Energy provisioning for the ESO Observatories in Chile

Roberto Tamai

ESO’s ELT Programme Manager

AGENDA

- ESO at glance
  - History, mission, facts sheet
  - Observing sites in Chile
- Electrical Power needs and strategy
- Timeline 2010-2022
  - La Silla
  - Paranal(VLT) - Armazones(ELT)
  - ALMA
  - CTA-S
- Effect on CO2 reduction
- Future Steps

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Establishment of ESO

- 1962
  - Intergovernmental Organisation created by 5 European Countries to build a large telescope, the 3.6m Telescope at La Silla Observatory, in the Southern Hemisphere
- Today: 16 Member States
  - Last: Poland (2015) and Ireland (28 Sep 2018)
  - 10-year partnership with Australia in La Silla Paranal programme signed in 2017
  - Brazil and ESO signed accession agreement in 2010, but accession process incomplete. BR not a member of ESO, but welcome to join/renegotiate at any stage
  - Chile is host country for the Observatories, but not a Member State

The ESO Mission & Strategy

- Mission:
  - Enabling major scientific discoveries by constructing and operating powerful ground-based observational facilities that are beyond the capabilities of individual member states
  - Fostering international cooperation in astronomy
- Strategy (in collaboration with scientists, institutes and industry)
  - Implement and operate the ELT as the world-leading extremely large telescope
  - Ensure that the current facilities remain at the forefront of astronomical investigations
  - Ensure that the Organisation is prepared for future projects when financial projections so permit
  - Retain ESO's leadership role in astronomy
- Goals:
  - Scientific discoveries & understanding of the Universe
  - Development of new technologies, impact in economy, international cooperation
  - Complementing other ground & space facilities

ESO today

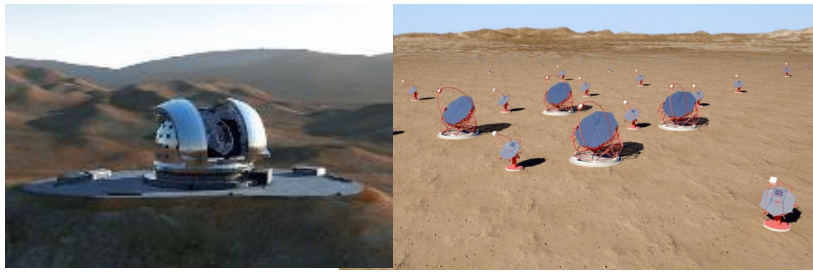
- Staff: total c.a. 800, Annual
- Budget: ~ 200 M€ (based on national income)
- Headquarters in Munich Area, Germany, offices in Santiago, Chile
- Observatories in Chile:

La Silla,
Paranal,
APEX(in partnership),
ALMA (in partnership)

(Under construction)

E-ELT on Armazones

CTA-S (as hosted project)



How are we organised to build it

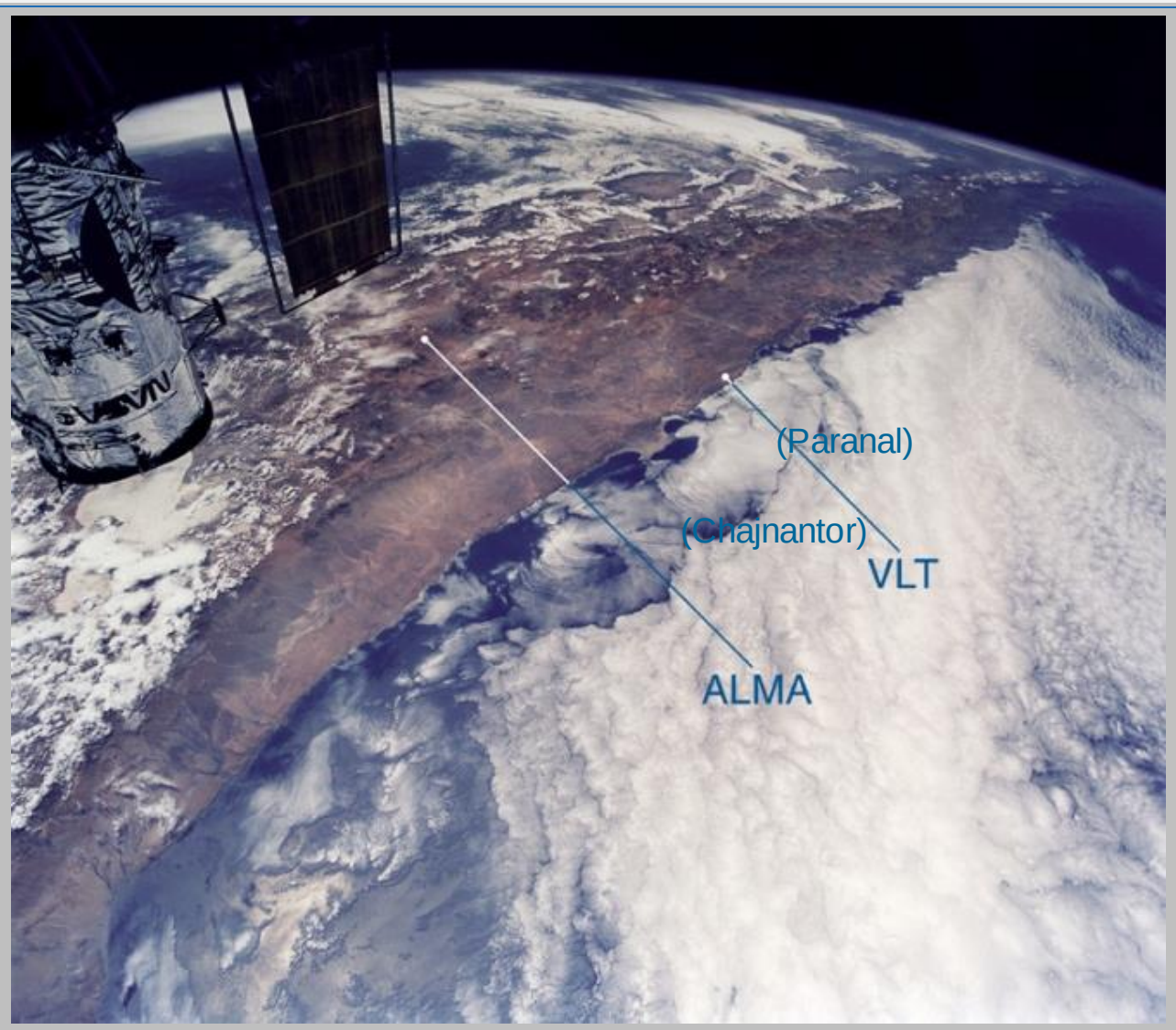
- **ESO** as “Prime” or “**System Architect**”
  - Defines the top-level scientific and technical requirements
  - Develops the system (observatory) concept and subsystem requirements
  - Subcontracts to (ESO Member States) industry for the construction
  - Assembles the subsystems together on-site (AIV)
- **ESO Member States Industry**
  - Detailed design and manufacturing of the subsystems based on requirements following competitive Call-for-Tenders
- Consortia of **Scientific Institutes**
  - Detailed design and manufacturing of the scientific instruments based on (collaborative) agreements

Why the ESO Observatories are in Chile?

- Excellent conditions in the Atacama Desert
  - Extremely dry
  - 90% clean sky
  - Low turbulence
  - Very limited light pollution
- Excellent vision to the Southern Hemisphere

Poor site

Chile



ESO and Chile

- First agreement signed in 1963, renewed 1995
  - Based on ”giving” observing time and funds to Chile in exchange for land and privileges
  - International Treaty of ESO fully recognized and endorsed by Chile
- At present: excellent relations with Chilean Government
- Both ESO and Chile agreed to discuss the future of the mutual relationship
  - Explore more cooperative approaches, particularly in engineering and technical areas.
  - Potential areas of mutual interest around industry 4.0: smart engineering, predictive maintenance, intelligent logistics, automatization, big data management and processing, machine learning and artificial intelligence.
- Possible membership put forward in 2012, but not progressed

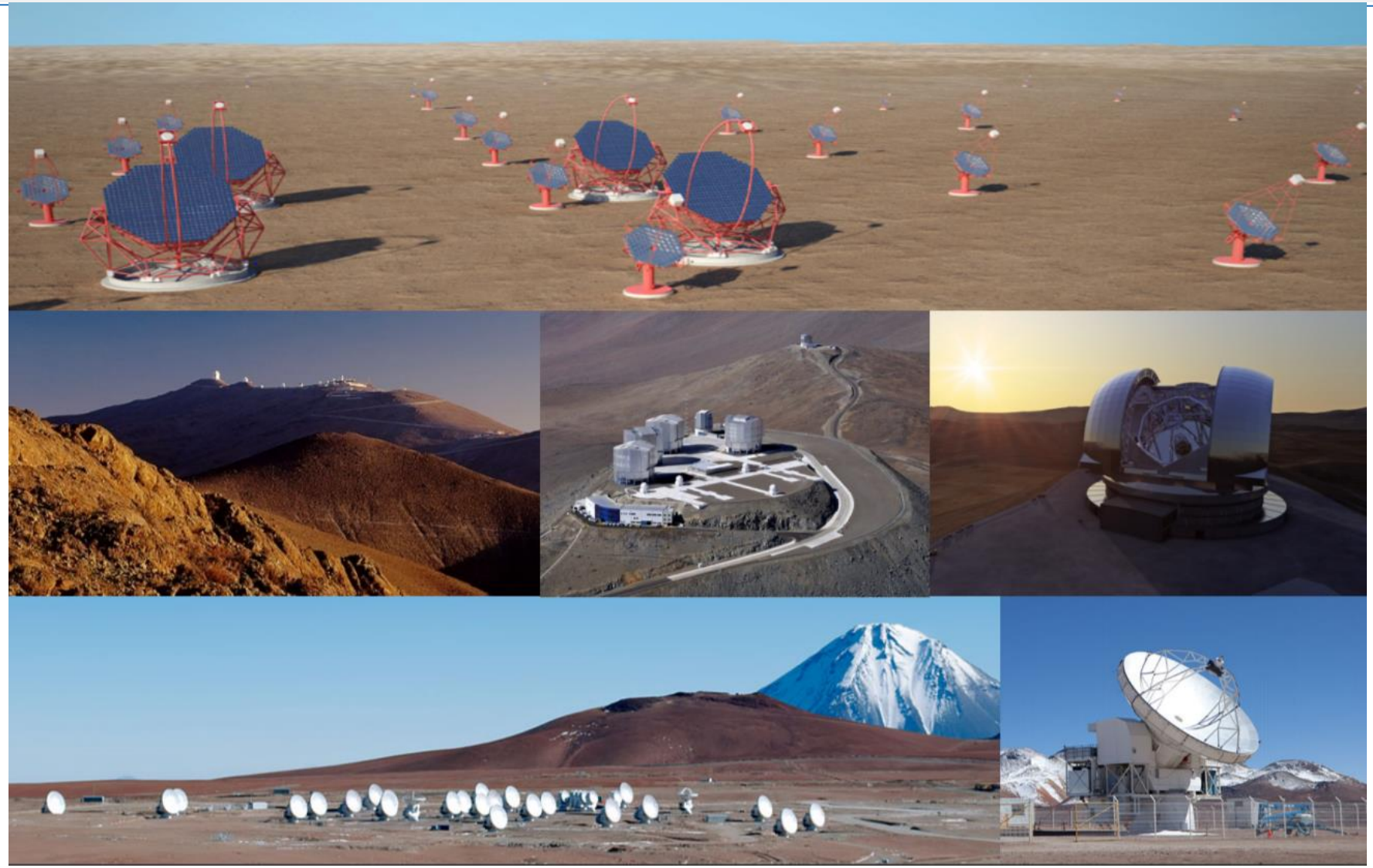
Support from Chilean Government

Support to ESO from the Chilean Government, triggered by the E-ELT Project, has been materializing as background information, guidance and written communications from Chilean Ministries and Governmental Agencies such as

- **Ministerio de Relaciones Exteriores de Chile**
  (Ministry of Foreign Affairs);
- **Ministerio de Energía de Chile**
  (Ministry of Energy);
- **Comisión Nacional de Energía de Chile** (CNE),
  responsible for policy-setting;
- **Superintendencia de Electricidad y Combustibles de Chile** (SEC), responsible for regulation;
- **Ministerio de Bienes Nacionales de Chile** (BBNN), responsible for Public Land.

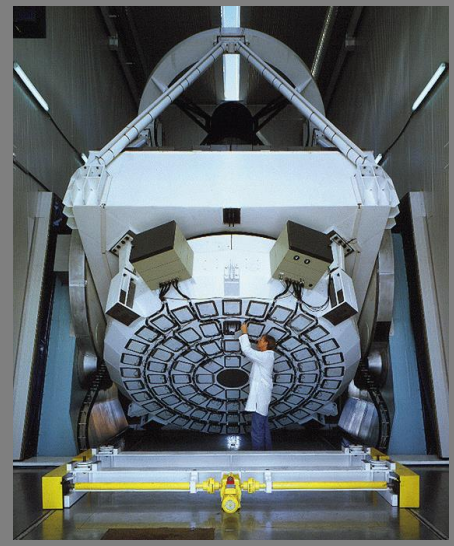
This has dramatically increased ESO's understanding about the possibilities of optimising the power supply to its Observatories.

ESO programme landscape

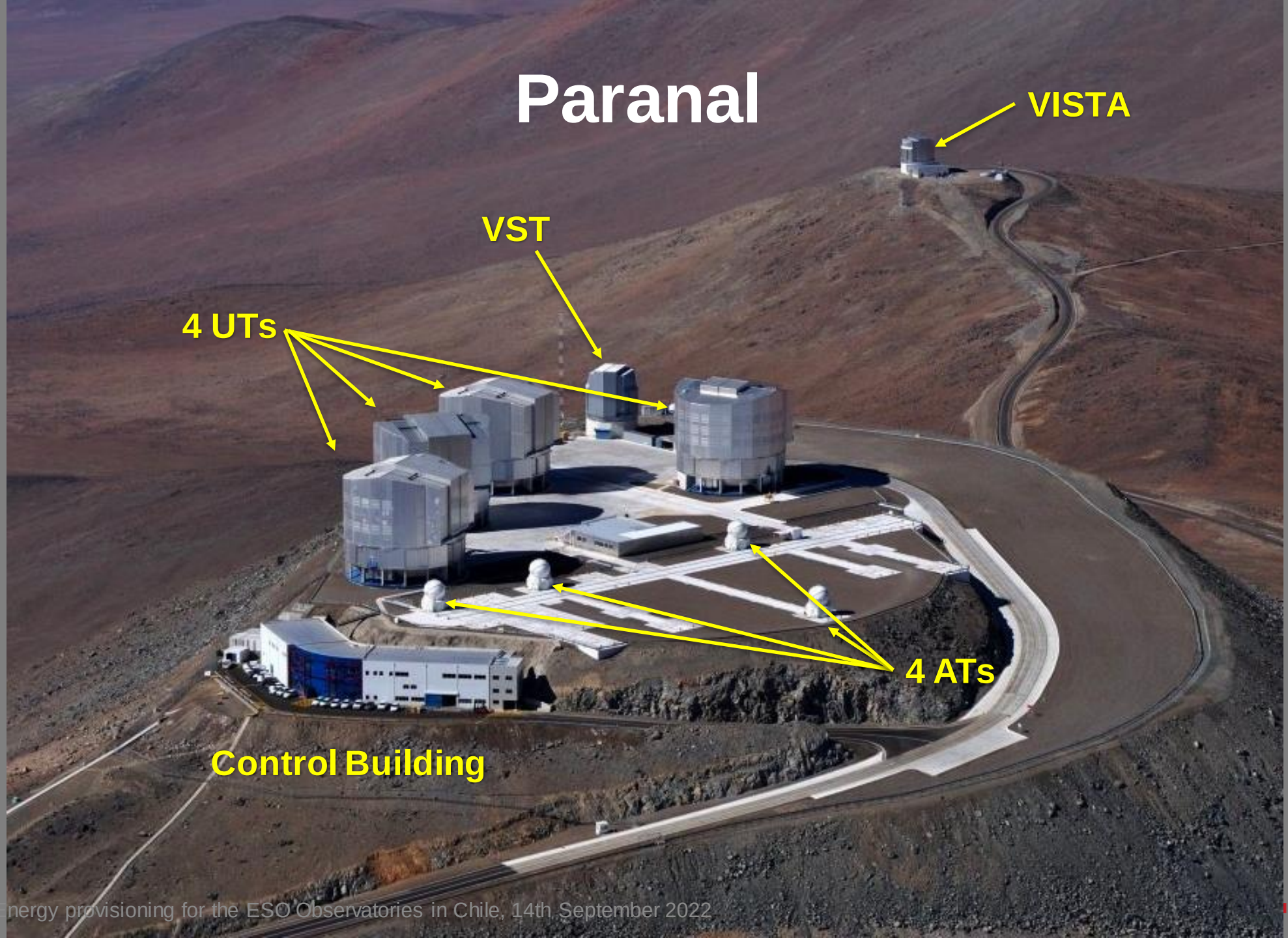


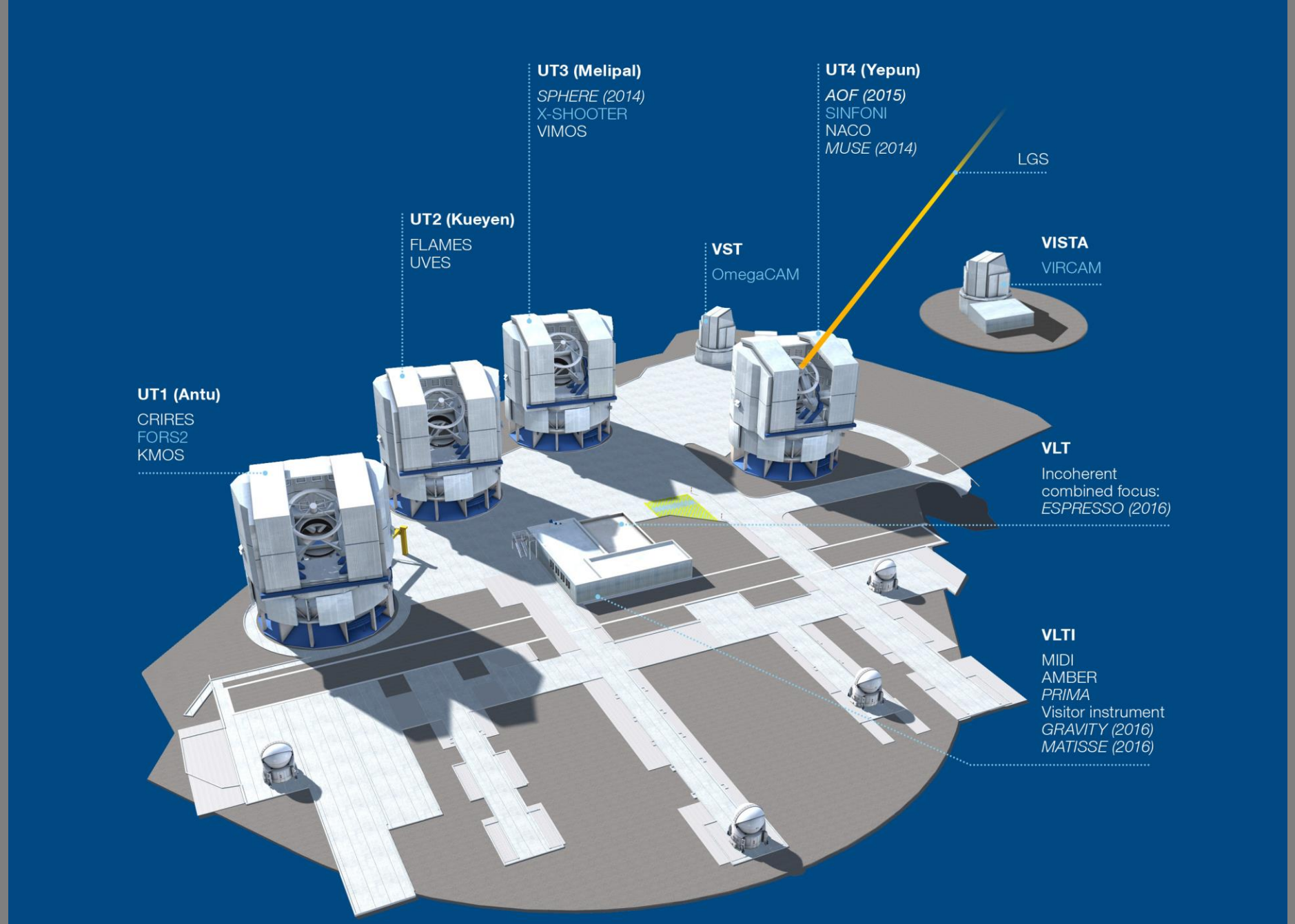
La Silla

ESO 3.6 Metre



New Technology Telescope – 3.5 Metre


Paranal
VISTA
VST
4 UTs
4 ATs
Control Building


UT3 (Melipal)
SPHERE (2014)
X-SHOOTER
VIMOS
UT4 (Yepun)
AOF (2015)
SINFONI
NACO
MUSE (2014)
LGS
UT2 (Kueyen)
FLAMES
UVES
VST
OmegaCAM
VISTA
VIRCAM
UT1 (Antu)
CRIRES
FORS2
KMOS
VLT
Incoherent
combined focus:
ESPRESSO (2016)
VLTI
MIDI
AMBER
PRIMA
Visitor instrument
GRAVITY (2016)
MATISSE (2016)

ALMA

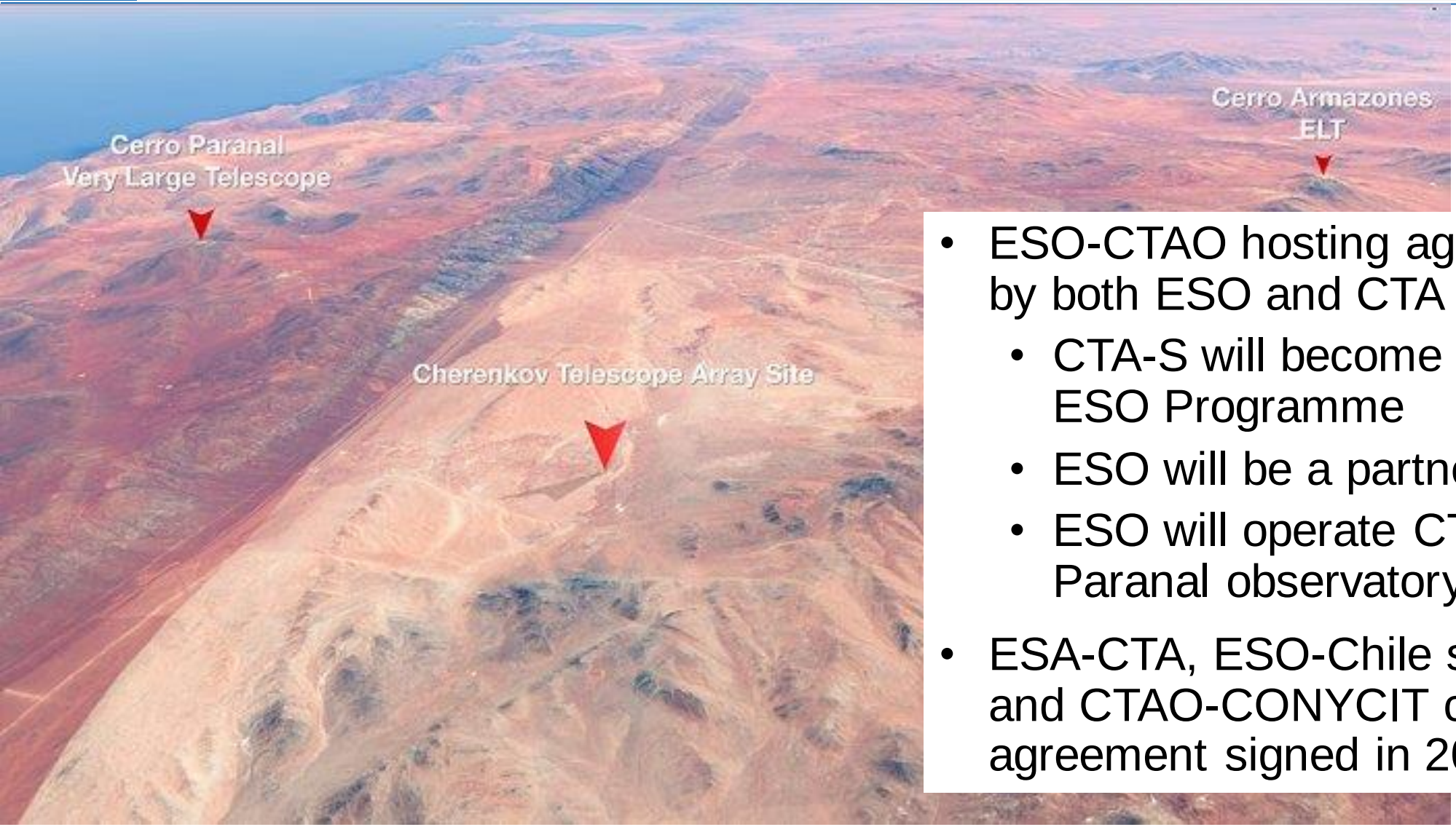
- Atacama Large Millimeter/submillimeter Array
  - 54 x 12m + 12 x 7m antenna's on Chajnantor at 5050
  - 7 – 0.35 mm (30-900 GHz) in 10^+ atmospheric windo
  - World's most powerful radio interferometer
  - Cold Universe: formation of planets, stars and galaxies

- Global partnership
  - North America (37.5%), East Asia (25%) & ESO (37.5%)
  - In cooperation with Chile


Otto
SCHEUERLE
ALMA

ELT

CTA-S in Paranal



- ESO-CTAO hosting agreement approved by both ESO and CTA Councils in 2016
  - CTA-S will become an ESO Programme
  - ESO will be a partner of CTAO (8%)
  - ESO will operate CTA-S as part of the Paranal observatory
- ESA-CTA, ESO-Chile site agreement, and CTAO-CONYCIT cooperation agreement signed in 2018

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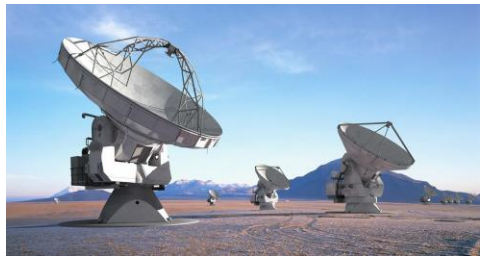
ESO Observatories-electricity needs

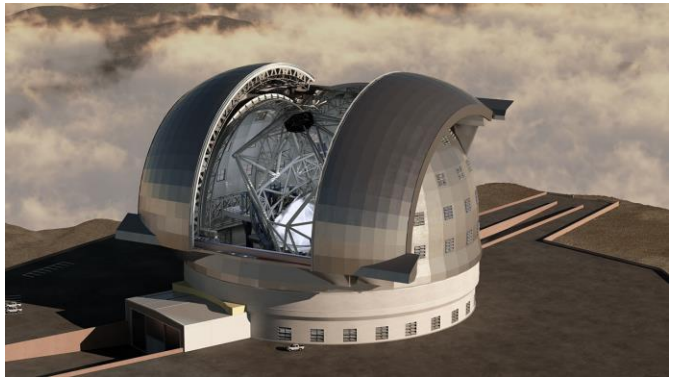
Paranal (VLT)
2 MW
10 GWh/yr

La Silla
0.6 MW
3.2 GWh/yr

ALMA
3.5 MW
20 GWh/yr



ELT
5 MW
25 GWh/yr when in full operation



Strategy Guidelines

- Best spots for astronomy come hand to hand with the lack of infrastructures, and this is dramatically true for power. As a result, for ESO, local generation was always the only option to start with.
- Operating local (Diesel-based) generation is polluting, expensive and resource intensive, hence searching for improvements has been a priority since day one.
- Improvements meant not only replace Diesel engines with more efficient LPG turbine(s), but also looking how to get to the closest grid access, and if this was too far, how to "convince" the grid to get closer to the Observatory!
- By continuously fostering agreements at high level and support from the Chilean Authorities, and by collaborating with the local Industries, the condition for the grid connection was created.
- Finally, seeking the collaboration with the private sector (Industry) to better harvest the Atacama potential for solar energy.

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Overall Timeline at glance

- All the Observatories were initially in areas not served by the grid and each had to start operations in island-mode with local Diesel-based generators (La Silla 1964, Paranal 1993, ALMA 2004 for the construction phase)
- To reduce operational costs, Diesel Generator were replaced by LPG turbine(s) (Paranal 2000, ALMA 2010)
- As accessing the grid became possible, the Observatory was connected to the grid as main source of energy (La Silla 1980, Paranal-Armazones 2017)
- Locally generated solar generated energy to cover part of the needs (La Silla 2016, Paranal-Armazones 2022)

La Silla

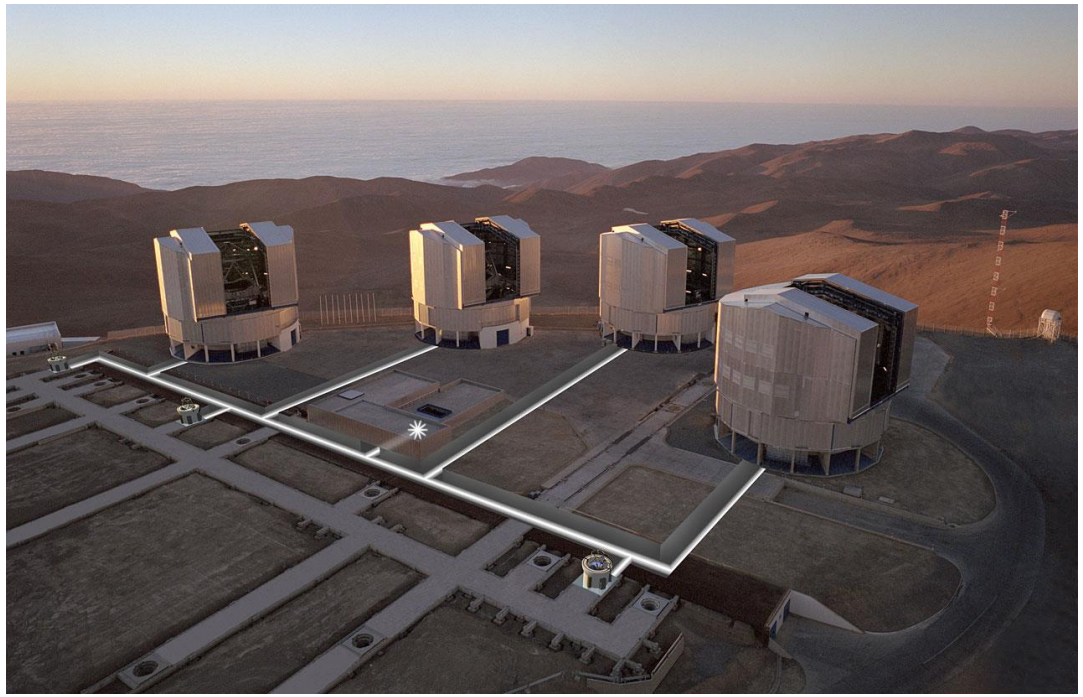
La Silla

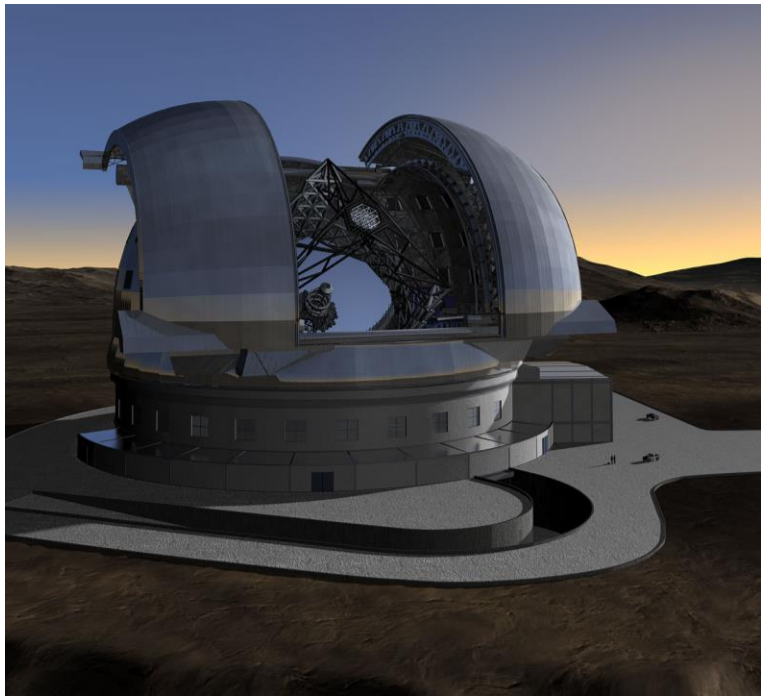
- La Silla started in the 60-ies with local generation in island-mode using Diesel engines.
- In the 80-ies the construction of a 25km 23kV overhead line connected La Silla Observatory to the Chilean grid backbone running North-South along the main road (Ruta 5)
- As no distribution zone was defined for this area, LSO was a free client with a maximum installed power of 600kW
- Being a free client, LSO was exposed to the high volatility of the local marked, that was de facto a monopoly from the only provider present in the area.
- In 2012, an action started to explore alternatives, including the use of solar energy.

La Silla

- After exploring different options, an agreement was signed with ENEL GREEN POWER for the provisioning of energy at regulated price from a local Photo-Voltaic Plant (day) and from the grid (night).
- The 2MW PVP was inaugurated on the 12th July 2016 and in operations since then. The PVP was financed, and it is operated by EGP. ESO provides the right to use the area where the PVP is placed

VLT and E-ELT





Paranal (VLT)

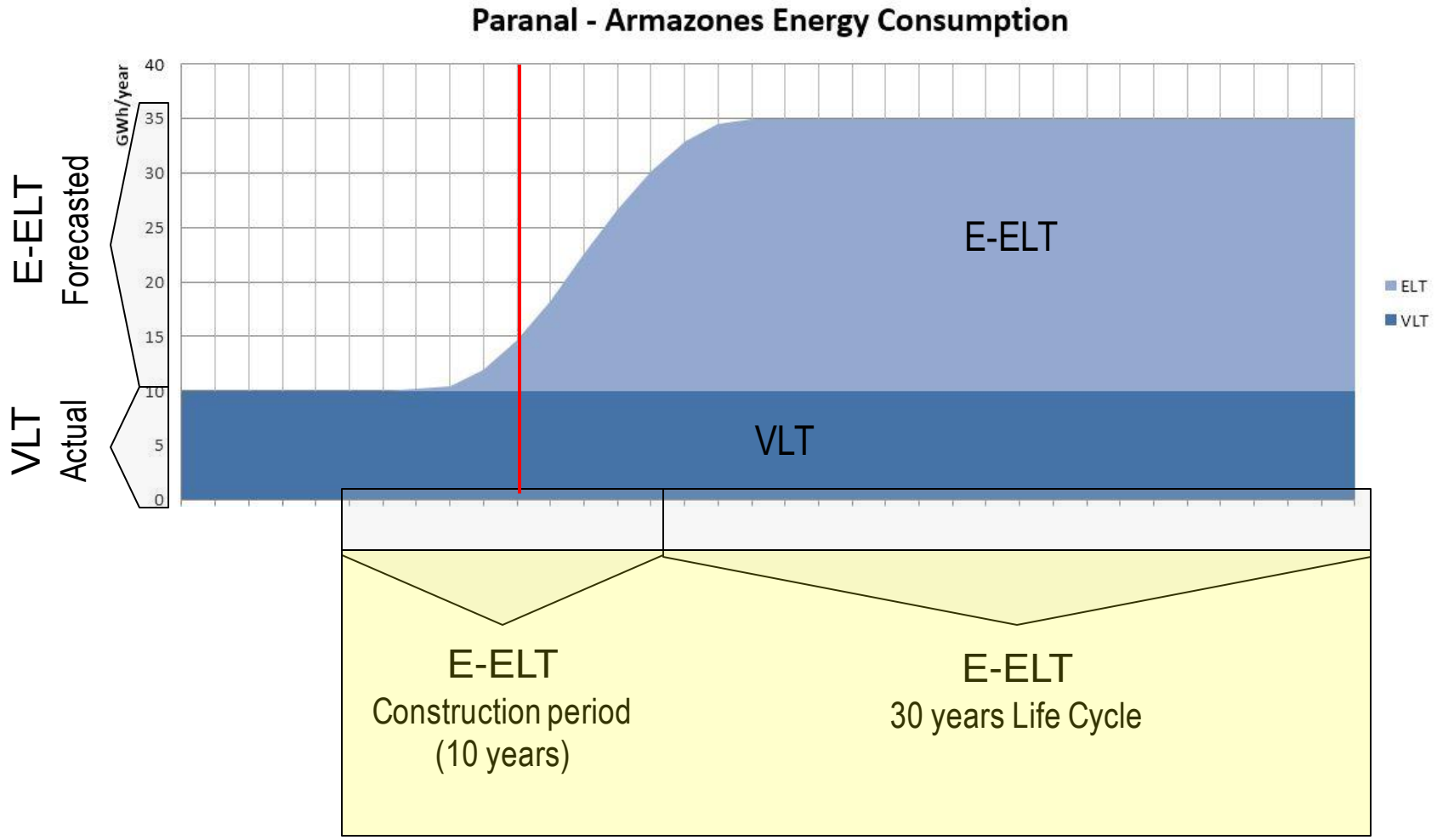
- The Paranal Observatory, home of VLT, VLT-I, VISTA, VST, started in the early 90-ies with local generation in island-mode using Diesel engines (3x856 kW_e).
- In 2005 a Multi Fuel Gas Turbine of 2.6 MW_e replaced the Diesel engines as primary generation, leaving the formers as backup unit.
- The internal distribution network is at 10kV.

Need for an electrical connection to the grid

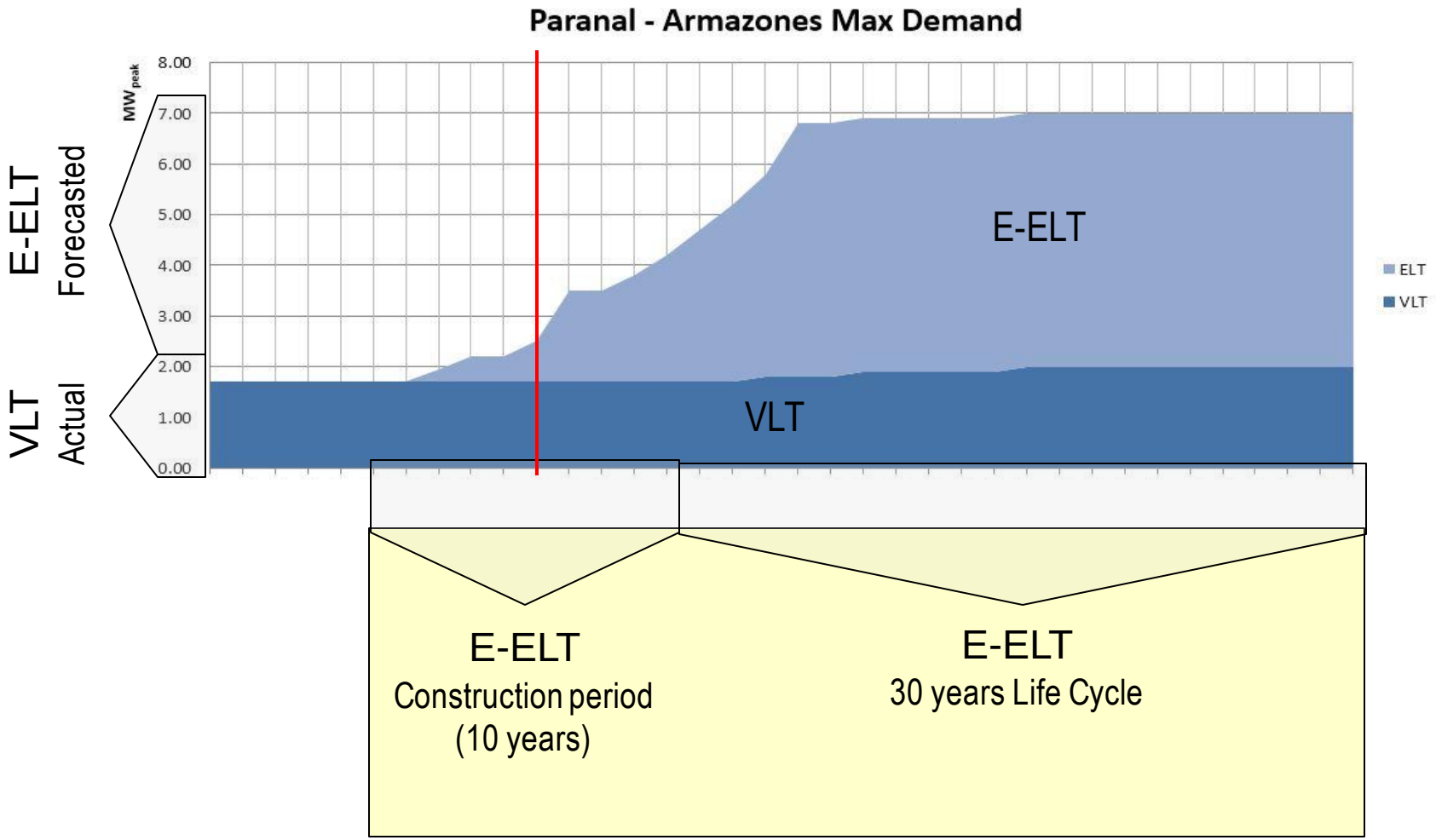
- Considering:
  - The expected increase of electrical power demand from the growing activities at Paranal, but mainly considering the future needs of the ELT that could not be covered by simply extending the existing installation but would require a new powerhouse at the Armazones base.
  - The higher price for local generation, due to the fuel cost, transportation cost, and intrinsic minor efficiency of local generation versus the mix available from a national grid
  - The lower reliability and higher operational costs of a local system w.r.t. being connected to the electric grid

  in 2010 ESO started to explore the possible options available to have the optimum electricity supply for Paranal and for the future ELT at Armazones to achieve for both a reliable system.

Paranal- Armazones energy demand

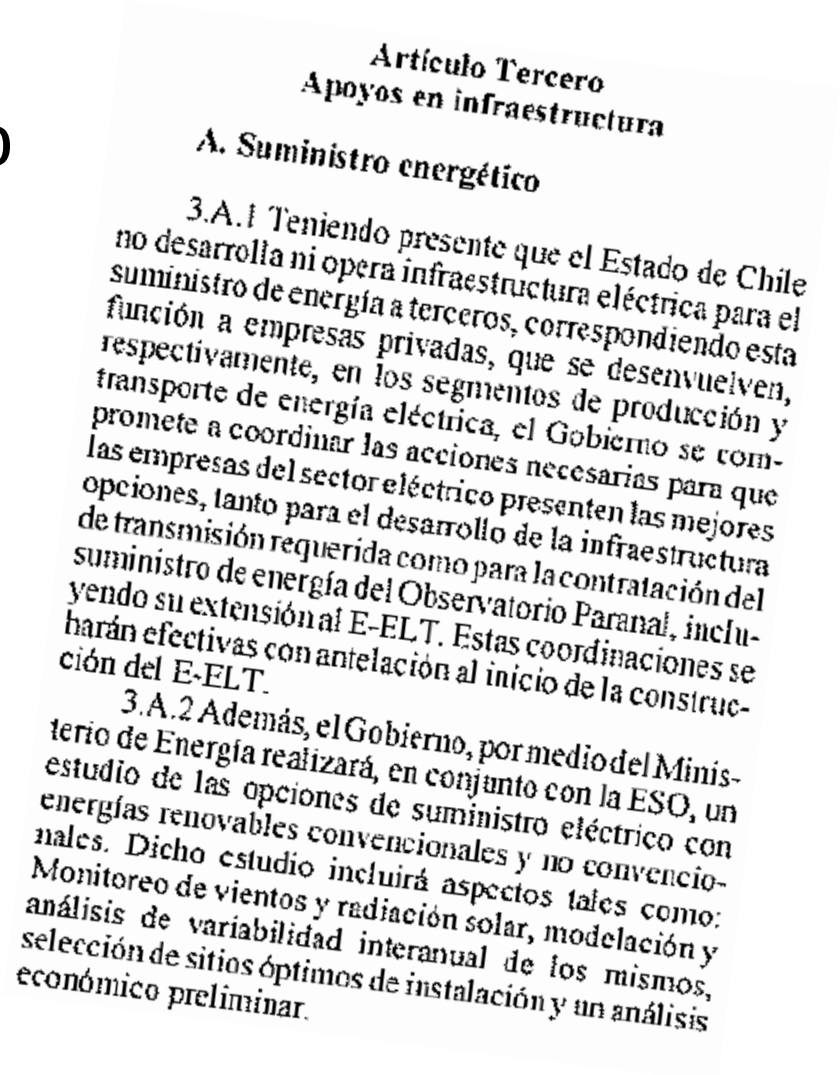


Paranal- Armazones power demand



Chilean Government commitment

- As part of the agreement between Chile and ESO for the construction of the ELT (Convenio entre Chile y la Organización Europea para la Investigación Astronómica del Hemisferio Austral, Decreto N° 584, de 1967 y Decreto 141 de 2011), despite not owning nor developing the electrical infrastructure, the Chilean Government committed to foster that the private sector would develop solutions for the provisioning of the ESO needs, together with the analysis of the possibility to use renewable sources



Artículo Tercero
Apoyos en infraestructura

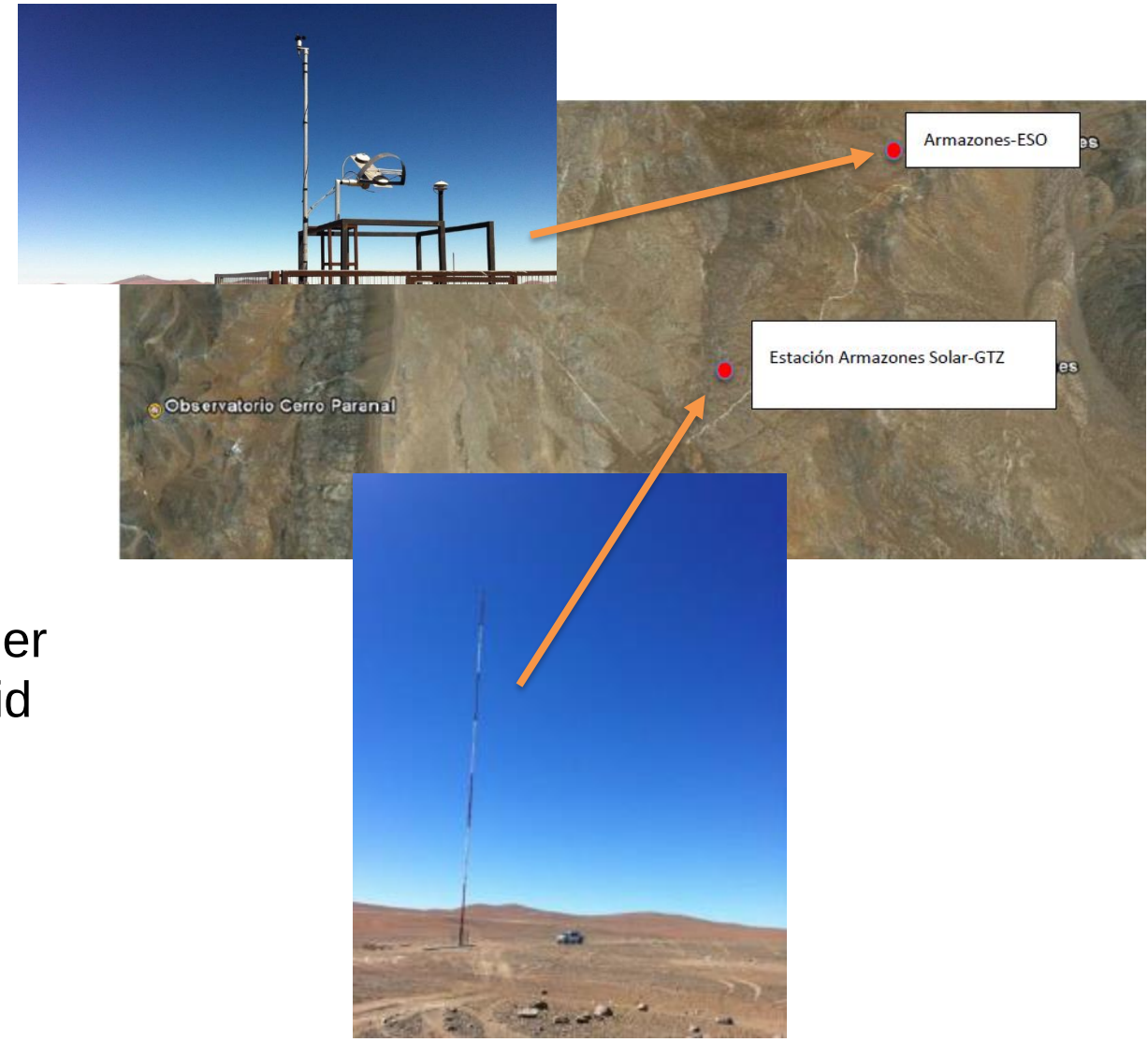
A. Suministro energético

3.A.1 Teniendo presente que el Estado de Chile no desarrolla ni opera infraestructura eléctrica para el suministro de energía a terceros, correspondiendo esta función a empresas privadas, que se desenvuelven, respectivamente, en los segmentos de producción y transporte de energía eléctrica, el Gobierno se compromete a coordinar las acciones necesarias para que las empresas del sector eléctrico presenten las mejores opciones, tanto para el desarrollo de la infraestructura de transmisión requerida como para la contratación del suministro de energía del Observatorio Paranal, incluyendo su extensión al E-ELT. Estas coordinaciones se harán efectivas con antelación al inicio de la construcción del E-ELT.

3.A.2 Además, el Gobierno, por medio del Ministerio de Energía realizará, en conjunto con la ESO, un estudio de las opciones de suministro eléctrico con energías renovables convencionales y no convencionales. Dicho estudio incluirá aspectos tales como: Monitoreo de vientos y radiación solar, modelación y análisis de variabilidad interanual de los mismos, selección de sitios óptimos de instalación y un análisis económico preliminar.

Chilean Authorities Support

- Accordingly, the Ministry of Energy performed a study including field measurements (Informe Final Inodu) on the solar radiation level available in the Paranal and Armazones area that is:
  - 800~1200 W/m2
  - 7,50 kWh/m2•day (horizontal) o
  - 2737 kWh/m2•year
- The study also recommended to focus on solar energy and indicated that the presence of a connectivity to the electrical grid would be an enabler to the introduction of a photovoltaic plant, as the grid could provide when the solar is not active.
- Other studies provided additional input, all consistently pointing to the need to create first the connection to the grid



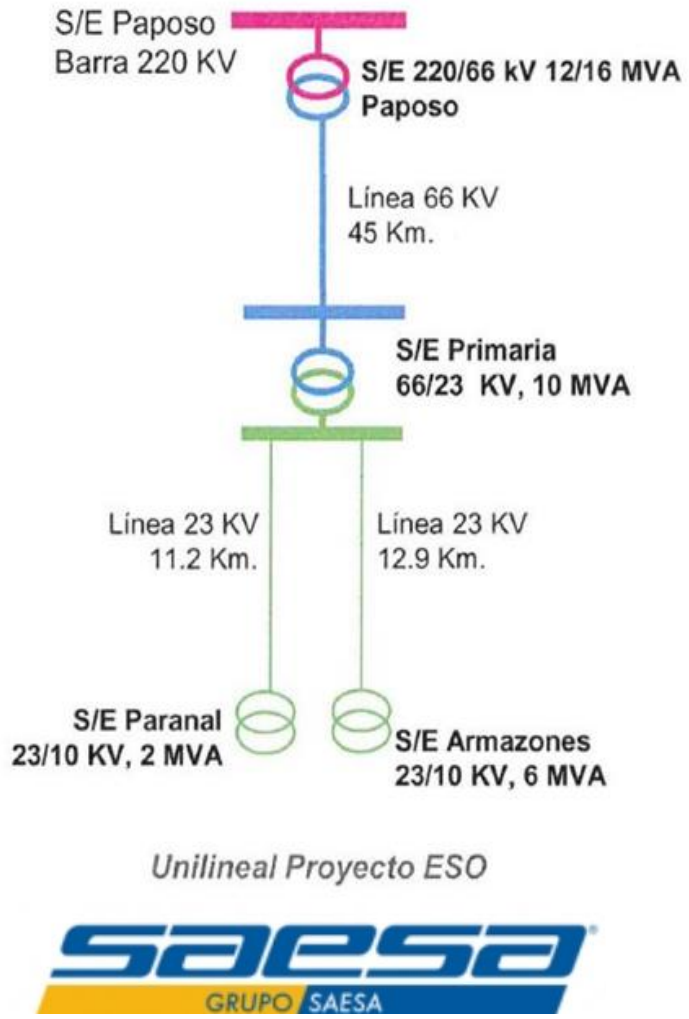
In search for the grid

- At the time, the Chilean grid was, actually, two separated zones with the Paranal/Armazones being in the gap between the two.
- With the support of the CNE, several technical alternatives were considered for either connect to the grid in the North (SING) or the one (SIC) South of the ESO area.
- The goal: to create a new concession area, part of the national grid, capable to provide reliable supply to the P/A Observatory

… finding the grid was not easy!

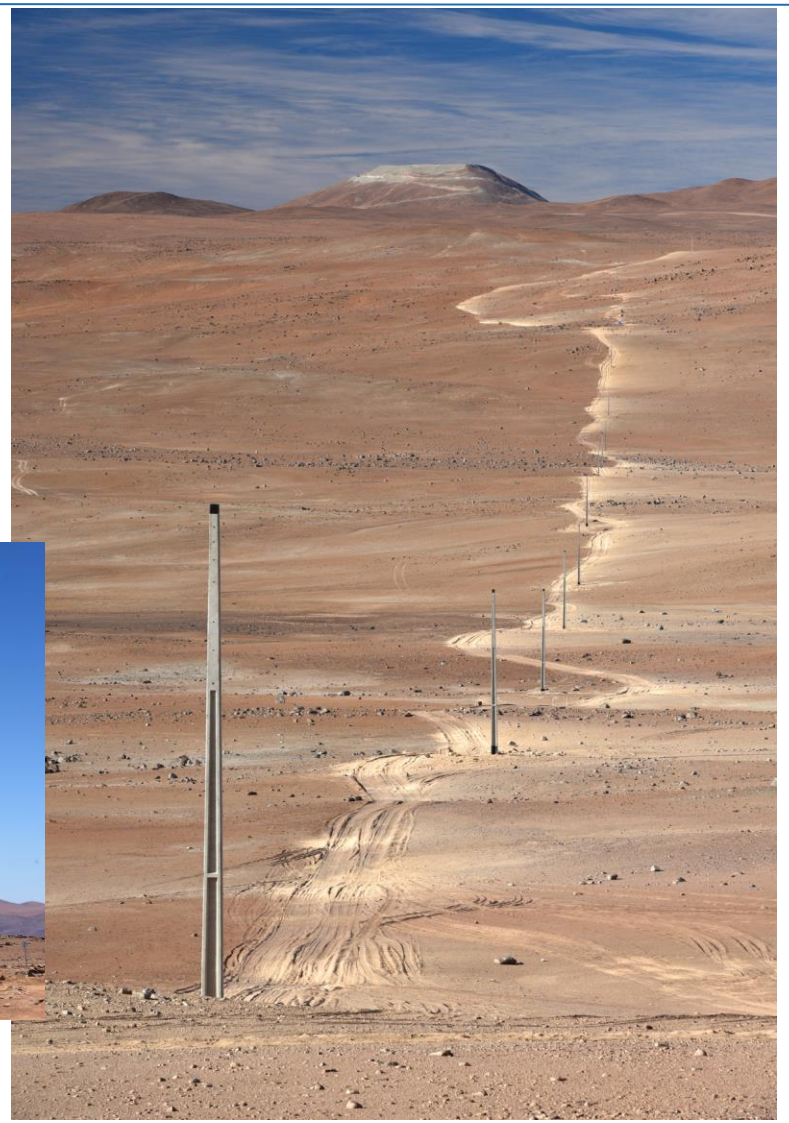
- The initial attempts to identify a private Company interested to establish a new concession area and to build the necessary infrastructure went void.
- Finally, with the support of the Chilean Authorities, the company SAESA accepted to be available to:
  - Build a new transmission line from the town of Paposo (the northernmost installation of the SIC)
  - Create a concession for the distribution of energy at regulated prices covering at least the P/A area
- ESO contributed with the right of ways for the to be constructed overhead lines.

VLT + E-ELT Grid connection



Extension of the Chilean Electricity Grid

- Construction by SAESA started on 27th May 2016
- Grid connection inauguration on the 26th May 2017



Connection of the P/A Observatory to grid

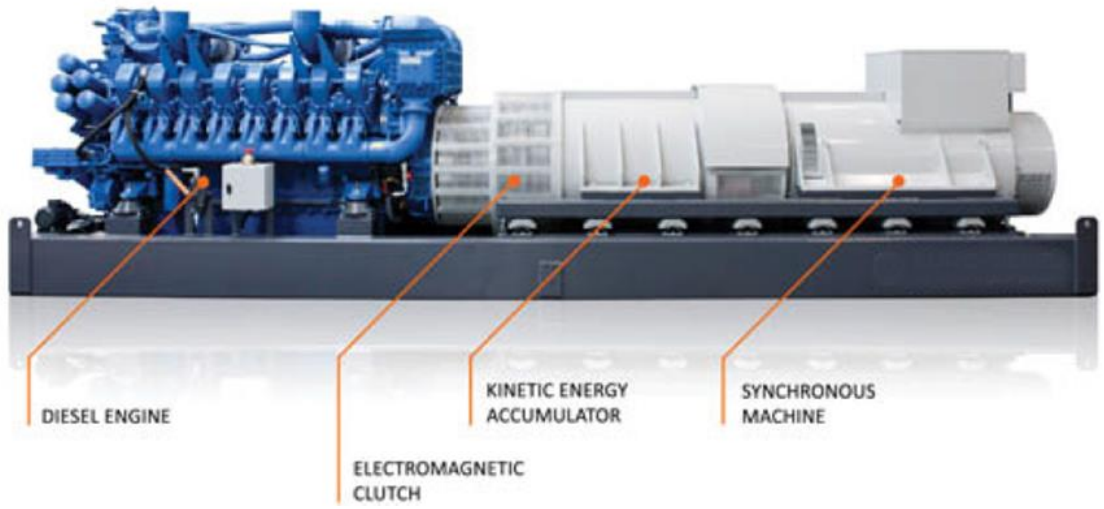
- Dec 2017 connection of Paranal/Armazones to the **Chilean electrical grid** now supplying to Paranal and ready for Armazones.
- Delivery and installation of the prefabricated substations.
- Paranal got “its first *supplied* electrical light” on 7th December (int17373)
- Armazones TE1 certificate recently accepted by Chilean Authorities!!
- Armazones Base Camp already connected to the grid.

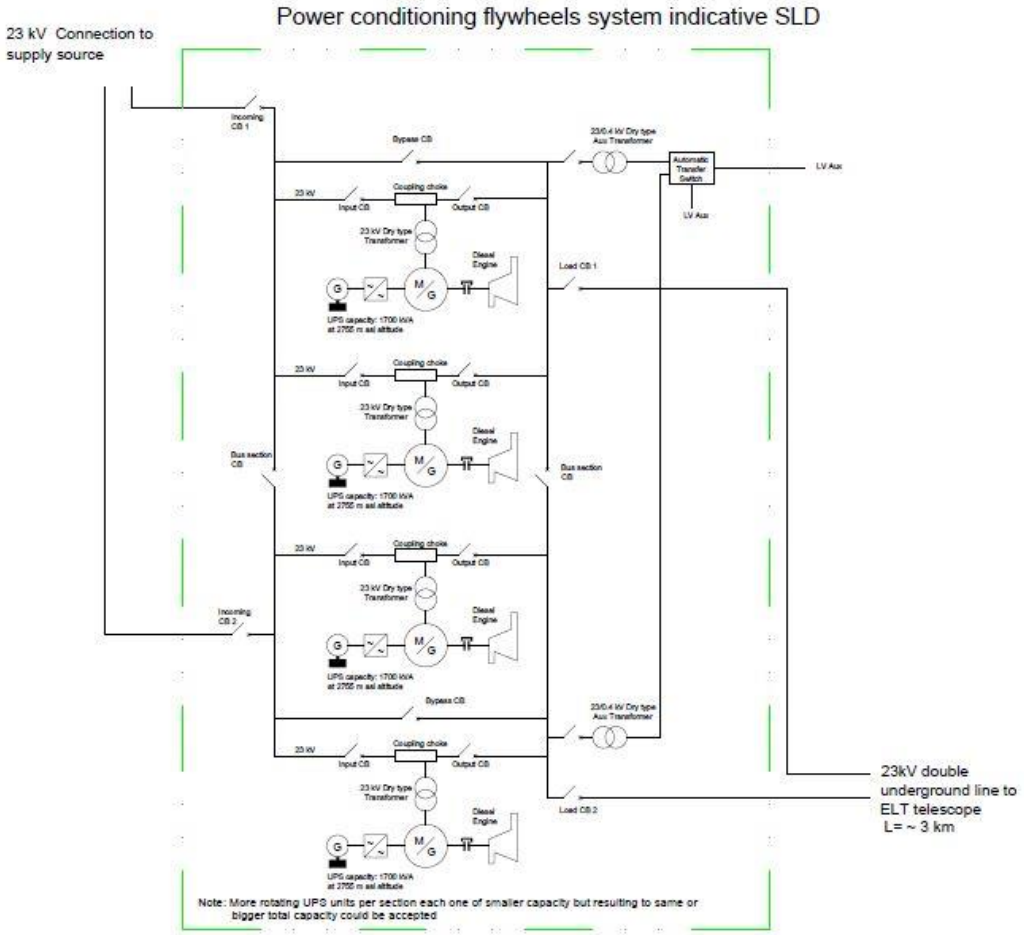
Moving forward

- The availability of the grid opened the possibility to consider solar energy too.
- SAESA was interested too, and a new agreement was set to:
  - SAESA to finance, build, and operate a photovoltaic plant in two sections capable each to cover the daily needs of Paranal and ELT respectively
  - SAESA to finance, deliver and operate for 30 years a Power Conditioning System (PCS) for the ELT to provide higher quality power and backup
  - ESO to contribute the areas where PVP and PCS have to be built and to commit to procure energy at regulated prices for the next 30 years.
- The agreement signed in 2019 is now under implementation
- The PVP was inaugurated in July 2022. The PCS is expected by 2024.

Working together to improve the efficiency

Implementation of a Power Conditioning System with backup generation to eliminate short and long power supply interruptions.





Working together to improve the efficiency

PV Park for Observatory auto-consumption made of two sections, 4MW to cover Paranal and 5MW to cover ELT. The PVP is halfway between Paranal and Armazones, and uses bifacial panels on trackers. 23kV outputs allows to connected the PVP directly to the existing distribution overhead lines.

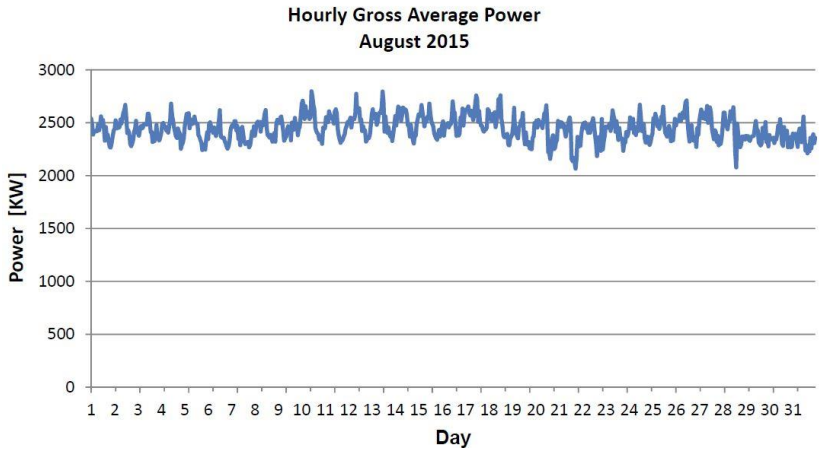
ALMA

ALMA Current power system status

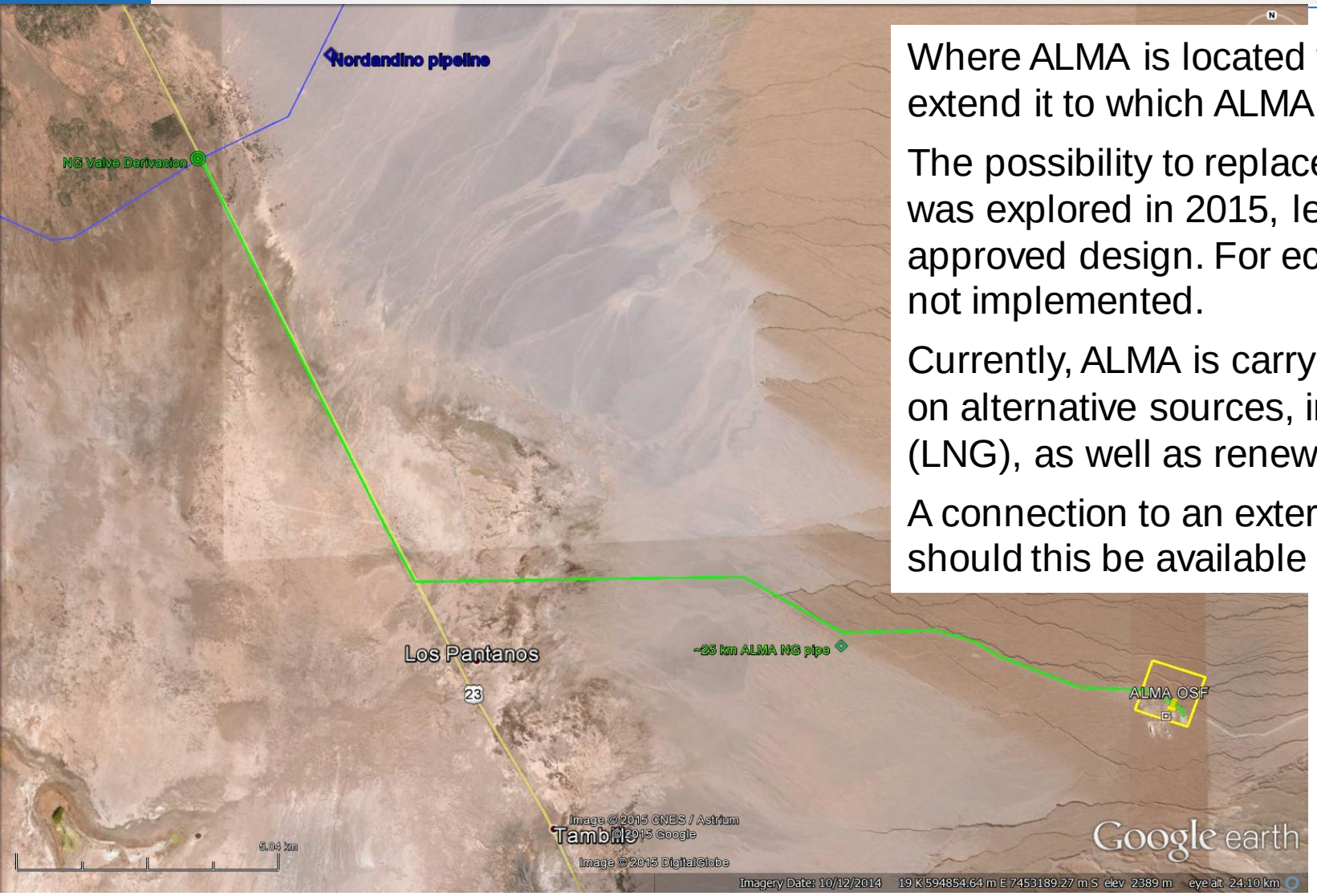
ALMA is currently supplied by its permanent power generation system (3 gas turbine-generators, 3,75 MW_e each) burning LPG

Current energy needs at ALMA:

- Consumption ~ 20 GWh/year
- Max demand < 3.5 MW
- Hourly Gross Average Power is fluctuating by about 0.75 MW each day and is kept smaller than 3 MW



ALMA Natural Gas connection Study



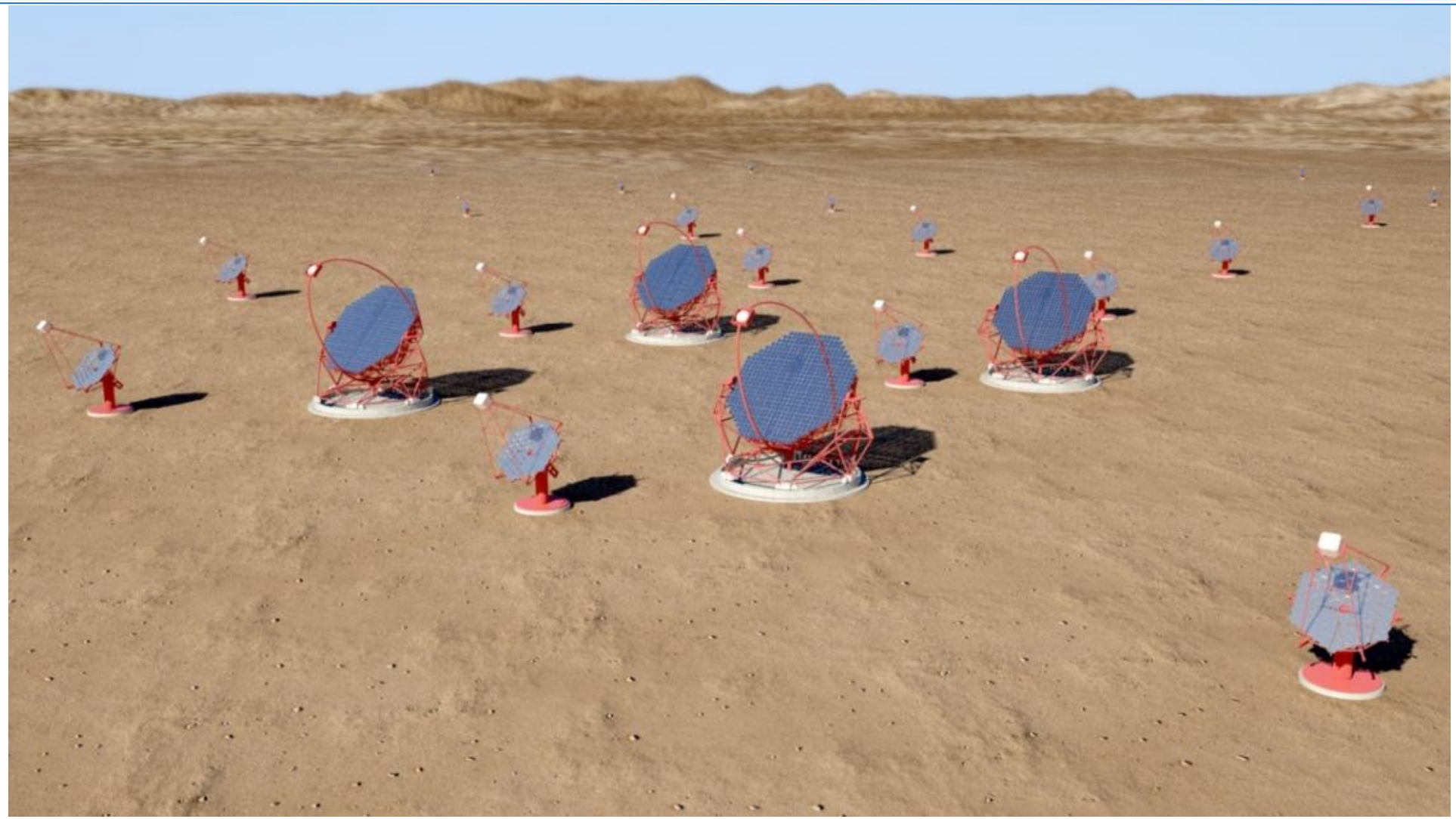
Where ALMA is located there is neither grid nor plans to extend it to which ALMA could connect.

The possibility to replace the LPG with NG (Natural Gas) was explored in 2015, leading to an environmentally approved design. For economic reasons, the project was not implemented.

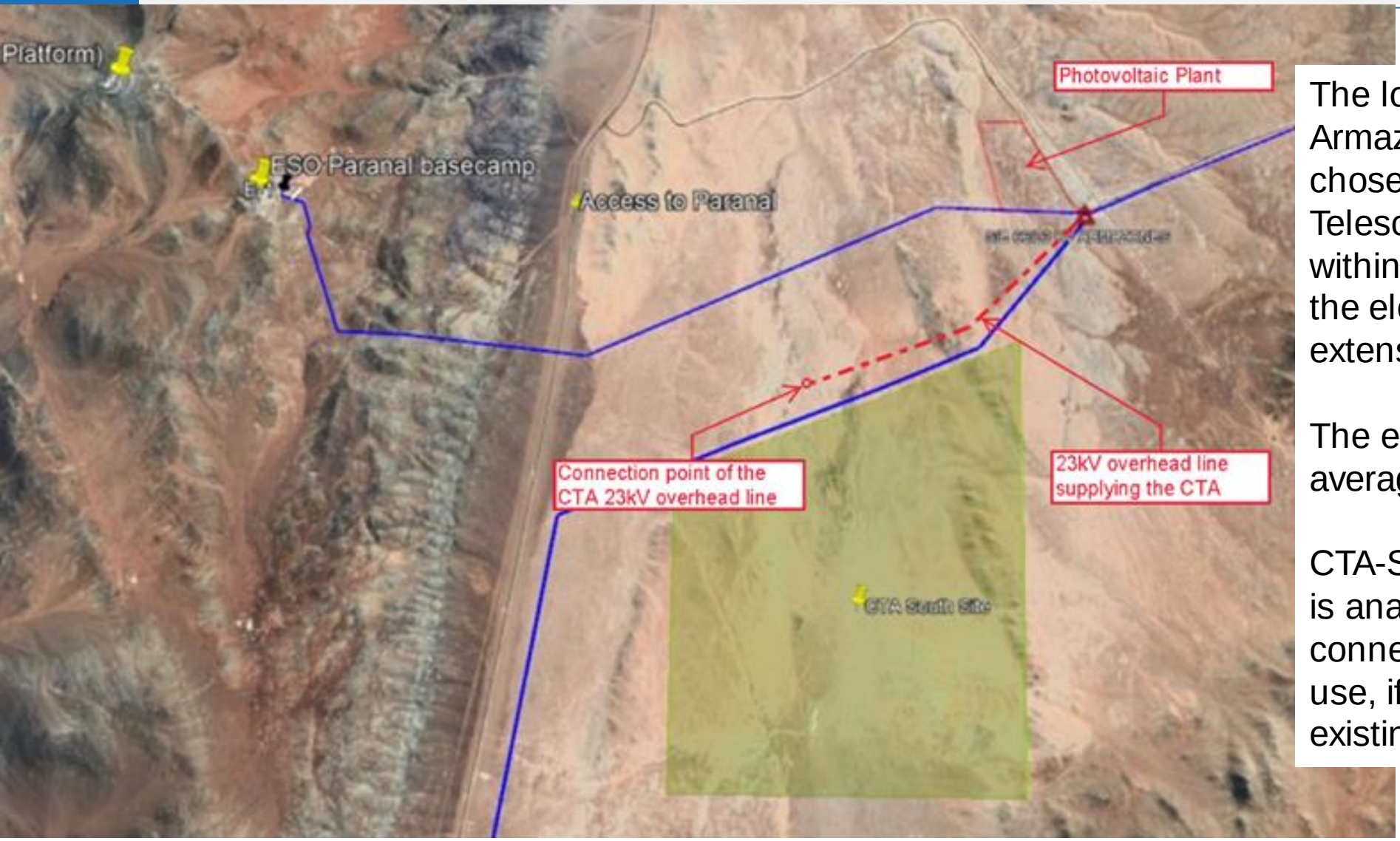
Currently, ALMA is carrying on a comprehensive analysis on alternative sources, including Liquefied Natural Gas (LNG), as well as renewable sources.

A connection to an external grid may be considered, should this be available in the future.

Cherenkov Telescope Array South (CTA-S)



Cherenkov Telescope Array South (CTA-S)



The location between Paranal and Armazones that has been chosen for the Cherenkov Telescope Array South (CTA-S) is within the area served by the electrical grid extension already done.

The expected consumption is on average 1.5MW.

CTA-S, in coordination with ESO, is analysing the optimal way to connect CTA-S to the grid and to use, if possible, energy from the existing Photo-Voltaic Plant.

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Effect on CO2 footprint

- The connection to grid and the introduction of solar energy not only had benefit in terms of providing cheaper and more reliable energy provisioning to the Observatories, but also lowered the CO2 footprint of ESO Observatories.
- The overall effect of the implemented changes on CO2 footprint has been evaluated, including the CO2 construction costs (as from table below), and reported in a SPIE 2022 paper (*). The final values are snapshotted in the next slide.

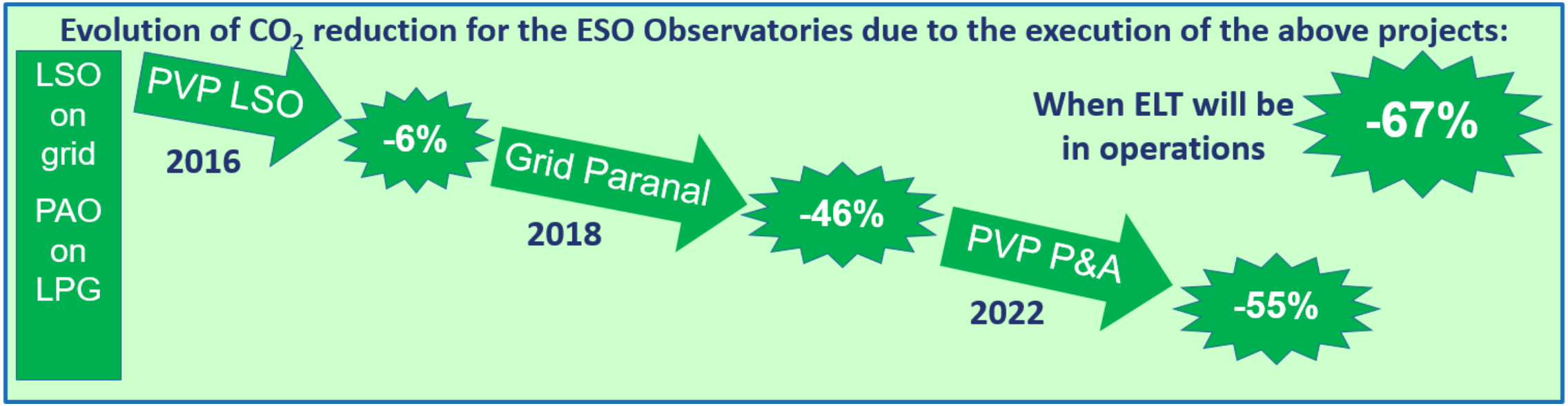
Table 1 – emission of CO_2 in g/kWh for different sources of electrical power

Year	2016	2017	2018	2019	2020	2021	2022+
Chilean Grid	443	435	400	442	455	455	455
Paranal LPG	745	745	-	-	-	-	-
PVP La Silla	56	56	56	56	56	56	56
PVP Paranal							44
PVP Armazones							44

(*) SPIE_AS22-AS103-46, G. Filippi et Al., "Power Evolution of electrical power provisioning for the ESO installations in Chile: a path for an astronomy with a lower CO_2 footprint.", SPIE 2022, Montreal

ACHIEVED/PROJECTED CO2 EMISSION REDUCTION

Year	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
total energy from solar (LSO+P+ELT) [MWh/y]	1350	1350	1350	1413	840	1350	6996	14979	17379	18979	19779	22179	23379	23779
total consumption (LSO+P+ELT) [MWh/y]	13395	13395	13395	13703	9817	13881	20857	23857	26857	30857	34857	38857	40857	44857
% from PVP versus total	10%	10%	10%	10%	9%	10%	34%	63%	65%	62%	57%	57%	57%	53%
total emission w/out projects [tCO2e]	9164	9142	9048	9352	6826	9558	14719	16954	19189	22169	25149	28129	29619	32599
total emission with projects [tCO2e]	8641	8631	4894	5511	4132	5777	6631	4715	5094	6256	7747	8581	8998	10653
total Reduction of emission [tCO2e]	522	512	4154	3841	2695	3781	8087	12239	14095	15913	17401	19548	20621	21945
incremental Reduction [tCO2e]	522	1034	5188	9030	11724	15506	23593	35832	49926	65839	83240	102788	123409	145354
emission savings (red/total w/o)	**6%**	6%	**46%**	41%	39%	40%	**55%**	72%	73%	72%	69%	69%	70%	**67%**



AGENDA

- ESO at glance
  - History, mission, facts sheet
  - Observing sites in Chile
- Electrical Power needs and strategy
- Timeline 2010-2022
  - La Silla
  - Paranal(VLT) - Armazones(ELT)
  - ALMA
  - CTA-S
- Effect on CO2 footprint
- Future Steps

Future Steps

- La Silla, APEX: No further development foreseen
- Paranal (VLT)
  - Increase the capacity of the PCS to cope with the increase activity due to ELT AIV and future operations, as well as CTA-S operations
- Armazones (ELT):
  - Install and operate the (ELT) PCS, as part of the overall agreement
- ALMA:
  - Complete the analysis for alternative energy sources
- CTA-S:
  - Connect to grid

For all the above:

- Maintain and extend the relationship with central and local authorities
- Coordinate with Chilean and Member States Industries

Energy provisioning for the ESO Observatories in Chile

Thank you!