SERC CHILE
SOLAR ENERGY RESEARCH CENTER

SERC Chile legacies and challenges

CHAPTERS

Academic Committee 2013 – 2017

Rodrigo Palma
Director / Main Researcher of Line 3 "Energy Coordination Systems for Rural and Urban Communities"

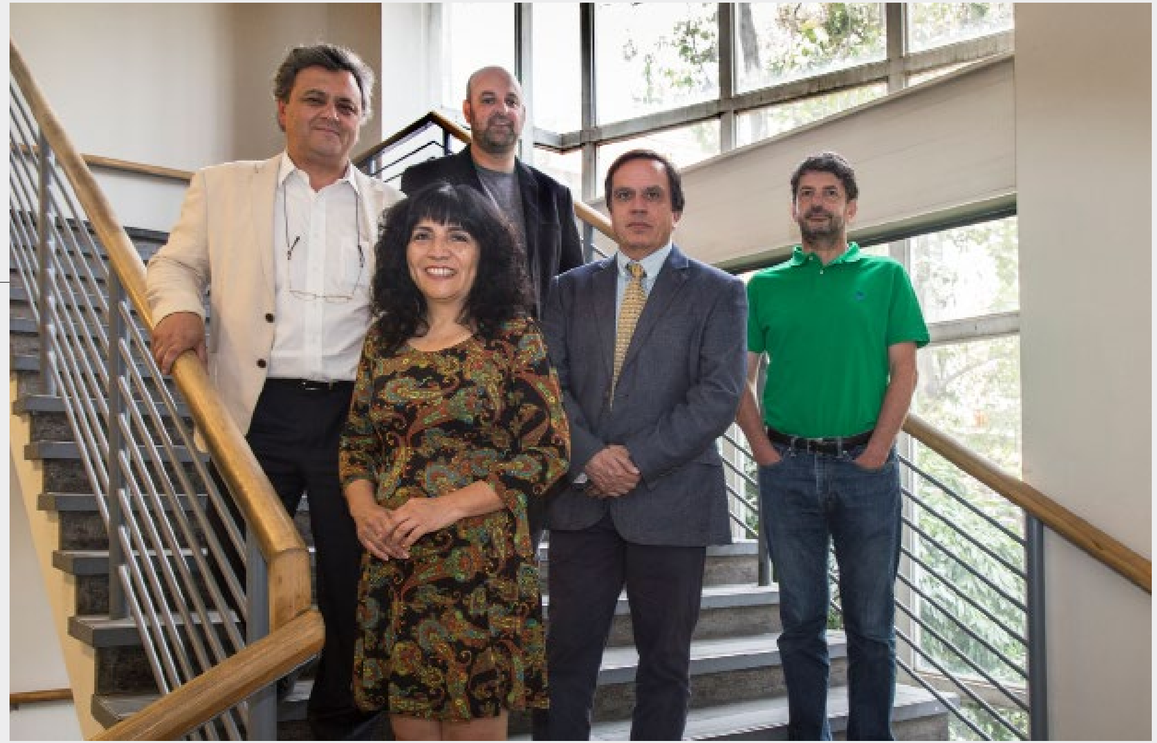
Luis Morán
Subdirector / Main Researcher of Line 2 "Electric Systems with High Penetration of Solar Energy"

Samir Kouro
Main Researcher of Line 1 "Solar Energy in the Industry/Mining"

Héctor Galleguillos
Main Researcher of Line 2 "Storage of Solar Energy"

Lorena Cornejo
Main Researcher of Line 5 "Solar Water Treatment"

Claudio Agostini
Main Researcher of Line 6 "Economic, Social, and Regulatory Aspects for the Development of Solar Energy"



From left to right: Rodrigo Palma, Samir Kouro, Luis Morán and Claudio Agostini.
Below: Lorena Cornejo. Héctor Galleguillos also belongs to the team; unfortunately he could not be in the photo session.

National Advisory Board 2013 - 2017

The National Advisory Board, which connects SERC Chile with society, is made up of:

Dra. Nicola Borregaard
Former Chief of the Sustainable Development Division of the Ministry of Energy and current general manager at EBP Chile.

María Eugenia Camelio
Director of the Fondap program at Conicyt.

Dr. Alejandro Jadresic
Former minister, president of the National Energy Commission

Dr. Alejandro Jofré
Former director of the Math Modelling Center at Universidad de Chile.

Dr. Andrés Weintraub
2000 National Award of Applied Sciences

In March 2018, the following scholars joined the SERC Chile National Advisory Board:

Dra. Bárbara Loeb
Dean of the Chemical Engineering Department at Pontificia Universidad Católica de Chile.

Máximo Pacheco
Economist. Former Minister of Energy

International Advisory Board

Its mission is to accompany the center's growth, strengthen its international presence, support research teams, and provide strategic orientations for the fulfillment of its goals. It is made up of:

Dr. Julián Blanco
Director of the Plataforma Solar de Almería Solar, Spain

Dr. Werner Platzer
Coordinator the International Business Development Program of the Fraunhofer Institute of Solar Energy Systems.

Dr. Paul Werbos
Former director of the National Science Foundation and former advisor of the President Barack Obama on energy matters.

Academic Promotion Team

SERC Chile also boasts the participation of pioneering scholars in the research of solar energy in Chile, who make up a team of academic promotion in Chile and abroad. They are:

Marcos Crutchick, dean of the Engineering Department at Universidad de Antofagasta.
Roberto Román, associate professor of the FCFM at Universidad de Chile and member of the Directive Committee of the International Solar Energy Society (ISES).
Raúl Sapiaín, former dean of the School of Mechanical Engineering at Universidad de Tarapacá.
Roberto Hernández, anthropologist, professor at Universidad de Chile joined this team at the beginning of the second phase of SERC Chile.

Under the Light of Adventure

This is an adventure of perseverance. Exploring new challenges on the possibilities the sun gives us is a historic opportunity because it makes us face the common task –from the science, public policy, the private world, and the society– to approach our future taking up the unavoidable and permanent commitment to develop renewable and environmentally friendly sources of energy.

In such scenario Chile shall play a leading role; not only because of the disadvantage or even fortune of not having fossil fuels where we are compelled to look for renewable energy from natural sources but also because such condition places us at a privileged position. Spending a couple of minutes at any spot of the desert in the North is enough to understand this: the sun is ours. Although this is a blessing, it is also a responsibility. We do not have other alternatives. We must lead our adventure towards what the sun is offering us.

We are determined to continue devoting all necessary efforts to further develop what we have accomplished at SERC Chile in the first five years of scientific research. This has been our challenge and drive since, in 2012, seven Chilean institutions –Universidad de Tarapacá (UTA), Universidad de Antofagasta (UA), Universidad Técnica Federico Santa María (UTFSM), Universidad de Chile (UCH), Universidad Adolfo Ibáñez (UAI), Universidad de Concepción (UdeC) and Fundación Chile (FCH)– responded to the call made by the Science and Technology National Committee, CONICYT by its Spanish acronym, to participate in the Fourth National Tender for Excellence Centers for Research in Priority Areas (FONDAP), in which six subjects were included, among them, solar energy, for the very first time in an explicit manner.

This was the perfect setup to unite intentions, knowledge, experience, and ideals within a group of researchers to materialize the creation of the Chilean Solar Energy Research Center (SERC CHILE by its Spanish acronym), which as of its origin took on the challenge of "developing a sound base of knowledge on solar energy to enhance the exceptional conditions of the northern area of our country, through research on scientific, technical and economic challenges, and on the opportunities offered by solar technology for the national power matrix", as pointed out by the petition of CONICYT.

Such scenario was and still is fascinating. The natural

"The main legacy of our line has been the development of technology that allows for the direct integration of solar energy, both thermal and photovoltaic, into industrial and mining processes. A concrete example has been the direct incorporation of photovoltaic solar energy to the process of electro-refining of copper. We researched and developed power converters and their control to adjust electricity coming from photovoltaic panels, which is inherently low-voltage direct current, very similar to the one used in electro-refining of copper, for it to be directly injected into the electrolysis process. In this way, many energy conversion and transformation stages are saved, thus making a much more efficient and cost-effective system. This technology can contribute to reduce the carbon in the mining industry".

Samir Kouro, main researcher, Line 1 "Solar energy in the mining industry"

"Our line has two main legacies. One is to have proven that the incorporation of high-power solar energy farms do not compromise safety in the operation of the Chilean electric systems. The second one was demonstrating the possibility to interconnect both the North and the Central systems by using alternating current high voltage transmission lines. This latter work was led by Dr. Claudia Rahmann. What we still need to continue analyzing is the behavior of larger interconnected electrical systems and with a higher participation of non-conventional renewable energies. If we want Chile to become an exporter of electricity, we shall start studying now the effects of interconnecting Chile to an electric grid constituted by several neighboring countries".

Luis Morán, main researcher, Line 2 "Electrical power systems with high penetration of solar energy".

conditions of the North provide an unlimited potential to produce electricity, heat, and light based on solar energy, as well as for the implementation of photovoltaic, thermal, and water treatment solutions due to its high irradiation levels and exceptional clarity indexes. Besides, these attributes turn it into an unparalleled place for the study, development, and testing of new solar technologies. However, such context also poses a number of barriers and hindrances that restrict the full development of this potential.

Therefore, during the first five years at SERC Chile, we have focused on the development of a holistic, yet multidisciplinary approach, to overcome, from a scientific viewpoint, the most important obstacles to massively and cost-effectively incorporate solar energy to the Chilean energy matrix, while taking advantage of the extraordinary potential of the North to its maximum extent to explore on specific solutions and technology.

This is how the center has become a protagonist in the promotion of solar energy nationwide, thus establishing the study of the technical, economic and social aspects that hindered the development of this source of energy. In order to do so, SERC implemented a model that integrates six interrelated research lines to generate new knowledge while finding solutions to mitigate the effects of such barriers in the use and development of solar energy:

Line 1: Solar energy in the mining industry.
Line 2: Electrical power systems with high penetration in solar energy.
Line 3: Solar energy coordination systems for rural and urban communities.
Line 4: Solar energy Storage.
Line 5: Solar water treatment.
Line 6: Economic, social, and regulatory aspects for the development of solar energy.

This first five-year adventure has allowed for achievements and progresses that largely exceed the initial guidelines established for each area. In general terms, SERC Chile has been capable of socializing the importance of the sun for the sustainable development of the country, a premise that has been made possible thanks to the work of the universities, authorities, foundations –such as Fundación Chile, which participated until December 2017– and various organizations that have materialized something as vital as permanent: after five years, thanks to this collaborative effort, Chile has a critical mass of researchers working and exploring the solar energy.

Under the Light of Adventure

It is an associative achievement that characterizes SERC Chile. No Chilean university alone could have gathered this amount of researchers –nor created a cooperation network with over 20 centers of excellence at a worldwide level– and made them devote themselves to developing new knowledge about this subject. The above has been a process actively supported by the authorities of each institution.

It is a huge satisfaction to have had achievements that go beyond the goals initially established. The sun has given us strength to obtain valuable results that propel us to the future with bigger and better perspectives. This research contributes to the development of all potentialities in the core areas of our project, such as the development of human capital (with over 400 undergraduate and graduate students); the contribution of new knowledge, and the expert advice to develop public policies related to the use of solar energy. In these three areas –which used to hinder the presence and use of solar energy in Chile– we have addressed our main achievements by socializing, publishing and promoting them within different settings, placing special emphasis on the comparative advantages of solar energy and its already existing positive impact on the economic development of Chile.

At the beginning, the local scenario revealed a growing demand for energy that not only affected the environment and the economy, but also had us importing energy to meet the needs of the country. By the end of the last decade, the price of energy had doubled, thus warning us that it was time to take responsibility to solve our dependence on imported sources of energy. This bleak context made, however, room for the sun. Among the strategic energy alternatives to deal with the problem, the Chilean government recognized the importance of deploying the potential of Renewable Energy as an opportunity to approach safety on this matter while meeting the environmental goals.

This was one of the first steps, along with the concern coming from CONICYT, and which encouraged the birth of SERC Chile. A great milestone of that time was the kick-off plenary meeting of the center, held in Mejillones, Antofagasta. It was evident there that there was a shared vision that has driven everyone to work on a surprisingly effective proposal, considering the amount of people and institutions involved therein. That gathering also proved that Chile has high-level niches of basic and applied research, which allowed for the creation of a solar energy research center. At the beginning, however, the introduction of renewable energies encounte-

"The main legacy of our line is that, in the past five years, we have managed to conceive a participative methodology called co-construction, which allows designing, implementing, operating and maintaining these solutions hand in hand with urban or rural communities who will benefit from such solution. Additionally, we have worked on a wide variety of models, mathematical algorithms, processes, control systems and specific equipment that constitute a "technological tool box" to be prepared to face the challenge. In this way, it is possible to break the cycle in which these products are brought in by experts from the outside and then transferred to the community. The experience has shown that the work must be gradually conducted with the communities; as such dialogue with people has an impact even on the design of the said solution. We have had satisfying surprises because sometimes communities have exposed things that were otherwise invisible to us and that, had they not been included, would have posed design problems".

Rodrigo Palma, main researcher, Line 4 "Energy Coordination Systems for Rural and Urban Communities"

"In the field of thermal energy storage as sensible heat, new mixtures of molten salts were developed, which pose various enhancements compared to solar salt usually used in thermo-solar plants. The new mixtures can work at a higher temperature range mainly as a result of their lower melting point. They also produce lower corrosion levels and one of them has a lower storage cost than solar salt. In thermal energy storage as latent heat, we found that bischofite, a byproduct from non-metallic mining, has good properties for energy storage, with similar characteristics to those of hydrated magnesium chloride but at lower cost".

Héctor Galleguillos, main researcher, Line 4 "Storage of solar energy"

red several limitations on its penetration rate. In 2012, there were only a handful of pilot plants and minor projects using solar technology in Chile (less than 1 MW in total). There was a huge scope to progress further, big barriers to tear down, but above all, an endless correlation of efforts to take up the challenges together.

Five years later, the adventure is growing stronger. The results supporting the impact of our research are far from getting to an end. We are pleased to highlight that today Chile has over 2,000 MW connected to the grid, the biggest historically recorded growth in the last three years worldwide. This is also an achievement that lies on both the shoulders of the private industry by the costs reduction in photovoltaic technology, and on the research done by SERC Chile, which among other matters, has confirmed the technical viability and strategies to include large amounts of power from photovoltaic plans without affecting the reliability and stability of electrical systems.

We have met these goals thanks to the cooperative work towards a common vision that will allow for our development as a country. Understanding the reason why we need to modify the use of conventional energy is contributing to a more robust structuration of a public policy to overcome the difficulties that hinder the growth of renewable energy in Chile, especially of solar energy. Hence, the center has been a relevant player through the participation of our researchers in the conduction and analysis of studies related to the development of governmental programs to foster solar energy in the country.

In this area, one remarkable achievement has been the relation with the Ministry of Energy, particularly the meeting held in 2015 between the former Minister of Energy, Máximo Pacheco, the Board of Directors and the International Consultancy Committee of SERC, where the impact that solar energy could have at an international level was discussed.

Another relevant activity in this area was the participation of a group of researchers of the Center in the development of a method used to make the energetic projections for Chile until 2050. This methodology is the roadmap Chile will follow, and it sets at least seventy percent of participation in the national energy matrix of renewable energies.

Although the following chapters of this document detail the most important specific achievements for each

Under the Light of Adventure

research line, it is interesting to highlight some successful work regarding public policies. Within this context, for example, our researchers participated in several studies to prove the technical viability of interconnecting the SING and the SIC, the two major Chilean power systems until 2017. The studies included both economic and technical aspects, such as stability evaluations that prove the safety of the system under severe contingencies and high levels of renewable energy. The results of this study allowed for a fundamental support in the decision-making process conducted by the regulatory bodies.

The center proactively helps CORFO (The Chilean Economic Development Agency) to determine the strategy to better develop the solar industry in the country, such as that of a new photovoltaic cell for the Atacama Desert. This new installation, which should have the capacity to get a more efficient use of the UV radiation while benefiting from the advantages offered by local conditions, is being simultaneously implemented with the technology necessary to help lowering the costs of solar energy to USD$25 per MWh.

SERC Chile researchers have also given technical advisory to the Ministry of Energy, through a study on the protections for residential photovoltaic systems that must be considered in the new law "Netbilling 20.571". Contributions have not only been limited to expand the scientific knowledge in the use of solar energy but also in how such energy can be used by communities. For example, the Solar Ayllu project aims at utilizing solar energy in the region of Arica-Parinacota, thus positively impacting quality of file. The results obtained from this project can be also implemented in other communities.

The infrastructure we have managed to install in the laboratories of six universities is also a much appreciated achievement, as it develops human capital. This has been possible thanks to the leveraging of projects raised from different sources of funding, deemed as an investment that strengthens both the universities and the country.

All these achievements allow us to demonstrate the radical change experienced, in the past five years, as a result of the way in which SERC Chile approaches the challenges in the country. Fifty researchers dedicated to the various use and application alternatives of solar energy in Chile, draw together as an acade-

"One of the milestones of our line was the erection of pre-industrial desalination pilot plants to obtain drinking water in small communities in the region of Arica-Parinacota. The area has deficiencies in water quality due to the natural existence of high arsenic and salt levels dissolved in the hydric sources used for its supply, thus affecting life quality and social-economic development of those communities considerably. Small-scale units for solar water treatment have also been developed -laboratory and pilot- to eliminate toxic and persistent pollutants coming from the productive activities of the agro-industry. These developments have been possible thanks to the sound progress made in the research related to the elimination of contaminants through Solar Photoelectro-Fenton processes, homogenous and heterogeneous photo-catalysis".

Lorena Cornejo, main researcher, Line 5 "Solar Water Treatment"

"Even though there is a more global contribution in having created a critical mass for the research of solar energy in Chile, one of the first legacies from our line is related to the identification of barriers to develop solar energy in the country, their corresponding analysis, both from investors and public policies perspectives so as to be able to tear them down. Progress has also been made in the establishment and quantification of social benefits derived from non-conventional renewable energy, particularly from solar energy in terms of its environmental effect, the energetic safety of the country, and finally in the development of rural communities with no access to electric energy".

Claudio Agostini, main researcher, Line 6 "Economic, Social, and Regulatory Aspects for the Development of Solar Energy"

Under the Light of Adventure

mic community from Arica to Concepción, plus over one hundred researchers who contribute with their knowledge to obtain outstanding scientific results. This new knowledge has been the outcome from teamwork and the incorporation of students coming from several locations worldwide who have turned this topic into their intellectual curiosity to finally end up in their thesis. The most valuable issue is the creation of a research community built around the solar subject in Chile. Such community largely exceeds the boundaries of academia and today is aligned with an ecosystem of innovation and entrepreneurship, public policy and the community.

After the first five years, our research supports the fact that we are facing an irreversible process with projections that will continue to change the course of our history -even further than the impact of saltpeter and copper in our physiognomy-, the appetite for adventure has only grown while discovering and becoming astonished by the potentialities of the sun.

After the first five years, we can explain our experience in one sentence: What is to come is even more fascinating than the path we have already gone through.

We will continue on this adventure, the persistent adventure for knowledge as it is light, it is energy.

5 year report

Planta Fotovoltaica Santiago Solar

Figure

198

Undergraduate students, 124 master's degree and 53 doctorate students conducted their theses under the supervision of SERC Chile researchers.

Spreading the knowledge

Both scientific promotion and the outreach towards the society have been part of SERC Chile's mission from its very beginning. Among others, there are initiatives such as "Explora" from CONICYT, fairs organized in Chile and in which SERC has actively participated. The scholars and researchers of the various lines have also given lectures and made presentations on solar energy in a number of schools. Universidad de Antofagasta has an itinerant laboratory that pays visits to regular and technical vocational schools.

SERC Chile was also featured in one episode of the program "Exploradores del átomo al cosmos" (Explorers from the atom to the cosmos) of Canal 24 Horas, which covered the subjects of solar energy storage and the work conducted with the local communities. Aside from the continuous and growing participation and organization of seminars and conferences (our researchers have participated in over 400 conferences), SERC Chile communicates its views and creates a discussion through opinion columns and interviews published in digital and printed media, depending on the contingency related to solar energy or to similar subjects. In the past five years we have been featured in the press over 120 times.

Solar Energy in the Academia

Universidad de Antofagasta launched a doctorate degree in Solar Energy that started its academic activities in 2016. The program currently has seven enrolled students. In 2013, Universidad Adolfo Ibáñez opened a master's degree program in Energy and Environment, while the doctorate program in Electrical Engineering at Universidad Santa María has been internationally recognized with the conferral of double degrees from the universities of Nottingham and the Technical University of Berlin in their Berlin and Dresden campuses respectively.

State of the Art Infrastructure

Universidad de Concepción built a laboratory of energy and systems in its Electrical Engineering Department furnished with unique equipment in the country that allows for the simulation of complex electrical systems.

Additionally, SERC Chile created and currently operates a pilot molten-salt plant at Universidad de Antofagasta, with a capacity of one ton that allows researchers to evaluate the dynamic behavior of salt mixtures on a large scale. In turn, Universidad de Chile has developed a technological procedure to find solar energy solutions on a small scale, specifically for micro-grids and their various configurations.

5 year report

Ayllu deploys

Solar Ayllu takes place in the Arica-Parinacota region (www.ayllusolar.cl). It is an innovative and significant SERC Chile initiative, which aims to transfer knowledge and provide technical consultancy from the academia to communities, with the goal to develop human capital that enables a sustainable development, and there through becoming a world-class reference in the use and export of solar energy.
Universidad de Tarapacá, Universidad de Chile and the Universidad of Antofagasta are the members of SERC Chile executing this project. They are supported by strategic partners such as Fundación Chile and BHP Billiton Foundation.
Solar Ayllu fosters, through its applied projects, the concepts of co-construction and sustainability. Co-construction is a methodology of participation and technology transfer that aims to preserve the project over the time and provides communities with a predominant role in its design and execution. The process is based on:

The process is based on:

- Creation of solar-energy based solutions that are cost-effective, replicable, and scalable in key areas to boost the development of such communities.
- Development of human capital to strengthen its abilities and adoption of tools to contribute to a sustainable development of the region and an effective use of solar energy.
- Achieving sustainability through effective solutions, business models, support networks, involvement from the community and an appropriate institutional framework.

In order to execute the project, four initiatives were jointly agreed with the communities from the four municipalities of the regions:

- Solar energy based-agricultural product processing in Caleta Vítor (municipality of Arica).
- River shrimp farming through intensive use of solar energy for the sustainable development of the town of Camarones (municipality of Camarones).
- Restoration of value for pre-hispanic cattle-drive routes: connecting communities through solar energy (municipality of Putre).
- Solar energy for camelid fiber processing and collection center (municipality of General Lagos).

In relation to human capital, we are working on the creation of a network of 36 schools, to promote knowledge and awareness of the solar potential in the region, the identification and support of innovative endeavors that use this source of energy, and the development of skills for local workers to take advantage from these opportunities.

Several other instances of academic formation have been promoted, such as:

Seminars and workshops on solar energy, with international expert, open to the community.

A diploma on solar energy given by the Universidad de Tarapacá.

Design of a Master degree program on topics related to solar energy.

Training of teachers from the primary educational system of the region, through theoretical-applied workshops using the methodology of Project Based Learning (PBL).

Establishment of a 36-school Network in the region, based on the PBL methodology by the year 2020.

Theoretical/applied training workshops for aboriginal communities and associations on the reference projects in each municipality of the region, with specific contents on associativity, business and energy management models.

Training workshops to entrepreneurs for the two versions of the "Sun Fever" announcements.

Training workshops to monitors, oriented to students from Universidad de Tarapacá, to become coaches for the construction of solar kits in aboriginal communities of the region.

Training workshops on solar energy in the context of the "My Solar Ayllu" announcement, addressed to social organizations and associations.

5 achievements to change history

1. Small-scale solar energy generation: The center has proposed new models and algorithms for the control and operation of solar micro-grids and water treatment systems, which are the foundation for a profitable development of micro-grids.

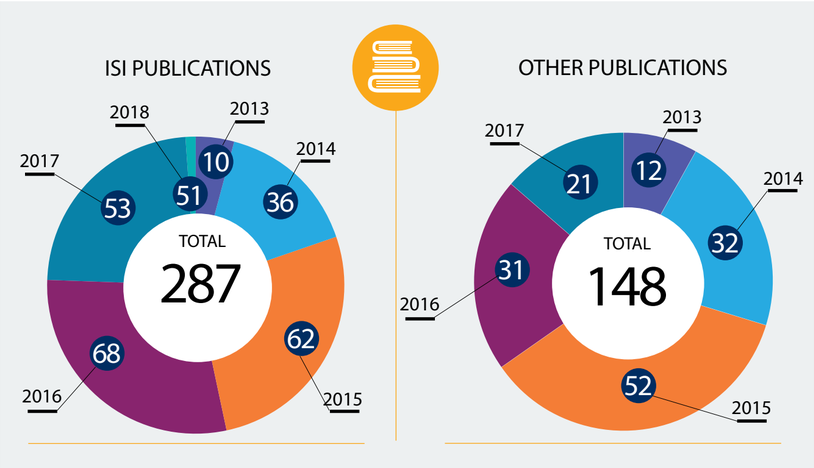
2. Storage: SERC Chile has proposed a new mixture of molten salts for thermal storage made up by 30% LiNO3 57% KNO3 13% NaNO3. The advantageous properties of this salt, a mixture that uses materials found in the north of Chile, has awakened the interest of Albemarle Corporation, a company dedicated to the lithium extraction in the surroundings of the Atacama Salt Flat, for its mass production, considering its positive impact on operational costs of CSP plants.

3. Integration of solar energy into interconnected systems: new mathematical models and tools have been proposed that allow the systematic study of the maximum solar energy penetration levels into interconnected systems, including the impact of diverse alternatives of energy storage systems.

4. Solar Mining: The Center has developed new power converter configurations that enable the integration of photovoltaic energy directly into mining processes, such as copper electro-refining.

5. Power electronics: Development of new topologies and configurations of power converters to be used in photovoltaic energy conversion systems and its integration to the grid.

5 year report



The sun reveals itself

SERC Chile researchers have acted as technical advisors in different settings, such as work-groups and committees on solar energy, proposals on legal and regulatory changes, in the Advisory Committee of the Strategic Solar Program (SLP), and in the regional governments of Antofagasta and Arica-Parinacota to manage several regional projects based on solar energy. Also, four researchers of the center were chosen among the 27 experts of the Energía 2050 Advisory Committee, an initiative that established a national plan for a sustainable and inclusive energy policy for the future.

In their relationship with the Government, they have promoted the incorporation of diverse public policy plans and management models to find new sources of funding and foster the development of solar energy in Chile. In this line, SERC Chile has actively participated in the work tables for the 2050 schedule of the Ministry of Energy and set up the "Solar Institute" to develop photovoltaic modules especially adapted to the local conditions, namely for high UV radiation.

SERC researchers' involvement was also key, along with CORFO, for Chile to host "SolarPaces", the world's most influential conference on solar thermal energy, and which had 500 guests from different countries. In September 2017, the center organized the "EnerSol" forum, a national gathering on solar energy put together along with Editec, and held for its third consecutive year in Antofagasta, in the context of FORONOR (Electronic Forum of the North).

AtaMoS-TeC: The most relevant R&D bet on solar matters

The exceptional conditions of the Atacama Desert allowed for the creation of AtaMoS-TeC (Atacama Module and System Technology Center), a project led by the institutions connected to SERC Chile along with the private sector, to develop technologies for the photovoltaic solar energy industry, on a technological bet for the sustainable development of our country.

CORFO granted the funds for the implementation of the project in August 2017, which will be led by a temporary board of directors until the formation of a consortium that must direct it in the coming years. The Universidad de Antofagasta, as a beneficiary, is the institution in charge of its execution.

Due to the dry climate, clear skies, high radiation, and high sunshine hours, among other characteristics, this area favors the implementation of these technologies, which aim at reducing the cost of energy to a target of 25 US$/MWH by the year 2025, while, in turn, contributing to create an industry of our own that can provide both the Chilean and the international market with goods and services.

At AtaMoS-Tec participates CEA INES (France), ISC Konstanz (Germany) and Fraunhofer Chile, renowned foreign institutions, along with Adrox Spa, Borg, Cintac, Colbún, Ecoenergías, Ecovisión, Fotcast, Geogrow Spa, Innova Renobable, Mondragón, New Energy, Novalquímia, Phibrand S.A., Snare, Solarpro, Solcor, Syntec, Tecno Andina, Venergía and Vidrios Lirquén S.A., companies that contribute with funding and relevant work.

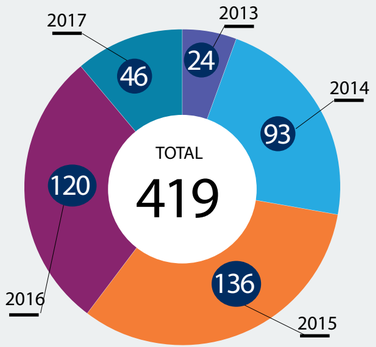
Professionals and researchers from all these institutions worked during more than a year on this proposal, which applied to receive funding from the Strategic Investment Fund (FIE) in the context of the roadmap for the Solar Strategic Program, created in 2015 to promote the creation of a local solar industry aimed to increase productivity in the country.

Considering the contribution made by CORFO, plus that of the associated institutions and companies, 13 thousand million pesos will be invested in a six-year period to develop or adapt solar energy technology to address the challenges and embrace opportunities given by the high solar radiation present in the Atacama Desert.

The competitive granting of funds for this initiative is emblematic, becoming the most relevant R&D project on solar energy to ever exist in the country.

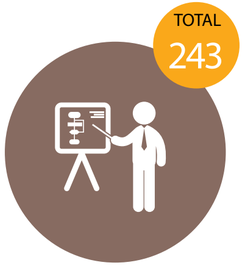
5 year report

Participation in congress Gatherings



Organization of Congress Gatherings

Collaborations

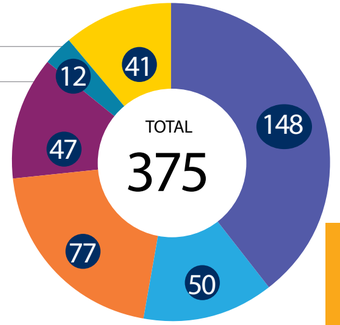


Figure

22 post-doctoral interns have participated in various research groups. Seven of them have been hired in the academic staffs of Chilean universities.

Undergraduated finished

Thesis



- 148 undergraduated finished
- 50 undergraduated in process
- 77 magister finished
- 47 magister in process
- 12 doctorate finished
- 41 doctorate in process

Postdocs Leveraged Funds

CLP$18.666 millions

Awards and distinctions

Line 1
Samir Kouro
IIEEE IES J. David Irwin Early Carrier Award (2015).
IEEE IES Bimal Bose Award for Industrial Electronics Applications in Energy Systems (2016). Promotion to Senior Member level IEEE (2016-2017).

Christian Rojas
Science Academy award for best thesis (2014).

Line 2
Marco Rivera
Outstanding Engineer AIE IEEE Award (2015).

Line 3
Pablo Estévez
IEEE Fellow category (2016-2017).

Line 4
Gustavo Cáceres
Expert Observer of the Energy International Agency (2015).

Líneas conjuntas
Edward Fuentealba (L1), Carlos Silva (L6), Ronald Fisher (L6) y Rodrigo Palma (L3) make up the Energía 2050 Advisory Committee for the Ministry of Energy (2014).

Conjoined lines
Roberto Román
Member of the Board of Directors at International Solar Energy Society (2016).

Carlos Fuentes (UTFSM) y Jannik Haas (UCH)
Roberto Ovalle award from the Chilean Institute of Engineers (2015).

Paz Castillo
Best Paper sobre energía fotovoltaica en IECON (2015).

Williams Flores
First Award for innovation on energy efficiency, ABB Chile.

National and international collaborations

SERC Chile has established several associations with international research centers. We have actively collaborated in more than 20 projects along with solar energy research centers worldwide.
SERC Chile has cooperation agreements with:

ISC International Solar Energy Research Center Konstanz (ISC Konstanz)
CEA INES (France)
Plataforma Solar de Almería (PSA)-Ciemat (Spain); Program of Environmental Applications PSA-Ciemat (Spain)
Universidad Nacional de Ingeniería (Peru)
Universidad de Almería (Spain)
Fraunhofer Germany
Universidad Nacional de Ingeniería (Peru)
Universidad de Almería (Spain)
Fraunhofer Germany

SERC has interacted at different levels with various consortiums and associations, such as Abengoa, ACERA, ACESOL, BHP Billiton Foundation, CDEC-SIC (The Economic Load Dispatch Center-Central Interconnected System by their corresponding Spanish acronyms), CDEC-SING (The Economic Load Dispatch Center-Interconnected System of the North by their corresponding Spanish acronyms), Colbún, E-CL, ENEL GREEN POWER, GDF-Suez, and VALHALLA. Studies and application projects were also developed with E-CL, Energía Verde, and Abengoa.

Researches across all the lines of SERC have consolidated collaboration networks with various institutions from the world. Joint activities include: collaborations in projects, conferences and journal publications, seminars, research stays and student internships, among others. Some of these institutions are:

- University of Waterloo, Canada
- University of Columbia
- Virginia Tech
- Universidad de Valencia
- Universidad de Sevilla
- University of Nottingham
- University of Auckland
- University of New South Wales, Sydney, Australia.
- University of Stuttgart
- Ryerson University, Toronto, Canada
- Toulouse INP
- France National Solar Energy Institute
- CIEMAT
- Plataforma Solar de Almería (PSA)
- Institute of Fluid Mechanics (Friedr LSTM)
- Friedrich-Alexander University, Germany
- Research Institute for Physical and Chemical Problems, Russia
- Institute of Energetic Technology, ETH, Switzerland
- Grupo de Pesquisa em Combustão - GPC, Brazil
- Universidad Federal de Santa Catarina, Brazil.
- Arizona State University
- Technische Universität Berlin
- Universidade de São Paulo
- Task Force
- IEEE Power & Energy Society
- Universitat Rovira i Virgili, Spain
- NTU, Singapore
- University of Jyväskylä, Finland
- Universidad Ibague, Colombia
- Universidad Autónoma de Yucatán, Mexico
- Universidad de la Plata, Argentina
- Research Center on Applied Energy (GREA) of the Universidad de Lleida, Spain
- Center for Life Cycle Analysis at Columbia University
- Cambridge University
- University of Bordeayx
- Belarusian State Technology University
- Argonne National Laboratory, Chicago
- National Renewable Energy Laboratory, Colorado, USA.
- German Aerospace Center DLR
- Instituto de Investigaciones fisicoquímicas Teórica y Aplicada INIFTA, La Plata, Argentina
- Rockwood Albemarle, Chile-USA
- Cellular Technology, USA
- Universidad Autónoma de Nuevo León, Mexico
- Universidad de Barcelona, Spain
- Universidade Federal do Rio Grande do Norte, Natal, Brazil
- Universidad de Guanajuato
- University of Manchester
- Universidad de Almería
- Hampshire College, Amherst, Massachusetts, USA.
- Lawrence Berkeley
- Sandia National Laboratories, Johns Hopkins University
- University of Edinburgh
- Imperial College London
- University of Washington

Lines of research

LINE
1
Solar energy in the industrial/mining fields

LINE
2
High-voltage electrical systems with high solar power penetration

LINE
3
Solar power coordination systems for rural and urban communities

LINE
4
Storage of solar energy

LINE
5
Solar water treatment

LINE
6
Economic, social and regulatory aspects in the development of solar energy

Solar energy in the industrial/mining fields

LINE 1

LÍNEA

1

Researchers:

Main researcher:
Samir Kouro, USM.

Associates:
Edward Fuentealba, UA.
Rubén Peña, UDEC.
Willy Kracht, UCH.
Daniel Sbarbaro, UDEC.
Mario Toledo, USM.

Postdoc:
Christian Rojas, USM.
Aitor Marzo, UA.
Pablo Ferrada, UA.

Guest Researchers:
Rodrigo Barraza, USM.
Valeria Del Campo, USM.
Rubén Blasco, Universidad Politécnica from Valencia, Spain.
Enrique Cabrera, ISC Konstanz, Germany.

Based on a multidisciplinary approach, it has contributed to new knowledge and technological development to boost the penetration of solar energy in different industries, which will both mitigate the dependence on fossil fuels and reduce carbon footprint of energy intensive industrial processes.

MAIN ACHIEVEMENTS:

- A huge breakthrough in the development of power converters for photovoltaic systems. In particular, the development of new partial power converters which reached 99.8% efficiency in the trials obtained in the center, thus positioning SERC at the international forefront.
- The development of submodular power converters, which enable a 9.3% of higher energy yield for PV modules under heavy soiling conditions, according to tests carried out in the laboratories. One thesis on this topic was awarded the first place in the second Contest on Energy Efficiency Innovation by ABB Chile.
- Development of new power converter interfaces for large photovoltaic plants to introduce a new direct connection concept of this type of systems to high-voltage direct current networks, which have been experimentally validated through both real photovoltaic modules and Photovoltaic emulators.
- Development of a new configuration of power converter and its control, which allows the direct injection of photovoltaic energy into the direct current used in electro-refining of copper. This also helps the reduction of the carbon footprint at a key process of copper production.
- Development of optimized control strategy hybrid photovoltaic thermal collectors, which allows capturing the maximum amount of solar energy, while converting it into both electric and thermal energy. This technology can increase the amount of solar energy penetration into industrial processes demanding simultaneous electric and thermal energy.
- Joint research project with the University of Stuttgart (CONICYT-BMBF) to determine the best stages in the copper production process where solar energy can be integrated on a larger scale.
- Successful experiments to produce hydrogen and synthesis gas from various carbon materials (coal, biomass, polyethylene, among others), using solar energy in the gasification process.
- Characterization and impact assessment of soiling on different types of photovoltaic energy technologies (monocrystalline, polycrystalline and amorphous silicon).

Samir Kouro

"Our research line is, inherently, multidisciplinary in nature. Thus, our team is made up of experienced researchers in a variety of fields related to solar energy, such as solar-thermal systems, automatic control, mining processes, and power electronics systems, among others, coming from diverse scientific-technological backgrounds.

Right from the start, one of our biggest challenges has been to fit the different areas of expertise and past work of each researcher towards topics directly focused on the use of solar energy in industrial and mining processes. When we started, the sustainable or low-carbon footprint mining industry, which includes the penetration of solar energy, both as a source of electricity and thermal energy, in various mining processes, was a little-explored subject in the international arena. In fact, even considering the progress and contributions made by SERC during the last five years, there is still a lot of room to explore and accomplish. This is why this research line will be one of the strategic focuses of SERC for the second stage. This is just another achievement of our center, pioneer in introducing the solar energy topic in the mining industry nationwide, which, in turn has encouraged different initiatives such as CORFO's proposal to create a Solar Mining Institute.

The last five years have been fascinating, both for the experience gained and the achievements and breakthrough made. For example, at the end of the second year, we made a visit to Chuquicamata mine with all the researchers of the line. The idea was to actually witness, on site and first hand, all stages of copper production process and thereby detect opportunities for the potential use of solar energy to reduce the carbon footprint of this significant national industry. This visit not only allowed us to share and exchange more ideas among researchers, but it also revealed that there are many ways to improve efficiency in various processes. Many ideas emerged from this visit, which later were materialized into research projects, several from which are still being developed.

In the five past years, we are satisfied to have made several yet very important contributions in the line. The one I experienced more closely is related to the direct use of solar photovoltaic energy in the electro-refining process, that is to say, directly using the electricity coming from the panels, which is of low-voltage DC type, in the copper electrolysis process that consumes the same type of energy. Accordingly, we saved many stages of conversion and transformation of electric power, thus making the system much more efficient. On the other hand, the technology needed to connect the panels directly to the electro-refining process did not exist internationally; it was researched and developed by SERC. This technology cannot only be applied to copper refining, but also to other metals, like aluminum and could be extended to other applications such as hydrogen production, using photovoltaic solar energy".

> "The last five years have been fascinating, both for the experience gained and the achievements and breakthrough made."

High-voltage electrical systems with high solar power penetration

LINE 2

LÍNEA

2

Researchers:

Main researcher:
Luis Morán, UDEC.

Associates:
Marcelo Cortés, UA.
José Espinoza, UDEC.
Marcelo Pérez, USM.
Claudia Rahmann, UCH

Guest reseachers:
Rolando Burgos, Virginia Tech, USA.
Marco Rivera, Universidad de Talca.

Postdoc:
Ricardo Alvarez, UCH.
Javier Riedemann, UDEC.
Miguel Torres, UDEC.

Through new knowledge and the development of diverse research works, this line has contributed to the safe connection of high-voltage photovoltaic power stations to the electrical systems. The research areas include the operation of electrical systems with large renewable energy sources, their planning, the expansion of power lines, and implementation of storage systems, the development of new power converters that act as interface between the photovoltaic modules and the electrical system and, the quality of the electrical supply.

MAIN ACHIEVEMENTS:

- Demonstration of the technical feasibility of connection between the two largest electrical systems in Chile (SING and SIC by their acronyms in Spanish), through a 600-kilometer AC. transmission line.
- Development of methodologies and mathematical models to carry out frequency stability studies in power systems with high photovoltaic generation.
- Development of control and operation strategies to compensate the decrease in electrical power generation due to the cloud effect in high-voltage PV parks.
- Development of strategies for the optimal connection of power storage devices in order to boost the operation in both; permanent and transitional schemes of high-voltage systems.
- Development and trial of mathematical models to simulate the operation of large photovoltaic farms in stationary and transitional state.
- Development of control and operation strategies to compensate the decrease in electrical power generation due to the cloud effect in high power PV farms.
- Development of synchronization algorithms of static-phase converters to improve the dynamic operation of the PV farms in case of eventualities.
- Research on the use of ion-lithium batteries and development of mathematical models in order to estimate the degradation of cells. These results have contributed to model ion-lithium cells' thermal performance thus enhancing its dynamic response.
- Development of algorithms in order to reduce the complexity of power converters models thus enabling their incorporation into the study of power systems and perform simulations more efficiently.
- Development of high-performance control strategies for high-voltage power converters.

Luis Morán

"When we started this research line in 2012, the incorporation of large photovoltaic farms to the electrical system was only a draft at projects or ideas. Although by that time there was research on this matter, the ones applied to the Chilean electrical system were scarce.

The energy crisis of those years led to a favorable scenario from the economic perspective, as the cost of energy increased dramatically to end up within the top countries with the most expensive electrical energy worldwide. This opened up opportunities to boost investments in the non-conventional sources of energy such as the solar energy, since at the beginning of that decade; the price of the electricity was over one hundred dollars per megawatt-hour (MWh). Therefore, at this price range, solar energy became to be competitive.

In that context, our research line was composed of researchers who worked on power systems and with experience in non-conventional renewable energies. We made up a team of five researchers, from different universities, who specialized in power systems, power electronics and control system. With this group, we aimed at evaluating the operating conditions of the interconnected electrical systems, like the Chilean one, when incorporating high-voltage photovoltaic farms (over 100 MW).

During this five-year period, we have had amazing results that had been published in journals or in conference presentations. Additionally, we have also made contributions to incorporate photovoltaic solar farms into the national electrical system, as our participation in the prospective study Energía 2050, from the Ministry of Energy, which enabled to develop a projection strategy for the 2050 Chilean power grid. Hence SERC had a remarkable participation to influence national policies. Another contribution was one study led by Claudia Rahmann which demonstrated the feasibility of interconnecting the two electrical national systems (SING and SIC). Today, this interconnection is currently taking place through the construction of transmission lines between Copiapó and Antofagasta.

> "If we want Chile to become an exporter of electrical energy, we shall start now conducting the feasibility studies to favor the electrical interconnection of the different countries while assessing the effects of such interconnection."

Our main contribution remains in demonstrating that the connection of high-voltage solar power stations does not interfere with the operation of the Chilean electrical systems; neither does the interconnection between the Northern and the Central interconnected systems by using alternate current lines.

Most of our challenges were met; however, there is still much research to do as this field needs to continue progressing. Now, the performance of more complex power systems has to be analyzed. If we want Chile to become an exporter of electrical energy, we shall start now conducting the feasibility studies to favor the electrical interconnection of the different countries while assessing the effects of such interconnection. This is one of the many challenges we have ahead now, along with evaluating electrical market policies to allow this large-scale energy export, huge task for the line which will be now led by Enzo Sauma from Universidad Católica de Chile".

Experimental Installation Fresnel. Authorized picture taken in 2015 by Prof. Roberto Román, at Sandia Laboratories (Albuquerque, New Mexico, USA)

Solar power coordination systems for rural and urban communities

LINE 3

Researchers:

Main researcher:
Rodrigo Palma, UCH.

Associates:
José Miguel Cardemil, UCH.
Pablo Estévez, UCH.
Eduardo Gálvez, UTA.
Roberto Hernández, UCH.
Guillermo Jiménez, UCH.
Marcelo Matus, UCH.
Patricio Mendoza, UCH.
Daniel Olivares, PUC.
Doris Sáez, UCH.

Guest researchers:
Jaime Llanos, UDEC.
Matías Negrete, PUC.

Postdoc:
Felipe Valencia, Universidad Nacional de Colombia, Medellín.

It seeks to get advantage of, in a cost-effective way, the existent solar potential, introducing active participation models from rural and urban communities countrywide.

MAIN ACHIEVEMENTS:

- Provision of a global framework and tools to design, implement and operate solutions based on solar energy, for both rural and urban communities.
- In light of the challenges encountered from the operation and control reliability perspective, when integrating the variable of renewable energy sources (wind and solar) in micro grids, the research group has reached a deep understanding of the following matters: modelling of different types of micro grids (topology, energy sources and optimization techniques); operation control and strategies, and joint construction of approaches for system planning, operation and maintenance.
- Proposal of an energy management system (EMS) based on a strategy for moving horizon estimation. For every decision-making step, an optimization problem based on estimate models for the renewable resource has been solved.
- Methodologies for specialists and community participation in sustainable energy projects.
- Proposal for sustainability index including financial, social and environmental techniques.
- Design of a procedure based on a neural network for electrical consumption with 2-day forecasting capability. The system was tested using real data from a micro network located in the north of Chile (ESUSCON). The financial aspect of the proposal was assessed based on different working conditions and the system was implemented in Huatacondo village. During that period, new projects were developed and implemented in locations such as Ollagüe and Romeral.
- Development of an approach to implement micro network projects from an institutional level, through a specific entity that considers methods involving the community in the operation and maintenance of the micro network in order to guarantee its long-term functionality.
- Identification of financial capacities, social capital and organizational structure, through participation in diverse governmental and private initiatives, to select a customized business model that allows both funding and O&M activities.
- Contributions made by our researchers in the publishing of seven books and chapters about the challenges in the energy field in Chile and its direct impact in the current energy related policies.

Rodrigo Palma

"When this research line started back in 2012, the community-scale solar systems and particularly the development of micro networks were yet incipient issues. As a result of this, our first challenge was to position this subject within the reach and interest of the scientific world. During this period, the target has been to create and develop a theoretical framework and tools to design, implement and operate solutions based on solar energy, in rural and urban communities.

Despite the fact that solar energy in communities is longstanding, it had a rather paternalistic view. So the unprecedented innovation has been integrating these communities to the productive solutions and introducing a sense of ownership. At the beginning, this was very innovative and we believe that SERC Chile has been part of this track.

The main legacy of our line is that, in the past five years, we have been able to attain a co-construction methodology that allows planning, implementing, operating and maintaining these solutions together with the benefitted communities. This way, bringing these technological projects from overseas by experts and then transfer them to the community is no longer the case. Experience has demonstrated that this work must be gradually developed with the community as this interaction also contributes to its design. We have encountered wonderful surprises, sometimes communities have raised issues that were invisible to us, and if not considered, would have ended up in design errors. Thanks to this constant dialogue, experts have been able to make appropriate rectifications and prevent consequences later when in operation.

It is also remarkable to have torn several barriers down. Having started Ayllu Solar, in Arica-Parinacota, is a relevant milestone as it would allow us to generate public goods that would, in turn, take down some of such barriers. We are aware that there are still many hurdles to overcome before this becomes a common practice. The goal is that gradually, based on the outcomes of this project, it becomes easier for developers and communities to come up and develop their own ideas; thus taking less time, being more efficient in the scope of such technological solutions, developing business and management models able to achieve sustainable solutions for the community therein.

We are pleased to have elaborated this toolbox. A box of models, of analysis, of methodologies and of participative processes which we could portray in publications and which are currently the ground of SERC Chile offer to come along with the development of distributed solutions for solar energy generation, that we believe, will have an impact in Chile in the years to come".

> "The main legacy of our line is that, in the past five years, we have been able to attain a co-construction methodology that allows planning, implementing, operating and maintaining these solutions together with the benefitted communities."

Storage of solar energy

LINE 4

Researchers:

Main researcher:
Héctor Galleguillos, UA.

Associates:
Gustavo Cáceres, UAI.
Ángel Fernández, UA.
Teófilo Graber, UA.
Francisco Gracia, UCH.
Mario Grágeda, UA.
Svetlana Ushak, UA.

Postdoc:
Elisa Alonso, UA.

This line seeks to preserve energy as latent and sensible heat through the use of salts and other compounds. It also explores storage through the generation and optimization of hydrogen.

MAIN ACHIEVEMENTS:

- Study of systems to reduce the melting point of solar salt (a mixture of sodium and potassium nitrates) and improve thermal stability. Our research line has experimented with other salts like the calcium nitrate, to reduce such melting point while also adding lithium nitrate to improve stability.
- Development of new storage systems for molten salts with lower melting points and high temperature of thermal stability, which allow for the reduction of operational costs and an increase in the thermal performance of the power supply block in concentrated solar energy plants.
- Study of salts that are residues or byproducts from the non-metallic mining industry, and which could be found in the region and be assigned added value. Bischofite was a relevant finding, as its thermos-physical properties are similar to those of magnesium chloride hydrates but it has a lower cost.
- The results show that materials such as bischofite are very attractive for the storage of energy as latent heat.
- In the area of non-thermal storage, different methodologies for the effective management of electrochemical energy preservation systems were researched, such as lithium batteries to reduce their costs, increase their capacity and safety, and extend their life cycle.
- Development of a model to estimate the thermal performance of lithium-ion in cellular surface. The results of this research helped to create the technical and scientific abilities in our country to develop lithium-based technologies to boost solar development.
- Development of an Energy Management System (EMS) for Huatacondo, a rural community located in the north of Chile that has an autonomous energy supply. A solution has been implemented from renewable sources (photovoltaic and wind-) and storage based on acid-led diesel batteries to generate energy and meet the demands of the town uninterruptedly.
- Proposal of a model that integrates short-term storage systems and planning for the operations of a cost-based centralized market. The model intends to offer arbitration services for primary and secondary and/or reserve energy. The results obtained showed that storage is an efficient way to provide electricity services.

Héctor Galleguillos

"Due to its variability, the application of solar energy also requires storage systems. In this sense, one of the challenges of our line was to gather scholars from the universities participating in SERC, who by then were just making their first attempts in thermal storage of solar energy, to create knowledge on efficient thermal storage systems, mainly through sensible and latent heat, thus contributing to their development in the country.

There were very few publications on this subject nationwide, but the members of our research line began, starting the third year, publishing a considerable amount of work in various scientific journals, most of them qualified as Q1 and with high impact factors. This trend continued in the following years.

We are very satisfied with the achievements of our line, especially with two important milestones. The first is that, on the subject of thermal energy storage as sensible heat, new mixtures of molten salts were developed, which have several benefits compared to the mixture commonly used in thermo-solar plants (solar salt). The new mixtures can work within a larger temperature range than before, primarily due to their lower melting point. Also, the new mixes produce lower corrosion rates than before and one of them has a lower storage cost than that of solar salt.

The second big finding is that bischofite, a byproduct of non-metallic mining, has good properties for energy storage, similar to hydrated magnesium chloride but at a lower cost.

These findings can broaden the use of this element, which is currently only commercialized as a chemical stabilizer for dirt roads, especially in mining works".

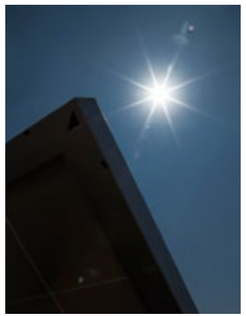
Rodrigo Palma, main researcher of this line for the second stage

"The world of applications, which can be either technological or seen as a black box system, is where we have the great task of determining how storage feeds strategic targets, the mining sector, and the interconnected system, among others. The challenge, guided by SERC's four strategic focuses, is to feed the Chilean system with innovative ideas on storage, placing it as an application and option that makes solar energy cost-efficient and environmentally-friendly.

Storage as a subject will be with us for many years. Chile should have a competence center on storage that interacts with other types of energy. That is a greater challenge that, thanks to this five-year work, we expect to provide powerful answers on the four established strategic targets, so that to attain relevant solutions.

Chile is in conditions of making a bet; likewise it does today with the sun, on the subject of storage itself. There are a couple of niches we should bet on, although we must be very selective.

There is a bet to make on lithium, to see how Chile invests in it in order to fulfill a role. There is a bet on molten salts, on storage in thermal solar plants, and there is a bet on hydroelectricity, a new understanding to consider its importance on a long-term view in a sustainable Chile".



"Due to its variability, the application of solar energy also requires storage systems. In this sense, one of the challenges of our line was to gather scholars from the universities participating in SERC."

Solar water treatment

LINE 5

Researchers:

Main researcher:
Lorena Cornejo, UTA.

Associate:
David Contreras, UDEC.
Francisco Gracia, UCH.
Héctor Mansilla, UDEC.
Ricardo Salazar, Universidad de Santiago.
Jorge Yáñez, UDEC.

Other Researchers:
Alejandro Cabrera, UTA
Patricia Palenzuela, Plataforma Solar de Almería, Spain.

Postdoc:
Sara Miralles, Universidad de Almería, Spain.

Researchers have focused on the use of solar resource as a driving force of different chemical and physical processes applied to desalination of seawater/brackish water and to the decontamination and disinfection of wastewater and natural waters.

MAIN ACHIEVEMENTS:

- Application of Photoelectro-Fenton solar, heterogeneous photocatalysis and photo-Fenton solar processes, among others, to the extinction of personal hygiene products, pesticides, drugs and other emerging pollutants which are considered dangerous worldwide.
- Use of zero-valent iron technology for the removal of arsenic, a contaminant that is naturally present in the waters of northern Chile.
- Treatment of wastewater generated in a slaughterhouse, as an example of the projection in the use of solar water treatment technologies in the decontamination of wastewaters.
- Economic evaluation of solar water treatment processes to determine their competitiveness against some more established treatments.
- Socialization and outreach of applying solar water treatment on specific problems in Chile.
- Implementation of two pre-industrial desalination pilot plants to get drinking water for small communities in the region of Arica-Parinacota, because of the existing poor water quality with high concentrations of arsenic, boron and salts.
- Creation of an updated solar map for the region of Arica-Parinacota to characterize solar radiation, where 6 meteorological stations were set up with horizontal, direct and diffuse measurement instruments of global radiation

Lorena Cornejo

"The University of Tarapacá had conducted research on solar water treatment for a 10-year period – mainly developing solar processes applied to water decontamination to remove arsenic and thereby help the different communities who suffered serious difficulties with the poor water quality.

The arrival of SERC Chile to the region allowed the set-up of this joint research line to strengthen the work on the use of solar radiation applied to solar water treatment, thus creating an inter-institutional team of researchers that was the foundation for the training of specialized human resources at pre and post-graduate level.

Until then, the research line on solar water treatment (SWT) was less advanced compared to other areas within solar energy. Although research on SWT began about 25 years ago worldwide, in Chile however, most of the progress made was theoretical and just a small part was applied research conducted in the region of Arica-Parinacota. It is precisely in this latter field where this research line has made relevant breakthroughs in Chile, trying to bring the different solar processes of existing water treatment closer to their real application.

> "The arrival of SERC Chile to the region allowed the set-up of this joint research line to strengthen the work on the use of solar radiation applied to solar water treatment."

The team of researchers was made up through an invitation extended to specialists from Universidad de Concepción, with whom we maintained collaborative relationships through other joint projects, and some other researchers from other universities who participated in the conception of SERC.

The rapport within the group has been fundamental to accomplish the targets set. One of them is having achieved a significant increase in the annual number of ISI publications.

During 2013, the first year of SERC Chile, four scientific papers were published, a figure which was gradually increasing to reach a total of 44 publications at the end of the project, a relevant number despite the reduced number of researchers of this line.

Even more remarkable is the enhancement made in the scientific quality of such publications, which is reflected both in the impact factors and in the quartiles of the journals. While in 2013 the cumulative impact factor barely reached 2,835 points and no publication fitted the first quartile (Q1), in 2017 these values increased to 5,508 and nine Q1 publications, respectively.

As already mentioned, the erection of pre-industrial desalination pilot plants was crucial to obtain drinking water in those small communities of Arica-Parinacota region, which have significant deficiencies in the availability of quality water due to the presence of arsenic and high concentrations of salts. In Taltape, a multi-effect distillation plant was erected with eight effects (stages), well above the three usual effects or stages of commercial plants. In this way, this technology fulfills the dual mission of providing water to the population, while in turn carrying out research tasks. On the other hand, in Cora 9 –Cuya- a membrane distillation plant has been installed to supply water to a community of fishermen.

Our research line has also achieved high yields in the elimination of toxic and persistent pollutants from agro-industry, through processes that also allow projecting the use of these solar technologies in the treatment of agricultural and/or industrial wastewater.

This type of water has very heterogeneous characteristics, which implies that each case must be carefully studied. As it cannot be treated by conventional processes -and as a consequence of its high degree of toxicity and low biodegradability-, industrial water poses a very high risk to natural water bodies, affecting their quality and if not treated properly, they may become useless".

Economic, social and regulatory aspects in the development of solar energy

LINE 6

Main researcher:
Claudio Agostini, UAI.

Associates:
Pilar Moraga, UCH.
Francisco Muñoz, UAI.
Carlos Silva, UAI.

Postdoc:
Shahriyar Nasirov, Universidad del País Vasco, Guipúzcoa, Spain.

The research line analyzed the existing barriers and challenges to the development and higher penetration of renewable energies, especially solar energy.

MAIN ACHIEVEMENTS:

- Classification of the main barriers to entry and their corresponding analysis, from the investors' point of view, in the development and identification of renewable energy technologies within the Chilean framework.
- Identifying the key development and deployment challenges for solar energy in Chile, which reveal three significant obstacles: regulatory and institutional; technical and infrastructure related; and economic and financial matters.
- Contribution in tearing some of the barriers down regarding solar energy. These efforts resulted in solar energy projects of 549 MW of capacity, which are currently being built in the country.
- Recommendations to overcome some of the already identified barriers, focusing on government leadership and a targeting strategy in order to both develop and modernize institutional structures so as to incorporate public policies and thereby improve the quality of interactions among involved organizations.
- Recommendations made based on conclusions drawn, among the development instruments, to the government's commitments to offer securities for loans or else to issue "green bonds"; corrective taxes on coal and diesel to internalize the negative spillover effects and promote the replacement of energy sources, and/or the introduction of cleaner sources to boost the rational energy use.
- Proposal to set a comprehensive process of national transmission planning, creating standard procedures of interconnection to regulate the open access to electrical transmission networks, while strengthening transmission prices.
- Highlight the three main advantages of solar energy which are especially relevant for Chile: first, to provide safe yet sustainable energy; second, to boost economic development; and finally to address climate change and environmental concerns.

Claudio Agostini

"The first challenge of our line was working interdisciplinarily, as we invited economists, electrical engineers and lawyers to answer, from different perspectives, relevant questions about the development of solar energy in Chile. It was important that our work had both, impact in the academic field through publications in scientific journals as well as on the design, evaluation and discussion of Chilean public policies.

The latter issue has been an extremely important topic. When SERC was founded, there were renewable energy projects with environmental approval for almost 21,000 MW in Chile, however less than 10% of them had been materialized. By then, there was little academic research on barriers encountered by renewable energy projects, especially solar and wind energy projects. Therefore, the first goal in our work was to reduce the existing gap and gain knowledge about the different kinds of barriers preventing investments in such projects and how to overcome them.

To analyze these issues, a team composed of researchers with extensive experience in regulatory and electric matters was created. Due to different reasons, the team changed over time and new researchers arrived, including a foreign postdoctoral researcher, who provided the group with new perspectives as well as a great boost to our work.

In this context, we designed and implemented three surveys: to investors of solar energy projects; to households which have solar technology for water heating systems; and to households that use photovoltaic panels to generate electricity. In Chile, there was no data available to analyze and determine the problems faced by investors in the development and implementation of solar projects, nor to assess the impact of the tax credit to install residential hot water systems based on solar energy, or to analyze the residential consumer perception and demand for non-conventional renewable energy. The data obtained from the surveys have helped us to gain a better understanding of solar energy integration while improving the academic research in these three dimensions.

Even though the contribution is rather general, through the generation of a critical mass in solar energy research in Chile, there are specific contributions made in each one of the scientific publications. Particularly, there are two specific areas of research publications that need to be highlighted. The first one is the identification of the barriers to the solar energy development in Chile, and their corresponding analysis, either from the investors' and/or public policies' perspective, so that they can be overcome.

The second one is the advancement made towards the establishment and quantification of the social benefits of renewable energies, particularly solar energy, in terms of the environment, energy expansion, and the development of rural areas that do not have access to electricity".

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> Even though the contribution is rather general, through the generation of a critical mass in solar energy re-search in Chile, there are specific contributions made in each one of the scientific publications.

The challenge of solar energy in Chile 2018-2022

Over time we have gotten better knowledge about the sun and becoming more and more fascinated by the adventure of understanding its potential as an opportunity to change history. As mentioned in the introduction of this annual report, in absence of fossil fuels, nature has provided us with the most privileged condition to find the energy we need from renewable sources.

This poses an obligation and a responsibility. We must extreme all our research efforts to continue expanding the knowledge necessary to develop the conditions to better benefit from solar energy in its entire splendor. The work done so far has greatly contributed to the academic community, authorities, and society allowing them to be more involved and committed to the new challenges. In this sense, we are pleased to receive the valuable support from Fraunhofer Chile and the Pontificia Universidad Católica de Chile at this new stage, contributing with their experience and knowledge to face the challenges ahead.

We are being part of a revolution. At this new stage, we have divided our main challenges into four strategic focuses and seven lines of research. Thus, our scientific work can make a real contribution in life through projects aiming at developing and positioning Chile as an internationally relevant player on these topics, even further from what we once were with saltpeter and from what we still are in the copper industry today.

These strategic focuses are:

I. Massive integration of large-scale solar energy to the interconnected system.

II. Solar- energy-based mining in Chile.

III. Generalized development and implementation of small-scale solar solutions.

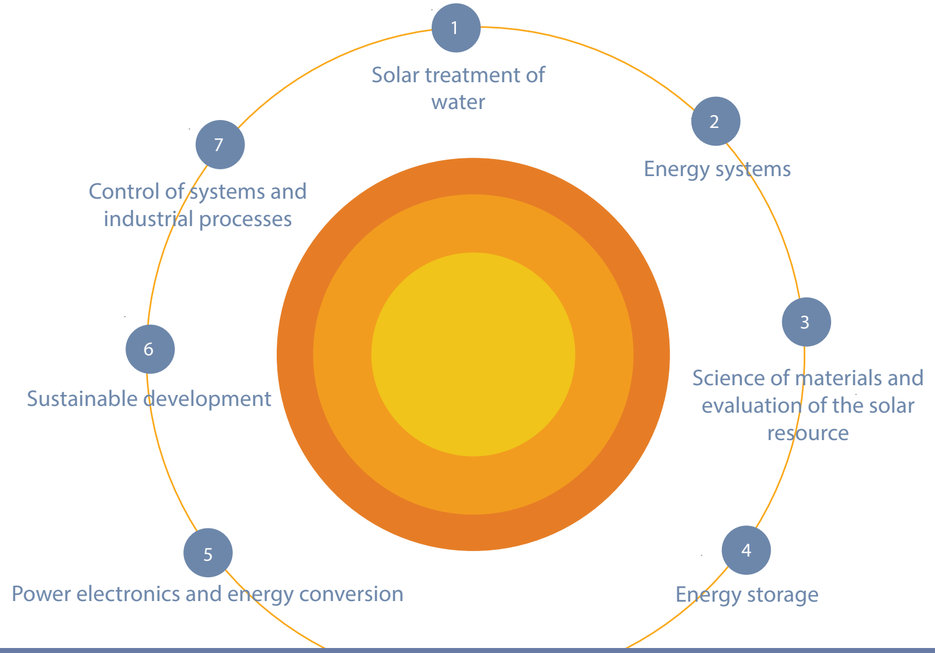
IV. Optimization and featuring of solar materials and resources under domestic conditions.

A Strategic Research Committee (CEI by its Spanish acronym) operates since early 2018, an advisor and independent group, contributing to analyze the progress made in the strategic focuses defined by SERC Chile for its second stage (2018-2022). The Committee is composed of Guillermo Jiménez, director of the Energy Center, from Universidad de Chile, Carlos Portillo, associate professor in the Department of Electrical Engineering from Universidad de Antofagasta; Hugh Rudnick, professor emeritus of the Department of Engineering from Pontificia Universidad Católica, Chile, and Daniel Sbarbaro, scholar of the Department of Electrical Engineering from Universidad de Concepción.

Below, we outline the seven scientific research lines that will comprise the new stage for SERC Chile, researchers of each research line, their objectives, and the results expected for 2022:
SERC Chile Research lines 2018 - 2022

1. Solar water treatment
2. Energy systems
3. Materials science and evaluation of the solar resources
4. Energy storage
5. Power electronics and energy conversion
6. Sustainable development
7. Control of systems and industrial processes

Lines of research SERC Chile 2018 - 2022



Results expected for all lines of research:

- Creation and transference of new knowledge
- Publications in the main academic journals
- Development of human capital associated to research objectives
- Active participation in the discussion of energy policies in Chile
- Collection of funds for new R&D projects

Solar treatment of water

Main researcher:
Lorena Cornejo, UTA

Associate researchers:
- Alejandro Cabrera (UTA)
- David Contreras (UDEC)
- Francisco Gracia (UCH)
- Héctor Mansilla (UDEC)
- Ricardo Salazar (USACH)
- Jorge Yáñez (UDEC)

Assistant researcher:
- Rodrigo Barraza (UTFSM)

Postdoctoral researchers:
- Sara Miralles (Universidad de Almería, Spain)
- Saravanan Rajendra (UCH)*

Objectives:

To establish conceptual bases in order to optimize the solar degradation processes on aqueous-phase pollutants arising from technological development for small-to-medium scale solutions, addressing the following strategic focuses:

- Understanding mechanisms that govern photo corrosion of copper sulfide minerals, particularly on chalcopyrite ($CuFeS_2$).
- Implementing natural and industrial solar water treatment systems, stressing the elimination of specific pollutants such as emerging organometallics, pathogenic microorganisms, pesticides, drugs, among others.
- Designing and preparing new solar-range active materials such as metallic and graphene oxide compounds, and from the ferrite type, which are easily recoverable with the use of magnetic fields.
- Enlarging the solar monitoring network in the Region of Arica-Parinacota.

Expected results:

We expect to have new technological devices or analytical methodologies for laboratory and/or semi-industrial scale water treatment. For example:

- New materials for solar water treatment technologies adapted to different matrixes.
- Implementation of small and medium scale photo-reactors.
- Improvement of new solar processes and technologies to provide profitable and effective water treatment solutions of different types and for several uses.
- Technical and cost-effective feasibility validation of technologies.
- Characterization of solar radiation in those areas with poor information.

Energy Systems

Main researcher:
Enzo Sauma (PUC)

Associate researchers:
- Rodrigo Escobar (PUC)
- Álvaro Lorca (PUC)
- Daniel Olivares (PUC)
- Rodrigo Moreno (UCH)
- Francisco Muñoz (UAI)
- Hugh Rudnick (PUC)

Assistant researchers:
- Matías Negrete (PUC)
- Marcelo Matus (UCH)

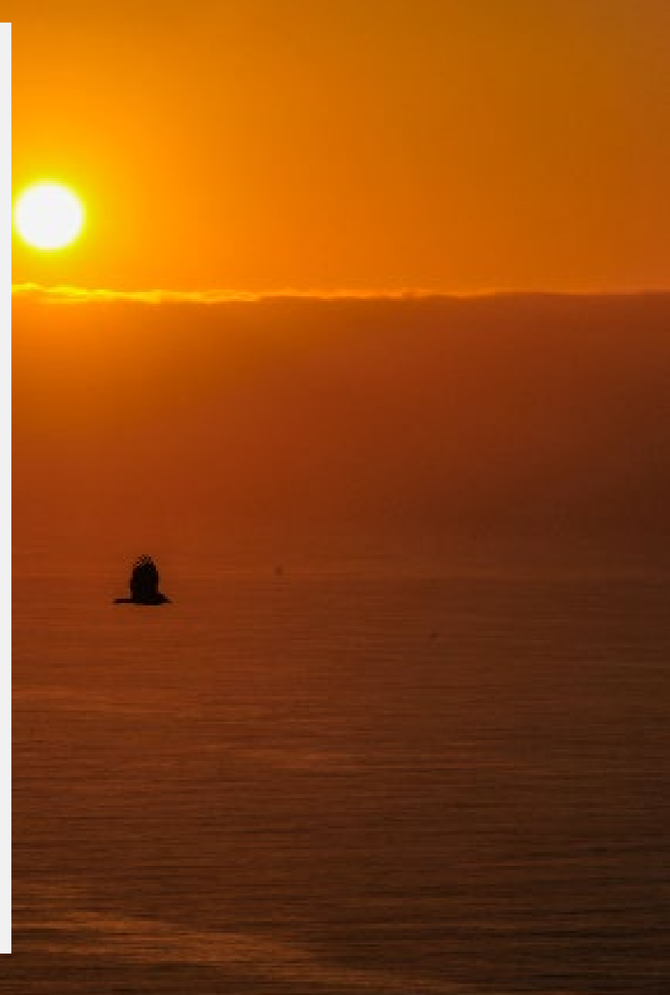
Postdoctoral researchers:
- Sebastián Oliva (UCH)

Objectives:

- Recommending planning tools for systems infrastructure characterized by high variability and uncertainty levels.
- Suggesting new auxiliary service schemes either for frequency and voltage regulation as well as for the massive integration of storage systems.
- Recommending suitable market designs to fit with different scale levels.
- Recommending public policies that boost the energy exchange in South America.

Expected results:

- Development of planning tools for power infrastructure, both for the operation of energy systems with high variability and uncertainty levels and for different storage systems.
- Evaluation of new scenarios of operation and expansion of the power grid, bearing in mind the cost of technology, the coordination between multiple players, technical aspects related to stability and systemic safety, variability and uncertainty, and the current regulatory framework.
- Analysis of new market opportunities for solar power at multiple levels.
- A set of public policies (and their corresponding market design) to promote an efficient massive integration of solar energy into the power grid.



Science of materials and evaluation of the solar resource

Main researcher:
Edward Fuentealba (UA)

Associate researchers:
• Valeria del Campo (UFSM)
• Pablo Ferrada (UA)
• Mario Grágeda (UA)
• Jaime Llanos (UCN)
• Aitor Marzo (UA)
• Eduardo Schott (PUC)
• Svetlana Ushak (UA)
• Javier Recio (PUC)
• Ángel Leiva (PUC)

Assistant researchers:
• Enrique Cabrera
• Carlos Portillo (UA)
• René Rojas (PUC)
• Ramón Zárate (UCN)
Paulraj Maniduraj (UdeC)

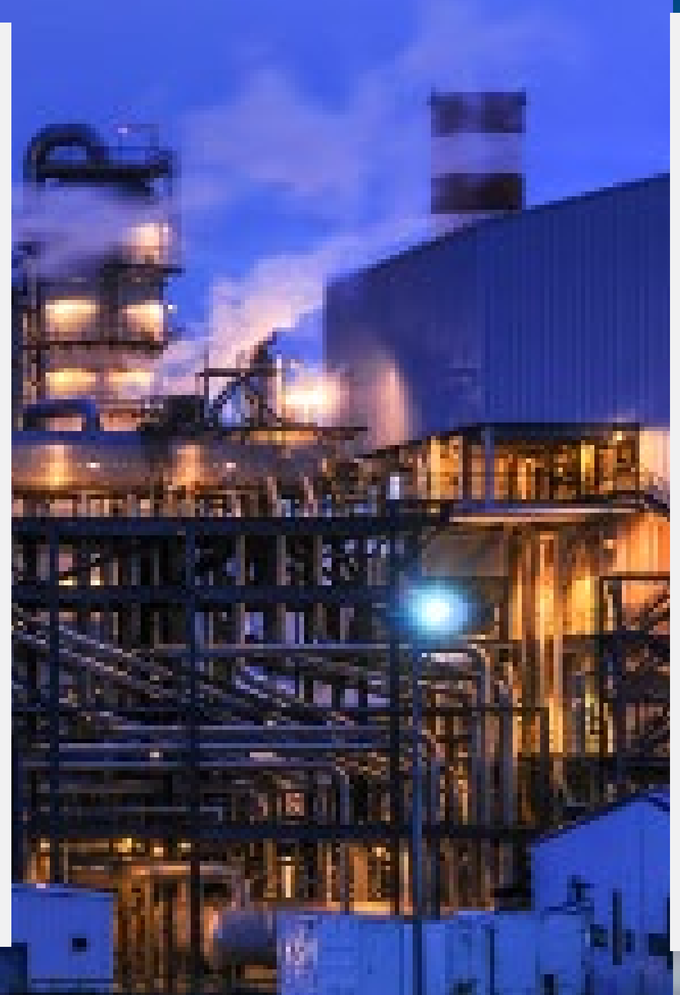
Postdoctoral researchers:
• Elisa Alonso (UA)
• Jonathan Correa (UFSM)

Objectives:

- Territorial characterization through the analysis of solar and environmental conditions, and their effects on solar energy technologies (dirt, corrosion, aging).
- Characterization, synthetization and optimization of domestic components and mining byproducts for the developing new energy storage materials in order to improve the profitability of solar technologies and the energy efficiency of buildings.
- Synthesis, processing, and characterization of materials to develop cellular and photovoltaic modules adapted to the domestic conditions.
- Development of a green chemistry for local applications aided by solar radiation.

Expected results:

- Generation of the necessary schematic information and environmental parameters suitable for solar technologies.
- New, optimized energy storage materials to improve efficiency and turn them into more profitable solar technology materials.
- Creation and optimization of materials to develop solar technologies adjusted to domestic conditions.



Energy storage

Main researchers:
Frank Dinter (FH)
Rodrigo Palma (UCH)

Associate researchers:
• José Miguel Cardemil (UCH)
• Marcelo Cortés (UA)
• Pablo Estévez (UCH)
• Claudia Rahmann (UCH)
• Mario Toledo (USM)
• Felipe Valencia (UCH)

Assistant researchers:
• Mercedes Ibatta (FH)

Postdoctoral researchers:
• Ricardo Álvarez (UCH)

Objectives:

- Identifying and developing cost-effective energy storage solutions for scenarios of high solar energy penetration, considering the challenges and opportunities provided by domestic conditions.

Expected results:

- A unified framework for the analysis and development of storage solutions.
- Evaluation and validation strategies for storage applications in different fields.
- New models, simulation strategies, and prototype design of storage applications.
- Strategic guidelines to define public policies related to solar energy storage.

Power electronics and energy conversion

Main researcher:
Samir Kouro (UTFSM)

Associate researchers:
• Javier Pereda (PUC)
• Marcelo Pérez (UTFSM)
• Carlos Restrepo (UTalca)
• Félix Rojas (USACH)

Assistant researchers:
• Patricio Mendoza (UCH)
• Freddy Flores (UTFSM)
• Javier Riedemann (PUCV)
• Sebastián Rivera (UTFSM)

Postdoctoral researchers:
• Andrii Chub (UTFSM)

Objectives:

- Researching and developing topologies and control for state-of-the-art power converters to allow an efficient and reliable interface of solar energy systems for both the grid and industrial processes.

Expected results:

- Developing new topologies and control of power converters to allow a larger solar penetration in grids and industrial systems.
- Pilot projects at an industrial level.
- Patents and technological transfers.

Sustainable development

Main researcher:
Claudio Agostini (UAI)

Associate researchers:
• Guillermo Jiménez (UCH)
• Claudia Moraga (UTA)
• Pilar Moraga (UCH)
• Shahriyar Nasirov (UAI)
• Carlos Silva (UAI)
• David Watts (PUC)
• Manuel Willington (UAI)

Assistant researchers:
• Luz Cárdenas (UCH)

Objectives:

Analyzing and recommending solar-energy based solutions to fully develop our solar energy potential while reaching higher penetration rates. The specific topics are the following:

- How to solve the lack of an effective open access non-discriminatory transmission policy.
- Look for solutions to deal with the strong resistance from local communities to new generation projects due to environmental concerns.
- Design and evaluate the necessary changes to the current regulatory framework, which distributes transmissions payments to energy generators based on line usage.

Exploring flexible solutions to allow a generalized use of small-scale solar energy technology. The specific topics are the following:

- The Chilean energetic policy could actually play a key role to both, balance the needs for energy of many isolated communities and small-size businesses and to meet the objective of reaching a sustainable economic development.
- The use of solar energy in small-size firms' productive processes could be a very profitable solution to particularly comply with the long-term sustainable development objectives of the country.
- Energy policies must also be considered legitimate by citizens and consider a great deal of participation within communities.

Creating an explicit link between solar resources and their corresponding economic and financial effects derived from the different solar radiation levels. The specific topics are the following:

- Generation of a framework and metrics to inform developers, investors and financial institutions on the profitability and risks associated to solar energy projects.
- The reduction of uncertainty on profitability and the associated risks would allow not only for the development and implementation of more and better projects, but could also help the government in terms of geographical planning to locate energy projects and future installation of transmission lines.

Expected results:

- Proposals for different public policies associated to dealing with the challenges faced when renewable energy penetration increases significantly, particularly solar energy.
- Proposals for a new regulatory framework for electrical markets with high penetration rates of intermittent energy sources.

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Control of systems and industrial processes

Main researcher:
Luis Morán (UDEC)

Associate researchers:
• José Espinoza (UDEC)
• Willy Kracht (UCH)
• Claudia Carrasco (UDEC)
• Rubén Peña (UDEC)
• Doris Sáez (UCH)
• Daniel Sbarbaro (UDEC)
• Eduardo Wiechmann (UDEC)

Assistant researchers:
• Miguel Torres (UdeC)
• Aymeric Girard (UAI)

Postdoctoral researchers:
• Nataly Cisternad (UdeC)
• Omar Behar (UdeC)

Objectives:

- Detecting and developing innovative control strategies and new technological opportunities to use solar energy on different industrial processes related to mining industry.

Expected results:

- New control strategies and simulation approaches.
- Development of new operation methods to combine the use of both conventional and solar energy, by using time power modulation in some processes for example.
- The use of solar energy will be considered in the electrical power systems through the use of co-generation photovoltaic plants and the direct use of solar energy in various industrial processes (thermal solar, solar radiation).

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www.gallos.cl

The adventure continues

When we started this journey, five years ago, there was a lot of uncertainty. With just one megawatt in the electric system, it was hard to imagine the challenge that we are passionate about today. We challenged ourselves to show that there is enough knowledge to have an impact and that our findings can not only facilitate the insertion of SERC in an international academic network, but also to develop projects with industrial partners and improve the human capital in the country.

This continues to be an adventure and in every adventure there are risks and expectations. We have become accustomed to go beyond our limits, and what moves us now is, precisely, move closer to the sun, applying for this purpose knowledge to facts. We hope that when that happens, the powerful results of our work as an applied science will create a virtuous cycle, which attracts more interest from future generations, from authorities, institutions, the academia and also from potential angel investors who understand our proposed path towards the future.

The first five years were a great bet on the sun… Now, our roadmap aims at having an impact based on our strategic focuses, turning solar energy into a sustainable engine for the development of the Chilean economy in the long run. We do know there will be new obstacles. There are many technological challenges to face –storage for example- that show us we are far from having reached our destination. The main problem of solar energy is that we must obtain alternative methods to supply the energy that the sun takes from us once it sets. Together with finding different solutions to increase the efficiency of conversion processes at a low cost, we have to conceive efficient systems that combine flexible storage and the resilience to supply solar energy in an inexpensive and safe way with a low environmental impact and high social approval.

We do not know what our findings will be and that is the beauty of science. Turning Chile into a solar country is our adventure today. Our efforts for SERC 2.0 focus on developing and using solar energy in Chile extensively, but not only at a domestic scale but also becoming exporter of such energy, adding all its generation capacity. We are also excited about incorporating solar energy to industrial productive processes to make them environmentally friendly.

The potential is huge, from short term solutions providing the mining sector with a more sustainable energy source to innovative proposals to attract data centers and export solar energy as synthetic fuels. To this extend, the role of SERC Chile has been, and will continue to be, key to determine which are the existing challenges and opportunities to achieve a massive solar energy penetration into the national power grid. SERC also plays a significant role providing answers from basic and applied research that creates the necessary knowledge to implement such solutions.

More people need to be encouraged, committed and educated; more decisions need to be made, more inventions to be proposed and designed, more ideas to dream of. We do not get tired of saying it again: Chile has a condition that entails an advantage and an opportunity. We do not have fossil fuels. We do not have another chance or other distractions. Renewable energy is our target and future. There, where we are heading, the sun will brighten our adventure.

SERC CHILE

SOLAR ENERGY RESEARCH CENTER

2013-2017

2018-2022