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Paraguay sells its electricity surplus of more than 40,000 GWh every year to its neighbors. Instead, this renewable, reliable, carbon-free energy should be harnessed to drive growth that's sustainable, eco-responsible, inclusive & brings economic complexity.

Itaipú Dam: Paraguay's Growth Potential

by Emily Davenport, Christine Folch, Connor Vasu

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I. Executive Summary

Paraguay (population 7 million), the world's highest per capita producer of hydroelectricity, enjoys a vast carbon-free electricity surplus and annual energy rent that totals nearly $1 billion from its participation in Itaipú Binational Dam (co-owned with Brazil), the largest hydroelectric dam in the world in terms of energy production. In fact, all of Paraguay's electricity is renewable, coming from Itaipú Dam, Yacyreta Dam (a binational dam co-owned with Argentina), and Acaray Dam. Because Paraguay does not have sufficient demand to consume its electricity production, it exports (the technical term is "cedes") the majority to its neighbors Argentina and Brazil for a below-market price.

As a middle-income country, Paraguay has had sustained economic growth averaging 4.8% per year over the past decade--among the highest and most stable in the entire Latin American region.[1] The Economist forecasts that Paraguay will have one of the fastest growing economies in the Western Hemisphere in 2018.[2] Nevertheless, in spite of impressive gains against poverty,[3] the primarily agro-exporting country's GINI index of 47.9 (2016) indicates a high level of inequality and that there are important strides to be made in terms of development.[4]

In this white paper, we outline suggestions for how to put Paraguay's electricity surplus to work by proposing how to harness the untapped electricity resources to drive an industrialization that is sustainable (socially, ecologically, financially), inclusive (alleviates poverty, raises living standards for the bottom of the pyramid), and builds internal economic complexity. Our Duke-based research team conducted interviews in the United States, looked to best practices and successful examples among other developing

countries as well as energy-rich countries. But most importantly, we traveled to Paraguay, where we were able to speak with representatives from multiple sectors and where we visited sites ranging from high-tech meat processing to industrial processing facilities to artisanal eco-responsible small-scale farms across the country. Based on these interviews, site visits, and the data gathered from comparative cases, we analyzed two basic approaches to using the surplus Itaipú electricity: 1) expanding and innovating upon current economic strengths (namely agro-export) through the addition of increased electricity resources; 2) building new industries at the edge of the technological frontier that take advantage of the surplus.

We find that the latter, building new industries, has the greatest potential for sustainable, ecologically-responsible, inclusive economic growth.[5] To illustrate why Paraguay should consider new industries rather than its traditional products or traditional large electro-intensive industries, we highlight a few notable global trends:

- 50% of all solar investment/spending in 2017 happened in China.[6]
- Industry innovations in the next ten years that impact electricity consumption.
  - Rise of 5G (10-40 times faster than current internet speeds)
  - "Internet of things" (where appliances and other components of houses and businesses are wired)
  - Autonomous vehicles and fleets (there are significant investments from Ford, GM, and other car manufacturers in this direction)

Following the example of South Korea and the other so-called "Asian Tigers," late industrializers that have experienced sustained growth and improved standards of living, we urge that Paraguay look to the technological frontier, rather than traditional sectors, for growth potential.

Here we illustrate how Paraguay might participate in two growing sectors: data processing centers and rechargeable batteries and battery packs. The first section of this white paper describes the economic situation of Paraguay and the status of its hydroelectric resources. The second section quickly covers general lessons learned from our site visits, including challenges to development and growth as well as commenting on the importance of flexibility in agricultural production and the ongoing development of eco-tourism. The third section delves in greater detail into data processing and battery production.

We hope that these suggestions foster discussion and creativity so that Paraguay can use its electricity surplus to generate jobs, development & economic complexity.

Figure 1: Visit to Frigorífico Concepción (Concepción Department). Photo: C. Folch

Paraguay--Economy Basics

Paraguay borders Bolivia to the north, Brazil to the east, and Argentina to the south. The GDP in 2016 was USD$27.44 billion and $4,080.20 per capita.[7] Paraguay's main trading partners are its Mercosur neighbors Argentina and Brazil. In 2016, Paraguay's exports totaled $9.24 billion (see Figure 2)--the top three products were soy, electricity, and cattle. That same year, Paraguay imported $12 billion (see Figure 3). Paraguay is, at present, the world's fourth-largest soy exporter (behind the United States, Brazil, and Argentina) and much of its soy sector is controlled by foreign nationals and transnational corporations.[8] Our team was able to visit Frigorífico Concepción, a world-class meat-processing plant with rising kosher exports to Israel, halal exports to the Middle East, as well as markets in Russia, Chile, Cuba, Vietnam and more. Similar to soy, many of its largest ranches and meat-processing facilities are owned by foreign nationals and companies based in Brazil.

Not only do imports exceed exports by 23%, the degree of complexity of the two charts shows the diversity of products imported greatly exceeds the diversity of the products exported. Although the major drivers of the Paraguayan economy are agro-exports, a Maquila law has fostered the development of maquilas principally on the Paraguayan-Brazilian border--60% of the 150 companies that operate in the export-oriented assembly factories are Brazilian.[9] Though this has been an important source of growth, it fosters limited economic complexity within Paraguay and does not reach the interior of the country because maquiladora companies are located on the border.

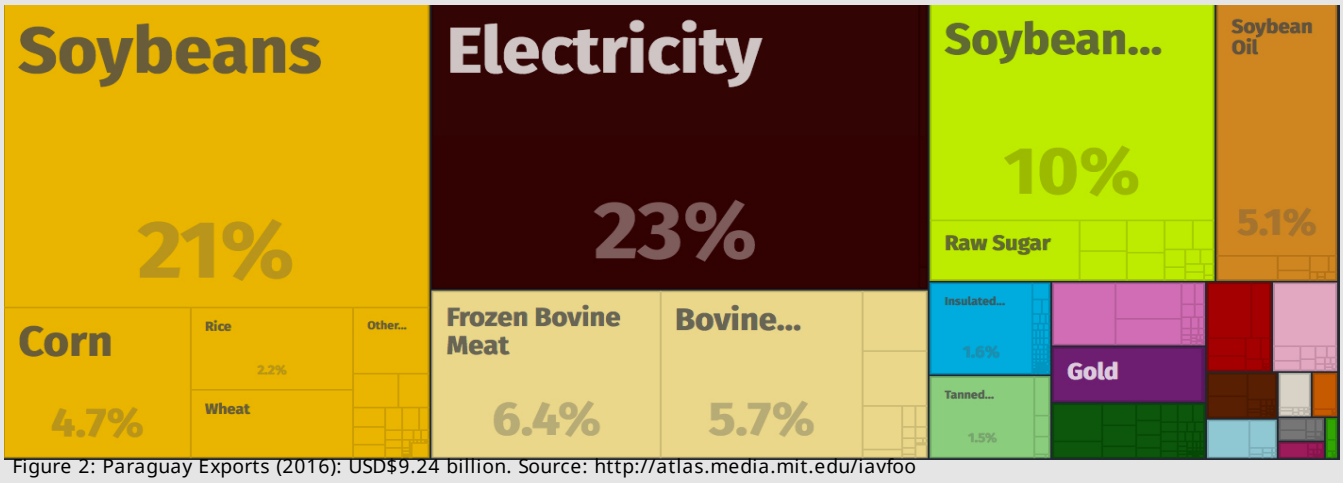

Figure 2: Paraguay Exports (2016): USD$9.24 billion. Source: http://atlas.media.mit.edu/iavfoo

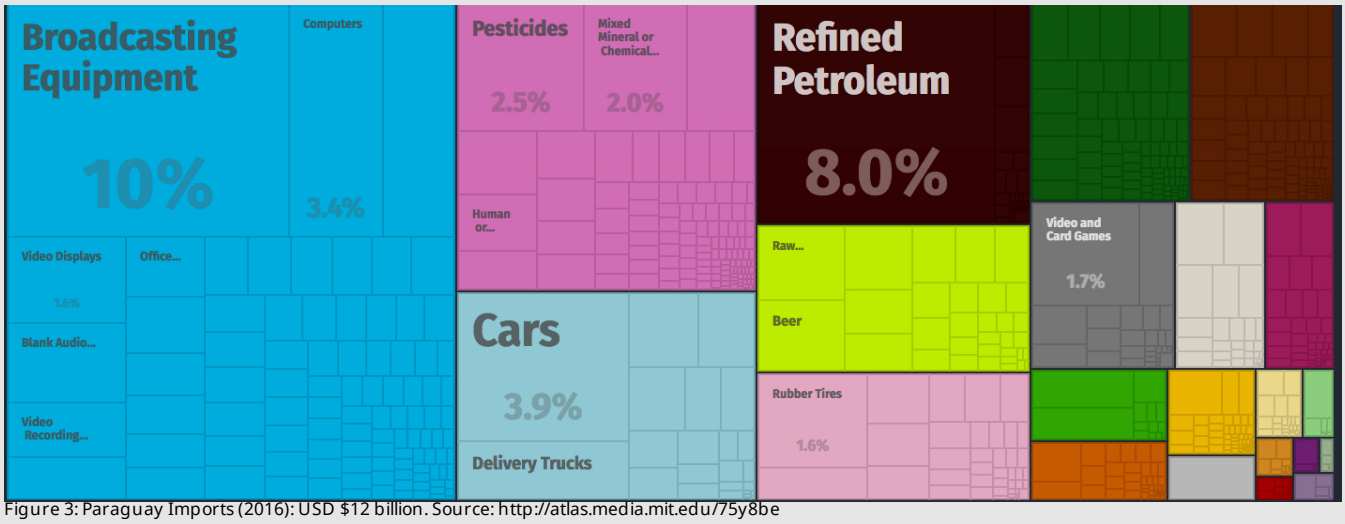

Figure 3: Paraguay Imports (2016): USD $12 billion. Source: http://atlas.media.mit.edu/75y8be

Paraguay's Current Situation

Figure 4: Itaipú Binational Dam (Brazil-Paraguay). Photo: C. Folch.

Paraguay--An Electricity Powerhouse, But With Time-Limits

Though it is landlocked, Paraguay possesses the third largest river fleet in the world.[10] The fast-flowing Paraná river serves as its eastern border with Brazil and its southern border with Argentina. In the 1970s and 1980s, two massive hydroelectric dams were built on the Paraná, Itaipú Binational (14,000 MW installed capacity) and Yacyreta Dam (3,100 MW installed capacity).[11] In 2016, the total electricity consumed in Paraguay was 14,855.1 GWh,[12] yet the production of electricity from Itaipú Binational alone was a world-record breaking 103,000 GWh, half of which belongs to Paraguay.[13] Paraguay consumed 11,227 GWh from Itaipú Binational in 2016 and sold its remaining 40,000 GWh to Brazil. The total quantity of electricity generated by Itaipú Binational is enough to power 20% of Brazil's annual consumption, 33% of the state of California, or almost 7 Paraguays.

As Paraguay's economy expands, this electricity surplus becomes more limited. Over the past decade, Paraguay's electricity consumption has grown between 4 and 11% per year, with the greatest growth in the residential sector and thus with only limited job-creation potential.[14] Should the growth continue at the higher end of current trends, in the mid-2030's, Paraguay's demand will consume all its installed capacity. Therefore, there is a rapidly closing window during which Paraguay could use its electricity to jumpstart a new industrialization.

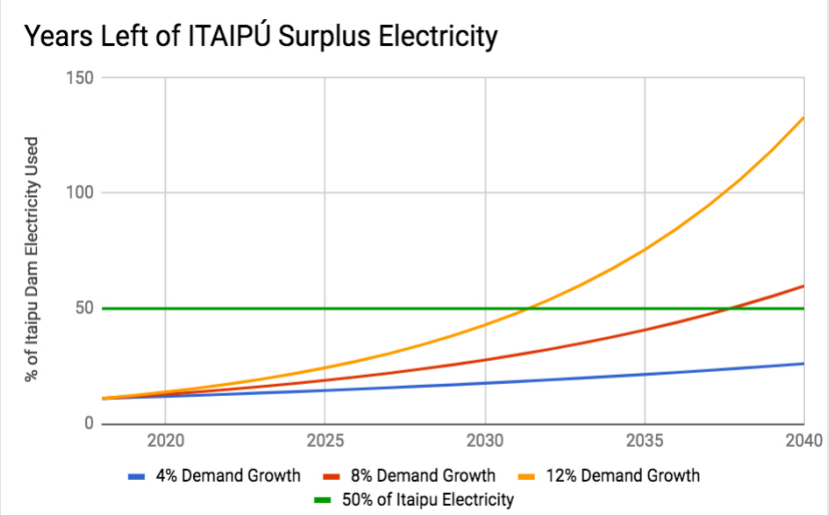

Figure 5: Years Left of Itaipú Surplus Electricity. Sources: Itaipú Binacional (2017) Memoria Anual 2016; VMME (2017) Balance Energético 2016.

Challenges in Infrastructure + Education

Economic growth requires two core components: an educated workforce and capable infrastructure. Although Paraguay has some advantages in each area, research and our own experience in the country has revealed shortcomings in both. Financial investment in the present will be necessary to address both.

In the cattle-dominated north, many parts of Ruta 5 have disintegrated, making the transport of products via truck very difficult. Though the Paraguay river (flowing from the border with Brazil through the heart of the country and to the border with Argentina) can serve as an important option for riverine transport, many of the "ports" we saw on the river were mere clearings of underbrush with no docks. Moreover, from Concepción (Concepción Department) to the northern border with Brazil, a distance of 170 kilometers, there are no bridges across the Paraguay river, effectively cutting off vast expanses of the Chaco region west of the river. We visited the INC (Industria Nacional de Cemento) cement plant in Vallemí (Concepción Department), where the country's supply of clinker (slag) is mined and processed out of a nearby mountain (see Figure 6). Although experts have estimated that the deposit has 1000 years of cement-making potential, Paraguay supplements local production with imports. The INC plant's capacity would need to be doubled to meet national demand.

Figure 6: Industria Nacional del Cemento, Vallemí (Concepción Department). Photo: C. Folch.

Paraguay's educational system merits rigorous analysis.[15] Some challenges include: public schools often hold classes for students either in the morning or in the afternoon, rather than the full day of classes. Recent studies suggest that, of those who begin university studies, only 10% graduate.[16]

Although it is beyond the scope of our white paper to detail how to address both, the resources of Itaipú have a role to play in improving education and investing in infrastructure. Because the Paraguayan government receives nearly $600 million annually in energy rent from Itaipú Binational,[17] we urge that the trend established to direct funds towards education be increased, with an emphasis on primary education as well as the formation of professionals and supporting entrepreneurial ventures.

Sidebar: Suggestions for Export-Oriented & Artisanal Agriculture and Eco-Tourism

Although not what we discuss in detail in this white paper, we nevertheless want to mention thoughts arising from our field visits and engagement with other potential uses of Paraguay's electricity surplus.

First, we see the ability and, indeed, necessity for **export-oriented cattle industry** (Paraguay ranks seventh in global exports of beef)[18] to co-exist with and complement **artisanal, small holder, and locally-oriented agricultural production**. Particularly noteworthy was our site visit to and stay at Fundación Paraguaya's Agricultural School and Hotel in Belén (Concepción Department)--begun in 2010, one of three schools started by the NGO.[19] There, dozens of young high-school aged Paraguayans learn ecology, agriculture, business management, and hospitality skills (they run the hotel). As a final project, students must submit business plans, including presenting their own financial viability calculations, and, once they pass examination, they receive a line of credit to make these business dreams a reality. Today, as a result, some of their organic, artisanal products (honey, dried herbs for teas) are available in supermarkets and grocers across the country. We spoke with a Concepcionero experimenting with sheep-breeding--a less com- mon venture for beef-dominated Paraguay--who mentioned that the Paraguayan ranching industry suffers from lack of well-trained labor, which could be addressed through the expansion of agricultural schools.

Figure 7: Ornamental plants at Escuela Agrícola-Belén (Concepción Dept). Photo: C. Folch


Figure 8: Tagatiyá Creek, crystalline & suitable for kayaking. (Concepción Dept) Photo: C. Folch

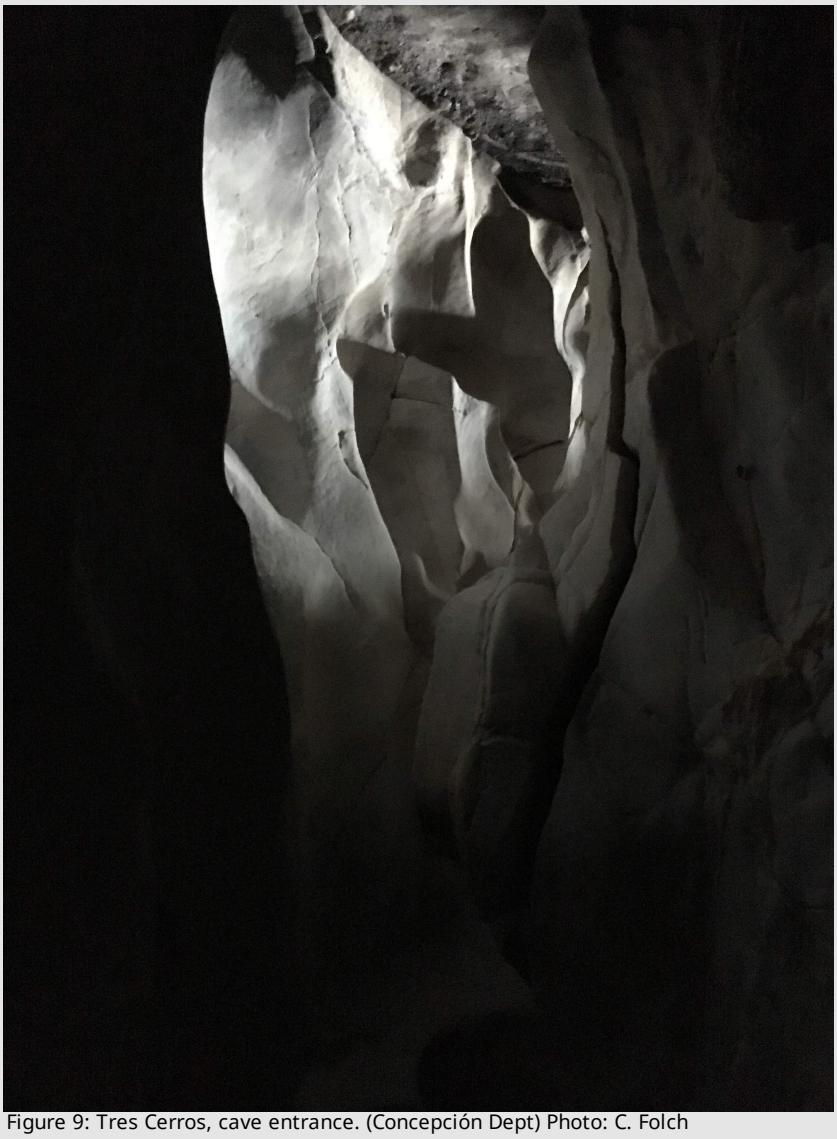

Figure 9: Tres Cerros, cave entrance. (Concepción Dept) Photo: C. Folch

Eco-tourism

Paraguay is a country with arresting natural beauty. In addition to visiting the deposits in Vallemí, we were able spelunk in a set of caverns in Tres Cerros only thanks to the capable maneuvering of two Concepcioneros who knew the region and were able to locate the route to the caves. To strengthen the eco-touristic potential, Tres Cerros and other sites need:

- **Improved access** to the country's natural beauty (roads, signs, maps of locations, geological description of the caves);
- **Government protection** of such sites against other forms of exploitation (so that Monday waterfalls in the east are not dammed, so that the cavern network and the forest surrounding Tres Cerros remain an eco-tourism destination, etc.).

Figure 10: Path to the caves. (Concepción Dept) Photo: C. Folch

Figure 11: Scaling Tres Cerros (Concepción Dept) Photo: C. Folch

Recommendation: Paraguay should consider recruiting global or regional players to construct data centers

Over the next five years, **data center traffic is set to triple** worldwide.[20] The so-called Big Four of Amazon, Apple, Google, and Facebook are constructing data centers at a torrid pace, attempting to match widespread increases in consumer demand and their aggressive expansion into untapped markets. Over the past seven years in the Southern Cone, Google and Amazon have constructed mega-facilities in Santiago and São Paulo, and Amazon has plans to build another center in Chile or Argentina. Crucially, all four companies have committed to powering their infrastructure, including data centers, with 100% clean energy.[21] Apple announced in April 2018 it has already achieved this goal.

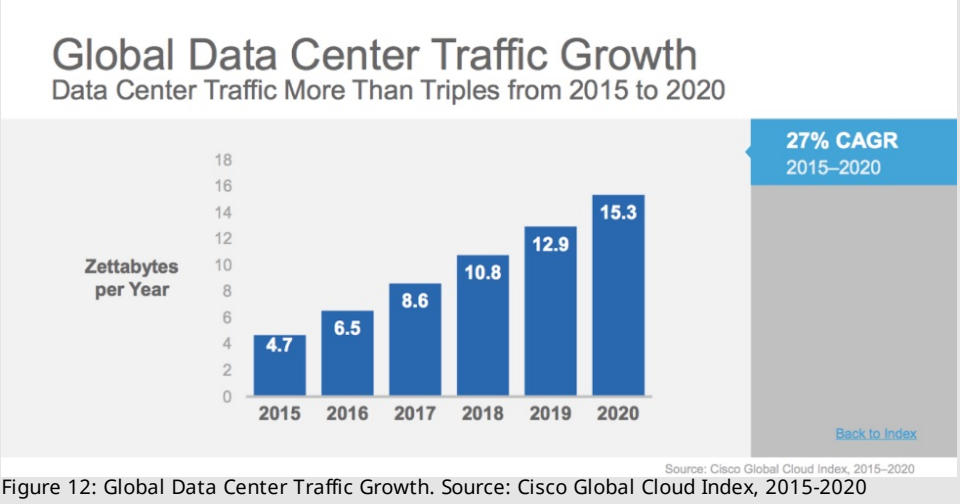

Figure 12: Global Data Center Traffic Growth. Source: Cisco Global Cloud Index, 2015-2020

Data centers require vast amounts of reliable electricity to power their servers.
A typical data center uses 13,684 MWh annually, which is equivalent to around 0.01% of Itaipu's annual energy production.[22][23] Regional players, such as TIGO, have entered the market in Paraguay. In 2017, TIGO finished construction on the country's first internationally accredited data center in Asunción.[24] The typical initial capital expenditures in a data center is $215 million, with $1,305 per net rentable square feet (NSRF).[25]

What can Paraguay offer?
First, Itaipú provides a flow of inexpensive, reliable, renewable energy that could power energy-intensive servers. Water from the Rió Paraná could be used to cool the facility. Second, 50 million people live within 500 miles/800 km of Itaipú dam, and the South American IT market is growing 20% annually. There exists a vast regional market that has not been fully tapped, and will become increasingly more valuable as Paraguay and Southern Brazilian states continue the process toward digitalization. Third, Paraguay's rate of natural disasters lies far below its neighbors, signaling a safer investment. Unlike Brazil, Bolivia, Argentina, or Chile, Paraguay experiences minimal earthquakes, storms, flooding, and landslides.

To promote more inclusive growth, Paraguay could **incentivize constructing colocation centers**, which rent out server space to varied tenants. The recently constructed 500kV lines linking Itaipú to Asunción and Encarnación can bring these benefits to much of the dozens of companies across the country. In the future, if Paraguay wishes to transition its economy from export-based agriculture to industry and technology, infrastructure like data centers will have to be built. Constructing data centers in Paraguay's window of opportunity when it has surplus energy could be an efficient use of resources.

Paraguay has a unique opportunity to use the natural resources in the region, the surplus of electricity and the low cost of labor in Paraguay to create a South American supply chain for lithium-ion battery packs for electric vehicles (EVs) or energy storage systems. Lithium ion battery use and manufacturing has grown in the past decade from a laboratory experiment to a global industry. Lithium ion batteries are the basis for electric vehicles, and as such the battery manufacturing industry is expected to grow from a capacity of 131 GWh in 2018 to over 1,500 GWh by 2030. Bloomberg New Energy Finance has estimated that **EVs will account for 55% of all new new car sales** and 33% of the global fleet, with 530 million EVs worldwide, by 2040, as seen in Figure 13.[26]

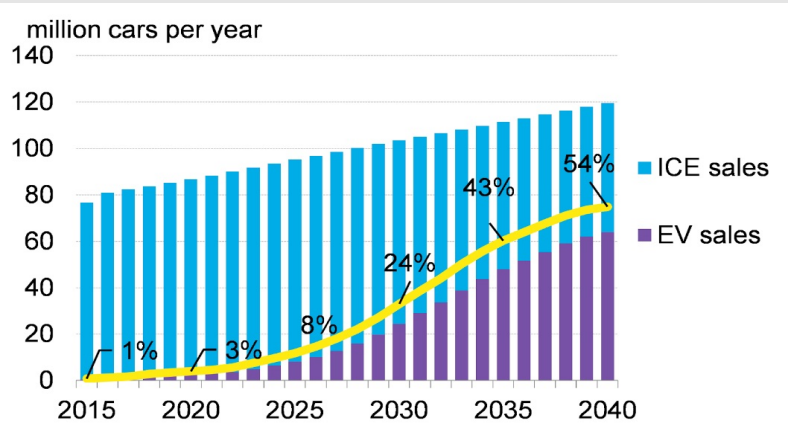

Figure 13: Annual Global Light Duty Vehicle Sales. Source: Bloomberg New Energy Finance Electric Vehicle Outlook 2018

This growth would make the energy storage industry as a whole worth $250 billion by 2040.[27] In order to compete with traditional internal combustion engines, electric vehicle battery pack costs have to fall to an estimated $125 - $150/kWh. Current battery prices are around $200/kWh, as seen in Figure 14.[28]

In the US, electricity is typically sold to industrial customers at $0.066/kWh versus the possible base rate of $0.0283/kWh in Paraguay.[29] Using the Nissan Leaf battery pack as an example, which requires ~59 GJ of energy in manufacturing and assembly, this price differential could lead to **a savings of $26.07/kWh** in electricity alone.[30] **This can help battery manufacturers reach the $150/kWh cost that will put EVs and gasoline cars at cost parity.**

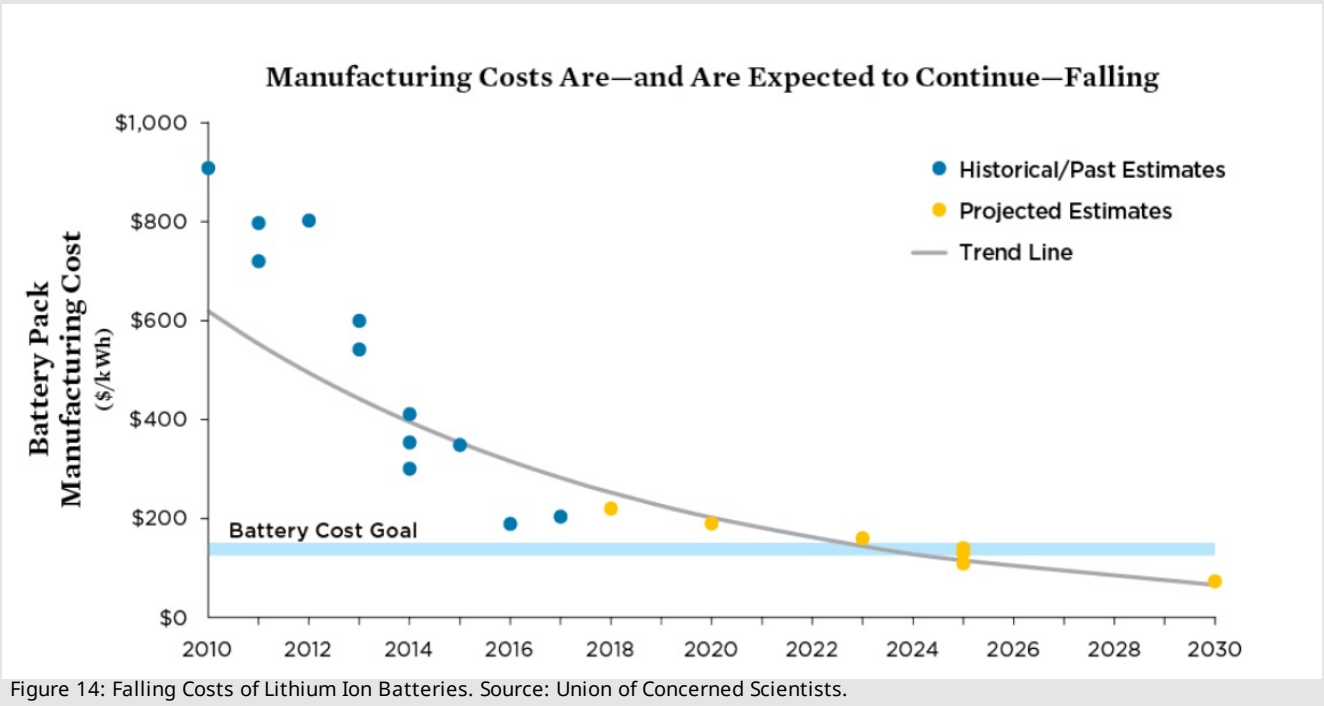

Figure 14: Falling Costs of Lithium Ion Batteries. Source: Union of Concerned Scientists.

Lithium Ion Batteries

Lithium ion batteries is a catch-all term for many different chemistries, of which Lithium Nickel Manganese Cobalt Oxide (or NMC for short) is the most common for electric vehicles. NMC batteries are made up of 6 primary materials: Copper, aluminum, graphite, nickel, cobalt, lithium and manganese.

Of these 6 materials, South America has large reserves of all but cobalt. Chile has been the world's leading exporter of lithium for years and over half of global lithium reserves are located in the "lithium triangle" region shared by Bolivia, Chile and Argentina.[31] Chile and Peru are leading exporters of copper, accounting for 40% of global supply in 2017.[32] Brazil is one of the top ten exporters of aluminum and has significant reserves of graphite, nickel and manganese that could be exploited.[33] Paraguay can take advantage of the low import tariffs between Mercosur members to bring these natural resources into the country. **Paraguay can then leverage its access to cheap, clean energy and its low cost workforce to create a battery manufacturing plant.**

Should Paraguay decide to target the automotive industry it could choose to operate either as an independent OEM or in conjunction with an established automotive company such as Tesla looking to expand their EV capacity. As an independent OEM, Paraguay could export finished battery packs to automotive factories present in southern Brazil for assembly into finished products. Brazil has a large, established automotive industry and is currently the world's 7th largest exporter of automobiles according to the OICA.[34] These cars would then go on to be sold worldwide, with a focus on the South American market. As of 2018, there is no electric vehicle manufacturing in Brazil. The presence of a locally sources battery pack feeding into an electric vehicle line in Brazil could help open up the South American market to electric vehicles. This would **create more linkages to Paraguay's electricity surplus,** as cheap Itaipú electricity would make driving costs for EVs much cheaper than imported gasoline.

In order to understand the potential costs and implications of such a plant on Paraguay's economy we looked to the recent creation of Tesla's Gigafactory in Nevada for guidance. Gigafactory 1 was announced in 2014 as a way for Tesla to save 30% on their battery pack costs. The factory is being built in phases in order to allow production to start

Suggested Supply Chain

1. Copper and lithium from Bolivia and/or Chile
2. Graphite and aluminum from Brazil
3. Cell and pack assembly in Paraguay
4. Integration into automobile industry in Brazil

as soon as possible and so the factory started running small-scale production in early 2016. Gigafactory 1 is expected to cost Tesla $5 billion to construct and will have an output of 35 GWh of batteries annually by 2020, enough for 500,000 cars. The factory is expected to employ over 6,500 local employees. Furthermore, Tesla is committed to using no fossil fuels to run the factory - Gigafactory 1 is powered by a large rooftop solar array and energy storage systems. [35] **Tesla is actively looking to build more Gigafactories around the world.**

Paraguay also has the opportunity to **use lithium ion batteries for residential energy storage** systems. Not only would this make Paraguay a player in a growing international energy storage market, it has the potential to optimize Paraguay's energy use. Almost half of all electricity use in Paraguay is from the residential sector[36] - meaning that the grid load is highly dependent on residential use patterns of a midday peak due to air conditioning use and an evening peak when people return home and lights are turned on. Residential energy storage systems could help smooth this curve, allowing for better utilization of their very steady hydropower production.

Acknowledgements

We wish to thank the Duke Energy Initiative for supporting this ongoing research project on Itaipú Binational Dam, Paraguay, and sustainable development, which has also been supported by the Franklin Humanities Institute Global Brazil Lab and the Duke Brazil Initiative.

And we especially thank the many Paraguayans and Brazilians we met in Paraguay, who were hospitable and gracious with both questions and answers. We thank Juan Carlos Duré Bañuelos for his coordination of many of the site visits, especially those in Concepción Department. There are too many to name all, but we thank Federíco Torres and Edson Torres, the staff of Frigorífico Concepción, Hotel Belen and Escuela Agrícola of Fundación Paraguaya, Industria Paraguaya de Cemento, Gabriela Galilea of Okimo, Nahum Dam of Factslides.com and Oddee.com, Christian Sosa and Piero Fiorio and all the members of ASEPY (Asociación de Emprendedores de Paraguay), Ana Barreto Valinotti and the Museo Casa de la Independencia, the energy researchers of G.I.S.E. (Grupo de Investigación en Sistemas Energéticos, FP-UNA), Benjamin Fern´ández Bogado of Radio Libre, and the Visitors/Press office of ITAIPÚ Binacional.

The perspectives in this report are solely the authors' and any shortcomings are our own. We hope that this serves as an invitation to dialogue and creativity.

Aguije!

For more, please visit https://itaipupost2023.com/.

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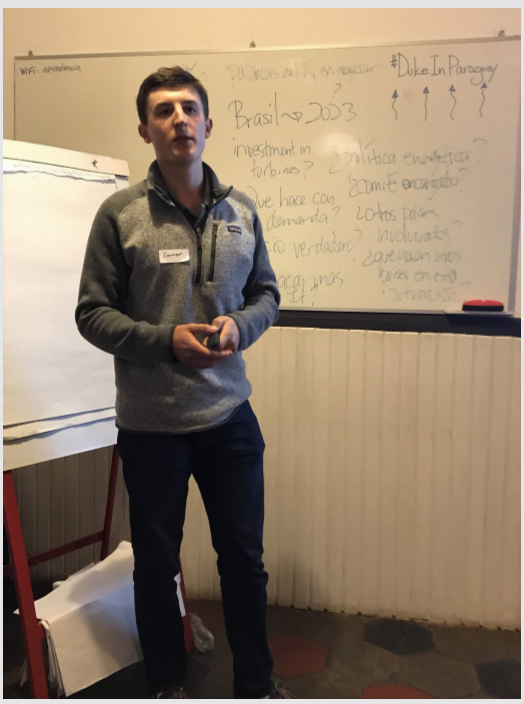
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Photos: C. Folch