar PV system configurations based on numbers 4 and 5 were analysed. In this additional analysis of PV systems, the rated power capacity of the solar PV is kept unchanged and different sizes of the battery storage are defined.

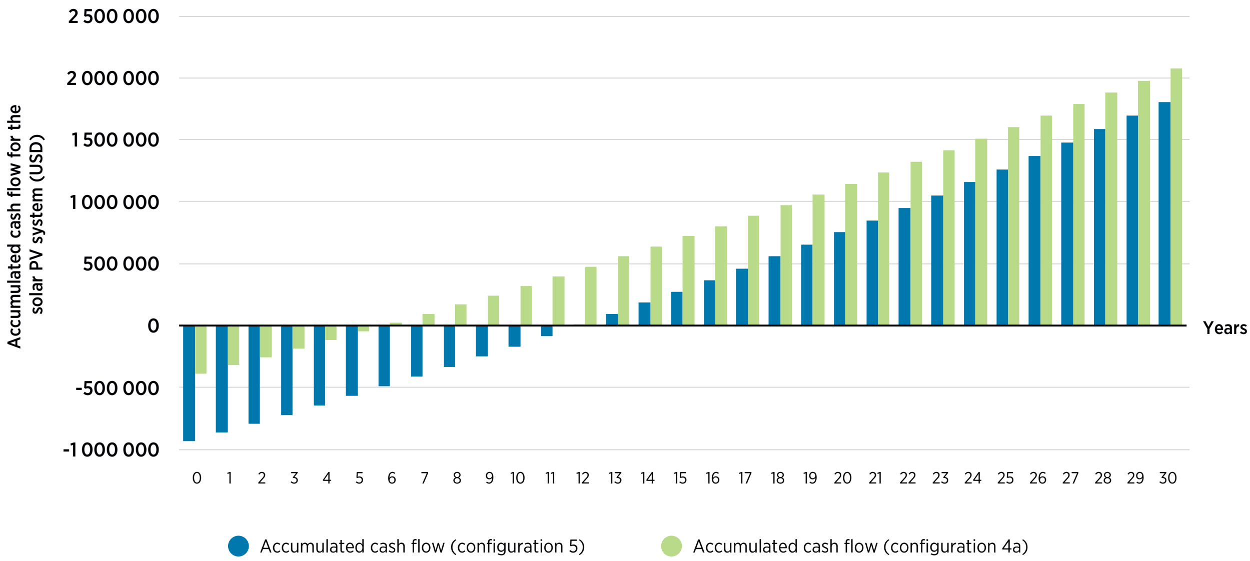
Table 19 lists the additional six solar PV system design configurations modelled, together with the associated technical and economic resulting parameters, such as electricity generation and payback period. As a result, a minimum payback period of six years is achieved for configuration 4a, while configuration 5c yields the longest payback. Figure 36 illustrates the economic results for configuration 4a in comparison with the first modelled solution, configuration 5. Based on the overall results, it can be observed that a reward system for the electricity fed into the grid has a positive impact on the economical results of the solar PV system.

For these additional configurations, further reductions of the battery energy storage solutions (BESS) system results in increased electricity exports to the grid but also increased electricity imports from the grid. Because the increased electricity imports are more expensive than the potential revenue from PEt surplus payments, further reductions in storage capacity must be carefully considered and may not result in an economically viable approach.

Table 19: Solar PV rated capacity and battery storage for the additional six solar PV system configurations assessed, and computed annual parameters

SYSTEM CONFIGURATION NUMBER	SOLAR PV RATED CAPACITY (kWp)	BATTERY STORAGE 80% DOD (kWh_e)	ELECTRICITY CONSUMPTION FROM GRID (MWh_e)	SOLAR PV ELECTRICITY STORED & USED (MWh_e)	SOLAR PV ELECTRICITY DIRECTLY USED (MWh_e)	ELECTRICITY EXPORTED TO GRID (MWh_e)	PAYBACK (YEARS)
4a	308	308	249	92	334	109	6
4b	308	616	180	177	317	31	8
4c	308	924	153	217	304	0	9
5a	385	385	214	99	362	206	8
5b	385	770	100	231	344	78	9
5c	385	1 155	63	284	327	36	10

Figure 36: Accumulated cash flow in the first 30 years of operation for the solar PV system configurations number 5 and 4a



Solar thermal system

The assumptions employed to perform the economic analysis of the solar thermal system are presented in Table 20. The data assumptions include the CAPEX of the three different elements of the solar thermal system: i) the solar field; this includes the cost of solar collectors (mirrors and receivers), foundation and support structures, electrical and installation labour; ii) the heat transfer fluid system; this covers the ullage system, pumps, expansion systems, piping and insulation, required foundation and support structures, and fluid; and iii) the thermal storage, which covers the components related to the storage component. Table 20 also includes assumptions considered in the assessment of the savings associated with the reduction in liquefied petroleum gas (LPG) consumption computed based on the outcome of the energy yield assessment in Chapter 4.1.

Table 20: Summary of data used in the economic analysis of the solar thermal system

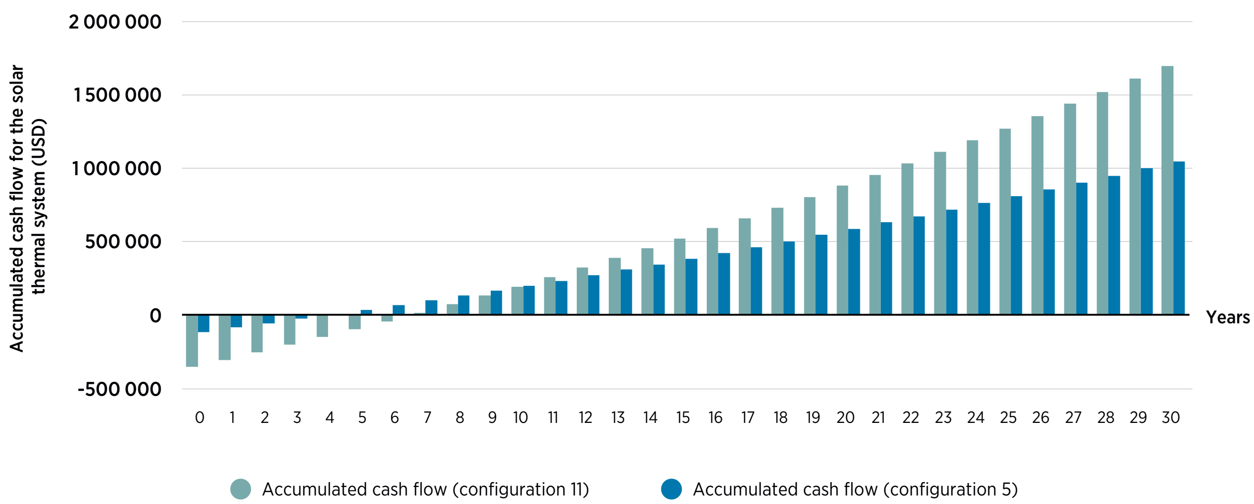
ELEMENT	PARAMETER	VALUE	REFERENCE
CAPEX	Solar field (USD/m^2)	97.49	AEE INTEC, 2021
	Thermal storage (USD/kWh$_{th}$)	75	Kurup and Turchi, 2015
	Site preparation (USD/m^2)	30	Kurup and Turchi, 2015
OPEX	Solar field + heat transfer fluid + thermal storage (% of CAPEX)	2.2	Dieckmann et al., 2017

Table 20: Summary of data used in the economic analysis of the solar thermal system *(continued)*

ELEMENT	PARAMETER	VALUE	REFERENCE
LPG	Efficiency boiler (%)	85	Own assumption
	Thermal energy delivered annually (MWh_{th})	983	Results from model
	Primary energy saved annually (MWh)	1 156	Results from model
	LPG saved annually (gallons)	38 892	Results from model
	Cost (USD/gallon)	1.46	CNE[5]
	Annual increase of cost of LPG (%)	2.5	Own assumption
Other	Inflation (%)	1	Own assumption

In terms of the payback period for the solar thermal system, Figure 37 presents the accumulated cash flow in the first 30 years of operation of the analysed configuration number 11. The results reveal that the payback period is estimated to be seven years, when the first positive accumulated cash flow is observed.

Figure 37: Accumulated cash flow in the first 30 years of operation for the solar thermal system configurations number 11 and 5



5 El Salvador's National Energy Council provided the data.

Photo: Henryk Sadura / Shutterstock.com.

The outputs of the modelling analysis indicate that configuration 11 may be slightly oversized for the facility's needs in 2020, as it generates an excess of heat equal to around 10% of total heat demand. Economic parameters will improve, and the payback period will almost certainly be reduced, if surplus heat is used, for example, by increasing the size of facilities. To evaluate the possibility of improving economic results, a smaller solar thermal design was evaluated. Solar thermal configuration number 5 was chosen because it meets approximately 48% of total heat demand and generates surpluses of approximately 3% of total heat required. In this case, and under the same cost assumptions as in Table 20, Figure 37 also illustrates the findings for configuration 5, which depicts that the concentrated solar thermal system has a four-year payback period.

Nonetheless, according to the information provided by Los Quesos de Oriente, the facility's heat demand has nearly doubled since the beginning of 2021, indicating that the facility is requiring more heat to keep up with increased production. As a result, solar thermal configuration number 11 would produce no heat surplus, and a different configuration would be more appropriate to assess once data on the facility's new heat demand profile are available.

4.3 MITIGATION ANALYSIS

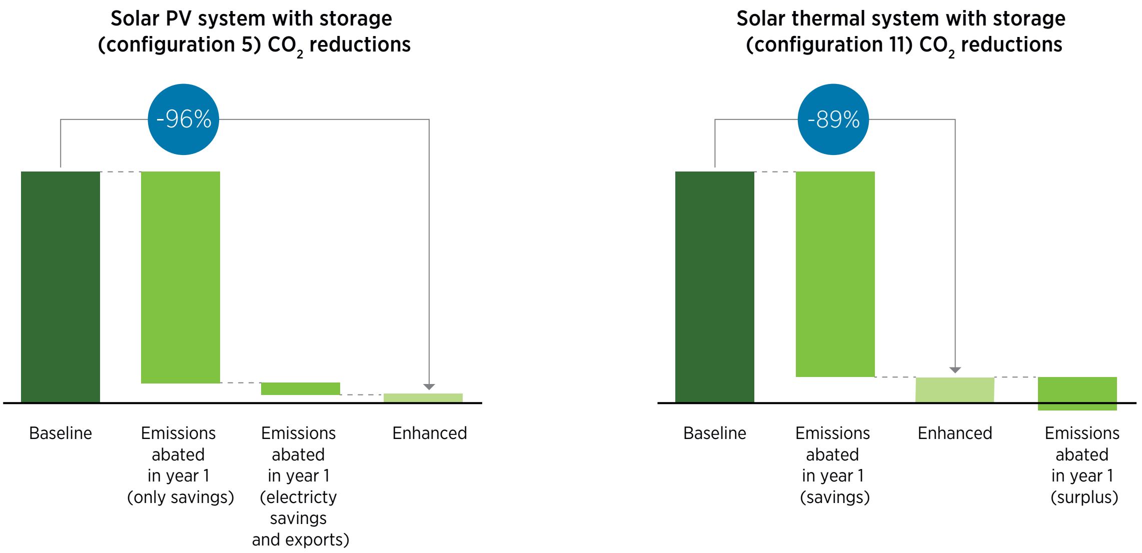
The abatement of GHG emissions for the solar PV system is evaluated based on the 2019 emission factor for displacement of generation, which was 0.5943 tonnes of carbon dioxide (t CO_2) per MWh. Table 21 shows the resulting annual GHG emissions abatement for the system configuration number 5 and additional configurations listed in Table 19. The emissions abated shown in Table 21 are computed based only on the grid electricity consumption savings and also considering exports to the grid.

Table 21: Annual GHG emissions abatement for the first year of operation of the solar PV system configurations analysed

PARAMETER	UNIT	5	4A	4B	4C	5A	5B	5C
Annual GHG emissions abated – based on the grid electricity consumption savings	t CO_2/year	364	253	294	310	274	342	363
Total annual GHG emissions abated – consumption savings + grid exports	t CO_2/year	388	313	313	313	388	388	388

For the concentrated solar thermal system, based on a GHG emission factor for the LPG of 6.1 kilograms per gallon, the configuration number 11 yields a GHG abatement potential of 237 t CO_2/year in the first year of operation. This GHG abatement potential is computed based on LPG savings and does not take into account the possible usage of the surplus of heat generated by the system. In addition, as a comparison, the system configuration number 5 yields a GHG abatement potential of 127 t CO_2/year. Figure 38 illustrates the percentages of annual GHG emissions avoided for the facility Quesos de Oriente's solar technology solutions in their first year of operation.

Figure 38: Annual GHG emissions abatement for the first year of operation of solar PV and thermal solutions (%)



5. SCALABILITY ANALYSIS

This chapter examines the scalability of the Quesos de Oriente case study, which was presented in Chapter 3.3 for both solar photovoltaic (PV) and solar thermal technology solutions, across the entire dairy industry in El Salvador. Two primary parameters are evaluated during the scale-up analysis: the spatial variability of the solar resource across the various dairy facilities and the spatial characteristics surrounding the facilities, such as the type of area (urban, semi-urban, or rural) and the potential free land area available within a 500-metre radius of the facilities.

5.1 SOLAR PV GENERATION

For the scale-up analysis of the electric system solution, the first step is to assess the degree of spatial variability of the solar resource in El Salvador. Table 22 presents the deviation with respect to the average forecast output of a solar PV system and average direct normal irradiance (DNI) and global horizontal irradiance (GHI) of the nine different regions in El Salvador (World Bank, 2021). The results show that in terms of solar resource there is a high degree of uniformity across the territory. Consequently, the scalability assessment considers two solar resource regions: one defined by the solar conditions at San Julian and a second one represented by the solar resource of San Salvador.

Table 22: Deviation from the average forecast PV output per kilowatt peak and square metre (m^2) as well as average DNI and GHI for the nine regions of El Salvador

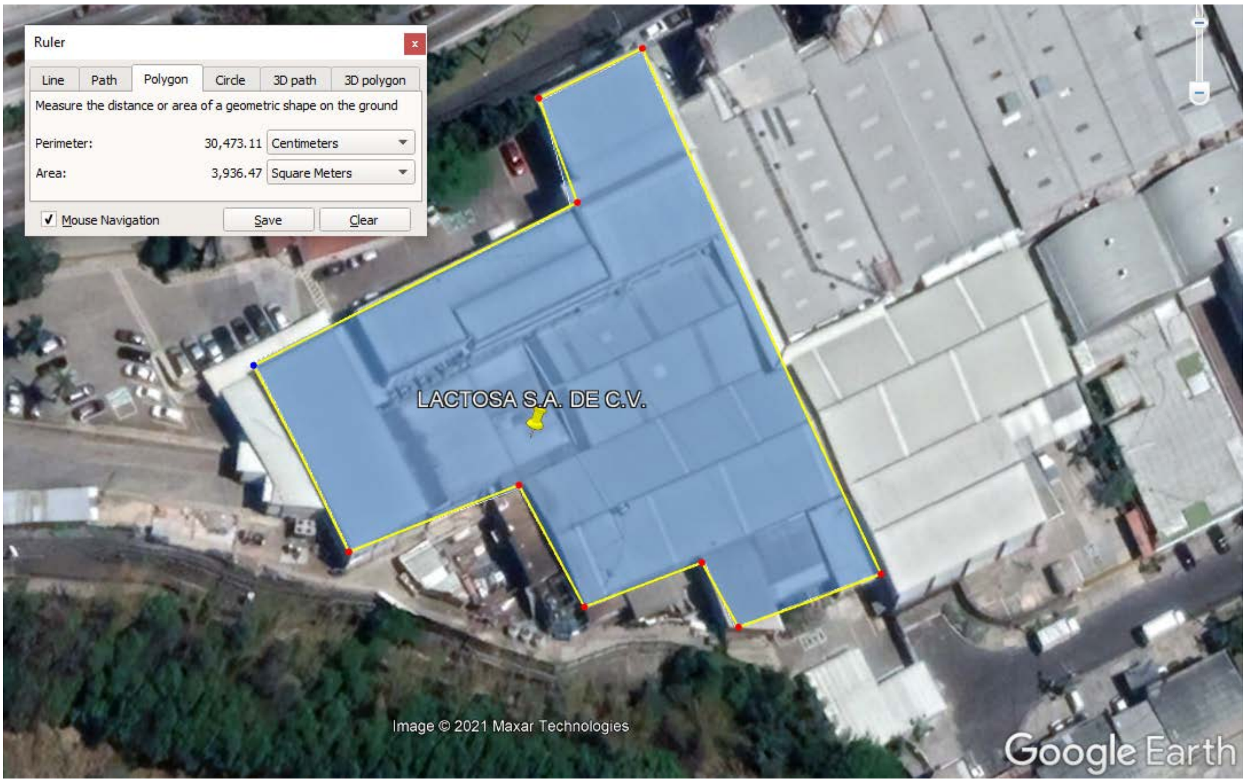
REGION	PV OUTPUT PER kWp (%)	PV OUTPUT PER m^2 (%)	DNI (%)	GHI (%)
Apopa	2.4	4.7	4.7	4.7
Guazapa	2.4	4.7	4.7	5.0
San Francisco Gotera	1.9	5.6	5.7	5.5
San Julian	-5.2	-9.5	-9.8	-3.2
San Salvador	0.5	1.1	1.1	-16.7
Santa Ana	2.5	3.5	3.4	4.0
Santa Lucia and Lourdes	-0.3	-0.7	-0.7	1.8
Sonzacate	-3.0	-6.2	-6.1	-1.4
Zacatzcoluca	-1.0	-3.1	-3.1	0.4

The second step is to identify the dairy facilities, their electricity demand and location characteristics. In the Appendix, Table 33 lists in detail the different dairy facilities, and includes their location characteristics, such as the department where these are located, the type of area (urban, semi-urban or rural), the estimated space (i.e. rooftop) area available, and the land availability in the surrounding of the facility. This table and the present scale-up analysis do not consider the dairy facility Los Quesos de Oriente, as this was assessed in detail in Chapter 4. 3.

The identified rooftop area should be considered as a first approximation, which can be easily better defined once the areas available are accurately identified. Priority has been given to the location data sourced from datasets from the National Energy Council (CNE – Consejo Nacional de Energía). Nevertheless, in some cases where the electricity consumption order of magnitude of the facility was not matched by the identified building size, alternative location data have been considered. In the Appendix section, Table 34 illustrates the source used to identify the location of each facility. Additionally, the type of area and availability of land in the vicinities of the facilities have been identified to understand the possibility of using additional space for the solar PV system in case the rooftop area available is not sufficient.

The identified rooftop area illustrated for each facility was analysed using Google Earth. Figure 39 depicts the characteristics for the facility Lactosa S.A. de C.V. The same approach was utilised for the estimations of all available space areas. It is to be noted that these shall be considered as a first approximation.

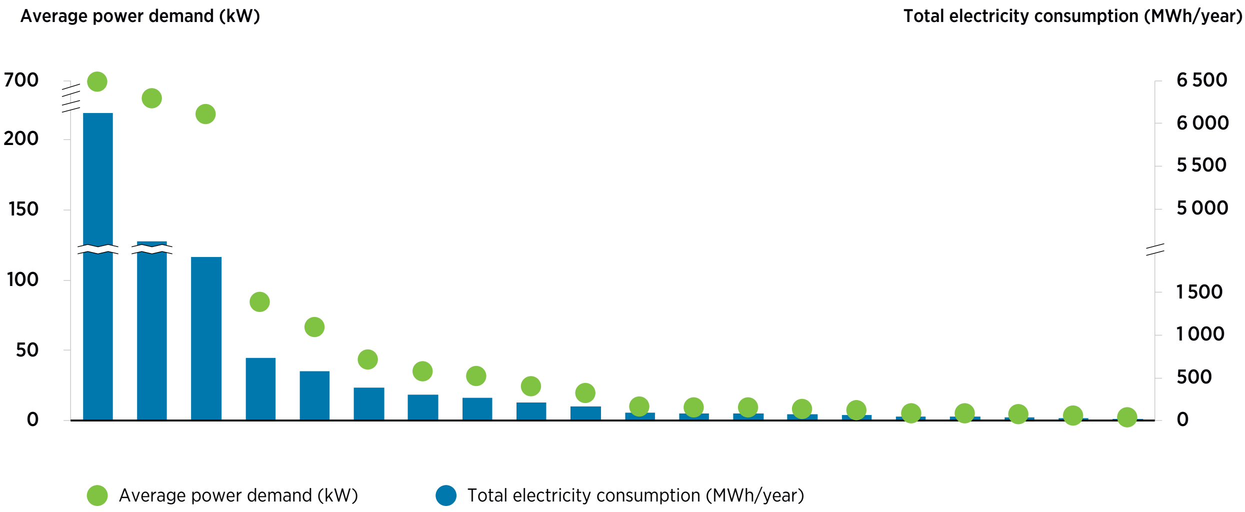
Figure 39: Identified rooftop for Lactosa S.A. (m²)



The aim of the present scale-up analysis is to minimise the GHG emissions of the dairy facilities associated with their electricity consumption. The hourly electricity consumption profile for each dairy facility is assumed to follow that of Los Quesos de Oriente, with the magnitude adjusted according to their respective annual electricity consumption data.

In the Appendix section, Table 34 lists the solar resource region associated to each dairy facility and characterises their respective power and electricity demand. Figure 40 depicts their main characteristics and shows that three facilities are the ones dominating the electricity demand of the subsector, namely Cooperativa Ganadera de Sonsonate de R.L., Lacteos del Corral, S.A. de C.V. (Lactosa) and S.A. de C.V. Agrosania.

Figure 40: Power and electricity demand characterisation for each dairy facility



Notes: kW = kilowatt; MWh = megawatt hour.

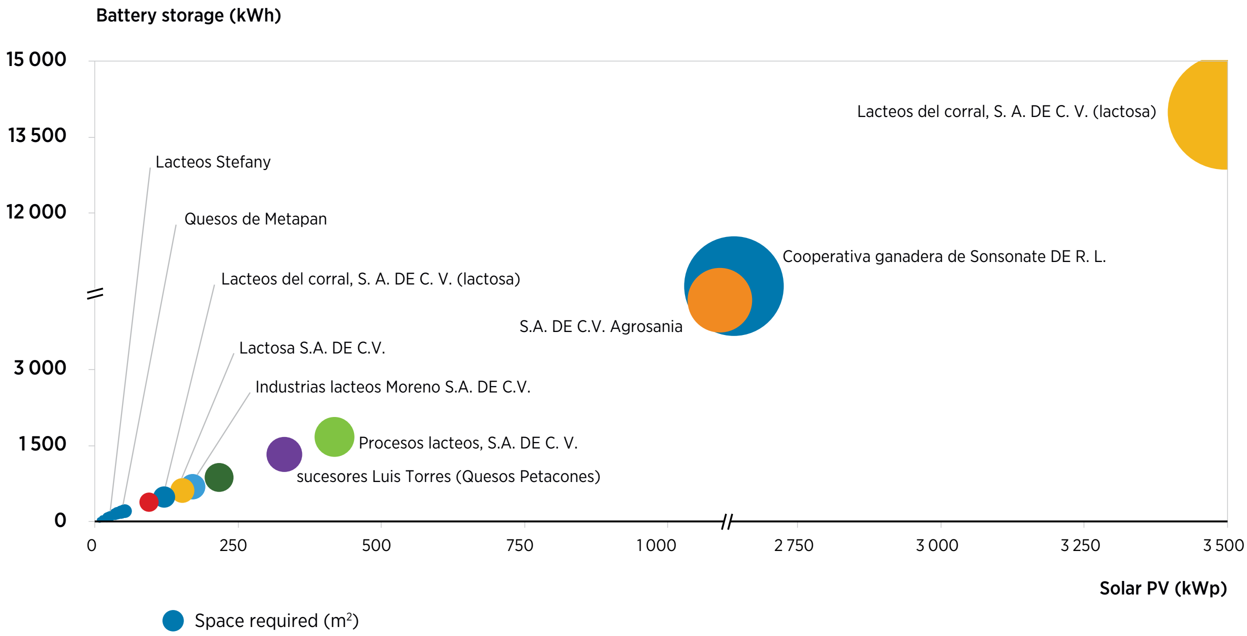
The availability of space for the solar PV system at the dairy facilities defines two separate scenarios.

- The first scenario assesses a case in which the space availability is not a constraint. Therefore, the solar PV system of the dairy facility is designed based on the parameters from configuration number 5 (see Table 6) . In this case, the system reduces grid imports to a minimum while still exporting surplus electricity to the grid.
- The second scenario assesses a case in which space availability is restricted to that identified in Table 33. In this case, if the space availability and electricity demand constraints are taken into account, the installed capacity of the solar PV is capped by the space available, and generation cannot cover completely the demand of the facility. Therefore, all the electricity generated by the solar PV is accounted as self-consumed, and the demand that is not covered is supplied by the grid. The battery storage capacity is not determined as it depends on the short-term interactions between electricity demand and generation.

As a result, Figure 41 depicts the corresponding design of the solar PV system and storage for the scenario without space availability restrictions. Besides, in the Appendix section Table 35 and Table 36 list the design of the solar PV system for the scenarios without and with space availability restrictions as well as their annual computed electricity generation, consumption from grid, self-consumption and exports to the grid. Finally, Table 23 and Table 24 summarise for the scenarios without and with space availability constraints respectively the combined installed solar PV capacity and accumulated electricity generation, grid consumption, self-consumption and exports to the grid for the whole dairy sector. The calculated GHG abatement potential is also shown, which is based on grid electricity consumption savings and green electricity fed to the grid.

The results show that when the space availability is considered in the assessment, the total installed solar PV capacity and the associated GHG abatement potential reduces significantly, where for the GHG this is up to a fourth of the resulting potential under no space constraints. However, it should be considered that the space availability analysis was developed during preliminary desk research.

Figure 41: Dairy facilities' design of the solar PV system and storage for the scenario without space availability restrictions



Note: kWh = kilowatt hour.

Table 23: Overview of technical electrical scale-up outputs and associated GHG emissions abated for the scenario with no space availability constraints

TECHNICAL PARAMETER	RESULTS
Total solar PV installed capacity (kWp)	9 047
Total battery storage capacity (80% depth of discharge [DoD]) (kWh)	36 190
Total space required for solar PV (hectares)	13
Total electricity consumption (MWh/year)	15 851
Total estimated generation solar PV (MWh/year)	15 227
Total electricity consumed from grid (MWh/year)	1 457
Total solar PV electricity self-consumed (MWh/year)	14 458
Total solar PV electricity exported to grid (MWh/year)	768
GHG emissions abated (tonnes of carbon dioxide [t CO_2] per year)	8 593

Table 24: Overview of technical electrical scale-up outputs and associated GHG emissions abated for the scenario with space availability constraints

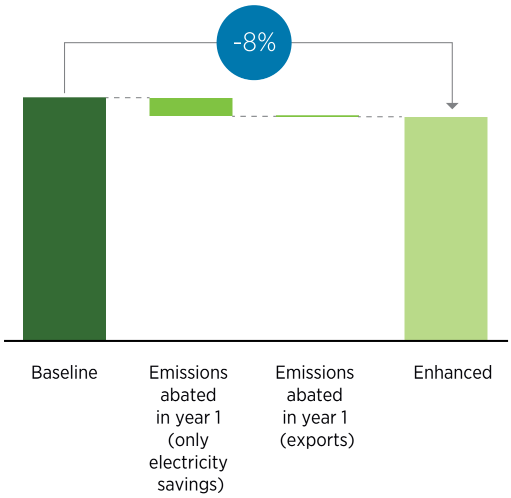
TECHNICAL PARAMETER	RESULTS
Total solar PV installed capacity (kWp)	2 058
Total battery storage capacity (80% DoD) (kWh)	1 923
Total space required for solar PV (hectares)	3
Total electricity consumption (MWh/year)	15 851
Total estimated generation solar PV (MWh/year)	3 467
Total electricity consumed from grid (MWh/year)	12 462
Total solar PV electricity self-consumed (MWh/year)	3 424
Total solar PV electricity exported to grid (MWh/year)	43
Annual GHG emissions abated (t CO_2/year)	2 035

The current study examined the spatial distribution of solar resources in El Salvador and concluded that the available resource is relatively uniform throughout the country. A second stage identifies the available space in dairy facilities for solar PV systems. This was followed by the characterisation of each dairy facility's electricity consumption profile, which was necessary for designing the solar PV systems.

The exercise considered two scenarios: one in which there were no space constraints at the dairy facilities and another in which there were space constraints at the dairy facilities. Without regard for space constraints, the total installed solar PV capacity exceeds 9 megawatt peak (MWp), with an associated annual GHG emissions reduction potential of 8 593 t CO_2 for self-consumption alone, and 9 049 t CO_2 for self-consumption plus grid exports. Due to the uncertainty associated with space availability constraints, the total installed solar PV capacity is reduced to around 2 MWp and the associated annual GHG emissions potential is reduced to 2 035 t CO_2 for self-consumption only, and to 2 060 t CO_2 for self-consumption and exports.

On a national scale, the food and beverage industry consumed 192 711 MWh of energy in 2020, which equals 114 528.3 t CO_2 (694 terajoules [TJ]) when the country's grid emission factor is used (CNE, 2020). Additionally, it is known that the dairy industry consumed 15 851 MWh of energy in 2020, out of the total sector consumption. In this line, Figure 42 shows that the upper bound of the scale-up analysis results indicate that widespread adoption of solar PV in the dairy sector could result in a 7.9% reduction in GHG emissions associated with the electricity consumption of the entire food, beverage and tobacco manufacturing subsector. This portion of emissions reductions is accounted for by the dairy sector's self-consumption of renewable energy as well as its exports to the grid.

Figure 42: Scale-up outcomes: GHG reduction potential in the food and beverage industry sector



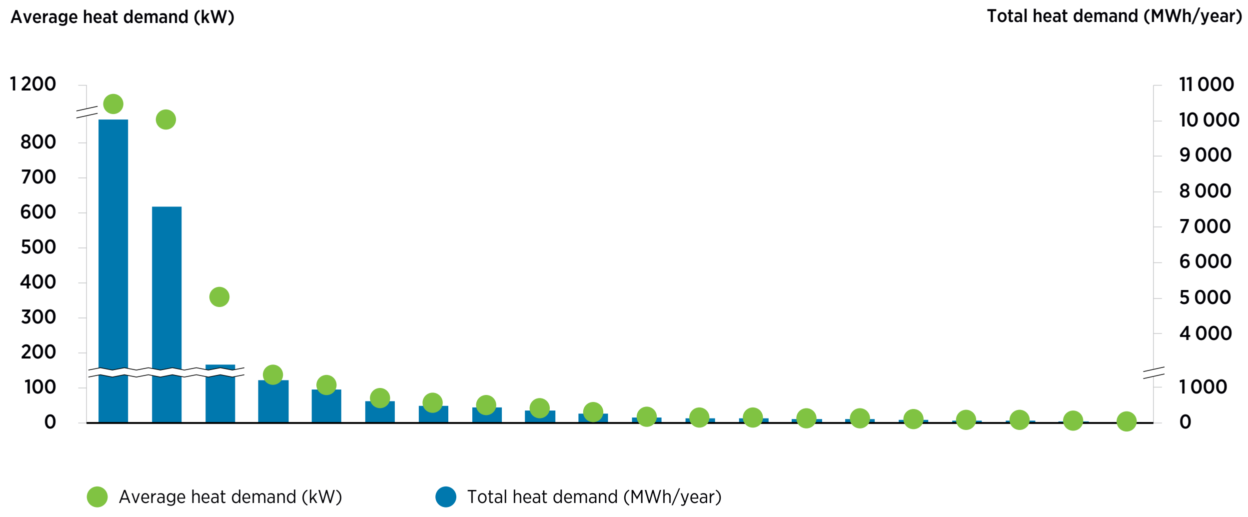
5.2 SOLAR THERMAL GENERATION

The concentrated solar thermal solution's scale-up analysis follows a similar methodology to the solar PV solution's scale-up analysis. The analysis looks at the extent of spatial variability in El Salvador's solar resource as well as the solar resource itself. As illustrated in Table 22, the deviation from the average forecast output of a solar system, as well as the average DNI and GHI of El Salvador's nine distinct regions, demonstrates a high degree of uniformity across the territory. As a result, the scalability analysis takes into account two distinct solar resource regions: one defined by the solar conditions at San Julian and another by the solar resource at San Salvador.

The location of dairy facilities, their type, estimated available space area and land availability in the immediate vicinity of the facility are shown in Table 34. According to the scalability analysis, the available space can be used entirely for concentrated solar thermal systems. Due to the fact that the applicability of concentrated solar thermal to Los Quesos de Oriente was discussed in Chapter 4.3, the results from Los Quesos de Oriente are not included in the current solar thermal scale-up analysis.

As with the solar PV scalability analysis, the goal of the concentrated solar thermal scale-up analysis is to reduce the GHG emissions associated with the dairy facilities' heat demand. Due to the lack of data on each facility's specific heat demand at the time of the analysis, it is assumed that their annual heat demand requirements correlate with their electricity consumption in the same way as they do for Los Quesos de Oriente. Similarly, their heat hourly demand profile is assumed to follow the trend described for Los Quesos de Oriente. Figure 43 illustrates the annual total heat demand and average heat demand for each dairy facility. Table 37 in the Appendix section details the solar resource region associated with each dairy facility and its associated heat demand.

Figure 43: Heat demand characterisation for each dairy facility



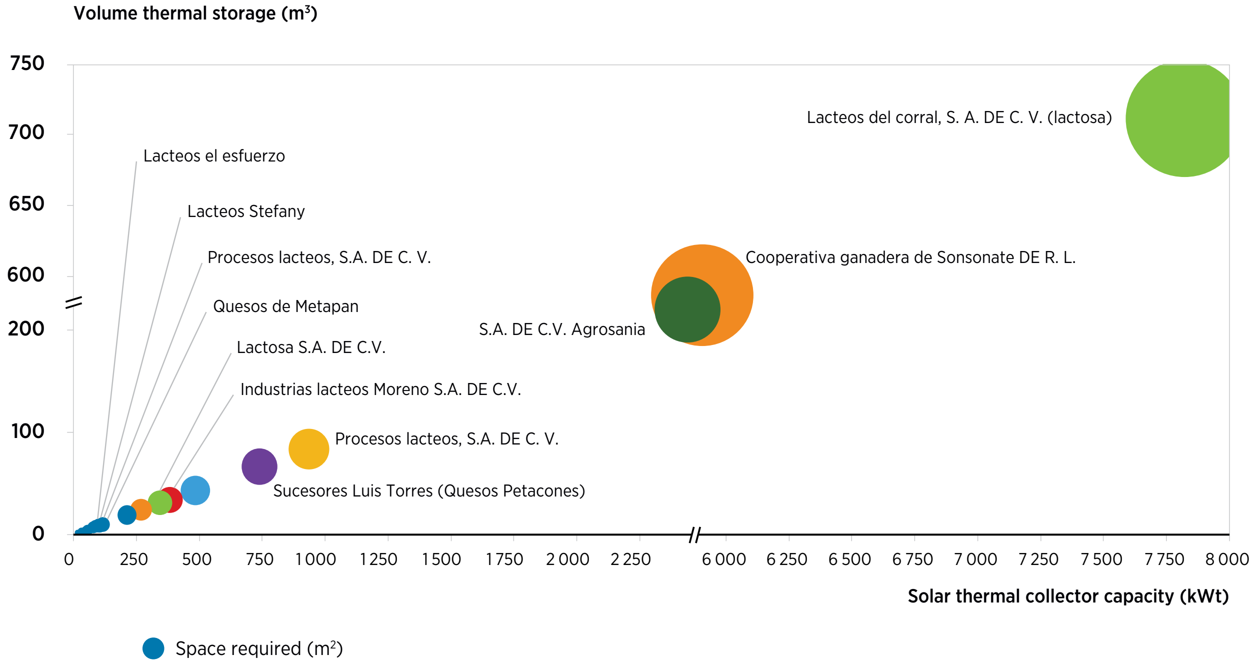
The availability of space at the dairy facilities for the concentrated solar thermal system defines two distinct scenarios.

The first scenario illustrates a situation in which space is not a constraint. As a result, the dairy facility's solar thermal system is designed using the parameters from configuration number 11 (see Table 16). In this case, the system's configuration results in significant thermal energy savings while producing very little heat surplus.

The second scenario illustrates a situation in which available space is limited to the areas listed in Table 34. In this case, the size of the concentrated solar thermal system is limited by available space, and the heat generated does not entirely meet the facility's demand. In this case, it is assumed that all of the heat generated by the concentrated solar thermal system results in thermal energy savings. The liquefied petroleum gas (LPG) boiler supplies the heat demand that is not met by the concentrated solar thermal system. The thermal storage capacity is not specified because it is determined dynamically by the interactions between generation and demand.

As a result, Figure 44 illustrates the concentrated solar thermal system design for each facility in terms of thermal storage volume and solar thermal collector capacity, as well as the space requirements indicated by the size of each bubble. Additionally, in the Appendix section, Table 38 and Table 39 detail the corresponding solar thermal concentrated systems design for each dairy facility in the absence and presence of space constraints, respectively. Additionally, the tables include annual thermal energy generation, thermal energy savings, thermal energy surplus, and thermal energy supplied by the LPG boiler.

Figure 44: Dairy facilities' design of the solar thermal system and storage for the scenario without space availability restrictions



Notes: m³ = cubic metre; kW_{th} = kilowatt thermal.

Finally, Table 25 and Table 26 summarise the results of the solar thermal scalability assessment for scenarios with and without constraints on available space. The tables detail the total heat sink and solar thermal collector capacities, as well as the associated total aperture reflective area, total volume storage capacity, and required space for the solar thermal collector field. Additionally, the solar thermal heat generated is listed, as are the associated savings and surplus, as well as the thermal energy to be supplied by the LPG boiler. In terms of mitigation potential, the tables include the GHG abatement potential associated with energy savings and surpluses based on a baseline scenario in which thermal energy needs are met by an LPG boiler. According to the results of the solar PV scalability analysis, when space availability is considered, the total installed concentrated solar thermal capacity and associated GHG abatement could potentially be reduced to slightly more than a third of the figures obtained under the scenario with no space availability constraints. It should be noted that the available space was analysed using only desk tools and that a more detailed assessment should be conducted.

Table 25: Overview of technical thermal scale-up outputs and associated GHG emissions abated for the scenario without space availability constraints

TECHNICAL PARAMETER	VALUE
Total heat sink power capacity (kW_{th})	4 901
Total solar thermal collector capacity (kW_{th})	20 242
Total aperture reflective area (m^2)	30 767
Total volume thermal storage (kWh_{th})	58 814

Table 25: Overview of technical thermal scale-up outputs and associated GHG emissions abated for the scenario without space availability constraints *(continued)*

TECHNICAL PARAMETER	VALUE
Total volume thermal storage (m^3)	1 806
Total space required solar thermal collector field (m^2)	70 352
Total thermal energy generated (MWh_{th}/year)	26 312
Total thermal energy savings (MWh_{th}/year)	22 812
Total thermal energy surplus (MWh_{th}/year)	3 500
Total thermal energy supplied by LPG boiler (MWh_{th}/year)	3 155
Annual GHG emissions abated, only thermal energy savings (t CO_2/year)	5 605
Annual GHG emissions abated, only thermal energy savings + thermal energy surplus (t CO_2/year)	6 465

Note: MWh_{th} = megawatt hour thermal.

Table 26: Overview of technical thermal scale-up outputs and associated GHG emissions abated for the scenario with space availability constraints

TECHNICAL PARAMETER	VALUE
Total heat sink power capacity (kW_{th})	1 780
Total solar thermal collector capacity (kW_{th})	7 349
Total aperture reflective area (m^2)	11 171
Total volume thermal storage (kWh_{th})	8 088
Total volume thermal storage (m^3)	248
Total space required solar thermal collector field (m^2)	25 543
Total thermal energy generated (MWh_{th}/year)	9 599
Total thermal energy savings (MWh_{th}/year)	9 113
Total thermal energy surplus (MWh_{th}/year)	486
Total thermal energy supplied by LPG boiler (MWh_{th}/year)	16 789
Annual GHG emissions abated, only thermal energy savings (t CO_2/year)	2 239
Annual GHG emissions abated, only thermal energy savings + thermal energy surplus (t CO_2/year)	2 359

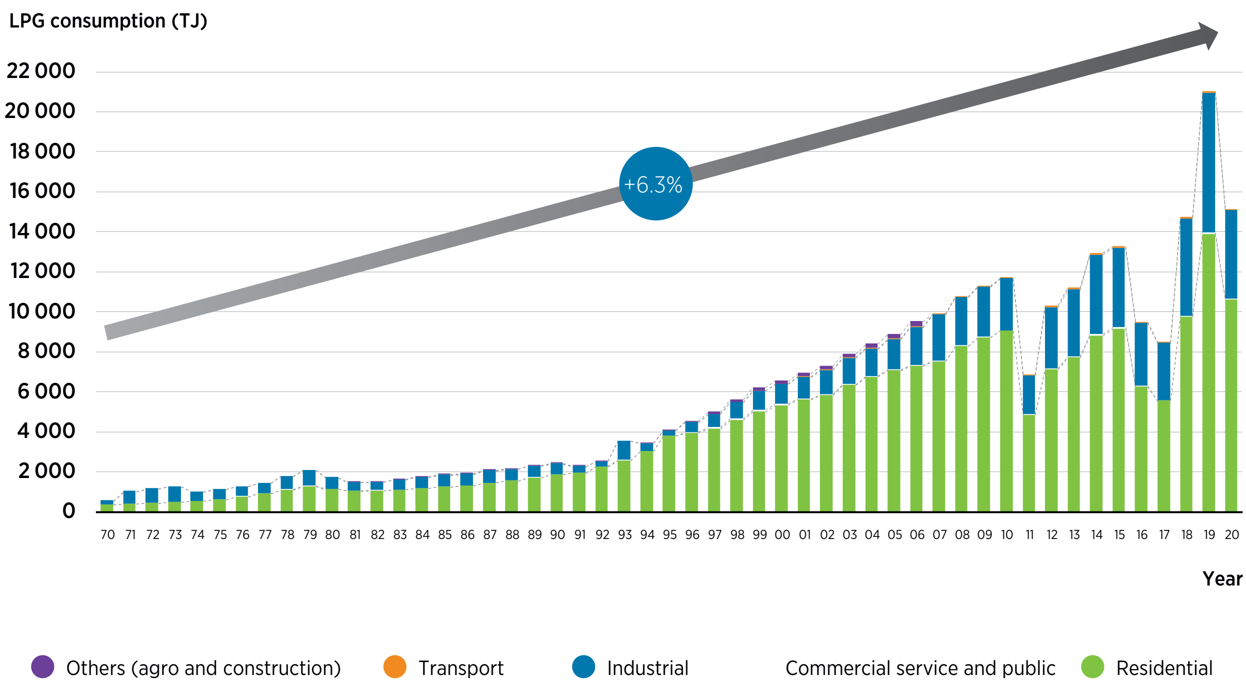
The scale-up analysis for concentrated solar thermal was conducted using the results from Chapter 5.1's solar resource and space availability analyses. Additionally, the heat demand profiles of all dairy facilities were characterised as part of this exercise, and this information aided in the design of the concentrated solar thermal systems.

In line with the solar PV scale-up study, the present analysis considers space availability as a potential constraint. The results indicate that in the absence of a space constraint, the installed concentrated solar thermal collector capacity would be around 20 megawatts thermal (MW_{th}), generating more than 26 gigawatt hours thermal (GWh_t) annually, which would reduce the dairy facilities' GHG emissions by 6 465 t CO_2/year if all of the heat generated was used. Incorporating a space constraint reduces installed capacity to approximately 7.3 MW_{th}, annual generation to approximately 9.6 GWh_{th}, and maximum GHG abatement potential to approximately 2 359 t CO_2/year.

According to CNE data combined with information from the Hydrocarbons and Mines Directorate, El Salvador's LPG consumption associated with the industry sector was 1 082 576 barrels in 2020, equivalent to a total primary energy consumption of 4 406 TJ. The associated emissions are estimated to be 251 086 t CO_2/year in El Salvador due to the industry's LPG consumption.

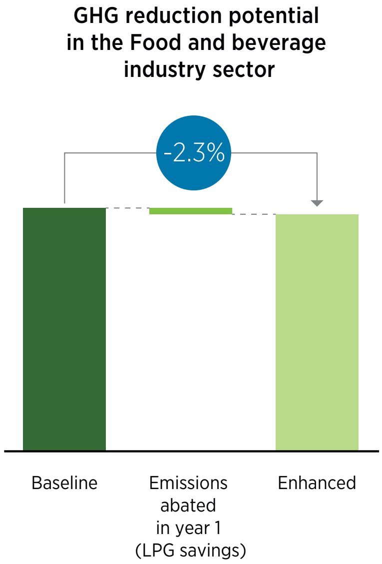
The consumption of LPG by the total energy sector from 1970 to 2020 is depicted in Figure 45, highlighting the incremental industry sector consumption over the last five decades. This demonstrates an opportunity for the industrial sector to transition to a more sustainable, environmentally friendly and cleaner source of thermal energy. The scale-up analysis for concentrated solar thermal was conducted using the results of Chapter 5's solar resource and space availability analyses. Additionally, the heat demand profiles of all dairy facilities were characterised as part of this exercise, and this information aided in the design of the concentrated solar thermal systems.

Figure 45: LPG consumption 1970-2020 (TJ)



The consideration of potential constraints on available space establishes the upper and lower bounds for the GHG mitigation potential of concentrated solar thermal in El Salvador's dairy sector. There is no granular data on what percentage of total industry sector consumption came from the dairy sector at the time of the analysis. However, as illustrated in Figure 46, the upper bound of the results from the scale-up analysis indicates that widespread adoption of concentrated solar energy in the dairy sector could result in a 2.3% reduction in GHG emissions associated with the industry's LPG consumption. This portion of emissions reductions is accounted for by the dairy sector's self-consumption of renewable energy as well as its exports to the grid.

Figure 46: Scale-up outcomes: GHG reduction potential in the whole industry sector



6. DISCUSSION AND RECOMMENDATIONS

The purpose of this study was to conduct a mitigation analysis in the agro-industry subsector of El Salvador to serve as a guide for addressing the early-stage implementation of renewable energy technology solutions in the industrial subsector, taking into account specific national considerations such as resource assessment, technology feasibility, appropriate infrastructure and equipment requirements, as well as the analysis details how the technology could be integrated into the existing energy sector, laying the groundwork for future large-scale implementation.

The analysis began with the identification of the renewable energy technologies to be analysed, as well as a national agro-industry facility that would serve as the foundation for developing the case study. The International Renewable Energy Agency (IRENA) and the National Energy Council (CNE – Consejo Nacional de Energía) launched a national consultation process via an online survey to engage and collect inputs and technical insights from key national stakeholders, including the CNE, the Ministry of Environment and Natural Resources (MARN – Ministerio de Medio Ambiente y Recursos Naturales), the Ministry of Agriculture and Livestock (MAG – Ministerio de Agricultura y Ganadería), academia, and the private sector. Solar energy was chosen as the renewable energy technology to be analysed, specifically photovoltaic (PV) and concentrated solar thermal, both of which incorporate storage systems.

Additionally, the case study of Los Quesos de Oriente was scaled across El Salvador's entire dairy industry sector for solar PV and solar thermal technology solutions. This plan for technology scaling up can serve as the basis for establishing new mitigation and co-adaptation targets for greenhouse gas (GHG) emissions reductions that will inform the Nationally Determined Contribution (NDC) revision. The findings of the analysis provide critical information for identifying technologies, estimating costs and quantifying potential emissions reductions. A subsequent analysis could address and investigate the data gaps identified in this analysis, incorporating them into the scale-up results to increase their certainty. For instance, surveys of various industrial sectors' heat demand can be conducted in order to create a national heat demand map classified by subsector and based on real-world heat demand profile datasets. Additionally, a thorough analysis of potential spatial constraints associated with solar technology implementation would be beneficial.

The analysis can be incorporated into the NDC and its implementation plan, assisting decision makers in developing sectoral plans for the energy and agriculture sectors, as well as establishing a path for the country's energy sector to transition from fossil fuel-based to zero carbon, with the goal of limiting climate change at its core. It is critical to recognise that without necessary climate policies and regulations, the identified technology plan options and associated GHG reductions will likely be unachievable. The following sections lay the groundwork for future policy developments that will enable El Salvador to implement mitigation measures that significantly contribute to the country's resilience and adaptation to climate change, as well as to the decarbonisation of the country's energy system.

6.1 INCENTIVISE THE DIRECT USE OF RENEWABLE ENERGY SOURCES

El Salvador has significant renewable energy potential that can be harnessed to increase energy security and independence at a lower cost than imported fossil fuels. The transition away from fossil fuelled generation and towards a green energy mix based on renewables has the potential to deliver significant long-term benefits, but it will require substantial investment. Governments, ministries, utilities, and other public and private stakeholders must all be involved and benefit from full participation in resolving these complex and dynamic issues in order to ensure a smooth transition to a cleaner, greener energy system. El Salvador is fortunate to have an abundance of renewable energy resources, which enables this transition to take place. To accomplish this, the government must enact action plans that accelerate the adoption of low-cost renewable energy and grid infrastructure at a rate that supports the decarbonisation of the power and heat sectors, as well as end-use electrification.

The technological pathways towards a decarbonised energy system have crystallised, with rapid deployment and scale-up solutions taking precedence. While technologies, markets and business models continue to evolve at a breakneck pace, there is no reason to wait for novel solutions. Significant advancement is possible with existing options. According to the IRENA *World Energy Transitions Outlook*, electricity will become the primary energy carrier by 2050, increasing from 21% of total final energy consumption in 2018 to more than 50% in 2050. IRENA's analysis indicates that sectoral boundaries are blurring in this context as end-use applications such as transportation, renewable energy and heating electrify. This increase is primarily the result of renewable energy being used in place of fossil fuels in end-use applications. Renewable technologies' annual growth rate will more than double as a result of this shift.

Direct use of renewable heat and biomass, including solar thermal, geothermal, biofuels and bioenergy feedstocks, entails directly utilising renewables for energy and feedstocks, including solar and geothermal for some heat requirements and sustainable biomass (including direct use of bioenergy) for heat and the production and use of biofuels and bioenergy feedstocks. Solar thermal energy use in industry will increase dramatically, eventually meeting 5% of the sector's heat demand. In industry today, direct renewable energy is primarily used in the form of biofuels and waste. This is primarily due to the use of waste products and by-products, such as bagasse and rice husk in sugar production and other traditional industries; biogas from sewage and farms for food processing; and black liquor in the pulp and paper industry. Additionally, the versatility of biomass enables competitive applications within and between industry sectors and other sectors of the economy. Realising cost-effective and sustainable biomass potential is contingent upon a variety of factors, including the cost and availability of local feedstocks, as well as biomass logistics. Solar heating and geothermal energy, in addition to biomass, could be used to replace fossil fuels. Breweries, dairy processing plants and textile processing plants are typical applications of these technologies.

Renewable energy policies that support the deployment of renewable energy for heating, cooling and transportation include regulatory measures that establish a market for these technologies, as well as fiscal and financial incentives, such as the elimination of fossil fuel subsidies and the provision of grants and tax credits for renewables, that facilitate adoption and make them more equitable for all types of users. Policy makers must create dedicated, transparent and long-term frameworks for the development of solar thermal energy and sustainable biofuels. These frameworks can take the form of roadmaps, industrial strategies and specific objectives. Regions, countries or mandates can support targets and roadmaps, and such mandates, in turn, can be implemented at the city level. The following Table 27 illustrates some examples.

Table 27: Measures at a city level to incentivise the direct use of renewable energy sources

REGION/COUNTRY	TARGET
India	India is targeting 20 million square metres (m^2) of solar thermal collectors by 2022
Economic Community of West African States	The Economic Community of West African States adopted the target to deploy solar thermal heating for around 50% of all health centres and schools, 25% of hotels and 25% of the agri-food industry by 2030
Country/regional policies	Biofuel blending in Brazil, the People's Republic of China, the European Union and the United States
Kenya Spain	National mandates and targets requiring the installation of solar thermal systems in new or existing buildings

Renewable energy technologies, particularly for low- and medium-temperature applications, have the potential to provide practical and cost-effective alternatives for process heat generation and as a renewable carbon source for the industry subsector. Policies that promote market development, enable scale-up, reduce technology costs and increase investment levels must be consistent with the needs of the energy transition. Given the significant amount of public finance injected into economies during the recovery period, such policies will shape the energy transition's direction and lay the groundwork for the significant increase in private-sector investment required until 2050 (IRENA, 2021a).

Photo: Jenson / Shutterstock.com

6.2 AVOID A LOCK-IN WITH FOSSIL FUELS

The negative long-term effects of natural gas may outweigh any short-term benefits effects. Due to the fact that natural gas emits approximately half the carbon dioxide (CO_2) per kilowatt hour (kWh) of electricity produced relative to coal, it is frequently used as a bridge fuel until renewable energy technologies overcome the challenges associated with producing secure and sustainable energy. Natural gas's role as a bridge fuel between more polluting fossil fuels and zero-carbon technologies is viewed in this context as a temporary one, as natural gas still emits CO_2. Investing today in natural gas infrastructure, on the other hand, may delay the transition to zero-carbon technologies and impede long-term emissions reduction efforts. The crowding-out effect is a notable example of natural gas's indirect effects. Crowd-out is a term that refers to the constant redirection of investments away from a desired technology due to the attractiveness of another. When different types of energy technologies compete for investment, crowding out occurs. A dominant technology can suffocate the market, preventing the emergence of alternative technologies. If natural gas continues to reroute resources as a result of its growing sociotechnical power, it risks crowding out renewables and reinforcing a dependence on fossil technologies. Carbon lock-in refers to the crowding-out effect's reliance on fossil fuel technology pathways. Existing fossil fuel infrastructures can stymie advancements in emerging renewable technologies, resulting in the continuation of fossil fuel infrastructures and technologies despite their environmental consequences (Gürsan and de Gooyert, 2021). As a result, carbon lock-in can act as a barrier to renewables and delay the transition, effectively locking energy systems into a fossil fuel-based future.

When renewables are not prioritised, their relative position to natural gas and other fossil fuels deteriorates, as they would be unable to expand their reach due to a lack of network and infrastructure. Transition costs are associated with every transition process; in this case, they refer to the total costs associated with the transition to more sustainable energy systems. Natural gas is occasionally considered a bridge fuel between polluting fossil fuels and zero-carbon technologies. However, natural gas plants must be used in the short term until zero-carbon technologies become available, as gas still emits GHGs. In this vein, when emissions pressures increase in the medium term, investments will need to be reallocated once more. Numerous studies demonstrate that these reallocations almost certainly increase the cost of the entire energy transition for countries. Additionally, investing in soon-to-be-phased-out technologies may stall the transition to zero-carbon technologies, resulting in negative environmental consequences (Gürsan and de Gooyert, 2021).

Solar and wind power plants have variable output and thus require the assistance of other technologies to provide reliable energy. Alternative renewable energy sources such as bioenergy, hydropower and geothermal can provide more reliable and continuous energy than solar and wind in El Salvador. As a result, these renewable technologies do not require synergy with natural gas to be viable and reliable, whereas natural gas would result in a more expensive and delayed energy transition for the country.

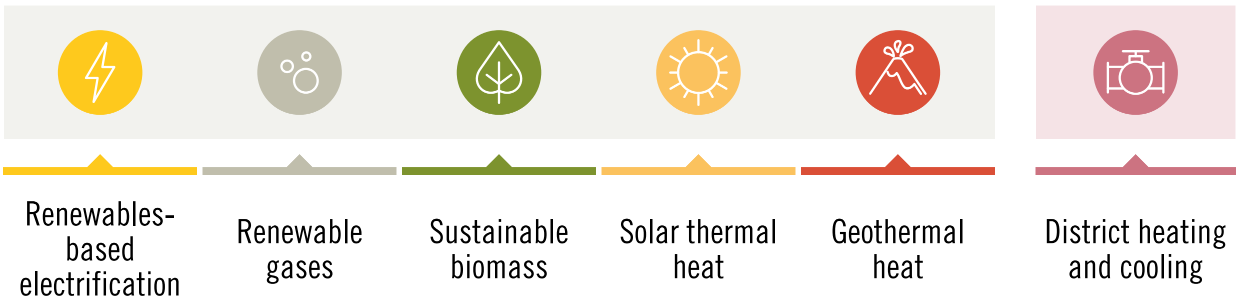
Photo: www.pexels.com/.

6.3 PROMOTE AWARENESS AMONG CONSUMERS AND CITIZENS AND DEVELOP A LONG-TERM ENERGY TRANSITION PLAN

Consumer and citizen engagement is critical for integrating the complex dynamics of social systems into the energy transition. Consumers and citizens are critical to the energy transition's success. On the one hand, they can persuade governments and businesses to accelerate their decarbonisation plans. For example, customer, shareholder and employee demand has been identified as a primary driver of corporate renewable heat procurement (IRENA Coalition for Action, 2020). On the other hand, citizens take proactive measures to reduce their energy consumption and dependence on fossil fuels. Sharing information and increasing public awareness through public campaigns is critical for citizens to adopt clean solutions and behavioural changes consistent with reducing energy consumption. For example, in heating and cooling, government actions – at the national and local levels – to raise awareness about the potential and benefits of renewable energy sources are critical to generating interest and building confidence among potential consumers and relevant actors. South Africa launched the Solar Water Heater Campaign to raise public awareness, while similar policies aided in the promotion of solar thermal solutions in Barcelona (Spain), Rizhao (China), and Cape Town (South Africa), among other cities (IRENA, IEA and REN21, 2020).

Accelerating the energy transition and maximising its benefits in this context requires an integrated energy planning approach that integrates targets and active commitments with holistic and long-term plans that include the deployment of energy transition technologies, the phase-out of fossil fuels and a thorough examination of their socio-economic impacts. A comprehensive long-term plan should be developed in collaboration with various ministries (e.g. energy and environment or climate change). For example, cross-sectoral planning for heating and cooling should integrate the transition with plans for other sectors (e.g. power and industry). The energy plan must take into account multiple transition pathways, including electrification, the use of green gases, sustainable biomass, solar and geothermal heat, and district heating and cooling, among other critical enabling infrastructure (Figure 47). The plan must take into account specific needs, macroeconomic conditions, resource availability, existing infrastructure, and the stage of development, accessibility and cost of technologies (IRENA, 2021a).

Figure 47: Solutions and enabling infrastructure for the energy transition in heating and cooling



6.4 CONCLUSIONS AND RECOMMENDATIONS FOR THE UPDATED NDC

Countries urgently need to develop transparent industry transition plans that can support the Paris Agreement's implementation. This represents an obvious opportunity for El Salvador, which is currently finalising its new National Energy Policy for the period 2020-2050 and its Sustainable Agriculture Transformation Plan for Productive Reactivation and Food Security.

This mitigation analysis in El Salvador's agro-industry subsector has demonstrated that, in terms of technical feasibility and GHG emissions abatement, industry sectors have a significant role to play as mitigation options for both their power and thermal requirements. The technology plan developed for the Quesos de Oriente case study established the viability of solar PV and concentrated solar thermal solutions in the national dairy industrial sector, demonstrating that their implementation is technically feasible and economically viable. The analysis validated solar technologies' potential, capability and scale for both adaptation and mitigation purposes.

The technology and mitigation analyses for Los Quesos de Oriente were developed as guidelines for addressing the early-stage implementation of renewable energy technology solutions with specific aspects, such as resource assessment, technology feasibility analysis, and appropriate infrastructure and equipment requirements. The technology plan has demonstrated that it meets the country's needs and is economically viable. Additionally, the analysis discusses how the technology could be integrated into the existing energy sector, thereby paving the way for a future implementation on a larger scale. The technology plan can serve as a foundation for establishing new mitigation and co-adaptation targets for GHG emissions reductions that will inform the revision of the NDC. The findings of the analysis provide critical information for technology identification, cost estimation and quantification of potential emissions abatement. The analysis can be incorporated into the NDC and its implementation, assisting decision makers in developing sectoral plans for the energy and agriculture sectors, and establishing a path for the country's energy sector transformation and a sustainable industrial transition.

When it comes to industrial transition planning, it is proposed that the following considerations be considered:

- **Encourage the diffusion of innovative renewable energy technologies** that support the transformation and adaptation of a modern energy system to a constantly changing and increasingly competitive environment. Developing policy tools, initiatives and strategies is critical for assisting regions in diversifying their economy. Increase employment and move up the value chain.

Photo: www.pexels.com/.

Photo: www.pexels.com/.

- **Incentivise the direct use of renewable energy sources** with renewable energy policies that support the deployment of renewable energy for heating, cooling and transport. This may include regulatory measures that establish a market for these technologies, as well as fiscal and financial incentives, such as the elimination of fossil fuel subsidies, that facilitate adoption and make renewable energy more equitable for all types of users. Policy makers must build focused, transparent and long-term frameworks for the development of solar thermal energy solutions. These frameworks might take the form of roadmaps, industrial strategies and specific objectives.
- **Avoid a fossil fuel lock-in**. The detrimental long-term and global implications of fossil fuels such as natural gas may outweigh their supposed benefits. Investing today in natural gas infrastructure may slow the transition to zero-carbon systems and hinder long-term emissions reduction efforts.
- **Increase consumer and citizen awareness**. Consumer and public engagement is critical for integrating the complex dynamics of social systems into the energy transition. Consumers may drive governments and businesses to accelerate their decarbonisation efforts.
- **Create a long-term plan for industrial transition**. Accelerating and maximising the advantages of the energy transition requires an integrated energy planning approach that incorporates targets and active commitments alongside holistic and long-term plans. A comprehensive long-term plan should be prepared in collaboration with other ministries.

Table 28 illustrates some examples of how countries plan to cut emissions to support low-carbon industrial transitions in the NDCs they have submitted under the Paris Agreement.

Table 28: Specific mitigation measures targeting industry in NDCs

COUNTRY	MEASURE TYPE	NDC	MEASURE
Uruguay	Mitigation and adaptation	1st NDC	"Use of solar collectors for domestic hot water in large users, industrial and residential users: 50 MW_{th} of installed capacity for 2025".
Costa Rica	Mitigation	1st NDC (updated)	"Costa Rica's commitment for the industrial thematic area is focused on its transformation through efficient and sustainable processes and technologies that use energy from renewable or other zero-emission sources. "By 2030, the areas of industry and services will have innovative production models or with a circular economy approach in the main agro-industry productive chains of agro-industry, services, construction, and the creative and cultural economy, among others".
Panama	Mitigation	1st NDC (updated)	"By the year 2030, the solar thermal evolution is expected to be: 247 904 m^2 solar thermal DHW and industry. Including incentives".
Paraguay	Mitigation	1st NDC (updated)	"Promote the use of solar thermal energy through the use of solar water heaters".
Honduras	Mitigation	1st NDC (updated)	"Integration of renewable energies in the national electricity grid and the processes of industrial air conditioning".
Morocco	Mitigation	1st NDC	Implementation of a pilot project for energy recovery from air compressors in 250 industrial companies (conditional).
Jamaica	Mitigation	1st NDC (updated)	"The country is also undertaking a range of pilot projects to explore biodiesel from cooking oil, the production of biogas using animal waste and increasing the use of biodigestors".

Notes: MW_{th} = megawatts thermal; DHW = domestic hot water.

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APPENDIX

SURVEY (SPANISH VERSION)

La Agencia Internacional de Energías Renovables (IRENA) es una organización intergubernamental que presta apoyo a los países en su transición a un futuro de energía sostenible, y sirve de plataforma principal para la cooperación internacional, centro de excelencia y repositorio de políticas, tecnología, recursos y conocimientos financieros en materia de energía renovable.

IRENA presta apoyo técnico para la identificación de tecnologías de energía renovable que puedan contribuir a los objetivos climáticos del país y mejorar el plan de acción nacional, explorando el vínculo entre los sectores de la energía y la agricultura mediante el uso de calor renovable para usos agrícolas productivos.

Esta encuesta forma parte de un esfuerzo conjunto de la Agencia Internacional de Energías Renovables (IRENA) y el Consejo Nacional de Energía (CNE) por garantizar una mayor participación de las partes interesadas de El Salvador para ayudar a identificar qué tecnología de energía renovable se ajusta mejor a las necesidades del sector agroindustrial y al contexto nacional. Su retroalimentación ayudará a priorizar los planes sobre la base del potencial de mitigación y criterios como la viabilidad técnica y económica.

La encuesta debería durar unos 10 minutos. ¡Apreciamos mucho su aporte!

Nombre y organización

> Por favor, indique su nombre y el nombre de su organización (por ejemplo, Carlos Juárez, Secretario de Energía)

Tipo de organización

> Por favor, seleccione el tipo de organización en la que trabaja.

Energía renovable en el sector de la agroindustria. Por favor, evalúe las siguientes afirmaciones

- El aprovechamiento de los recursos renovables del país está estrechamente vinculado a la seguridad alimentaria y a la erradicación de la pobreza.
- El sector agroindustrial tendrá que reducir gradualmente su dependencia de los combustibles fósiles para poder ofrecer más y mejores alimentos con la utilización de energías renovables y reduciendo su huella de carbono.

Capacidades para el desarrollo de energía renovable en el sector de la agroindustria. Por favor, evalúe las siguientes afirmaciones

- El país cuenta con suficientes recursos humanos para el uso de energía renovable con fines productivos en el sector agroindustrial.
- El país tiene suficiente capacidad técnica para el uso de energía renovable con fines productivos en el sector agroindustrial.

- El país tiene suficiente capacidad financiera para el uso de energía renovable con fines productivos en el sector agroindustrial.

Aplicaciones del calor en el sector de la agroindustria con energía solar térmica. Favor de evaluar las siguientes afirmaciones para la aplicación en usos productivos

- Los sitios con actividad agroindustrial suelen combinar un buen recurso solar y disponibilidad de tierras.
- La aceptación social de las tecnologías solares térmicas para usos agrícolas productivos es bien entendida y abordada en el país (es decir, con respecto a la tierra sin conflicto de uso).
- Existen barreras (por ejemplo, sectoriales, tecnológicas, normativas y/o regulatorias) que no se han abordado adecuadamente en el país para permitir el desarrollo de aplicaciones de la energía solar térmica para usos agrícolas productivos.
- En general, considero que la tecnología térmica solar se adapta bien a los usos agrícolas productivos del país.

Aplicaciones del calor en el sector agroindustrial con energía geotérmica. Favor de evaluar las siguientes afirmaciones para la aplicación en usos productivos

- Los sitios con actividad agroindustrial suelen combinar buen recurso geotérmico y disponibilidad de tierras.
- La aceptación social de las tecnologías geotérmicas para usos agrícolas productivos es bien entendida y abordada en el país (es decir, con respecto a la tierra sin conflicto de uso).
- Existen barreras (por ejemplo, sectoriales, tecnológicos, normativos y/o reglamentarios) que no se han abordado adecuadamente en el país para permitir el desarrollo de aplicaciones geotérmicas para usos agrícolas productivos.
- En general, considero que la tecnología geotérmica se adapta bien a los usos agrícolas productivos del país.

Aplicaciones del calor en el sector agroindustrial con bioenergía. Favor de evaluar las siguientes afirmaciones para la aplicación en usos productivos

- Existe un amplio excedente de materias primas de biomasa como resultado de procesos agroindustriales, la cual se encuentra disponible a largo plazo y durante todo el año para ser utilizada con otros fines (por ejemplo, para producir calor).
- Los sitios con actividad agroindustrial suelen combinar excedentes de materias primas de biomasa y disponibilidad de tierras.
- Existen barreras (por ejemplo, sectoriales, tecnológicos, normativos y/o reglamentarios) que no se han abordado adecuadamente en el país para permitir el desarrollo de aplicaciones de la biomasa para usos agrícolas productivos.
- En general, considero que la tecnología de la biomasa se adapta bien a los usos agrícolas productivos del país.

Mejores prácticas en materia de autoconsumo de energía renovable. Favor de evaluar la siguiente declaración sobre la base de su conocimiento del contexto nacional

- Existen regulaciones nacionales adecuadas para el autoconsumo de energía renovable (por ejemplo, esquema prosumidor, feed-in tariffs, net metering, net billing, etc.)

En vista de lo anterior, ¿qué tecnología consideraría más apropiada para el desarrollo del plan piloto tecnológico para procesos agrícolas productivos en El Salvador? Por favor, evalúe la siguiente afirmación en base a su experiencia en el sector.

- Tecnología solar térmica
- Tecnología geotérmica
- Tecnología de la bioenergía
- Otros

¿Qué sector de la agroindustria es más intensivo en energía y es probable que sea el responsable de las mayores emisiones de gases de efecto invernadero? Favor de evaluar los siguientes sectores agroindustriales.

- Industria de elaboración de café
- Procesamiento de frutas y verduras
- Industria del azúcar y derivados
- Acuicultura (piscifactorías o producción de algas)
- Mercados no tradicionales (por ejemplo, pimientos, plantas, otros)
- Otros

Observaciones adicionales (Opcional)

¿Le gustaría sugerir una tecnología de energía renovable o plan en particular para el uso de calor en procesos agroindustriales?

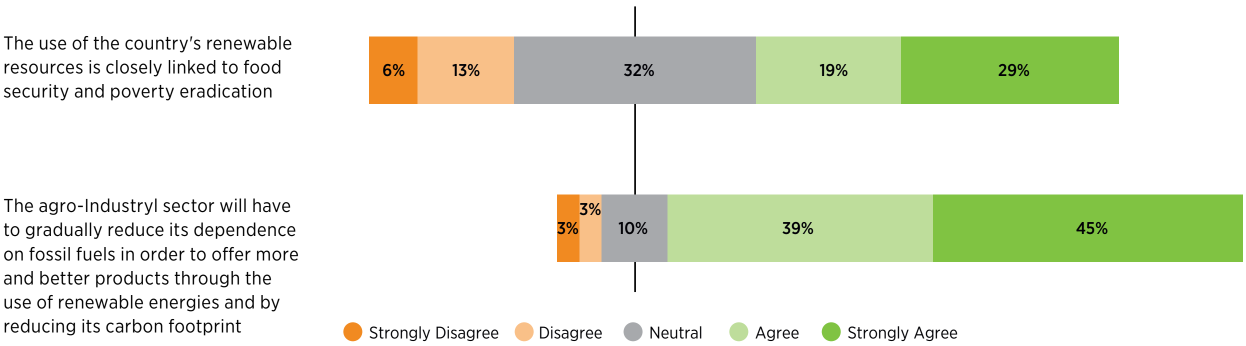
Por favor, siéntase libre de proporcionar cualquier comentario adicional.

SURVEY'S RESULTS

Renewable energy in the agriculture and agro-industry sector

This question assessed whether renewable energy is considered to be closely linked to agriculture and the food industry, as well as social awareness of the need for sustainable and emissions-free agriculture and agro-industry sectors. Figure 48 shows 50% of the survey participants agreed or strongly agreed that renewables are related to food security and the eradication of poverty. In addition, 84% of the participants reached a very high agreement that agriculture and agro-industry should gradually reduce their fossil dependence and greenhouse gas (GHG) emissions. The results show the importance of linking clean and green technologies to the agro-industry sector. Overall, the results are positive and show a high-level national buy-in.

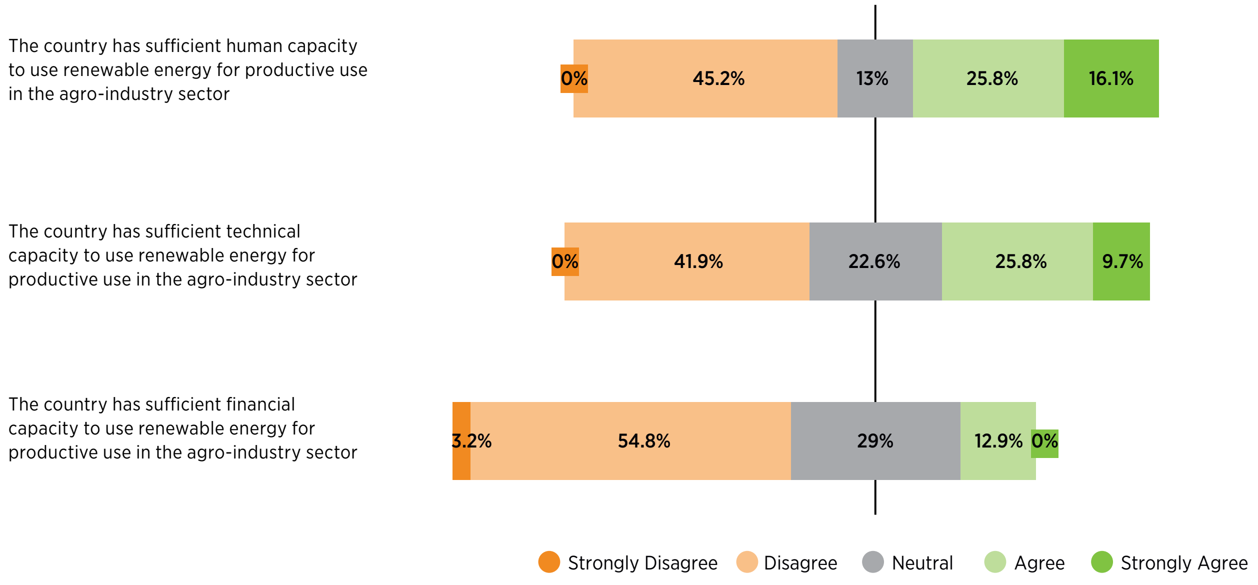
Figure 48: Perception of interaction between renewable energy and the agro-industry sector



Capacities for renewable energy development in the agro-industry sector

This question assessed whether the country is perceived to have sufficient human, technical and financial capacity to evaluate and develop the use of renewables for productive use in the agro-industry sector. Figure 49 shows that almost 60% of survey participants consider funding to be the main national lack of capacity. Moreover, the results also show medium to high negative statements for both human and technical capacities (above 40%). It may therefore be of interest, at a later stage, to assess at national level whether technical capacity is to be assessed and addressed, potentially by means of a capacity needs assessment, in order for the country's workforce to be able to implement renewable energy technology projects.

Figure 49: The extent to which capacities are sufficient to implement renewable energy projects

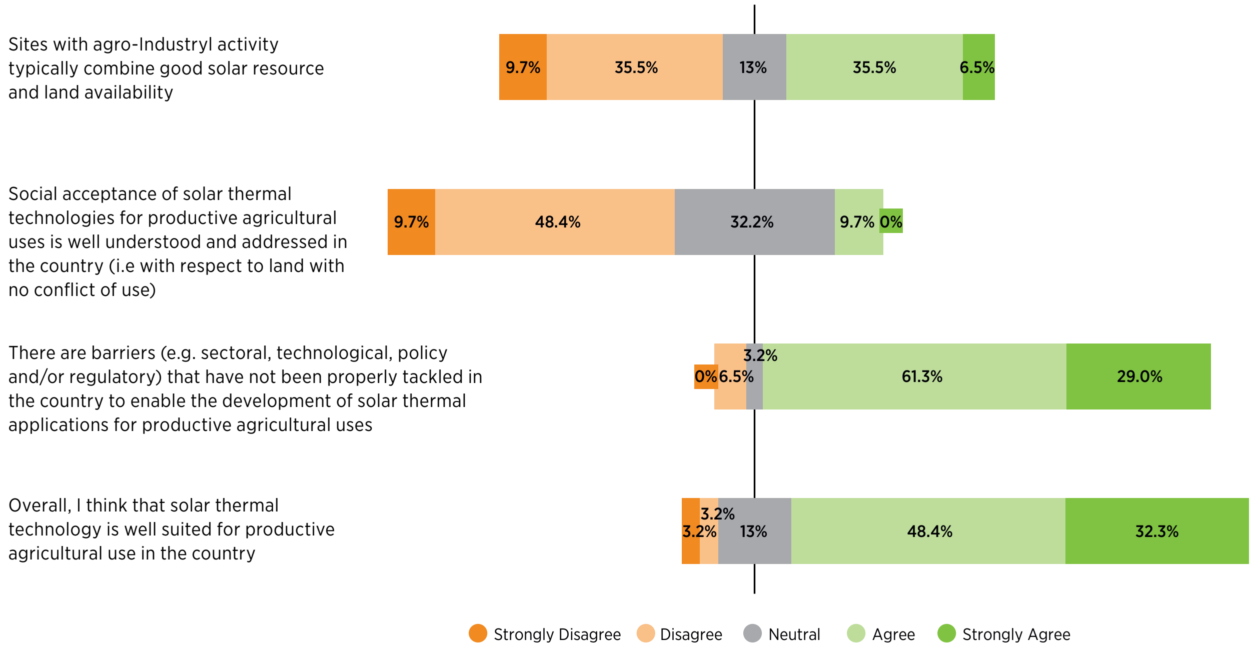


Heat applications in the agro-industry sector with solar thermal energy

This question assesses whether solar thermal technology is potentially appropriate to meet the energy requirements of agro-industry heat processes. The assessment is based on availability of resources, social acceptance of technology and potential barriers to implementation. As shown in Figure 50, there is a clear discrepancy between participants on the combined availability of good solar resources and land at agro-industry sites, with a share of 42% positive versus 45% negative answers. With regard to the social acceptance of solar thermal technologies for productive agricultural use, the results show a critical possibility that the technology may not be well understood and addressed at national level, resulting in a potential land conflict of use. Therefore, there is a clear need for improving social acceptance in the deployment of the technology, as it is crucial for successful project implementation. It is key to assess and address potential social conflicts, such as public opposition, which are generally due to lack of awareness of technology and climate change topics. In this line, there is typically a correlation between people's awareness of climate change and its impacts and their willingness to act against it.

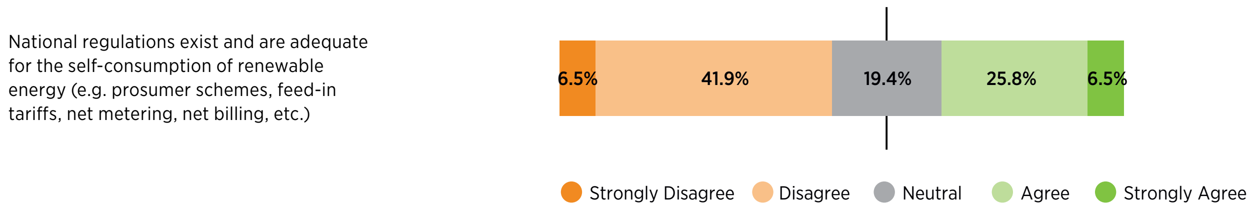
In addition, a strong agreement can be seen from the participants that there are currently barriers to development, such as sectoral, technological, policy and/or regulatory ones. Finally, the results show a high agreement among participants, reaching 80%, on finding solar thermal technology that is generally well suited for productive agricultural use in the country.

Figure 50: Solar thermal technology in the agro-industry



Best practices on renewable energy self-consumption

Figure 51: Renewable energy self-consumption in El Salvador



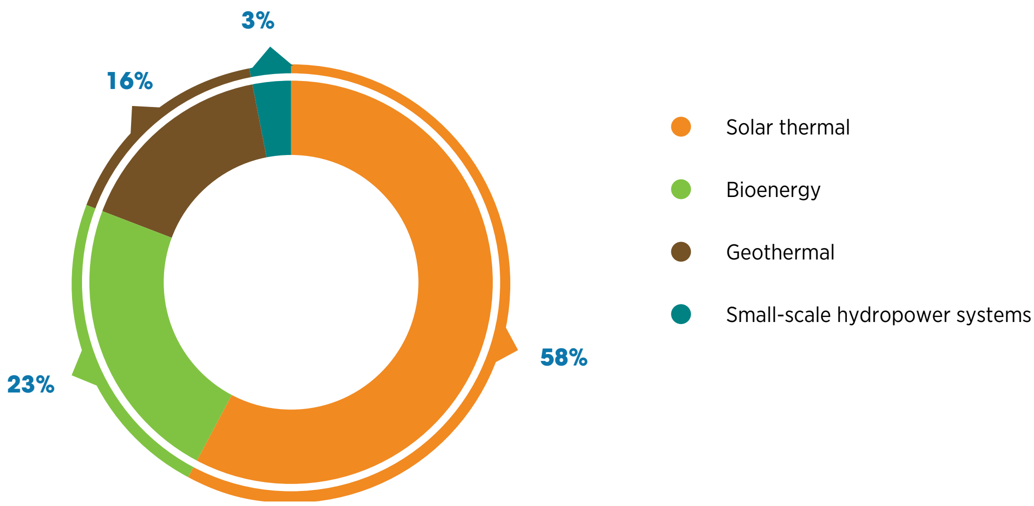
This question examined whether the country has national regulations in place that would be appropriate and encourage the self-consumption of renewable energy. Results show that 42% of survey participants disagree with the statement, while only 26% are in agreement.

In this context, it might be of interest to address best practices (e.g. national policies and regulations) on self-consumption of renewable energy. Enabling self-consumption tends to trigger private investment in energy transition and is a potentially cost-effective strategy for countries to meet energy and climate targets. Self-consumption also contributes to awareness-raising and behavioural change, with citizens seeing themselves as part of the solution, taking ownership of the transition and becoming involved in the solution.

Technology identification support for the pilot plan

This question addressed the technical expertise and overall national background knowledge of survey participants to support the identification process of the appropriate technology for the development of the case study. Participants were asked which technology they would consider more appropriate for the development of the technology plan for productive agro-industrial processes in El Salvador. Figure 52 shows 58% of survey participants selected solar thermal technology, while bioenergy and geothermal energy yield lower results, 23% and 16%, respectively.

Figure 52: Technology identification for pilot plan



SOLAR RESOURCE ASSESSMENT AND WEATHER CHARACTERISTICS

Table 29: Monthly global horizontal irradiance (GHI) data at the site

	GHI (kWh/m²/month)				
MONTH	PVGIS	METEONORM 8.0	NASA-SSE	NREL-NSRDB	SOLCAST
Jan	176.1	180.7	180.1	183.2	179.3
Feb	182.6	172.7	180.0	181.3	177.9
Mar	210.5	208.3	208.6	211.8	209.4
Apr	195.8	193.7	198.0	197.7	193.6
May	175.0	186.2	182.6	184.8	170
Jun	160.9	183.1	171.9	171.0	173.6
Jul	174.8	203.8	192.2	195.6	197.2
Aug	185.6	186.8	191.3	193.2	191.1
Sep	182.7	178.7	160.5	166.2	166.3
Oct	175.3	171.8	169.6	161.7	163.1
Nov	167.6	167.4	167.7	167.4	165.2
Dec	173.9	167.4	171.7	173.5	169.4
Year	2 160.8	2 200.6	2 174.3	2 187.6	2 156

Notes: kWh = kilowatt hour; m² = square metre; PVGIS = Photovoltaic Geographical Information System; NASA-SSE = National Aeronautics and Space Administration's Surface Meteorology and Solar Energy; NREL-NSRDB = National Renewable Energy Laboratory – National Solar Radiation Database.

Table 30: Monthly diffuse horizontal irradiance (DHI) data at the site

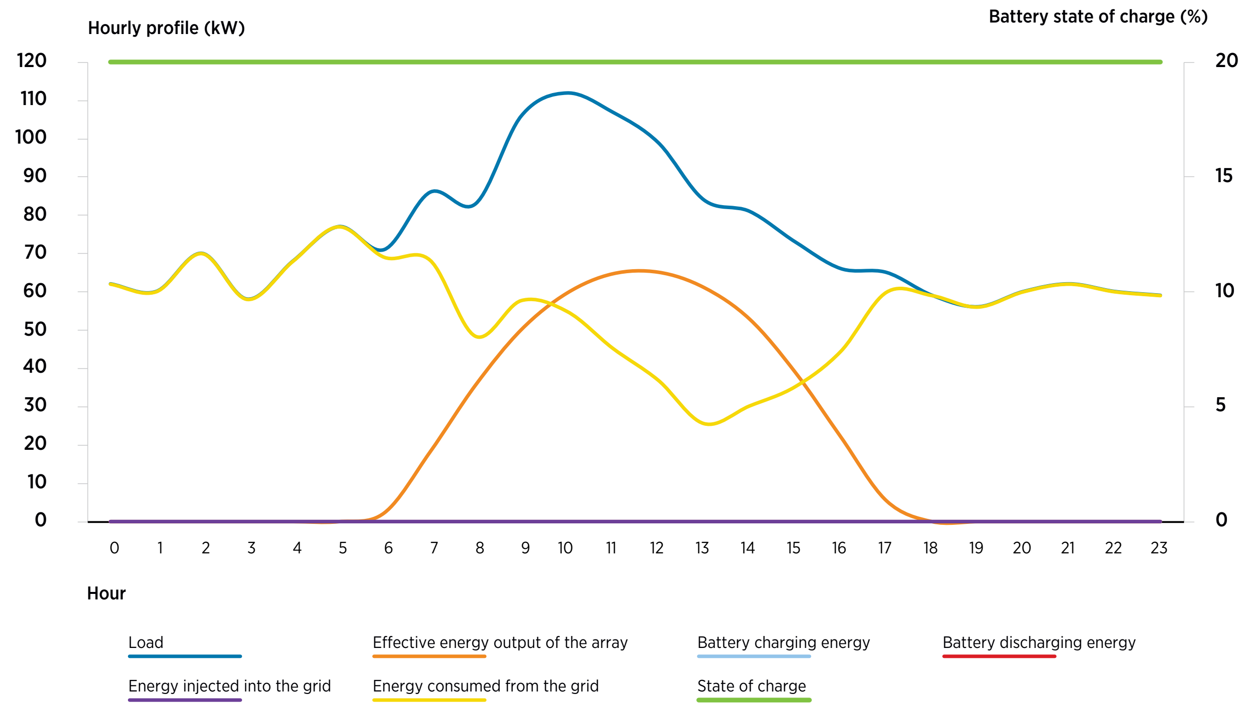
	DHI (kWh/m²/month)				
MONTH	PVGIS	METEONORM 8.0	NASA-SSE	NREL-NSRDB	SOLCAST
Jan	35.5	40.1	35.0	32.1	37.9
Feb	32.9	48.8	35.8	38.0	40.5
Mar	46.1	60.0	50.2	49.8	57.9
Apr	83.2	74.0	59.1	76.1	84.6
May	87.6	83.8	67.6	84.1	70.6
Jun	71.5	76.3	65.1	79.4	76.6
Jul	79.9	74.8	63.9	72.1	70.6
Aug	74.6	77.6	64.8	74.7	73.1
Sep	112.8	72.8	63.6	81.2	71
Oct	56.3	67.2	55.2	68.7	64.3
Nov	41.6	52.0	39.9	38.4	37.5
Dec	33.7	42.2	34.4	28.5	32.3
Year	755.8	769.5	634.6	723.0	717

Table 31: Monthly average ambient temperature data at the site

	AMBIENT TEMPERATURE (°C)				
MONTH	PVGIS	METEONORM 8.0	NASA-SSE	NREL-NSRDB	SOLCAST
Jan	26.5	27.0	25.4	26.9	25.7
Feb	26.7	27.5	26	27.2	26.5
Mar	27.9	28.1	26.4	28.6	27.2
Apr	27.1	28.6	26.8	29.1	27.3
May	27.6	28.3	26.2	28.5	26.9
Jun	26.7	27.3	25.7	27.7	26.3
Jul	26.5	28.0	26	27.7	27.2
Aug	26.6	27.8	25.9	28	25.8
Sep	26.8	26.8	25.2	27.2	25.8
Oct	26.9	26.9	25.2	27.3	25.5
Nov	27.4	26.8	25.5	27.1	25.4
Dec	26.5	27.1	25.5	26.4	25.8
Year	26.9	27.5	25.8	27.6	26.3

HOURLY PROFILES FOR CONFIGURATIONS 1, 3, 7 AND 10

Figure 53: Hourly profiles on 13 March for configuration 1 of the solar PV system



Note: kW= kilowatt.

Figure 54: Hourly profiles on 3 October for configuration 1 of the solar PV system

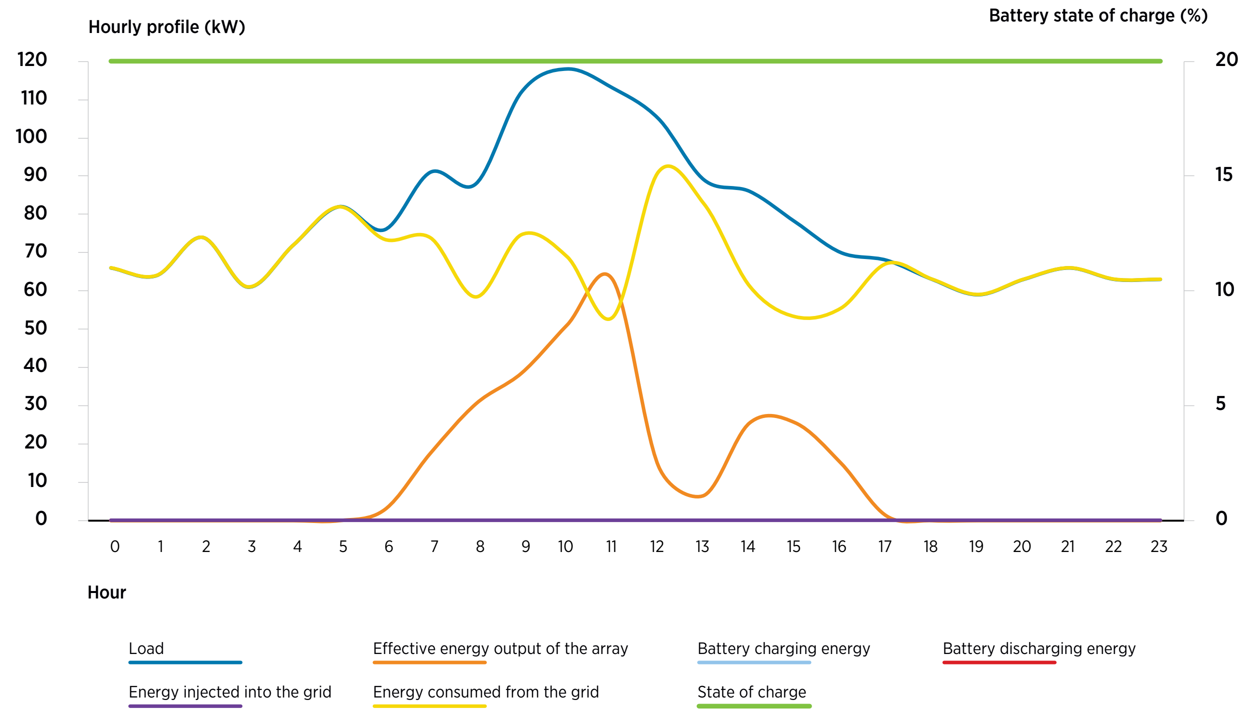


Figure 55: Hourly profiles on 13 March for configuration 3 of the solar PV system

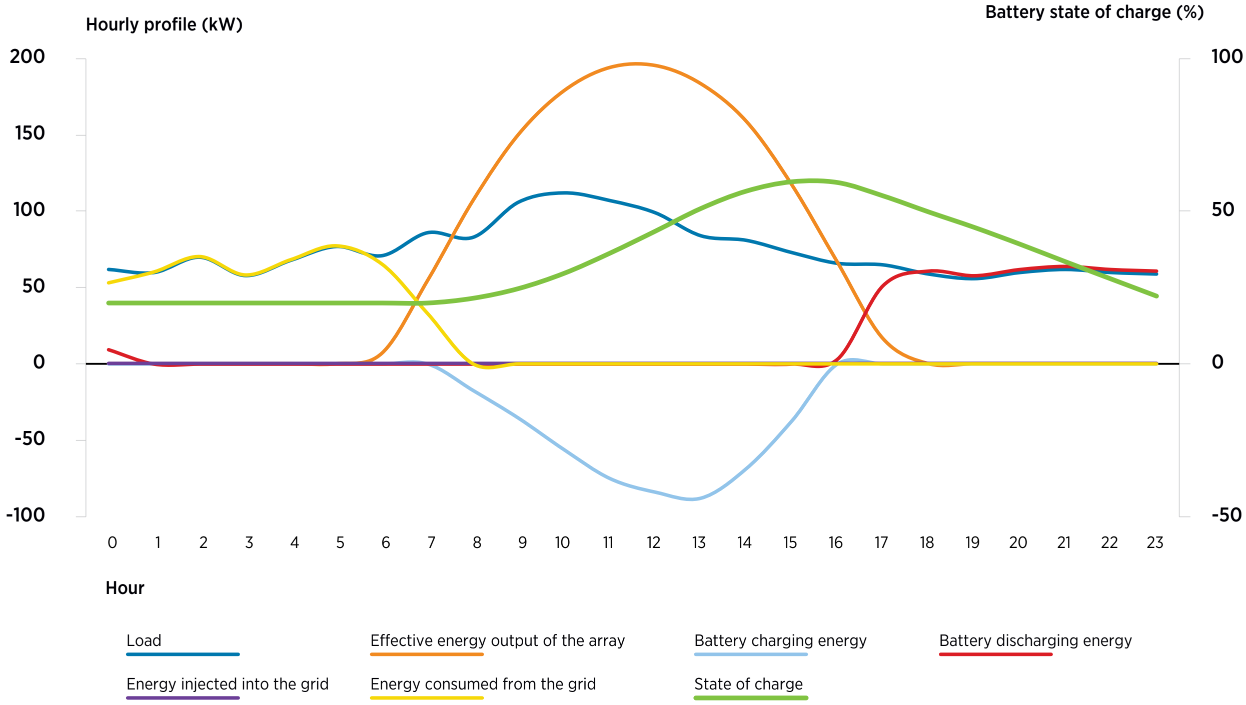


Figure 56: Hourly profiles on 3 October for configuration 3 of the solar PV system

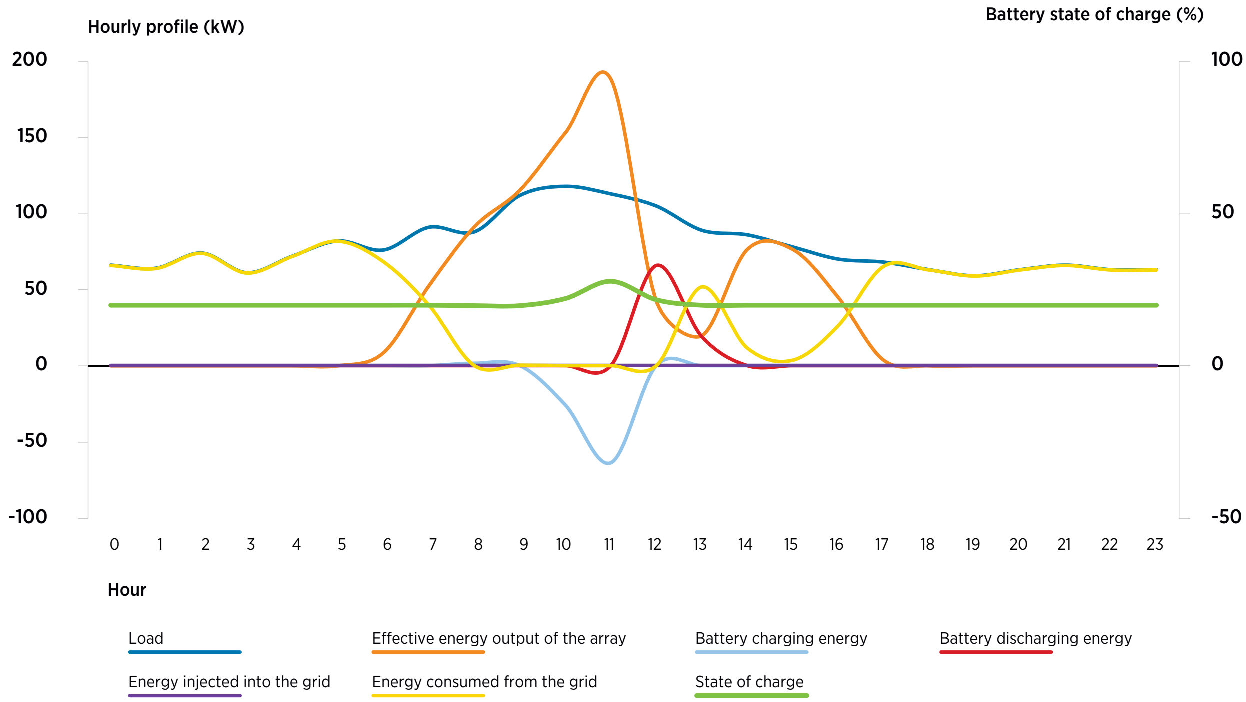


Figure 57: Hourly profiles on 13 March for configuration 7 of the solar PV system

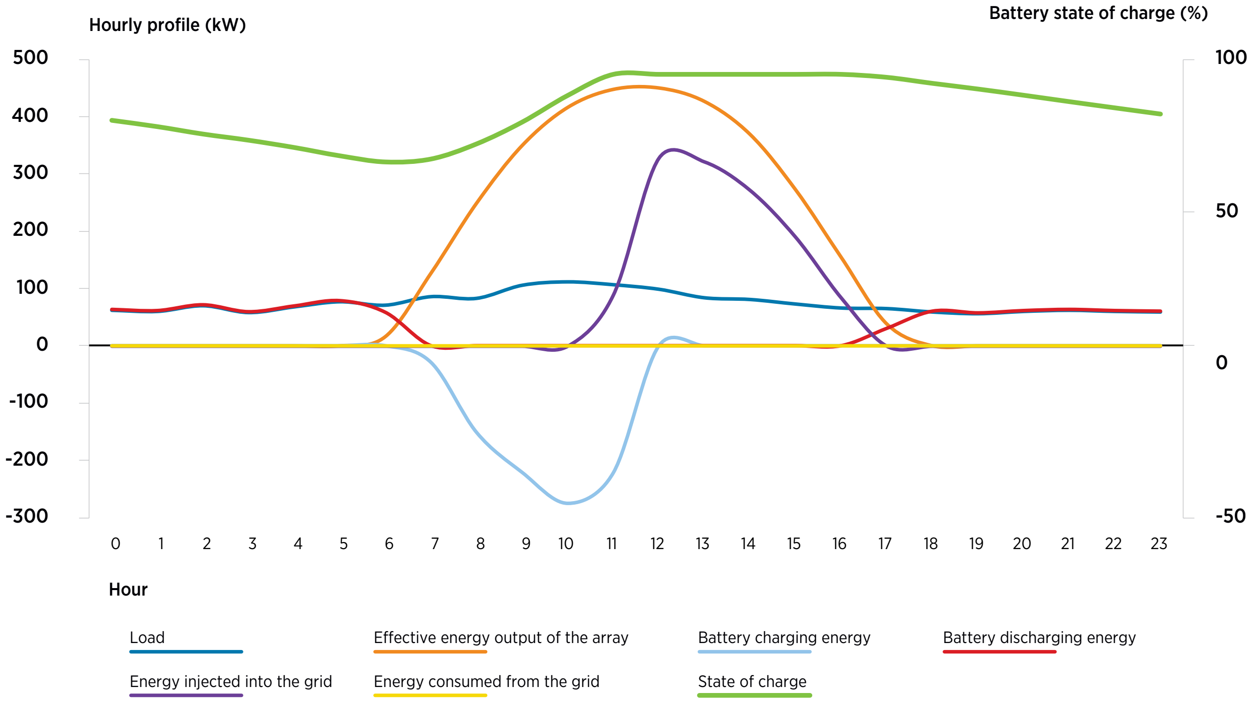


Figure 58: Hourly profiles on 3 October for configuration 7 of the solar PV system

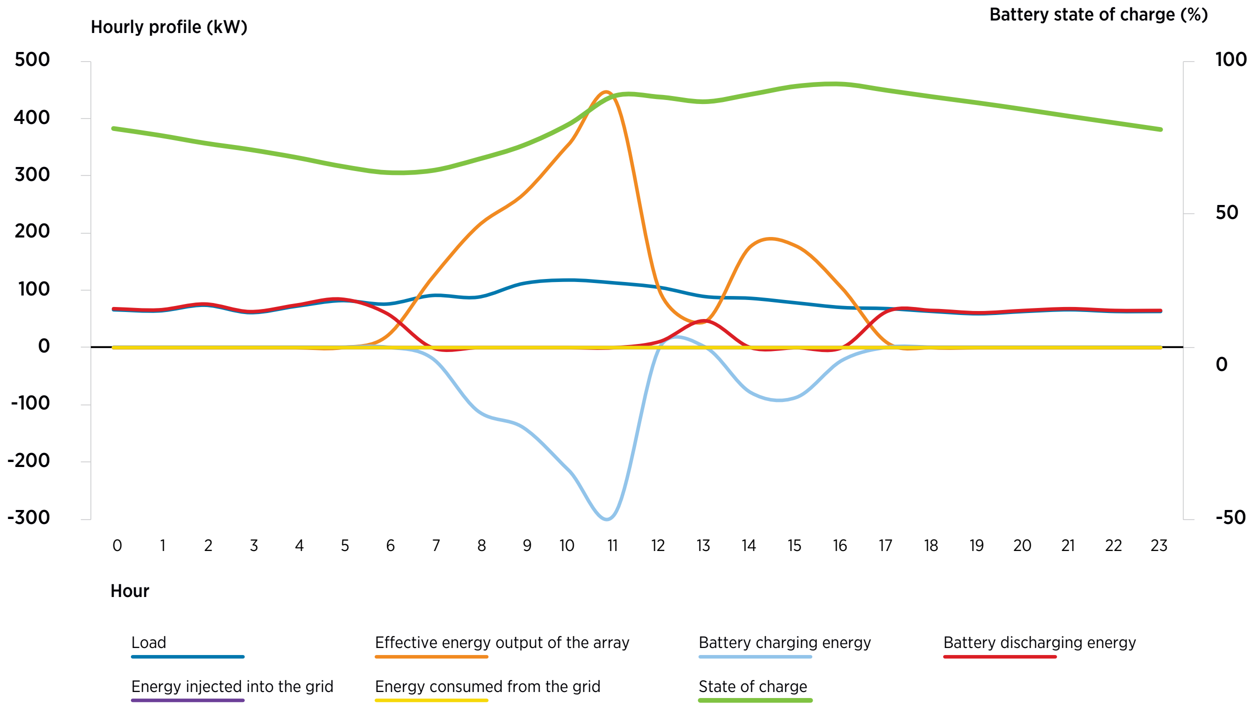


Figure 59: Hourly profiles on 13 March for configuration 10 of the solar PV system

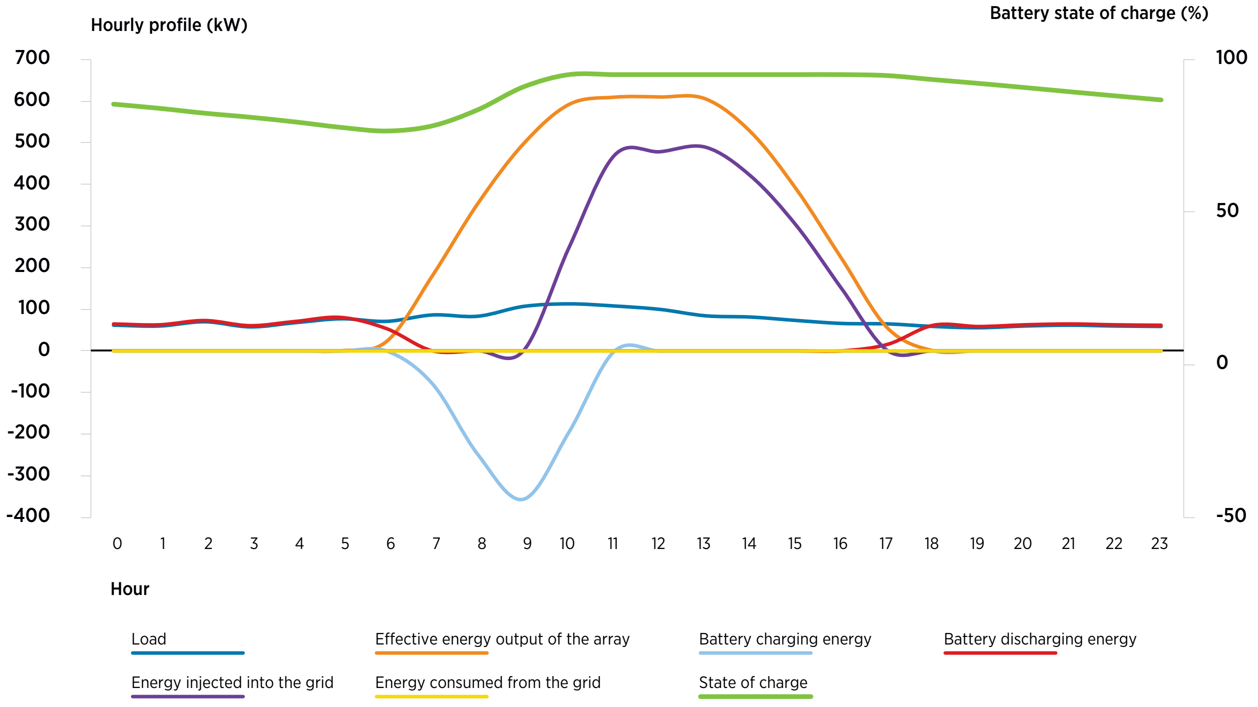
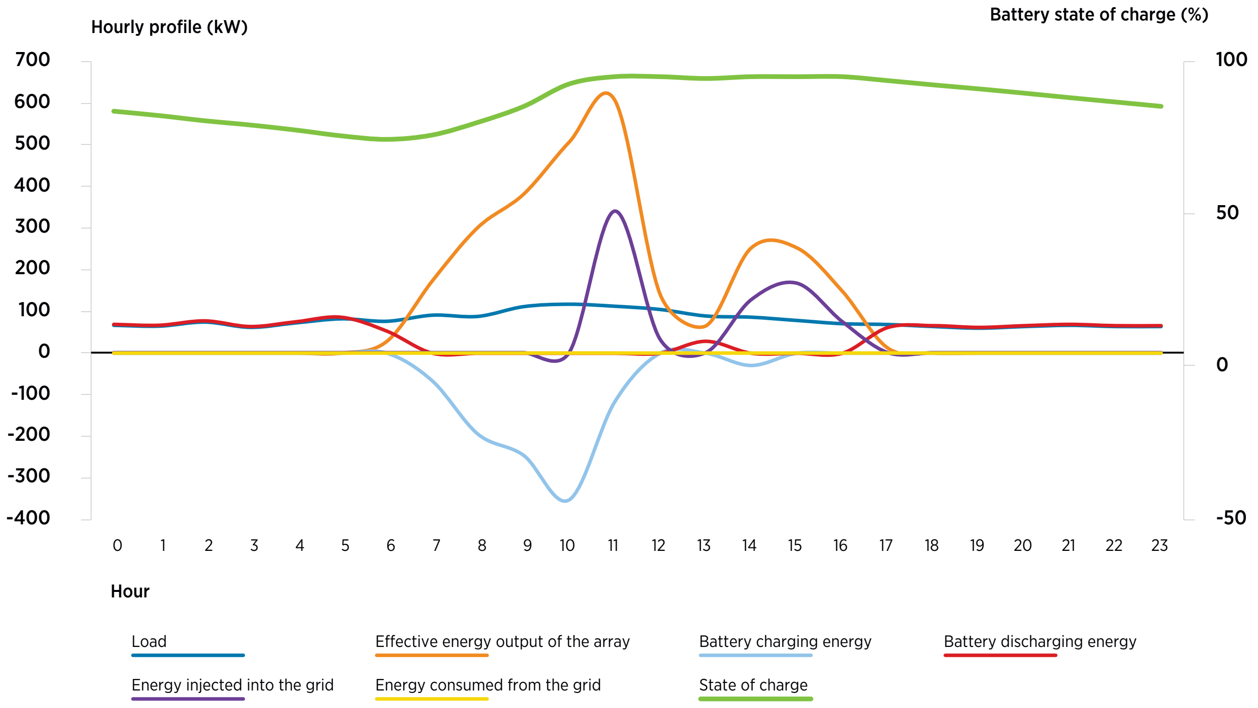


Figure 60: Hourly profiles on 3 October for configuration 10 of the solar PV system



SUMMARY OF SOLAR THERMAL CONCENTRATED PARAMETERS

Table 32: Summary of concentrated solar thermal parameters as defined in System Advisor Model v.2020.11.29

ELEMENT	PARAMETER	VALUE
Solar field	Design point direct normal irradiance (watts [W] per m^2)	950
	Target solar multiple	2.5
	Header pipe roughness (metres)	$4.57\ 10^{-5}$
	Heat transfer fluid pump efficiency	0.85
	Piping thermal loss coefficient (watts per square metre, per degree Kelvin [W/m^2K])	0.45
	Wind stow speed (metres per second [s])	25
	Receiver start-up delay time (hours)	0.2
	Collector start-up energy (kilowatt hour electrical [kWh_e]/solar collector assembly [SCA])	0.021
	Tracking power per SCA (W/SCA)	125
Heat transfer fluid (HTF)	Field HTF minimum operating temperature (°C)	10
	Field HTF maximum operating temperature (°C)	220
	Freeze protection temperature (°C)	10
	Minimum single loop flow rate (kilogram [kg] per s)	1
	Maximum single loop flow rate (kg/s)	12
Collectors	Stow angle (degrees)	170
	Deploy angle (degrees)	10
	Tracking error	0.988
	Optical geometry effects	0.952
	Mirror reflectance	0.93
	Dirt on mirror	0.97

Table 32: Summary of concentrated solar thermal parameters as defined in System Advisor Model v.2020.11.29 *(continued)*

ELEMENT	PARAMETER	VALUE
Plant heat capacity	Hot piping thermal inertia (kilowatt hour thermal [kWh_{th}]/ kelvin per megawatt thermal [$K\ MW_{th}$])	0.2
	Cold piping thermal inertia ($kWh_{th}/K\ MW_{th}$)	0.2
	Field loop piping thermal inertia (watt hours thermal [Wh_{th}]/ kelvin per metres [K/m])	4.5
Receivers	Internal surface roughness (metres)	$4.5\ 10^{-5}$
	Absorber absorptance	0.963
	Envelope absorptance	0.02
	Envelope emittance	0.86
	Envelope transmittance	0.964
	Optical bellows shadowing	0.935
	Dirt on receiver	0.98
Storage system	Initial hot heat transfer fluid (%)	100
	Cold tank heater temperature set point (°C)	20
	Cold tank heater capacity (megawatt electrical [MW_e])	0.5
	Hot tank heater temperature set point (°C)	40
	Hot tank heater capacity (MW_e)	1
	Tank heater efficiency (%)	99
Plant	Fraction of rated gross power consumed at all times (MW_e/MW_{th})	0.0055
	Auxiliary heater boiler parasitic (MW_e/MW_{th})	0.023
	Unavailability time fraction of the system (%)	-4

LOCATION OF DAIRY FACILITIES IN EL SALVADOR

Table 33: List of dairy facilities, location characteristics and source of data

DAIRY FACILITY NAME	DAIRY FACILITY CODE	DEPARTMENT	TYPE OF AREA (URBAN, SEMI-URBAN OR RURAL)	SPACE AREA (m^2)	IS THERE LAND AREA AVAILABLE WITHIN 500 M RADIUS (YES OR NO)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	Santa Ana	Urban	1 844	Yes
	5346709 – 5392451	Sonsonate	Urban	9 025	Yes
	5372072 – 5419144	Sonsonate	Urban		
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	San Salvador	Semi-urban	1 443	Yes
Lacteos Del Corral, S.A. de C.V. (Lactosa)	519297501	San Salvador	Urban	4 000	No
	5404352 – 5452825	San Miguel	Rural	3 000	Yes
Lacteos el Esfuerzo	1222347 – 1222347	Sonsonate	Urban	557	No
	1222350 – 1222350	Sonsonate	Urban	232	No
Lacteos Morazan	5253279 – 5286783	Morazán	Rural	N/A	Yes
Lacteos Stefany	515383601	Chalatenango	Rural	891	Yes
	5487361 – 5540941	La Libertad	Urban	2 605	No
Lactosa S.A. de C.V.	207045401	La Libertad	Urban	3 937	Yes

Table 33: List of dairy facilities, location characteristics and source of data *(continued)*

DAIRY FACILITY NAME	DAIRY FACILITY CODE	DEPARTMENT	TYPE OF AREA (URBAN, SEMI-URBAN OR RURAL)	SPACE AREA (m^2)	IS THERE LAND AREA AVAILABLE WITHIN 500 M RADIUS (YES OR NO)
Procesos Lacteos, S.A. de C.V.	502588701	Antiguo Cuscatlan	Semi-urban	413	Yes
	2500746 – 2500746	Antiguo Cuscatlan	Urban	613	No
	2500877 – 2500877	San Salvador	Urban	811	No
	5007587 – 5007335	San Salvador	Urban	239	yes
	5085781 – 5094137	San Salvador	Urban	983	No
Productos Lacteos Jerusalen	1240256 – 1240256	Sonsonate	Urban	424	Yes
Quesos de Metapan	5521234 – 5575859	Santa Ana	Urban	169	Yes
S.A. de C.V. Agrosania	1256273 – 1256273	Sonsonate	Rural	1 927	Yes
	1256276 – 1256276				
	5205297 – 5230736				
	5208571 – 5234538				
Sucesores Luis Torres (Quesos Petacones)	215772701	San Vicente	Semi-urban	2 571	Yes
	518638101	San Vicente	Urban	135	Yes

SOLAR RESOURCE REGION AND POWER AND ELECTRICITY DEMAND CHARACTERISATION FOR EACH DAIRY FACILITY

Table 34: Solar resource region and power and electricity demand characterisation for each dairy facility

DAIRY FACILITY	SITE	SOLAR RESOURCE REGION	AVERAGE POWER DEMAND (kW)	MAXIMUM POWER DEMAND (kW)	MINIMUM POWER DEMAND (kW)	TOTAL ELECTRICITY CONSUMPTION (MWh/year)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	San Julian	43	70	31	380
	5346709 – 5392451 5372072 – 5419144	San Julian	528	849	380	4 624
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	San Salvador	34	55	25	300
Lacteos del Corral, S.A. de C.V. (Lactosa)	519297501	San Salvador	699	1 125	504	6 126
	5404352 – 5452825	San Julian	24	39	17	212
Lacteos el Esfuerzo	1222347 – 1222347	San Julian	7	11	5	62
	1222350 – 1222350	San Julian	4	7	3	37
Lacteos Morazan	5253279 – 5286783	San Julian	0	0	0	1
Lacteos Stefany	515383601	San Salvador	9	15	7	80
	5487361 – 5540941	San Julian	5	8	4	43

Table 34: Solar resource region and power and electricity demand characterisation for each dairy facility *(continued)*

DAIRY FACILITY	SITE	SOLAR RESOURCE REGION	AVERAGE POWER DEMAND (kW)	MAXIMUM POWER DEMAND (kW)	MINIMUM POWER DEMAND (kW)	TOTAL ELECTRICITY CONSUMPTION (MWh/year)
Lactosa S.A. de C.V.	207045401	San Julian	31	49	22	268
Procesos Lacteos, S.A. de C.V.	502588701	San Salvador	9	15	7	81
	2500746 – 2500746	San Salvador	84	134	60	732
	2500877 – 2500877	San Salvador	5	9	4	47
	5007587 – 5007335	San Salvador	3	5	2	25
	5085781 – 5094137	San Salvador	10	17	8	91
Productos Lacteos Jerusalen	1240256 – 1240256	San Julian	2	3	1	14
Quesos de Metapan	5521234 – 5575859	San Julian	8	13	6	71
S.A. de C.V. Agrosania	1256273 – 1256273 1256276 – 1256276 5205297 – 5230736 5208571 – 5234538	San Julian	218	351	157	1 912
Sucesores Luis Torres (Quesos Petacones)	215772701	San Julian	66	106	48	579
	518638101	San Julian	19	31	14	167

TECHNICAL CHARACTERISTICS OF THE SOLAR PV SYSTEM DESIGNED FOR EACH DAIRY FACILITY

Table 35: Technical characteristics of the solar PV system designed for each dairy facility, space required and resulting annual parameters under the scenario where there are no space availability constraints

DAIRY FACILITY	SITE	SOLAR PV (kWp)	BATTERY STORAGE (80% DOD) (kWh)	SPACE REQUIRED FOR SOLAR PV (m^2)	ELECTRICITY CONSUMPTION (MWh/year)	ESTIMATED GENERATION SOLAR PV (MWh/year)	ELECTRICITY CONSUMED FROM GRID (MWh/year)	SOLAR PV ELECTRICITY SELF-CONSUMED (MWh/year)	SOLAR PV ELECTRICITY EXPORTED TO GRID (MWh/year)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	217	867	3 112	380	366	34	347	19
	5346709 – 5392451 5372072 – 5419144	2 639	10 557	37 901	4 624	4 452	418	4 224	227
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	171	684	2 457	300	287	28	273	14
Lacteos del Corral, S.A. de C.V. (Lactosa)	519297501	3 496	13 986	50 210	6 126	5 870	573	5 578	292
	5404352 – 5452825	121	483	1 734	212	204	19	193	10
Lacteos el Esfuerzo	1222347 – 1222347	35	142	509	62	60	6	57	3
	1222350 – 1222350	21	85	305	37	36	3	34	2
Lacteos Morazan	5253279 – 5286783	0	1	5	1	1	0	1	0
Lacteos Stefany	515383601	46	184	659	80	77	8	73	4
	5487361 – 5540941	24	98	351	43	41	4	39	2
Lactosa S.A. de C.V.	207045401	153	613	2 199	268	258	24	245	13

Table 35: Technical characteristics of the solar PV system designed for each dairy facility, space required and resulting annual parameters under the scenario where there are no space availability constraints *(continued)*

DAIRY FACILITY	SITE	SOLAR PV (kWp)	BATTERY STORAGE (80% DOD) (kWh)	SPACE REQUIRED FOR SOLAR PV (m^2)	ELECTRICITY CONSUMPTION (MWh/year)	ESTIMATED GENERATION SOLAR PV (MWh/year)	ELECTRICITY CONSUMED FROM GRID (MWh/year)	SOLAR PV ELECTRICITY SELF-CONSUMED (MWh/year)	SOLAR PV ELECTRICITY EXPORTED TO GRID (MWh/year)
Procesos Lacteos, S.A. de C.V.	502588701	46	185	664	81	78	8	74	4
	2500746 – 2500746	418	1 671	6 000	732	702	68	667	35
	2500877 – 2500877	27	108	386	47	45	4	43	2
	5007587 – 5007335	14	57	204	25	24	2	23	1
	5085781 – 5094137	52	209	750	91	88	9	83	4
Productos Lacteos Jerusalen	1240256 – 1240256	8	31	112	14	13	1	12	1
Quesos de Metapan	5521234 – 5575859	40	161	579	71	68	6	65	3
S.A. de C.V. Agrosania	1256273 – 1256273 1256276 – 1256276 5205297 – 5230736 5208571 – 5234538	1 091	4 365	15 671	1 912	1 841	173	1 747	94
Sucesores Luis Torres (Quesos Petacones)	215772701	331	1 323	4 749	579	558	52	529	28
	518638101	95	381	1 366	167	160	15	152	8

Note: DoD = depth of discharge; kWp = kilowatt peak.

Table 36: Technical characteristics of the solar PV system designed for each dairy facility, space required and resulting annual parameters under the scenario where the space availability is a constraint

DAIRY FACILITY	SITE	SOLAR PV (kWp)	BATTERY STORAGE (80% DOD) (kWh)	SPACE REQUIRED FOR SOLAR PV (m^2)	ELECTRICITY CONSUMPTION (MWh/year)	ESTIMATED GENERATION SOLAR PV (MWh/year)	ELECTRICITY CONSUMED FROM GRID (MWh/year)	SOLAR PV ELECTRICITY SELF-CONSUMED (MWh/year)	SOLAR PV ELECTRICITY EXPORTED TO GRID (MWh/year)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	128	n.a.	1 844	380	217	163	217	0
	5346709 – 5392451 5372072 – 5419144	628	n.a.	9 025	4 624	1 060	3 564	1 060	0
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	100	n.a.	1 443	300	169	131	169	0
Lacteos del Corral, S.A. de C.V. (Lactosa)	519297501	279	n.a.	4 000	6 126	468	5 658	468	0
	5404352 – 5452825	125	483	1 802	212	212	19	201	11
Lacteos el Esfuerzo	1222347 – 1222347	37	142	529	62	62	6	59	3
	1222350 – 1222350	16	n.a.	232	37	27	10	27	0
Lacteos Morazan	5253279 – 5286783	0	n.a.	0	1	0	1	0	0
Lacteos Stefany	515383601	48	184	688	80	80	8	76	4
	5487361 – 5540941	25	98	365	43	43	4	41	2
Lactosa S.A. de C.V.	207045401	159	613	2 284	268	268	24	255	14

Table 36: Technical characteristics of the solar PV system designed for each dairy facility, space required and resulting annual parameters under the scenario where the space availability is a constraint *(continued)*

DAIRY FACILITY	SITE	SOLAR PV (kWp)	BATTERY STORAGE (80% DOD) (kWh)	SPACE REQUIRED FOR SOLAR PV (m^2)	ELECTRICITY CONSUMPTION (MWh/year)	ESTIMATED GENERATION SOLAR PV (MWh/year)	ELECTRICITY CONSUMED FROM GRID (MWh/year)	SOLAR PV ELECTRICITY SELF-CONSUMED (MWh/year)	SOLAR PV ELECTRICITY EXPORTED TO GRID (MWh/year)
Procesos Lacteos, S.A. de C.V.	502588701	29	n.a.	413	81	48	33	48	0
	2500746 – 2500746	43	n.a.	613	732	72	660	72	0
	2500877 – 2500877	28	108	403	47	47	4	45	2
	5007587 – 5007335	15	57	213	25	25	2	24	1
	5085781 – 5094137	54	209	782	91	91	9	87	5
Productos Lacteos Jerusalen	1240256 – 1240256	8	31	116	14	14	1	13	1
Quesos de Metapan	5521234 – 5575859	12	n.a.	169	71	20	51	20	0
S.A. de C.V. Agrosania	1256273 – 1256273 1256276 – 1256276 5205297 – 5230736 5208571 – 5234538	134	n.a.	1 927	1 912	226	1 686	226	0
Sucesores Luis Torres (Quesos Petacones)	215772701	179	n.a.	2 571	579	302	277	302	0
	518638101	9	n.a.	135	167	16	151	16	0

HEAT DEMAND CHARACTERISATION FOR EACH DAIRY FACILITY

Table 37: Solar resource region and heat demand characterisation for each dairy facility

DAIRY FACILITY	SITE	SOLAR RESOURCE REGION	AVERAGE HEAT DEMAND (kW)	MAXIMUM HEAT DEMAND (kW)	MINIMUM HEAT DEMAND (kW)	TOTAL HEAT DEMAND (MWh/year)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	San Julian	71	164	25	622
	5346709 – 5392451 5372072 – 5419144	San Julian	865	1 995	309	7 575
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	San Salvador	56	129	20	491
Lacteos del Corral, S.A. de C.V. (LACTOSA)	519297501	San Salvador	1 146	2 643	410	10 035
	5404352 – 5452825	San Julian	40	91	14	347
Lacteos el Esfuerzo	1222347 – 1222347	San Julian	12	27	4	102
	1222350 – 1222350	San Julian	7	16	2	61
Lacteos Morazan	5253279 – 5286783	San Julian	0	0	0	1
Lacteos Stefany	515383601	San Salvador	15	35	5	132
	5487361 – 5540941	San Julian	8	18	3	70
Lactosa S.A. de C.V.	207045401	San Julian	50	116	18	440

Table 37: Solar resource region and heat demand characterisation for each dairy facility *(continued)*

DAIRY FACILITY	SITE	SOLAR RESOURCE REGION	AVERAGE HEAT DEMAND (kW)	MAXIMUM HEAT DEMAND (kW)	MINIMUM HEAT DEMAND (kW)	TOTAL HEAT DEMAND (MWh/year)
Procesos Lacteos, S.A. de C.V.	502588701	San Salvador	15	35	5	133
	2500746 – 2500746	San Salvador	137	316	49	1 199
	2500877 – 2500877	San Salvador	9	20	3	77
	5007587 – 5007335	San Salvador	5	11	2	41
	5085781 – 5094137	San Salvador	17	39	6	150
Productos Lacteos Jerusalen	1240256 – 1240256	San Julian	3	6	1	22
Quesos de Metapan	5521234 – 5575859	San Julian	13	30	5	116
S.A. de C.V. Agrosania	1256273 – 1256273 1256276 – 1256276 5205297 – 5230736 5208571 – 5234538	San Julian	358	825	128	3 132
Sucesores Luis Torres (Quesos Petacones)	215772701	San Julian	108	250	39	949
	518638101	San Julian	31	72	11	273

TECHNICAL CHARACTERISTICS OF THE SOLAR THERMAL SYSTEM DESIGNED FOR EACH DAIRY FACILITY

Table 38: Technical characteristics of the concentrated solar thermal system designed for each dairy facility, space required and resulting annual parameters under the scenario where there are no space availability constraints

DAIRY FACILITY	SITE	HEAT SINK POWER CAPACITY (kW_{th})	SOLAR THERMAL COLLECTOR CAPACITY (kW_{th})	VOLUME THERMAL STORAGE (m^3)	SPACE REQUIRED SOLAR THERMAL COLLECTOR FIELD (m^2)	HEAT DEMAND (MWh_{th}/year)	THERMAL ENERGY GENERATED (MWh_{th}/year)	THERMAL ENERGY SAVINGS (MWh_{th}/year)	THERMAL ENERGY SURPLUS (MWh_{th}/year)	THERMAL ENERGY SUPPLIED BY LPG BOILER (MWh_{th}/year)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	117	485	43	1,685	622	638	552	86	70
	5346709 – 5392451 5372072 – 5419144	1 430	5 905	527	20 523	7 575	7 771	6 725	1 047	850
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	93	383	34	1 331	491	491	426	64	65
Lacteos del Corral, S.A. de C.V. (Lactosa)	519297501	1 894	7 823	698	27 188	10 035	10 026	8 712	1 314	1 323
	5404352 – 5452825	65	270	24	939	347	356	308	48	39
Lacteos el Esfuerzo	1222347 – 1222347	19	79	7	276	102	104	90	14	11
	1222350 – 1222350	12	48	4	165	61	63	54	8	7
Lacteos Morazan	5253279 – 5286783	0	1	0	3	1	1	1	0	0
Lacteos Stefany	515383601	25	103	9	357	132	132	114	17	17
	5487361 – 5540941	13	55	5	190	70	72	62	10	8

Table 38: Technical characteristics of the concentrated solar thermal system designed for each dairy facility, space required and resulting annual parameters under the scenario where there are no space availability constraints *(continued)*

DAIRY FACILITY	SITE	HEAT SINK POWER CAPACITY (kW_{th})	SOLAR THERMAL COLLECTOR CAPACITY (kW_{th})	VOLUME THERMAL STORAGE (m^3)	SPACE REQUIRED SOLAR THERMAL COLLECTOR FIELD (m^2)	HEAT DEMAND (MWh_{th}/year)	THERMAL ENERGY GENERATED (MWh_{th}/year)	THERMAL ENERGY SAVINGS (MWh_{th}/year)	THERMAL ENERGY SURPLUS (MWh_{th}/year)	THERMAL ENERGY SUPPLIED BY LPG BOILER (MWh_{th}/year)
Lactosa S.A. de C.V.	207045401	83	343	31	1 191	440	451	390	61	49
Procesos Lacteos, S.A. de C.V.	502588701	25	103	9	360	133	133	115	17	18
	2500746 – 2500746	226	935	83	3 249	1 199	1 198	1 041	157	158
	2500877 – 2500877	15	60	5	209	77	77	67	10	10
	5007587 – 5007335	8	32	3	110	41	41	35	5	5
	5085781 – 5094137	28	117	10	406	150	150	130	20	20
Productos Lacteos Jerusalen	1240256 – 1240256	4	17	2	60	22	23	20	3	3
Quesos de Metapan	5521234 – 5575859	22	90	8	314	116	119	103	16	13
S.A. de C.V. Agrosania	1256273 – 1256273 1256276 – 1256276 5205297 – 5230736 5208571 – 5234538	591	2 441	218	8 485	3 132	3 213	2 780	433	352
Sucesores Luis Torres (Quesos Petacones)	215772701	179	740	66	2 571	949	974	843	131	107
	518638101	52	213	19	740	273	280	242	38	31

Table 39: Technical characteristics of the concentrated solar thermal system designed for each dairy facility, space required and resulting annual parameters under the scenario where there are space availability constraints

DAIRY FACILITY	SITE	HEAT SINK POWER CAPACITY (kW_{th})	SOLAR THERMAL COLLECTOR CAPACITY (kW_{th})	VOLUME THERMAL STORAGE (m^3)	SPACE REQUIRED SOLAR THERMAL COLLECTOR FIELD (m^2)	HEAT DEMAND (MWh_{th}/year)	THERMAL ENERGY GENERATED (MWh_{th}/year)	THERMAL ENERGY SAVINGS (MWh_{th}/year)	THERMAL ENERGY SURPLUS (MWh_{th}/year)	THERMAL ENERGY SUPPLIED BY LPG BOILER (MWh_{th}/year)
Cooperativa Ganadera de Sonsonate de R.L.	5116041 – 5128730	114	473	42	1,643	622	622	538	84	69
	5346709 – 5392451 5372072 – 5419144	629	2 597	0	9 025	7 575	3 417	3 417	0	4 158
Industrias Lacteos Moreno S.A. de C.V.	5145261 – 5161367	93	383	34	1 332	491	491	427	64	64
Lacteos del Corral, S.A. de C.V. (Lactosa)	519297501	279	1 151	0	4 000	10 035	1 475	1 475	0	8 560
	5404352 – 5452825	64	263	23	915	347	347	300	47	38
Lacteos el Esfuerzo	1222347 – 1222347	19	77	7	269	102	102	88	14	11
	1222350 – 1222350	11	46	4	161	61	61	53	8	7
Lacteos Morazan	5253279 – 5286783	0	0	0	0	1	0	0	0	1
Lacteos Stefany	515383601	25	103	9	357	132	132	114	17	17
	5487361 – 5540941	13	53	5	185	70	70	61	9	8
Lactosa S.A. de C.V.	207045401	81	334	30	1 161	440	440	380	59	48

Table 39: Technical characteristics of the concentrated solar thermal system designed for each dairy facility, space required and resulting annual parameters under the scenario where there are space availability constraints *(continued)*

DAIRY FACILITY	SITE	HEAT SINK POWER CAPACITY (kW_{th})	SOLAR THERMAL COLLECTOR CAPACITY (kW_{th})	VOLUME THERMAL STORAGE (m^3)	SPACE REQUIRED SOLAR THERMAL COLLECTOR FIELD (m^2)	HEAT DEMAND (MWh_{th}/year)	THERMAL ENERGY GENERATED (MWh_{th}/year)	THERMAL ENERGY SAVINGS (MWh_{th}/year)	THERMAL ENERGY SURPLUS (MWh_{th}/year)	THERMAL ENERGY SUPPLIED BY LPG BOILER (MWh_{th}/year)
Procesos Lacteos, S.A. de C.V.	502588701	25	104	9	360	133	133	115	17	17
	2500746 – 2500746	43	176	0	613	1 199	226	226	0	973
	2500877 – 2500877	15	60	5	209	77	77	67	10	10
	5007587 – 5007335	8	32	3	111	41	41	35	5	5
	5085781 – 5094137	28	117	10	406	150	150	130	20	19
Productos Lacteos Jerusalen	1240256 – 1240256	4	17	2	59	22	22	19	3	2
Quesos de Metapan	5521234 – 5575859	12	49	0	169	116	64	64	0	52
S.A. de C.V. Agrosania	1256273 – 1256273 1256276 – 1256276 5205297 – 5230736 5208571 – 5234538	134	554	0	1 927	3 132	730	730	0	2 402
Sucesores Luis Torres (Quesos Petacones)	215772701	175	721	64	2 506	949	949	821	128	105
	518638101	9	39	0	135	273	51	51	0	222

ANNEX

TECHNOLOGY READINESS LEVELS FOR RENEWABLE ENERGY SYSTEMS

The technology readiness level (TRL) index is a globally accepted benchmarking tool for tracking progress and supporting the development of a specific technology from basic technology research (TRL1) to actual system demonstration under all expected conditions (TRL9). In this context, Table 40 presents a typical scale that serves for renewable energy technologies.

Table 40: Technology readiness levels

LEVEL	CHARACTERISTICS
1	**Basic principles observed and reported** – Identification of the new concept, expected barriers, applications, materials and technologies based on theoretical fundamentals/literature data.
2	**Technology concept and/or application formulated** – Enhanced knowledge of technologies, materials and interfaces is acquired, evaluation about the feasibility, Initial numerical knowledge.
3	**Analytical and experimental proof of concept** – Proof of concept validation. Key parameters characterising the technology (or the fuel) are identified.
4	**Technology validated in lab** – Standalone prototyping implementation and test (reduced scale).
5	**Technology validated in relevant environment** – Integration of components with supporting elements and auxiliaries in the (large-scale) prototype. Other relevant parameters concerning scale-up, environmental, regulatory and socio-economic issues are defined and qualitatively assessed.
6	**Technology pilot demonstrated in relevant environment** – Demonstration in relevant environment of the technology fine-tuned to a variety of operating conditions. Environmental, regulatory and socio-economic issues are addressed.
7	**System prototyping demonstration in an operational environment** – (Full-scale) pre-commercial system is demonstrated in operational environment. Manufacturing approach is defined.
8	**System complete and qualified** – Technology experimented in deployment conditions (i.e. real world) and has proven its functioning in its final form. Full compliance with obligations, certifications and standards of the addressed markets.
9	**Actual system proven in operational environment** – Technology proven fully operational and ready for commercialisation. Full production chain is in place and all materials are available. System optimised for full rate production.

Source: De Rose, A. et al. (2017).

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