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GLOBAL ENERGY INTERCONNECTION

A BOLD INITIATIVE FOR A SUSTAINABLE ENERGY FUTURE

Huang Lei and Wang Qiankun

THE COVID-19 pandemic has been raging across the world since the beginning of 2020, dealing a serious blow to the global economy and society. As we reflect on its painfully learned lessons, a far worse disaster—the unfolding climate and environmental crisis—is charging right for us.

A defining question of our century, and of our immediate future, is how to save our home planet from catastrophic ruin and get us back on track of sustainability. China's concept of Global Energy Interconnection recognizes the importance of energy inter-connectivity for clean energy transition and represents one of the boldest visions for low-carbon development at the national, regional, continental, and global level.

DEEP TROUBLE

Throughout the thousands of years of human history, we as human beings have created splendid civilizations both materially and spiritually, especially since the beginning of the first Industrial Revolution in the 1870s. Yet, as Jeffrey D. Sachs has put it, when it comes to human development, there is a mix of both good news and bad news.

The good news is that humanity has never been more wealthy, powerful, and capable than it is today. The total annual output of the world economy is estimated at $130 trillion. Another way of putting it is that the globe's 7.6 billion people produce an average output of $17,000 per person. Technological systems are so remarkable and sophisticated that people enjoy just about every convenience one can imagine.

Huang Lei is Director-General of the Operations Bureau at Global Energy Interconnection Group (GEI) as well as Director-General of the Operations Bureau of the Global Energy Interconnection Development and Cooperation Organization (GEIDCO). **Wang Qiankun** is Executive Director of GEI Group North America Office and Executive Director of GEIDCO's North America Office. You may follow him on Twitter @FrankQiankun.

Nevertheless, civilization always comes with a price. As humanity transitions from being subject to the whims of Mother Earth to conquering nature, our planet is becoming more and more uninhabitable. The UN 2030 Agenda for Sustainable Development, adopted by world leaders convening in the UN General Assembly in September 2015, clarified 169 targets under 17 Sustainable Development Goals covering economic, social, and environmental areas in a holistic manner. According to the latest progress report by the UN Department of Economic and Social Affairs, however, there remain substantial gaps in achieving many of these targets and goals.

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Among all the urgent crises facing humanity, climate change is becoming the most urgent *and* deadly one.

Global warming speeds ahead. Since the onset of the Industrial Revolution, the average global surface temperature has risen by 1.1 degrees Celsius. If this trend continues, the temperature will have risen by more than 3 degrees Celsius by the end of the twenty-first century, bringing with it unprecedented human catastrophes. The earth's system is tipping out of balance. Geologists call this the Anthropocene in reference to the fact that, for the first time in the history of our planet, the atmospheric, geologic, hydrologic, biospheric, and other earth system processes are now altered by humans in a dramatic way. With large-scale glacial melting worldwide, a drastically rising sea level, and shrinking land area, we will see extreme events like hurricanes, tsunamis, and earthquakes increase in both frequency and scope. The atmosphere, hydrosphere, cryosphere, and lithosphere will undergo systemic transformations. The Earth's ecosystems are in danger of severe degradation. Biodiversity is facing grave challenges.

We are not on track to fulfill SDGs. The UN Sustainable Development Solutions Network, which is headed by Sachs, has underscored the fact that not a single UN member state is on track to fulfill them on time. According to both the UNFCCC and the World Meteorological Organization, the world is best described as being on red alert, and we only have about a ten-year window left to avoid the irreversible impacts of climate change. This represents, essentially, a systemic failure. Without prompt action, global civilization may suffer serious setbacks. Sustainable development needs to be understood as both the international community's most urgent task and the highest priority.

Energy is at the heart of the fundamental transformation that needs to occur. Science tells us that the root cause of the climate crisis is fossil energy. The burning of fossil fuels accounts for 70 percent of total greenhouse emissions, which science tells us is the primary cause of global warming. Given that all the SDGs are interrelated to each other, none of the elements for sustainable development are separable from energy. In other words, energy is the foundation of sustainable development and its impacts are global. The current energy system is dominated by fossil fuels, which leads to environmental pollution and climate change.

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A sustainable energy system can be established mainly by shifting the world's primary energy sources from carbon-based fossil fuels (coal, oil, and natural gas) to zero-carbon renewables (wind, solar, hydro, geothermal, ocean, biomass) alongside next-generation nuclear energy by the year 2050. The fundamental question is how. Politicians and diplomats have done their part by adopting the 2030 Agenda and the Paris Climate Agreement. Now it is time for engineers to come up with practical and systematic solutions.

Boldly Going Forward

Since the earliest days of their development, power systems have run up against, and then across, jurisdictional boundaries. There have been two major drivers of this expansion.

The first has been economics, in particular a desire to lower the overall investment and operating costs of the power systems. Expanding power systems across borders allows developers and market participants to take advantage of economies of scale on both the supply and demand side, enabling the development of larger resources and access to cheaper supply sources.

At the same time, cross-border power system integration can bring about a number of security benefits. Larger power systems are more diverse in terms of both supply and demand. They therefore require relatively fewer resources to meet peak demand needs, allow for the sharing of reserves between jurisdictions, and increase overall system security by augmenting the diversity of available resources.

More recently, a third driver has become more relevant against the backdrop of the energy transition we need to achieve: the integration of increasing shares of variable renewable energy sources.

Renewable energy resources are characterized by intermittency and uneven distribution. The sun shines only during the day, and even then, cloud cover sometimes disrupts solar energy reaching photovoltaic panels. Likewise, wind fluctuates in strength.

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Furthermore, the highest concentrations of renewable energy (such as the sunniest and windiest places) tend to be located far from where people live. Solar power must be carried from deserts to population centers. The potential for wind power is often highest in remote places as well, including offshore locations. Tremendous hydroelectric potential can be found in distant rivers flowing through unpopulated mountain regions.

Larger power systems are able to integrate higher shares of various renewables. This is because with larger balancing areas there is a natural smoothing of the underlying resource, and bulk renewable power could be delivered over long distances to where it is most needed.

At the UN Sustainable Development Summit held in September 2015, Chinese President Xi Jinping proposed the concept of Global Energy Interconnection as a means to meet global power demand with clean and green alternatives. As a major global platform for the large-scale exploitation, transmission, and use of clean energy, Global Energy Interconnection can be understood as a combination of Smart Grid technology, UHV Grid technology, and Clean Energy technology. Its structure is characterized by global interconnection dominated by clean energy with heightened and more efficient electricity generation standing at the heart of the endeavor.

The concept of Global Energy Interconnection offers a breathtaking vision of how to harness the world's unevenly distributed intermittent renewable energy resources to achieve the fundamental transformation of our energy system. Global Energy Interconnection represents one of the boldest global initiatives to achieve the goals of the 2030 Agenda and the Paris Climate Agreement. It is a strategy fit for the scale of the most important challenge the world faces today.

The Global Energy Interconnection initiative is ideally supported by the success story of China's ongoing energy transition. In recent years, China has faced an energy transformation challenge domestically. China's best supplies of renewable energy (especially wind and solar power) are located in western China, whilst most of China's population and energy demand is concentrated on or near its Pacific (eastern) seaboard. China has been solving this problem by building a massive power grid based on ultra-high-voltage (UHV) transmission, which minimizes heat loss along the way. Long-distance UHV transmission is efficient and economical, and China has made major strides in developing this technology.

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Since 2004, China has vigorously developed the UHV power grid and achieved all-around breakthroughs in technology, equipment, standards, and engineering. As of 2019, China has built the world's largest UHV AC/DC hybrid power grid. A total of 11 UHV AC projects and 14 UHV DC projects have been put into operation, and 3 UHV AC projects and 4 UHV DC projects are under construction with a total length of UHV transmission lines (in operation and under construction) of 45,000 km and a transregional transmission capacity of 150 GW. Thus, UHV projects have become a major channel for China's power transmission from west to east and from north to south. Supported by strong and interconnected power grids, by the end of 2019 the installed capacity of hydropower, wind power, and solar power had reached 360 GW, 210 GW, and 200 GW, respectively. This increased the proportion of non-fossil fuels in primary energy consumption from 9 percent in 2010 to 15 percent in 2019.

It's Feasible

Global Energy Interconnection has brought about new motivation into the global energy transition initiative. Right now, technological, economic, and political conditions are already in place to build the Global Energy Interconnection.

First, *technologies associated with building Global Energy Interconnection are ready*. Technology is ready for large-scale and long-distance power delivery. Critical UHV and smart grid technologies have advanced. ±1100kV UHV DC transmission lines can run over 6000 km with a transmission capacity of 12 GW. Hence, the world's major clean energy bases and load centers are within UHV transmission range. Also, with advanced large grid operation control technologies, a number of countries and regions have established large-scale power grid security, and stability control and defense systems. They have done so by combining high-precision simulation, wide-area monitoring, and protection and control to ensure the safe and reliable operation of interconnected power grids.

Second, *transmitting RE over long distances is economically feasible*. Renewables are increasingly outcompeting conventional energies. In terms of production, the levelized cost of energy (LCOE) of onshore wind, offshore wind, PV, and solar thermal generation has decreased by 39 percent, 29 percent, 82 percent, and 47 percent, respectively, over the past decade. In 2019, 56 percent of new large-scale renewable energy power generation cost less than fossil fuel generation. By 2025, it is expected that wind and PV power generation will become more competitive than fossil energy.

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Instead of being supported by favorable subsidies, renewables will be well positioned to gain market share only due to its market competitiveness. In terms of energy allocation, UHV transmission projects are able to provide savings for consumers. UHV power transmission can carry bulk hydropower from the lower reaches of the Congo River to the western, northern, eastern, and southern parts of Africa via UHV DC lines. The retail at receiving ends would be 2-6 US Cents/kWh lower than the local utility power price.

And third, *the political will of nations on cross-border grids has been growing*. Global Energy Interconnection has a great chance to gain further political support. The purpose of Global Energy Interconnection is well aligned with global efforts to implement the 2030 Agenda and the Paris Climate Agreement.

Already, nearly 180 countries have introduced relevant policies to encourage low-carbon development, including setting specific targets of renewable energy proportion and carbon emission mitigation. Against this backdrop, governments and international organizations are increasingly recognizing the significant role of a robust national grid as well as transnational power grids in harnessing both domestic renewable energy resources and resources from neighboring countries.

PRACTICAL SOLUTION

Global Energy Interconnection provides a practical solution to tackle the most urgent climate and environmental crisis humanity is facing. Its implementation would have far-reaching implications on global energy supply, economic growth, and lifestyles.

First, *energy transition can be accelerated.* Global Energy Interconnection would function as a platform for production, transmission, and consumption of clean energies. This would ensure a more affordable, sustainable, reliable, and resilient energy supply for the whole world. Dominant resources in the power system would increasingly transition from fossil fuels to clean energies such as hydro, wind, and solar.

Governments and international organizations are increasingly recognizing the significant role of a robust national grid as well as transnational power grids in harnessing both domestic renewable energy resources and resources from neighboring countries.

According to research by Global Energy Interconnection Development and Cooperation Organization (GEIDCO), the share of clean energy in the mix will reach somewhere between 70 and 80 percent if Global Energy Interconnection is implemented. Emissions of sulfur dioxide, nitrogen oxides, and respirable particulate matter in the world will decrease dramatically. Water pollution and ecological damage caused by fossil energy extraction, processing, transportation, storage, and combustion will be greatly reduced. Most importantly, by 2050 CO2 emissions from energy consumption would fall to around 11.8 billion tons, which is only half the level of 1990. This would constitute a significant contribution to fulfilling the promised goal of the Paris Climate Agreement to control the global temperature rise within 2 degrees Celsius.

Second, *universal access to electricity can be ensured*. Currently, the global electricity access rate stands at around 85 percent, meaning that there are still about 840 million people living without access to modern electricity service. The establishment of Global Energy Interconnection would largely improve the ability of power delivery from low-cost renewable resources sites to electrify rural areas. It is estimated that the global electricity access rate would rise to 95 percent by 2035 and 100 percent by 2050.

Third, *economic growth can be fueled*. The establishment of Global Energy Interconnection would involve multiple industrial chains, propelling the development of emerging industries such as new energy, new materials, high-end equipment, intelligent manufacturing, electric vehicles, energy storage, energy conservation, environmental protection, and ICT, which would create new growth engines for the global economy.

It is estimated that a total of $35 trillion would be needed for the establishment of Global Energy Interconnection through 2050, contributing substantially to world economic growth. For less developed countries and regions with abundant renewable energy resources, Global Energy Interconnection represents a unique opportunity to transform resource advantages into economic ones, supporting poverty alleviation efforts.

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And finally, *it can serve as a catalyst for improving geopolitical relations.* Historically, major geopolitical, and even military conflicts, originated in part from the fight for control of limited fossil energy resources. The establishment of Global Energy Interconnection would help create a "sharing economy."

Countries with limited clean energy resources would be able to source electricity from neighboring countries, while countries with abundant renewable resources could find places beyond their borders to market their excess generation. In doing so, green electricity would be shared among countries and regions. Physical electricity interconnection enables frequent power trade between neighboring countries, which in turn enhances their economic ties, thus creating a community with shared interests.

PROGRESSING TO REALITY

Cross-border and regional electricity interconnections have been expanding around the globe for many years. Transnational power grid interconnection lines run nearly 10,000 km, with a total transfer capacity of about 250 GW. Several regional interconnected power grids have been formed in Europe, North America, Latin America, Africa, and Asia with ultra/extra high voltage AC/DC transmission systems of 330 kV and above. This lays a solid foundation for well-functioning regional power trade.

In recent years, cross-border grid interconnection has been gaining momentum against the backdrop of large-scale development of renewable energy in a bid to cut GHG emissions. What follows is a brief examination of the above by continent: Asia, Europe, Africa, North America, and Latin America.

Let us begin with the countries of Southeast Asia. In this region, states have already been interconnected by a dozen extra high voltage AC and DC links. According to the power grid development plan proposed for the Association of Southeast Asian Nations (ASEAN) by the Heads of ASEAN Power Utilities/Authorities (HAPUA), 16 AC and DC projects are expected to be built by 2025 to enhance grid interconnections among ASEAN countries.

GEIDCO, together with the ASEAN Center for Energy and the UN Economic and Social Commission for Asia and the Pacific, jointly conducted a major study that was aimed to present technically feasible pathways for energy interconnectivity. Once implemented, these will help to achieve higher penetration of clean energy in ASEAN. In addition, the same study aimed to quantify the primary benefits of these pathways for sustainable development. Moreover, the study reviewed different regional initiatives to advance regional power integration. This included a China-Myanmar-Bangladesh interconnection with transmission capacity of 4 GW, a China-Vietnam interconnection Project with transmission capacity of 4 GW, and a Kalimantan-Java Island (Indonesia) submarine cable interconnection with transmission capacity of 3 GW.

GEIDCO, the State Grid Corporation of China (SGCC), and the Korean Electricity and Power Corporation (KEPCO) are leading a pre-feasibility study for a China-South Korea power grid interconnection project. The transmission capacity would be 2.4 GW, and have a transmission cost of about 2 cents / kWh. The electricity price would be about 7 cents / kWh. This is very competitive compared to the average wholesale price in South Korea. The project would become part of the Belt and Road Initiative's energy cooperation endeavors, which would be of great value for clean energy transition in the northwest section of South Korea.

Interconnectors between European countries have already synchronized 5 regions and covers 36 countries. Grid interconnection and electricity market integration have enabled a high level of power exchange among the member states. Current interconnector capacity amounts to 11 percent of installed generation capacity across European countries. In 2018, a total of 440 TWh was exchanged, representing 12 percent of total power consumption. In 2017, the European Council adopted a 15 percent goal for electricity interconnection between EU member states. Every two years the European Networks of Transmission System Operators for electricity (ENTSO-E) identifies key cross-border transmission projects such as Projects of Common Interest (PCIs), which will be given priority in approval and financing processes.

According to GEIDCO's analysis, power flow in the EU and its periphery would have a pattern of intra-continental power transmission from north to south and encompass imported power from Asia and Africa. A fully integrated, high-voltage European power grid would connect wind power bases in the North, Baltic, Norwegian, and Barents seas, hydropower bases in Northern Europe, and solar energy bases in North Africa, West Asia, and Central Asia. Inter-continental and inter-regional power exchange in Europe would reach 133 GW by 2050.

The African continent is split into five different power pools, presently at different stages of development and with very little interconnection capacity between them. Power pools essentially serve as platforms for regional electricity infrastructure planning and development. Despite sustained integration efforts, and growth in generation and transmission capacity within each power pool since 2010, the degrees of infrastructure and market integration effectively achieved vary widely between pools. Further developments in intra-pool and inter-pool interconnection capacity are envisaged and supported by the Program for Infrastructure Development in Africa (PIDA). In 2018, USAID rolled out a Power Africa Transmission Roadmap to 2030.

Also, in 2018 the government of Guinea and GEIDCO jointly launched an initiative to establish the Africa Energy Interconnection and Sustainable Development Alliance (AEISDA). Supported by 20 African countries and more than 100 public-private sector players, the alliance is promoting clean development and cross-border power grid interconnection projects in Africa.

Five synchronous power grids are operating in North America, including the eastern North America power grid, the western North America power grid, the Texas power grid in the United States, the Québec power grid in Canada, and the Mexico power grid. With more than 800 GW of installed capacity, the eastern North America grid is the largest synchronous grid in the world. Within these synchronous areas, substantial interconnection capacity is already in operation across the Canada-U.S. border, enabling a tight coupling between electricity systems and power markets of the two countries. This results in enhanced electric reliability and security as well as in increased economic benefits. Still, there is a need to strengthen and better integrate electrical grids both on regional and national scales in order to shore up power system resiliency, robustness, and sustainability.

A GEIDCO study proposes that, by 2050, North America could build one inter-continental, seven cross-border, and 18 regional interconnection projects to support clean energy transmission and use. Power flow in North America would reach 200 GW, achieving mutual support from eastern and western power grids in North America, as well as between North, Central, and South America. The scale of cross-border power transmission capacity would reach 66 GW, and the power transmission capacity across the North American continent would be 10 GW.

A Central American Electrical Interconnection System (SIEPAC) project is linking several Central American countries and further integrating their electricity systems. The first interconnection was completed in 2014, and funding for a second line was secured from the Inter-American Investment Corporation in late 2018.

In South America, existing, under construction, or planned grid interconnections are mainly concentrated in two geographical areas. The northern section includes Colombia, Ecuador, and Venezuela. The southern section covers Argentina, Brazil, Paraguay, and Uruguay. A large program to integrate the electric systems of five Andean Community nations is currently being pursued.

According to GEIDCO's analysis, the power flow in Central and South America would feature hydropower transmission from north to south, wind power transmission from south to north, solar power transmission from west to east, and inter-continental mutual power support between South America and North America. The cross-border, inter-regional and inter-continental power transmission capacity could reach 91 GW by 2050.

Political distrust and perceived risks to national security have often overshadowed the potential economic benefits when making policy decisions.

ADDRESSING CHALLENGES

Despite the multi-faceted economic, social, and environmental benefits of building interconnected power grids, challenges still hinder the scaling-up of such cross-border infrastructure. Comprehensive measures should be taken to help bridge the gaps and mitigate the risks for establishing Global Energy Interconnection.

The first such challenge can be described as *facilitating the process of reaching political consensus*. One overriding requirement for regional integration to be successful is that participating states need to have the political will to cooperate with their neighbors. Over the past few decades, several inter-government cooperation initiatives and institutions have been established for regional power integration. However, political distrust and perceived risks to national security have often overshadowed the potential economic benefits when making policy decisions. For example, energy importing countries are often concerned about external supply disruptions. And in many cases, conflicting priorities between participating countries or insufficient ownership of the regional development agenda hinders the alignment of legal and regulatory frameworks.

If there is a single lesson for the governance of cross-border power system integration, it is that enabling and enhancing the presence of regional institutions is paramount. This is reflected in cases that span a broad spectrum and include bilateral trade, multi-country trading around a set of regional rules, and the full integration of competitive markets in industrialized countries. Significant progress can already be seen in multiple regions of the world, but much more work is still needed.

For cross-border energy projects, regional political institutions could play a critical role in coordinating the interests of member states and keeping political conflicts to a minimum. Regional regulatory institutions are essential for the formation of a variety of agreements as well as the harmonization of market design and regulatory policies—regardless of the degree of power system integration. Regional market frameworks can help facilitate independent or external investment and organize cross-border power trade. Good cross-border power system governance mechanisms can effectively coordinate market development as well as the long-term planning process. They can enable gradual shifts toward more coordinated and aligned policy and regulatory frameworks. These are essential elements for creating a credible and predictable investment climate for infrastructure investors.

The second challenge revolves around *allocating costs and benefits in a fairer way*. An essential challenge in cross-border interconnection projects is allocating the benefits of cooperation and distributing the cost of capital-intensive power infrastructure among different stakeholders (including transit countries) fairly. Materializing the socio-economic benefits of energy access through affordable electricity in poverty-stricken areas also often requires fiscal support and economic policy intervention. In such cases, how governments allocate budgetary support and recover costs on the supply and demand sides require detailed cost-benefit analysis and careful design of price-setting mechanisms.

When multiple jurisdictions are involved in regional power system integration, cost- and benefit-sharing mechanisms between different parties, including transit countries and regions, need to be carefully negotiated. In addition to monetary cash flows, a fully developed framework should include social and environmental costs and benefits. These include right-of-way costs, environmental or biodiversity offsetting, system resilience, security investments, as well as external benefits from emission reductions, increase in social welfare, economic spillover effects, and so on. The EU's Agency for the Cooperation of Energy Regulators (ACER) is an example of a regional institution that coordinates cost-sharing arrangements. This suggests that having an unbiased central institution play a role in cost allocation can help move interconnector development forward.

The third challenge is centered on *mobilizing financial resources for cross-border power projects*. Infrastructure projects are generally capital intensive and require longer time horizons to develop properly. In many developing countries, they come at high contracting and bidding costs, and suffer from weak domestic capital markets and credit ratings. While public fiscal space is often limited, such projects could also be unattractive to private financing.

Development finance institutions play an important role in enabling necessary cross-border power infrastructure investment. Multilateral, regional, and national development finance institutions have helped develop many regional interconnection initiatives, and have contributed to capacity-building, technical assistance, and feasibility studies. Systemic reforms in global financial regulatory mechanisms might be required for development banks to commit more financial resources to riskier regions. For cross-border projects in particular, cooperation between multilateral, regional, and national development finance institutions will need to be strengthened and expanded. This will allow different financial institutions to complement each other's comparative advantages. Such cooperation could help support resource-pooling as well as financial capacity building.

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The fourth and final challenge can be described as *addressing social and environmental concerns properly*. Given the potential impact of infrastructure construction on land use and local communities, proper line siting and land acquisition could be a costly and time-consuming endeavor, especially in a multi-jurisdiction setting. Potential negative impacts of large-scale energy infrastructures on the environment are another risk factor in cross-border energy projects and could lead to social unrest or project cancelation.

High standards of social and environmental safeguards and stakeholder engagement are crucial in complex infrastructure projects such as grid interconnection. Meanwhile, developers could also be challenged by lengthy project development and additional investment in due diligence and project design.

International engagement in regional projects particularly need to prioritize local ownership of infrastructure projects. For cross-border energy projects with inherent complications, it is important to ensure high standards of social and environmental safeguards in terms of poverty reduction, environmental sustainability, and biodiversity impacts are coherently implemented and given sufficient space for stakeholder engagement.

New Global Village

Energy, information, and transportation are three of most significant infrastructure categories that support our modern society. Thanks to the advancement of information technology and telecommunication, and given that access to the internet is nearly universal, we can justifiably call our world a new global village. With development of highways, railways, and civil aviation, the world is now accessible from all directions.

Technological improvement of the power industry is making large-scale generation, transmission, and distribution of renewable energy resources possible.

Electricity has traditionally been an energy sector characterized by local balance, which means electric power is supposed to be generated where it is needed. Now, change is going to happen. Technological improvement of the power industry is making large-scale generation, transmission, and distribution of renewable energy resources possible.

Think back to 60 years ago: few then dared imagine that personal computers would be found in every home in mere decades; fewer still that smartphones would become an essential tool in our everyday lives. With just these two technological novelties in mind, it is obviously fair to say that we should never underestimate the potential of Global Energy Interconnection.