A new mix of power for the ESO installations in Chile: greener, more reliable, cheaper.

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ABSTRACT

The highest sky quality demands for astronomical research impose to locate observatories often in areas not easily reached by the existing power infrastructures. At the same time, availability and cost of power is a primary factor for sustainable operations. Power may also be a potential source for CO2 pollution. As part of its green initiatives, ESO is in the process of replacing the power sources for its own, La Silla and Paranal-Armazones, and shared, ALMA, installations in Chile in order to provide them with more reliable, affordable, and smaller CO2 footprint power solutions. The connectivity to the Chilean interconnected power systems (grid) which is to extensively use Non-Conventional Renewable Energy (NCRE) as well as the use of less polluting fuels wherever self-generation cannot be avoided are key building blocks for the solutions selected for every site. In addition, considerations such as the environmental impact and - if required - the partnership with other entities have also to be taken into account. After years of preparatory work to which the Chilean Authorities provided great help and support, ESO has now launched an articulated program to upgrade the existing agreements/facilities in i) the La Silla Observatory, from free to regulated grid client status due to an agreement with a Solar Farm private initiative, in ii) the Paranal-Armazones Observatory, from local generation using liquefied petroleum gas (LPG) to connection to the grid which is to extensively use NCRE, and last but not least, in iii) the ALMA Observatory where ESO participates together with North American and East Asian partners, from replacing the LPG as fuel for the turbine local generation system with the use of less polluting natural gas (NG) supplied by a pipe connection to eliminate the pollution caused by the LPG trucks (currently 1 LPG truck from the VIII region, Bio Bio, to the II region, ALMA and back every day, for a total of 3000km). The technologies used and the status of completion of the different projects, as well as the expected benefits are discussed in this paper.

Keywords: power supply, Observatories in Chile, power transmission line, photovoltaic power plant, green energy, lower CO2 footprint, gas pipeline, environmental study, NCRE.

1. INTRODUCTION

The need to locate observatories often in areas not easily reached by existing power infrastructures often results in the decision to build local generation facilities. Either way, whether locally generated or from the grid, power is a main line in the Observatories' budgets as well as one of the main contributor to, among other elements, CO2 pollution.

The global landscape for energy has changed considerably over the last 20 years. As energy prices are increasing and vary unpredictably, ESO has been keen to look into ways to control its energy costs and also limit its ecological impact. The organization has already managed to successfully reduce its power consumption at La Silla, and despite the additions of the VISTA and VST survey telescopes, power use has remained stable over the past few years at the Paranal Armazones Observatory, site of the VLT. For ALMA, the actual power consumption in operation is lower than anticipated during the design phase, mostly due to optimizations in the antenna power consumption. Despite this, reducing cost and environmental impact of power consumption is still a key priority.

As such, and according to one of the goals set in its green initiatives [2], namely "To have a strategy that supports reducing costs, lowering complexity, and increasing operating and energy efficiency", ESO is undertaking the following projects:

- An agreement with industry that allows to feed the La Silla Observatory with solar power (section 2);
- The connection of the Paranal Armazones Observatory to the Chilean grid (section 3);
- On behalf of the ALMA partnership, the provisioning of Natural Gas (NG) to the ALMA Observatory via a gas pipeline (section 4).

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The above projects aim to provide to the Observatories power sources that have acceptable reliability, are more affordable, and have smaller CO2 footprint. The expected/achieved benefits are discussed in section 5.

2. LA SILLA PHOTOVOLTAIC PLANT

The ESO La Silla Observatory (LSO) is located at the outskirts of the Chilean Atacama Desert, 600 km north of Santiago de Chile and at an altitude of 2400 meters. The favorable conditions that made the site attractive by night for astronomy are also defining the site as a very good location for solar power installations.

For many years ESO tried to find a provider that could deliver energy at regulated price and be released from the stress of searching a provider, this also, thanks to the SEC (Superintendencia de Electricidad y Combustibles) recognized condition of regulated customer that LSO has. Unfortunately no company was available to do so. The only way was to find a generator, i.e., a company producing energy, and that originated the agreement which ESO signed in July 2014 with the Chilean company, Astronomy and Energy (at the time a subsidiary of the Spanish LKS Group, but now part of ENEL Green Power, EGP), to install a solar farm at the LSO location. The agreement allowed the construction of a solar farm within the ESO territory and the use of the existing medium voltage line between the Observatory and the Chilean power grid in exchange of provision of energy at a better, more stable price (regulated price defined by Chilean Authorities, versus free market price) and the covering of the maintenance and operations of the line. This made up for the cost reduction goal, providing a 40% savings in the yearly power budget line. From the environmental point of view the agreement allows the La Silla Observatory to replace energy from the grid, coming from a mix of generation sources, to 100% solar energy during day time.

The construction work for the solar farm started in December 2015 and was completed in May 2016 (Figure 1).

Figure 1: From bare land to solar farm

The solar plant, named also La Silla in honor to the nearby observatory, has an installed capacity of 1.7MW. The installation covers an area of approximately 100 000 m2, at about 5 km from the Observatory and it is intended not only to produce energy, but also to test new technologies. Indeed the whole surface is divided in three areas where three different types of panel technologies are used and compared (see Figure 2):

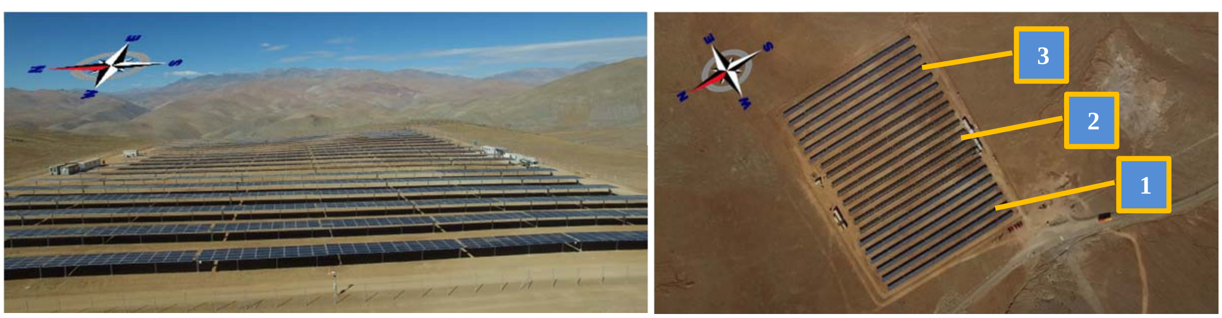

Figure 2: The solar farm is divided into three areas with different type of modules.

- The first section is build using normal poly crystalline modules. This section is used as reference benchmark for the other two.

- The second section is built using high efficiency bifacial monocrystalline N-type photovoltaic modules, i.e., panels with active surface on both sides. This allows a higher efficiency as also the radiation reflected from the ground is used to produce energy. To front side production, the rear side is expected to add another 15 to 30%, depending on the reflectance of the ground surface. It is not foreseen to change the natural surface reflection by adding special material, like white sands.
- The third section is done using traditional panels, but equipped with advanced electronics (SMART panels) that allows managing the loss of power due to the mismatch in the level of generation of a single panel or among various panels due to shading, soiling, aging, temperature gradients, and more. The Smart Module should be able to solve these problems and allowing an increase of productivity up to 20% more energy with respect to traditional panels.

No matter the type of panel, they are organized in rows with alignment North-South. Each row is made by sets of 4x9 panels. Each set is mounted on a motorized axis that allows the structure to tilt east-West in order to optimally position the panel surface against the sun during the day from sunrise to sunset (tracking) increasing the efficiency of generation. The spacing between the rows is calculated to minimize the shade from one row to the next. Figure 3 provides some details of the construction of the solar farm.

Figure 3: The structure sustaining the panel with the rotating table and a detail of the bifacial modules..

The cabling connecting the panel rows delivers the direct current generated in the panels to the electronics converting it into alternate power that is then changed with a transformer to the voltage level needed to be delivered to the already existing medium voltage line (23kV) that connects the LSO to the grid (Figure 4).

Figure 4: Inverters, transformer, and connection to 23kV medium voltage line.

The installation is completed by the control system for the tracking, the weather monitor, safety systems like cameras and perimeter beams, physical fence, connection to the line, communication system for remote control and operations. Some examples of such systems are given in Figure 5.

Figure 5: Tracking control, sun and weather station, perimeter security, communication and support installations.

The plant is intended to be operated as unmanned installation and has no illumination during night, to be compatible with the requirement of the close-by La Silla Observatory.

3. PARANAL POWER LINE TO GRID

The ESO Paranal Armazones Observatory (PAO) is located in the Chilean Atacama region, on the coastal ridge, about 1000 km north of Santiago de Chile and at an altitude of 2600 meters. The PAO hosts the ESO VLT/VLTI as well as the VISTA and VST survey telescopes. In the nearby Cerro Armazones, ESO has started the construction of the E-ELT, which will belong to the Paranal Armazones Observatory. Currently the power demand is met by a local generation plant using a Multi Fuel Gas Turbine and Liquefied Petroleum Gas (LPG) as fuel. The LPG is delivered by truck to the observatory from refineries that are up to 1500km away.

In collaboration with the Chilean authorities, in 2013 a study[1] was carried out to assess the possibility to use NCRE for the Paranal and future E-ELT installation. The recommendation was that “the development of a transmission line (*to the existing grid*) would satisfy the primary system goal, which is to facilitate astronomic observation in a more reliable, cost effective, and environmentally friendly manner. Therefore the decision was taken to explore the possibility to connect the PAO area to the Chilean interconnected power systems, where non-conventional renewable energy sources are going to constitute an ever-growing share of the power and energy mixes.

After an open call for tender that ended in an unsuccessfully way, followed by dedicated searches with the companies operating in the area and not, the company SAESA (Sociedad Austral de Electricidad SA) expressed their interest in performing an investment to extend the grid line and to supply ESO at regulated price.

The Chilean grid system is still divided into two main areas: the SING (Sistema Interconectado Norte Grande), that serves from Arica to Antofagasta, and the SIC (Sistema Interconectado Central), that serves from south of Antofagasta to the Chiloe island. The SIC handles 79% of the total national electricity and the SING does 20%. The remaining 1% is made up by small local grids in the southernmost areas. Although there is already in construction the connection between SING and SIC, at the time of writing, the two are disconnected.

Paranal is mid-way of the no-grid-land and the closest grid is the northern end of the SIC at the Paposo town. The location of the new lines to connect to the Chilean grid the Paranal and Armazones area is shown in Figure 6.The project foresees the following main items:

- The 220/66 kV Paranal substation to be built to the side of the Paposo 220 kV substation, to connect to the SIC transmission system.
- The 66kV line (~45km) from the Paposo area to the ESO area.
- The 66/23 kV Armazones substation that ends the main line and from where the final distribution lines start.
- The 23kV line (~11km) to the Paranal base camp, that will feed also the VLT/VLTI, VST, and VISTA,
- The 23 kV line (~13km) to the Cerro Armazones, where the E-ELT will operate.

[1] “ESTUDIO DE MEJORA ENERGETICA CON ERNC EN OBSERVATORIO PARANAL” by inodú

Both the 66kV and the 23kV lines will use overhead construction, using some steel towers and some concrete poles for the 66kV, according to the local geological shape and concrete poles for the 23kV ones.

Both the lines and the substations will be built by a Chilean company specialized in power transmission and distribution.

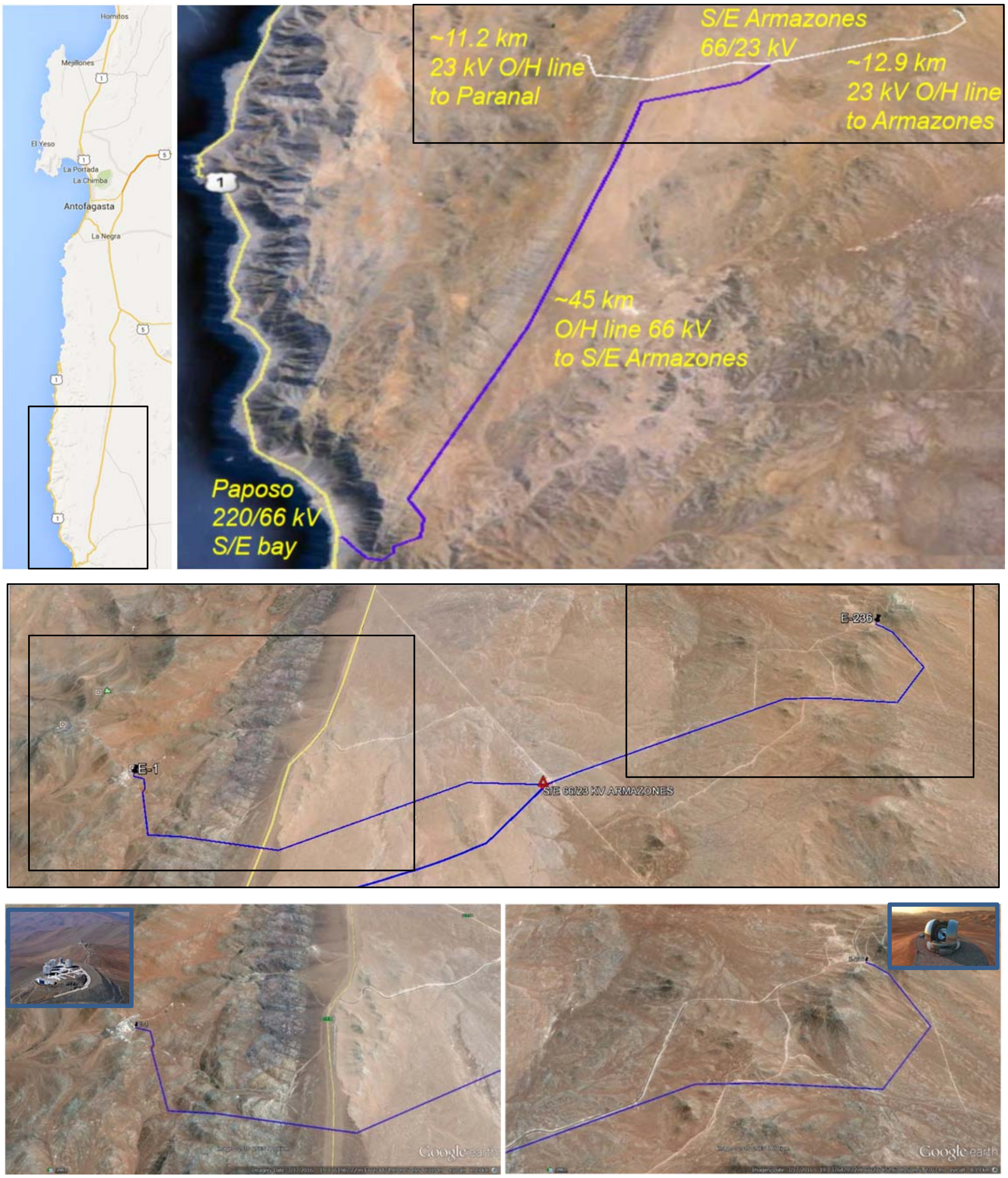

Figure 6: Detailed view of the lines in the ESO area.

The project has already completed successfully the environmental analysis and the procurement of long lead items, like the transformers (Figure 7).

Figure 7: The 220/66kV and 66/23kV transformers and other material for the grid connection.

The construction is expected to be completed by July 2017, in time for the start of the EELT construction activities at the Cerro Armazones site.

Once in operation, it is expected that the PAO budget line for power will be reduced by 20 to 30%, part of this will also come from the operational savings due to less people having to follow up on the power generation system. On the environmental side, the accessibility to grid means replacing LPG locally produced electricity with the one from the grid, which thanks to the NCRE component has a lower environmental footprint.

4. ALMA NATURAL GASGAS PIPELINE

In addition to the initiatives already described in the previous sections, that take place in the ESO Observatories, ESO is also leading the possible implementation of a gas pipeline for the ALMA Observatory [3] on behalf of the ALMA partnership with its North American and East Asian partners. The ALMA Observatory is located in the Atacama Desert, in the Northern part of Chile, close to San Pedro de Atacama with the ALMA Operations Support Facility (OSF) at an altitude of 2900m and the radio antennas at an altitude at 5000m. The current power generation system for ALMA, located at the OSF, consists of three Multi-Fuel Gas Turbines (MFGT) of 3.75 MW each (see Figure 8), using mainly LPG fuel. ALMA consumes about 20 GWh per year.

Figure 8: The ALMA power generation system consisting of three multi-fuel turbines.

In the case of ALMA, neither the connection to the grid (the closest presence of the grid is the SING in Calama, about 150km away) nor a pure solar installation (without connectivity to the grid, the cost for energy storage would be prohibitive) are at present viable solutions. At the same time, the presence of a main gas pipeline (Gasoducto Nor Andino[2]) in San Pedro offers an alternative. The economic analysis made by ESO indicated that the cost of construction of a pipeline to San Pedro could be offset over not too many years with the savings due to the lower cost of the NG with respect to the LPG.

With that in mind, a project to build a gas pipeline from where NG can be tapped from the main gas pipeline close to San Pedro de Atacama and the ALMA OSF installation at 3000m was started. In addition to the lower emissions that are characteristic for the NG with respect to other fossil fuels, the use of a pipeline for the transport also eliminates the negative effects, and accident risks, caused by the LPG trucks traffic, currently 1 LPG truck from far away refineries to the II region, ALMA OSF (Operation Site Facility) and back every day, for a total of 3000km. The gas-pipeline also removes the daily risk of LPG refilling human or technical errors from the truck to the tank.

The layout of the pipeline was selected to minimize the environmental impact by closely following existing roads, instead of taking the shortest cut. From the existing Nor Andino gas pipeline, the new construction will follow first the public road 23-CH for about 10km to the ALMA gatehouse, towards the town of Toconao, then for another 15km the private access road to the ALMA OSF where the generation plant is located (see Figure 9). In May 2016, the required Environmental Impact Study has been submitted to the Chilean authorities, and according to the current plan, construction completion is expected during 2018.

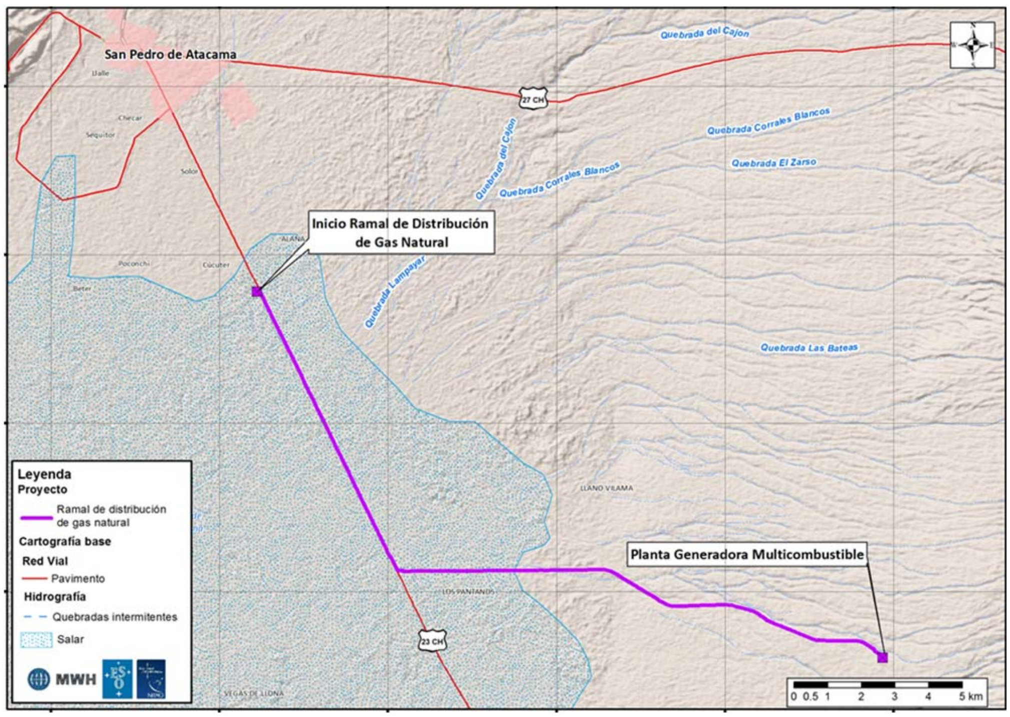

Figure 9: Layout of the projected pipeline

[2] Actually, this pipeline was built in the late 1990s to transport the gas extracted in the the Bolivian and Argentinian gas fields to the Mejillones harbor, on the Chilean Pacific coast, for export. Nowadays it is used in the other direction, with tankers shipping Liquefied NG (LNG) from North America, Australia and other countries, to the regasification plant in the harbor and the gas flowing in the direction of the Andes.

The project has the following key elements:

- "Estación de Medición y Regulación" (EMR): station at the beginning of the pipeline in charge of the pressure regulation from the main gas pipeline (70 to 90 bar) to the one used in the "new" pipe (35 bar). Also, this equipment will contain the meter that will indicate the consumption and an odorant agent will be added to the gas so that it can be detected by humans in case of leakage (NG is basically methane and has no smell).
- 25km of piping installed underground.
- Four intermediate valves to allow to separately close sections of the pipeline (for maintenance/repair reasons).
- The connection to the three MFGT at the ALMA OSF.

One of the key elements of the new system is the use of reinforced polymeric pipe. This is made of High Density Polyethylene (HDPE) reinforced with the use of carbon fibers (Figure 10). With respect to traditional steel pipe, this technology offers:

- A faster installation as it comes in reels of 1500m, requiring much fewer connections than a line using 12m segments of steel pipe;
- Being flexible, it allows to easily follow the ground and to avoid natural objects, like protected trees or cacti, and other obstacles, like archeological areas.

Figure 10: The reinforced polymeric pipes, the installation method, and pipe-to-pipe and pipe-to-other connections.

Another important aspect of the project has been the preparation of the Environmental Impact Study or EIA (Estudio de Impacto Ambiental) that ESO has submitted to the Chilean Authorities in May 2016. As part of this, the existing conditions in terms of natural and human environments have been analyzed. This covers: air quality, noise, vibrations, soil, geomorphology, landscape, natural or cultural attractions, use of the territory, protected areas, biotic environment, archeology. Against this baseline, one has to qualify and quantify the impact that the new project will have to any of the mentioned components. Impacts that are classified as relevant have to be tackled in order to either reduce or mitigate or compensate them. Figure 11 shows two moments of the environmental impact study preparation: meeting with a local community to explain the project, and capturing a bat to identify the species living in the area that will be affected by the project in the construction phase.

Figure 11: Two moments of the preparation of the environmental impact study: meeting with the local communities and census of the fauna (a bat in this case).

5. EXPECTED/ACHIEVED ENVIRONMENTAL BENEFITS

The three projects described in the previous sections are quite different and contribute different types of benefits. What connects all of them is that after being implemented, the emission footprint of the three Observatories, LSO, PAO, and ALMA, will be lower.

In the case of LSO the comparison is rather easy: between the use of grid energy from the SIC up to May 2016 versus the 100% solar during daytime from the solar farm, from that date. According to [5], the average emission for the production of the energy of the SIC was in 2015 0.346tCO2eq/MWh. This takes into account that for the SIC around 43% is renewable energy, namely 29% hydro and 13% NCRE[3]. The LSO consumes yearly about 3 GWh corresponding to 1038tCO2eq. The new solar farm yearly production is about 4700MWh. This is enough to fully offset the LSO during daytime (that for simplicity is considered 50% of the total) and still leaves a relevant amount of energy to be delivered to the SIC. A calculation provided by EGP indicates that the solar farm production is equivalent to the consumption of approximately 2000 households. This improvement has been already delivered, as the solar farm is in operation since May 2016.

In the case of PAO, the current and projected energy need is indicated in Figure 12, with an average of 10GWh/year for the Paranal installation (VLT, VISTA, etc.) that will ramp up over the next 8 to 10 years to about 35GWh/year to cover the needs of the construction and later operations of the E-ELT at the Cerro Armazones site.

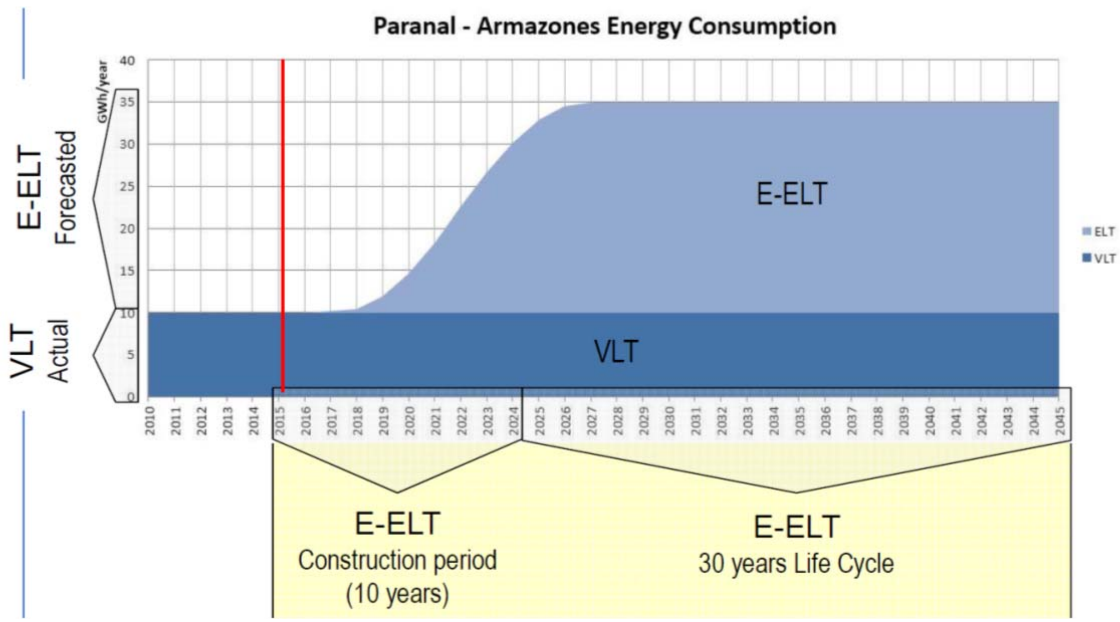

Figure 12: Current and projected energy demand for Paranal and Armazones installations.

For PAO, one has to compare the generation of power using LPG versus the use of SIC grid power. In this case it is also relevant to look at how the mix of power of the SIC will evolve. Green energy is strongly supported by the Chilean government. The new Chilean Energy Policy (called 2050) has a target of 60% of the grid energy coming from renewable sources by the year 2035, and 70% by 2050. While today the law imposes a minimum of 20% of NCRE by 2025. For simplicity: it is assumed that PAO has the same transfer rule as ALMA for LPG generation (0.745tCO2/MWh) and that CO2=CO2eq (that means ignoring the greenhouse effect that other gasses have and considering only the CO2). For the SIC it is assumed the 2015 mix (as indicated for the LSO case, namely 0.346tCO2eq/MWh), and not the future reduction that will be due to the increased NCRE contribution that has been announced by the Chilean government. The comparison is in Table 1.

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[3] According to the April 2016 “Reporte Mensual Sector Energético” from the Comisión Nacional de Energía (CNE) [4]

Table 1: Comparison of CO2 emission for PAO between LPG generated energy and energy from the grid

	2016	2017	2025
PAO GWh/year	10	10	35
tCO2 using LPG	7 450	7 450	26 075
tCO2eq using SIC	-	3 460	12 110
Reduction/year	-	3 990	13 965

For the ALMA case, replacing LPG with NG as fuel will result in a reduction of CO2 as NG has approximately 16% less CO2 emission as compared to LNG[4]. The current (and for the moment projected) energy need of ALMA is 22 GWh/year, which, considering the ALMA gas turbines efficiency in their current operation, corresponds to about 260 000 MMBtu of fuel energy per year. Table 2 provides the comparison in terms of absolute value between operating the turbines with LPG and with NG. NG is also better for other gasses like NOx.

Table 2 Comparison CO2 production for LPG and NG operations

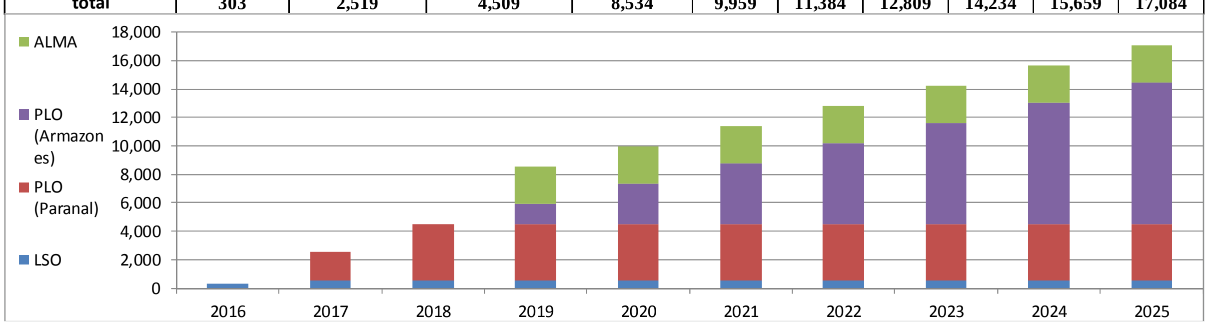
	GWh/year	MMBtu/year	KgCO2/MMBtu	tCO2/year
Natural Gas (NG)	22	260,000	53.07	13,798
Propane Gas (LPG)	22	260,000	63.07	16,398

In Table 3 all contributions in terms of CO2 reduction are summed up over the next 10 years. The assumptions are:

- for PAO it is assumed that the line will arrive mid-2017 and that from 2019 there will be a linear ramp up due to the start of the EELT construction, up to the operational level;
- for ALMA it is assumed the pipeline will arrive in 2018.

Table 3: expected CO2 reduction in t/year as consequence of the implementation of the planned projects

	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
LSO	303	519	519	519	519	519	519	519	519	519
PLO (Paranal)	0	2,000	3,990	3,990	3,990	3,990	3,990	3,990	3,990	3,990
PLO (Armazones)	0	0	0	1,425	2,850	4,275	5,700	7,125	8,550	9,975
ALMA	0	0	0	2,600	2,600	2,600	2,600	2,600	2,600	2,600
total	**303**	**2,519**	**4,509**	**8,534**	**9,959**	**11,384**	**12,809**	**14,234**	**15,659**	**17,084**



[4] According to Table A.3. Carbon Dioxide Uncontrolled Emission Factors from US Energy Information Agency (EIA) [6]

Other environmental benefits are:

- In the case of PAO and ALMA the benefits both in terms of lower emissions and less overall risks that one can achieve by avoiding the LPG delivery by trucks.
- In the case of PAO, the creation of the transmission line could foster ESO to install new NCRE facilities improving the overall energy mix.
- For all cases, a reduction in CO2 means also reductions in other greenhouse gasses.

6. CONCLUSION

When all described project will be implemented, the ESO contribution to Astronomy will be more environmentally friendly and more affordable, implementing the initial vision

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