Navigating Cuba's Energy Choices: Design Variables and Insights from Duke University's "Energy for Emerging Markets" Case Competition

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Executive Summary

Cuba's energy decision makers are facing challenging choices as they consider the country's energy needs in coming decades. A shifting tide in domestic policy and international relations is ushering in new economic activity that will increase demand for electricity on the long run. Meanwhile, recent events with Cuba's traditional energy partners have highlighted concerns around reliance on foreign fuel sources for electricity production. These factors create a compelling mandate for the government to chart a transition to cleaner sources of energy and greater resiliency of its energy system. Inherently, energy systems are technically complex, capital-intensive, highly regulated, and involve a wide variety of disciplines and stakeholders. While there are a multitude of questions to address, such topics can be distilled into several key ***design variables***. These design variables broadly fall into three categories: *technology*, *policy*, and *finance*. The designers of Cuba's energy system must decide which technologies to utilize, what policies are needed to enable new approaches, and how capital will be attracted to enable the required investment. By working with international academic partners, Cuba can benefit from new insights and innovative approaches to rapidly evolving its energy system to meet its future needs.

Navegando las Opciones Para la Energía de Cuba: Variables de Diseño y Visiones desde la Competencia de Caso de Estudio Sobre "Energía en Mercados Emergentes" de la Universidad de Duke

Resumen

Los decisores Cubanos responsables por la energía de Cuba se enfrente al desafío de considerar las opciones adecuadas para garantizar las necesidades energéticas del país en las próximas décadas. Cambios en la política interna y en las relaciones internacionales están dando paso a una nueva actividad económica que aumentará la demanda de electricidad a largo plazo. Mientras tanto, los eventos recientes con los socios tradicionales para el suministro de energía de Cuba, han puesto de manifiesto preocupaciones acerca de la dependencia de las fuentes de combustible extranjeras para la producción de electricidad. Estos factores crean un mandato convincente para que el gobierno trace una transición a fuentes de energía más limpias y una mayor resiliencia de su sistema energético. Inherentemente, los sistemas de energía son técnicamente complejos, intensivos en capital, altamente regulados, e involucran una amplia variedad de disciplinas y partes interesadas. Si bien hay una multitud de preguntas, las consideraciones fundamentales pueden ser abordadas con un grupo de variables claves de diseño. Estas variables de diseño se dividen en tres categorías: tecnología, política y finanzas. Los diseñadores del sistema energético de Cuba deben decidir qué tecnologías utilizar, qué políticas se necesitan para permitir nuevos enfoques y cómo se atraerá el capital para permitir la inversión requerida. Al trabajar con socios académicos internacionales, Cuba puede beneficiarse de nuevas ideas y enfoques innovadores para desarrollar rápidamente su sistema energético para satisfacer sus necesidades futuras.

Background

Today, 98% of Cuba households have access to basic electricity[1]. After the breakup of the Soviet Union, the loss of oil imports created an economic crisis in Cuba, resulting in a loss of 70% of its foreign trade and 30% of its GDP[2] between 1989 and 1992. This initiated a decade termed Cuba's "Special Period", during which energy scarcity crippled the country's infrastructure, and led to system shutdowns. These challenges triggered a robust nationwide effort to use locally available energy resources, increase the resource and energy efficiency of all processes, and create a national network of professionals dedicated to energy and sustainability. Institutions like the Center for Study of Renewable Energy Technologies (CETER), founded in 1992, and Cubasolar founded in 1994 were among those created to support the sustainable energy development effort[3]. As a result of these efforts, Cuba has doubled its GDP without increasing CO_2 emissions above the 1990 levels[4]. Today Cuba's economy is recognized for producing high human development outcomes (e.g. education, health care, social services while maintaining an ecological footprint consistent with the planet's average bio-capacity[5].

However, Cuba's energy system is in urgent need of expansion and upgrading. For example, 41% of Cuba's total imports correspond to fuels and lubricants, and 98% of the country's power production continues to be based on fossil fuels. Reducing energy imports and modernizing the electricity grid are key enablers for Cuba's development. Cuba has an extensive electrical system with about 2000 MW of base load generation in large thermoelectric installations and a peak load of 3600 MW assimilated by small fuel oil and diesel generators that synchronize with the grid to match the demand. Projections indicate a 40% increase in demand in the next 15 years to support the nation's development. One of the country's stated goals is to match this demand with new renewable energy sources, resulting in a 24% penetration of renewable biomass,

[1] Anuario Estadístico de Cuba 2015, Oficina Nacional de Estadísticas e Información de la República de Cuba
[2] José Antonio Suárez J. A., Anibal Beatóna P., at al. Energy, environment and development in Cuba, Renewable and Sustainable Energy Reviews, Volume 16, Issue 5, June 2012, Pages 2724–2731
[3] www.cubasolar.cu
[4] Gap Minder Tools, www.gapminder.org
[5] Human development report 2016, UNDP

wind, and solar sources (approximately 2,000 MW additions) on to the national grid by 2030.

Methodology

The Nobel Prize winner Herbert Simon once noted that designers are people who "devise courses of action aimed at changing existing situations into preferred ones." In the design process, designers make choices between options based on their goals, and these choices then make other possibilities either more or less possible. In designing complex systems like the electricity grid, this design process is often not transparent to all participants. Technologies are selected, investments are made, and policies are developed - but it can be difficult for any individual to understand how their choices are shaped and constrained by others' decisions – or how their decisions will impact others. In these situations, options selected to meet individual or local objectives often lead to sub-optimal outcomes for the system as a whole.

As Cuba considers their energy choices, it is worthwhile to step back and evaluate the most important design variables shaping its energy future. This paper outlines the key design variables that Cuban energy stakeholders may consider in implementing its energy transition. The findings reported in this paper are drawn from a global graduate school case competition on *Energy in Emerging Markets* that was held in November 2016 at Duke University in Durham, North Carolina, USA. The competition attracted graduate students from around the world, including several parts of the USA, Canada, and even Hong Kong. The top twelve teams were selected to compete in the final round[6], and were asked to submit written proposals addressing the question: *What vision should guide Cuba's energy infrastructure investment and development to meet its future needs?* The most important insights from these submissions have been distilled into a set of variables that Cuban decision makers may consider when trying to

[6] Final teams represented the following universities: Carnegie Mellon University, Colorado School of Mines, Columbia University, Cornell University, Duke University, Hong Kong University of Science and Technology, Johns Hopkins University, the University of North Carolina at Chapel Hill, the University of Maryland, the University of Pittsburgh, Washington University in Saint Louis, and Yale University.

balance the needs for reliability, affordability, and environmental sustainability in its energy system.

Design Variables

For Cuba to meet its ambitious energy goals, it will require more than just adding renewable power sources to the existing system; in fact, this transformation of the energy system will need to be done in an integrated manner, considering the inter-dependence and interaction of technological, policy, and financial elements. Each of the twelve finalist teams in the case competition developed their own approach to evolving Cuba's energy system, outlining how they would select the right technology mix, modernize the grid, create the right policy framework, and attract outside investment. The purpose of this paper is not to define the right integrated solution for Cuba; this is a massive task, and is best pursued by Cuba's own leaders who know the system and the needs of the population. Rather, the purpose of this analysis is to provide guidance to highlight the most important variables, and anticipate the consequences that might result from specific choices.

Technology

Securing Dispatchable Generation

Cuba currently relies on imported fossil fuels for the majority of its electricity production, comprising approximately 95% in 2016. The use of such fuels creates significant costs as well as uncertainty. In 2016 the island saw imports from Venezuela drop suddenly as production in Venezuela shrank. Exposure to such supply reliability risk can dramatically affect the country's energy security in a short period of time. Beyond the cost and risks associated with using foreign oil for electricity production, oil is a carbon-intensive fuel source, contributing significantly to local air pollution and global climate change. Cuba has the opportunity to transition away from this fuel and avoid some of the negative consequences associated with the use of fossil fuels for electricity production.

In many cases the transition to a sustainable energy matrix will still require the use of fossil fuels. Then increasing generation efficiency will reduce environmental impacts.

The use of natural gas with combined cycle technology increases by 50% the efficiency of generation compared to oil[7]. Natural gas as an alternative to oil was recommended by a number of student teams as a method of transitioning away from oil. In fact, all student teams recommended a transition to natural gas except Columbia University, who placed a preference on domestic fuel use over fuel type. Though teams largely agreed on the fuel switch, teams differed in the plan for rollout. Cornell, for example, stressed new build NGCC plants while most other teams emphasized the conversion of oil-fired plants. Transitioning to natural gas would not only require a conversion of generators on the island but also investment in storage and processing. As an example of such infrastructure, floating storage regassification units (FSRU) were recommended by John Hopkins and Carnegie Mellon universities.

Beyond fossil fuel generation, biomass and other renewable options were recommended as sources of baseload power to Cuba. Most teams except for the University of Maryland emphasized a shift towards more biofuels, recommending anywhere between 6-21% of the energy mix shifted by 2030. Cuba can take advantage of the large quantity of bagasse produced by the sugar industry.[8] Specific ideas for biomass implementation are to shift towards biodiesel for rural diesel generators[9], to utilize HYV seeds and improved technology to increase bagasse production[10], and to generate vegetable coal from biomass[11]. Washington St. Louis proposed a more radical idea for securing firm power: installing a submarine cable and importing power from the United States. Though this approach certainly would require overcoming significant technological and political barriers, the option was assessed to be cost-effective in the long term. In addition, it's worth noting that no teams recommended expansion of hydroelectric resources given the siting restrictions on the source.

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[7] Alessandro Franco and Claudio Casarosa, *On some perspectives for increasing the efficiency of combined cycle power plants.* Applied Thermal Engineering, Volume 22, Issue 13, September 2002, pages 1501-1508.
[8] Alexis Sagastume Gutierrez, et al. *The Biomass Based Electricity Generation Potential of the Province of Cioenfuegos, Cuba*. Waste Biomass Valor, October 2015.
[9] University of North Carolina at Chapel Hill
[10] University of Pittsburgh
[11] Washington University in St. Louis

In summary, the choices available to Cuba for meeting its baseload power needs all involve tradeoffs between energy reliability, national security, affordability, and environmental impact. For Cuba's energy leaders, the options discussed here highlight the opportunities and constraints that Cuba faces as they evolve toward a new and better energy system to meet their needs.

Introducing Variable Renewable Energy Resources

The shift to more variable renewable energy sources requires a careful assembling of various technologies into a seamless whole. The most common resources, promoted by the majority of student teams, included utility-scale solar PV, wind energy, and electrical energy storage. Recommendations for less established technologies included floating solar PV[12], floating wind turbines[13], underwater turbines[14], power-to-gas energy storage[15], and community solar[16]. Each of these resources has its own costs, generation profile, siting restrictions, and environmental concerns to consider.

Figure 1: Cuba proposed energy mix by 2030

	Carnegie Mellon University	Colorado School of Mines	Columbia University	Cornell University	Duke University	Hong Kong University of Science and Technology	Johns Hopkins University	University of North Carolina-Chapel Hill	Washington University	Yale University
Oil/Diesel	39.7%	45.0%	55.8%	61.0%	29.2%	22.0%	41.0%	0.0%		
NG	30.0%	13.0%	4.9%	15.0%	46.9%	53.8%	31.7%	56.7%		
Fossil Fuels	**69.7%**	**58.0%**	**60.7%**	**76.0%**	**76.1%**	**75.8%**	**72.7%**	**56.7%**	**65.0%**	**70.0%**
Biomass/Biofuels	13.7%	14.0%	21.0%	8.0%	14.6%	11.7%	5.5%	7.2%	14.0%	16.1%
Hydro	2.0%	2.0%	1.7%	1.0%	1.1%	1.2%	0.5%	1.0%	1.0%	1.0%
Solar	6.3%	16.0%	9.2%	8.0%	2.8%	6.5%	10.9%	16.8%	10.0%	5.7%
Wind	8.3%	10.0%	7.4%	7.0%	5.4%	4.9%	10.4%	18.4%	10.0%	7.3%
Underwater Turbines	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Renewables	**30.3%**	**42.0%**	**39.3%**	**24.0%**	**23.9%**	**24.2%**	**27.3%**	**43.3%**	**35.0%**	**30.0%**
TOTAL	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**	**100.0%**

Note: University of Pittsburg and University of Maryland are not included in this analysis because their recommendations were not quantified in this way.

Introducing more renewable energy could have a dramatic upside for the island, but it will also present significant complications. As countries across the globe are

[12] Washington University in St. Louis
[13] Washington University in St. Louis
[14] University of Maryland
[15] Hong Kong University of Science and Technology
[16] Johns Hopkins University

transitioning to cleaner energy sources, they are discovering that the operation of the entire energy portfolio is more important than the performance of any one technological element. For example, Germany has found that their increasing integration of renewables has paradoxically resulted in more carbon emissions. This is because they also are eliminating their nuclear facilities at the same time, and relying more heavily on coal for dispatchable power. As Cuba goes through a similar transition, it can be a leader in modernizing and decarbonizing its power sector. However, there is an inherent variability and unpredictability with these intermittent technologies, which can be difficult to manage. Planners will have to construct a portfolio of technologies that complement each other, and include assets for system balancing and backup. Two teams—the Colorado School of Mines and Cornell University—recommended the strategic rollout of microgrids to accommodate variability in renewable electricity generation and improve the resilience of the greater grid infrastructure on the island.

It is clear that Cuba's energy leaders will need to adopt a sophisticated portfolio approach, and understand the unique challenges that emerge over the course of the energy transition. As renewables achieve greater levels of penetration, there are risks to grid stability that either cannot be managed or may require unexpected investments in backup systems. Learning from other countries' experiences and anticipating problems before they happen will allow Cuba to be successful in this complex and critical effort.

Siting New Resources

Siting for new infrastructure is critical to the success of the proposed energy mix. Ad hoc proliferation of variable renewable energy generators can be costly and ineffective, particularly if it isn't well-coordinated with transmission system development and local population and economic growth patterns. New generation assets must be designed and located to accommodate existing and future load centers. They must also be sited to not overload existing transmission and distribution infrastructure, otherwise new infrastructure must be put in place. Based on this insight, the Colorado School of Mines outlined four priority geographic areas for renewables development—Le Habana, Mantanzas, Holguin, and Isla de la Juventud—based on their solar and wind availability and their population and growth expectations.

Productivity, logistics and aesthetics are key considerations when siting these new assets. Offshore wind turbines were recommended for development along the Northern coast by Johns Hopkins and the University of Maryland, while large-scale solar was recommended to be located near major demand hubs. Some teams proposed community solar as an attractive option for smaller communities[17] along with a network of smaller, distributed grids that could be constructed to support the needs of those communities[18]. For the natural gas infrastructure, Cornell University recommended that gas plants, import terminals, and storage facilities be co-located to minimize the need for additional infrastructure. The teams also recognized that many of these recommendations are already included in Cuba's energy infrastructure development plans and the published foreign investment portfolio. In this case, the student proposals confirm that established plans that Cuba has already committed to.

Of course, these approaches will also have their own special challenges. For example, wind turbines and natural gas regassification units will likely be visible from land, and could impact community acceptance, tourism considerations, and other stakeholders. Submarine cabling and subsea pipelines would likely pose high costs and environmental risks that are not well-understood. Beyond these potential risks, decision makers will have to consider the production of each resource at each location on the island. This is highly site dependent and full analysis of the tradeoffs between technologies and siting will help inform the optimal energy solution.

Policy

Setting and Regulating Tariffs

Regulation and rate structures play a vital role in encouraging participation in the power sector, both for producers and consumers. Developers are looking to make investments

[17] Johns Hopkins University
[18] Colorado School of Mines and Duke University

that will be recovered over extended periods of time. They will expect a high level of regulatory certainty to ensure that they can secure their return on investment.[19] This process begins with the system operator. Three teams—Cornell, Carnegie Mellon, and Johns Hopkins—all promoted a single-buyer structure where UNE was the sole distributor of electricity but did not own all of the generation assets; the University of North Carolina, on the other hand, recommended a more co-operative ownership model. To ensure that UNE can guarantee electricity supply and support inward investment, four teams explicitly recommended long-term power purchase agreements (PPAs). Investors want certainty that their costs can be adequately covered and that there is standardization of processes on the island. And to ensure that UNE is getting the best deal, Duke and Carnegie Mellon both recommended that Cuba auction each project to outside developers.

Beyond producers, consumers also need incentives to participate in the system to encourage the development of Cuba's economy and the wellbeing of its citizens. The country has seen moderate GDP growth in recent years, and is expecting dramatic increases in tourism in the short term. This sector will require cheap, reliable, and clean energy sources. Creative tariff structures can appropriately balance the needs of producers and consumers, while also maintaining safety, reliability, and environmental sensitivity. Differential tariffs[20] were recommended to help UNE limit its losses, and tariffs could also vary based on type of customers and geography to promote government objectives. These tariffs must also be accompanied by improved mechanisms to ensure payment[21].

Other, more intricate tariff schemes were recommended by some student teams. The University of Pittsburgh, for example, recommended carbon credits to incentivize renewable energy. The team from Duke University recommended taxing transportation

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[19] Johns Hopkins University
[20] University of Pittsburgh
[21] Johns Hopkins University

to the island and tourism facilities as a method for raising money to build the power infrastructure needed to support industry on the island.

Encouraging Foreign Investment

Setting tariffs correctly can play a key role in securing investment, but additional protections and incentives could further eliminate risk for new entrants in the market. Firms that have not previously invested in Cuba may be wary of the enforceability of contracts on the island. One solution is to grant the right to Alternative Dispute Resolution[22] in an alternative jurisdiction to investors; establishing clear local protocols for arbitration would also improve transparency and set expectations.

Beyond legal protections, market incentives could be put into place to further encourage investment. Five of the seven teams that addressed this variable looked towards tax incentives as a viable path. Cuba has already taken steps in this direction with its new foreign investment law 118, which stipulates 0% income tax for eight years, and 15% thereafter. Additional incentives are given for projects in the Mariel Special Development Zone where the ongoing rate is 12%. This implementation is aligned with many student team proposals, such as Yale University's broad plan for tax cuts. Johns Hopkins University further proposes targeted tax breaks for a specific industry like renewable energy[23], to decrease the initial burden of investments. These options would of course reduce the amount of taxes that government receives, but may be appropriate for attracting the necessary investment to the island.

Another area to target for attracting investment is government processes. Developers are looking to make a return as soon as possible. By streamlining government processes, for example project permitting and licensing, Cuba can make it faster for investors to initiate a project. This may be the cheapest option of all listed above, though a shifting in Government resources and a training of employees may be required.

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[22] Johns Hopkins University

[23] Washington University at Saint Louis, University of Pittsburgh, and Columbia University

Pursuing Climate Policy

The Government of Cuba has already established a target to produce 24% of electricity with renewable energy sources by 2030. This standard is admirable compared to the goals of similar island nations. The majority of student teams were optimistic that more renewable energy could be incorporated into the mix, with ranges between 24-50% of total annual generation. Beyond renewable energy penetration, Cuba's energy leaders could potentially focus on reducing carbon emissions as a primary objective. This extends the conversation beyond renewables to the benefits of other forms of fossil fuels. A market mechanism may also be appropriate to balance the cost of new generation sources with the carbon output of those sources. Carbon taxes have been garnering increased attention in recent years, and could help improve the cost competitiveness of renewables while extracting additional rents for the government.

The energy industry, due to its complex nature, involves the participation of actors from across multiples disciplines, including finance, energy, and planning, among others. Thus to achieve a renewable energy or emissions target, government operations from many agencies must be coordinated. For this purpose, Cornell University recommended the creation of an "Agency of Sustainability" to coordinate the various Government Ministries. This agency could be an important mechanism to ensure coordination to achieve Cuba's goals and serve as a model for the Caribbean.

This is not only a tactical question, but a critical strategic consideration for Cuba. Specifically, what legacy does Cuba want to leave in the global mobilization to address climate change, and what can the country realistically achieve by 2030? Cuba may not contribute a large portion of the world's emissions, but its historical role in promoting sustainability, and its vulnerability to climate-driven storms, sea level rise, and other factors would suggest a prominent global role of the country. Cuba will need to decide what this means both in words and in deeds.

Educating and Training Stakeholders

Across all student proposals, education and training was stressed as a necessary component of any energy transition in Cuba. Education is also an area of historical focus and strength for Cuba, so it has a strong foundation to build from in this area. These strategies are targeted at two distinct populations: Cubans and non-Cuban citizens. Educating the Cuban population is aimed at gaining buy-in for new initiatives as well as training the workforce to support the inevitable changes. The University of Washington at Saint Louis urged a promotional campaign that stresses the benefits of a new energy system and the need for foreign investment. Once the government has chosen its path, it will have to begin retraining and retooling the workforce[24] to be able to build and maintain the new energy system.

Cuba also can attract investment by opening up and expanding educational opportunities on the Island. The country has historically excelled as a leader in human capital development. The country can establish itself as a leader in energy-related areas such as distributed generation and biomass, while supporting non-energy areas with an established record such as the medical field[25]. The University of Pittsburgh recommended that Cuba increase the number of opportunities for students from Latin America to study in Cuba. Such initiatives would improve the talent pool on the Island and increase regional collaboration.

Finance

Partnering with the Right Institutions

Contracts in the power sector can last decades, so it is important to fully vet and weigh the potential benefits and drawbacks of different partners. For example, the Cuban Government has already struck a deal with Siemens to upgrade the country's infrastructure and install more renewables. Other technology partners will provide products to improve efficiency, make the grid more resilient, and better meet the needs of its energy consumers. Coordinating the multiple technologies and partners in a

[24] Cornell University, Duke University, and HKUST
[25] Duke University

portfolio approach only increases the due diligence and evaluation required to optimize the system over time.

Equally important is choosing the right financing partners for these transactions. On this topic, teams in the competition suggested a wide variety of potential partners. International oil companies and renewable companies may be particularly interested in investing directly in generation assets. For projects that are less attractive to the private markets, eight of the twelve teams pointed towards the international development banks as a viable option for financing. Cuba has already signed an MOU with The Development Bank of Latin America (CAF), and can pursue similar agreements with other multilateral organizations to secure debt for infrastructure projects. Additional recommendations for international funding were sovereign wealth funds[26], bilateral transitions with companies or countries[27], and NGOs[28] with a clean energy mandate. On a local level, small business owners[29] could be engaged to build the smaller scale projects such as community solar, and local manufacturers[30] can be incentivized or mandated to provide for their energy needs.

Structuring the Deals

Deal structure and ownership will have a big impact on the ability to both attract foreign capital and secure a good investment for Cuba. As with Cuba's potential partners, the student teams recommended a similarly diverse set of deal structures. Traditional debt and equity are viable paths to choose, with the option for fully private or public-private partnerships. For large projects, Johns Hopkins University recommends a joint venture between Cuban stakeholders and foreign corporations. For transmission and distribution, the government of Cuba could issue infrastructure bonds[31].

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[26] Cornell University
[27] Colorado School of Mines
[28] University of Maryland
[29] Johns Hopkins University
[30] Washington University at Saint Louis
[31] Johns Hopkins University and Carnegie Mellon University

Other, more creative deal structures were proposed by some of the teams. One such structure is the yieldco structure[32] which helped support the growing solar market in the United States. With the yieldco, generation assets are placed into a special purpose vehicle and outside investors can buy equity in exchange for steady dividends that are based on reliable expected cash flows. Here, the Government would manage the yieldco while foreign investors owned equity until they receive their return on investment, at which point full ownership of the assets is turned over to the government. Other creative deals include the trade of local minerals for finished technologies such as battery energy storage devices[33], and the monetizing of additional fossil fuel reserves to create a fund for reinvestment in the Island[34].

Conclusion

Cuba is already committed to an ambitious transformation of its energy system in coming years, and is expected to spend over $3.5 billion to develop the new generation, transmission, and distribution systems to deliver much-needed power. For this vision to become reality, Cuba's energy system designers must take a systems approach, and anticipate the potential risks that this transition may create. Around the world, there are many examples of countries aggressively moving toward low-carbon economies and energy systems. However, there are also many cautionary stories about how technological, policy, and financial elements of the plan were not well aligned, and produced sub-optimal results. Throughout its history, Cuba has shown real creativity and commitment in meeting the needs of its people; for example, by developing effective systems of education and health care. By working together across its diverse energy stakeholders and external partners, Cuba has a compelling opportunity to achieve similar results in transforming its energy system.

[32] Washington University in Saint Louis
[33] University of North Carolina at Chapel Hill
[34] Duke University