The Role of Smart Grid Technologies as Enablers of Clean Energy Policies in Islands of Developing and Developed Countries

ISGAN discussion paper
Annex 4, Subtask 3.1

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Abstract:
Islands of developing and developed nations offer a unique opportunity to demonstrate the role of smart grids in enabling clean energypolicies. This paper summarizes key messages and lessons learned from recent initiatives and publications focusing on smart grid architectures tailored for island contexts.

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Introduction

Addressed at high-level policymakers, this paper summarizes key messages from recent publications on sustainable energy systems in islands and remote territories. The diversity of islands of developing and developed nations offers a unique opportunity to demonstrate how deploying large amounts of intermittent renewable energy sources (RES) within smart grid architectures tailored to local energy contexts can be a cost-effective complement, and even an alternative, to current fossil-fuel solutions. This paper covers the following topics:

- The energy supply challenges faced by islands
- Ways in which renewable energy technologies can improve sustainable electricity supply
- Ways in which smart grid technologies can help enable the integration of large amounts of intermittent RES
- Lessons learned from demonstration projects in islands
- The importance of island systems in the global context of clean energy systems in developing and developed countries.

Island Energy Supplies

This paper focuses on a small subset of the world's islands and their electricity systems. The size, location, and political and economic situations of islands are diverse. For instance, the United Nations Department of Economic and Social Affairs lists 52 small island developing states, representing about 50 million people, spread over three geographic regions: the Caribbean; the Pacific; and Africa, Indian Ocean, Mediterranean and South China Sea. In the European Union (EU), the European Commission has identified 286 islands, home to almost 10 million people. A few of the EU islands are densely populated; a large number of small islands are sparsely populated with a population varying from 50 people to 5 million (Eurelectric 2012).

With few exceptions, the economic and social situations of islands are less favorable than those of their mainland counterparts. This evidently leads to varying market and investment conditions—the smaller the population, the smaller the market, and thus the greater the challenge of establishing a sustainable energy system (Eurelectric 2012).

Island and remote territories, whether in developed or developing countries, face considerable challenges in meeting their energy needs sustainably, affordably, and reliably. Island energy systems, despite their diversity, share common characteristics and are subject to the following common challenges (Eurelectric 2012):

- **Security of supply** linked to limited capacities for interconnections and diversification: Although islands close to the mainland are often already interconnected, more remote places cannot afford to interconnect. Bulk gas shipping or gas/power interconnection with the nearest mainland are more expensive than importing oil, and these power systems are too small to justify other investments at market conditions. Because of their isolation, islands have to take extra measures to ensure security of supply (Eurelectric 2012). As a result, most islands do not enjoy many options for diversifying their energy supply and usually rely on oil-fired diesel engines to generate their power.

- **Quality and reliability of supply** resulting from operational constraints: Dependable and reliable electricity service is critical to economic development and quality of life. Electricity systems—particularly those in remote areas or on islands without physical connections to other electricity grids—must therefore constantly monitor electricity demand and produce exactly the quantity of electricity demanded by their customers. Because of their small size, island electricity systems are sensitive to intermittent generation such as wind and solar, which can have a significant impact on the operations of fossil-fuel generation (International Renewable Energy Agency [IRENA] 2012).
- **High structural costs:** Because they are small, islands lack economies of scale in financing and power production.In many cases 10-20% of GDP is spent for fuel imports, and spikes in fuel prices result in economic stress. In certain cases (for example in the Pacific basin) transportation cost and transaction cost add substantially to project development cost.(Eurelectric 2012; International Energy Agency Renewable Energy Technology Deployment [IEA-RETD] 2012)
- **Dependence on fossil fuel imports** for power generation and transportation: Figure 1 shows that the electricity prices within the Caribbean and Pacific island nations are driven by the cost of fossil fuels. In many islands under the administration of a continental country, the electricity prices are subsidized to match the prices on the mainland. In a context of continuously increasing demand, islands are vulnerable to oil price volatility in both economic and political terms (Eurelectric 2012; IEA-RETD 2012).

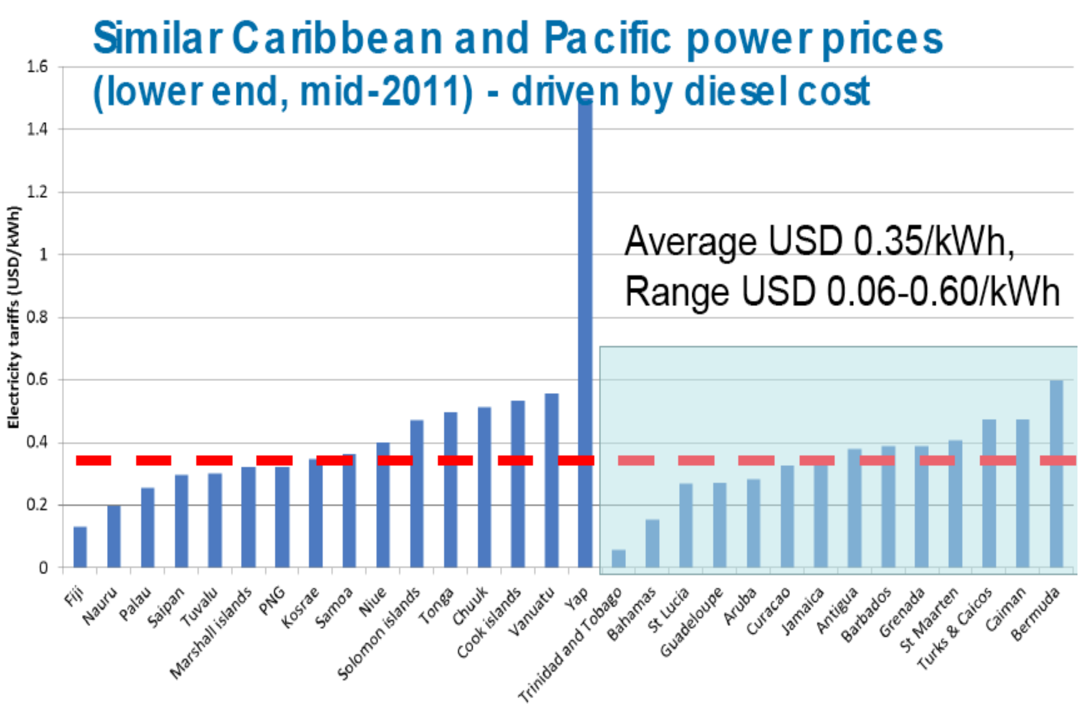


Figure 1: Distribution of electricity prices within Caribbean and Pacific island nations
(Image from Gielen 2012) Note: USD = U.S. Dollar

- **Emission targets or requirements:** The dependency of islands on diesel engine generation makes it difficult and costly to comply with forthcoming emission targets or requirements. In addition, difficulties in accessing technology and overcoming nontechnology barriers (e.g., maintenance and financing) can hamper the deployment of alternative energy technologies (Eurelectric 2012; IEA-RETD 2012).
- **Lack of jobs and economic activity** and desire to use indigenous renewable resources to overcome this problem.

Renewable Energy Technologies: Achieving Sustainable Island Energy Systems

Renewable electricity-generating technologies offer a viable and cost-effective alternative to fossil-fired power plants. Some of these technologies, notably wind and solar, have seen recent dramatic price decreases. Onshore wind turbines can produce electricity at a levelized cost of 5¢ to 16¢/kWh (U.S. cents, 5% discount rate). Photovoltaic (PV) systems are at about 22¢/kWh and dropping (5% discount rate, 25% capacity factor). These technologies are rapidly moving closer to "grid parity," meaning that they might soon be able to produce electricity at a cost comparable to that of traditional, fossil-fired technologies (IRENA 2012). As shown in Figure 2, at current prices for diesel fuel, they can actually be less expensive in remote areas.

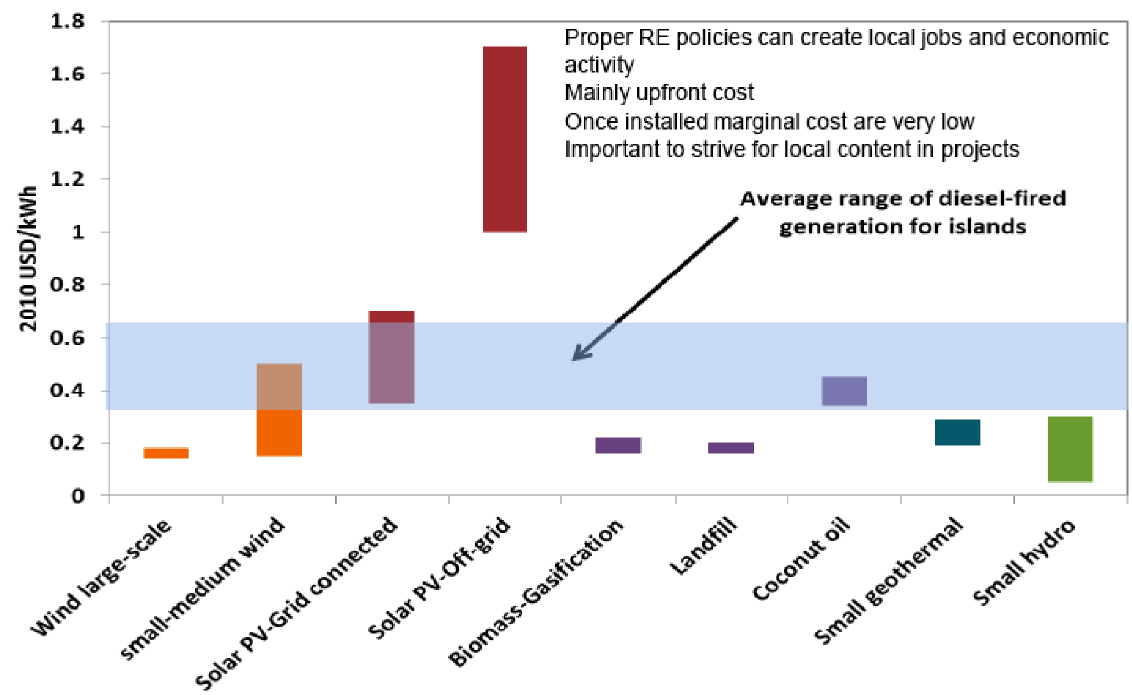
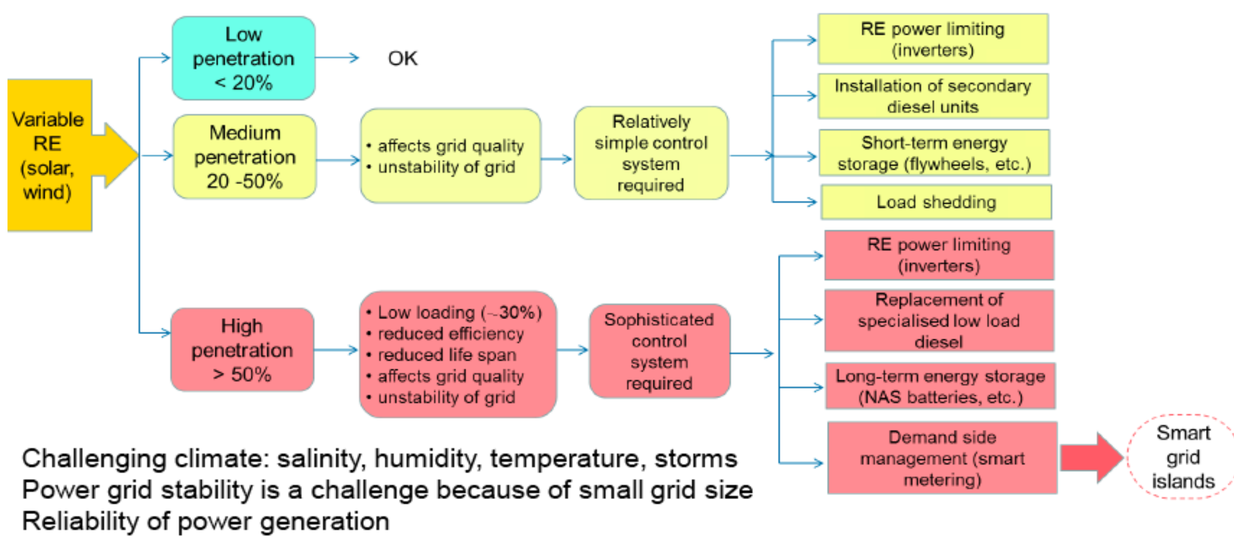


Figure 2. Levelized cost of renewable power generation for Pacific islands, evaluated at 10% discount rate.*(Image from Gielen 2012)*

The advantages of renewable electricity are many, including reduced environmental impact, potential for lower costs, and diminished dependence on imported fuels. Some forms of renewable electricity, however—notably, wind and solar—can aggravate the operational challenge of meeting electricity demand (IRENA 2012). The intermittency, defined as high variability in the available power from a power station, is a major obstacle. For relatively low penetration rates, the impact of intermittent RES is limited and can be easily absorbed by the electrical system, even when not interconnected. As their proportion increases, though, it becomes more difficult to define solutions to offset any imbalances between production and consumption. In addition, in the short term, these plants affect the profitability of existing thermal power stations because even though these power stations are still needed to mitigate the intermittency, they are forced to limit the amount of energy they inject into the grid. Diesel generator efficiency is typically lower at partial load. For some renewable energy plants, intermittency can be associated with the difficulty of predicting fluctuations in production. This is true for wind power, which depends on wind, and to a lesser extent, for PV energy, which depends on the sun (Jarry et al. 2013a).

Smart Grid Systems: Enabling Widespread Deployment of RES

The instantaneous power injected from intermittent RES is often limited to a threshold, typically between 20% and 50%, of total power demand. Beyond this threshold, which is set by the operational rules of a system operator, additional capacity is often curtailed to maintain the quality and reliability of supply. Integrating further capacity, then, requires adding flexibility to the system at the production sites, on the networks, and on the demand side. As shown in Figure 3, the coordination of these flexible systems through smart grid architectures using an information and telecommunications backbone enables the large-scale penetration of intermittent RES, hence reaching energy policy goals.



Note: RE = renewable electricity; NAS =sodium-sulfur

Figure 3. Strategies to integrate intermittent RES depending on the energy level of penetration
(Image from Gielen 2012)

Four main applications of smart grid technologies are of interest in deploying large amounts of intermittent RES:

- **Better monitoring and control of the grid:** Sensors allow for better monitoring of the system status at any time. This enables system operators to anticipate incidents and improve their decision making, resulting in optimized and safer grids. Control tools enable a better integration of distributed production while respecting system stability and quality. Automation functions or aggregation of distributed generation through a local "virtual plant" make interaction with renewable generation possible (Jarry et al. 2013b).
- **Forecasting:** Using the sensors collecting real-time data on the state of the grid, the generation, and the demand, information and communication technologies (ICT) enable enhanced forecasting. This, in turn, improves the optimization of the mitigation means used to compensate potential intermittencies of production. This includes developing methods of day-ahead forecasting for renewable energy generation (especially PV and wind) and of intraday forecasting (a couple of hours) for PV generation. These improved forecasting methods enable the day-ahead scheduling of production plans, taking into account dispatch constraints such as maximizing evening production, minimizing impact of renewable energy generation forecast errors, and managing the long-term state of charge of energy storage systems (Jarry et al. 2013b).
- **Demand side management:** Smart meters and other smart equipment installed at customer locations are an important step toward smart grid implementation. Their applications open up a major field of innovation downstream from the meter. Consumers will play a decisive role in tomorrow's electricity system and consumption will be more and more controllable. It will compensate the often-imperfect predictability of wind and solar energy. In case of small systems like those on an island, the curtailable loads should be directly controlled by the dispatch authority.

  For residential customers, mass-market solutions should be targeted; for example, by taking advantage of existing gateways such as Internet boxes or smart meters that may be used to switch off the curtailable loads. Generally, customers will not accept their loads being controlled by the intermittency of the sun or the wind unless the considered load presents a certain buffering capacity such as water heating, cold storage, or electric vehicle charging systems. Nevertheless, in a day-ahead approach with good weather forecasting, load management can probably help to increase the share of renewables (Jarry et al. 2013b).
- **Energy storage:** Deploying energy storage in smart grids will enable high penetration of intermittent energy sources. With remotely controlled energy storage, it will be possible to exceed the instantaneous renewable power threshold while maintaining the stability and security of the electricity system. Until recently, electricity storage was feasible only for very large systems, with pumped hydropower used for storage, or for very small amounts of electricity, with lead-acid batteries used as the storage media. Several families of energy storage technologies have improved during the last decade in terms of performance and costs. Field experiments aimed at validating earlier laboratory tests and obtaining broader feedback in the perspective of large-scale deployment have started in many island systems. These experiments target energy storage systems coupled directly with intermittent RES, ranging

from rooftop PV to wind farms, or used for the operational regulation of the grid at the local or system-wide level (Jarry et al. 2013a; IRENA 2012).

Combining these solutions into smart energy architectures requires, as a first step, a progressive roadmap for developing ICT systems (Jarry et al. 2013b). These systems will be developed on top of existing operating systems. As a result, the systems will need to integrate data from past, present, and future systems, as well as from multiple equipment suppliers, through a strong telecommunications backbone that reaches the key components of the grid. Such a roadmap should include management and operational tools that can realize the full value of the intelligence of these systems and enable development of new applications that harness the full potential of the gathered data.

Lessons Learned From Demonstration Projects

A range of technical and economic solutions strongly reduces the negative impacts of integrating RES into the grid. Numerous demonstration projects, with a small number illustrated in Figure 4, are currently evaluating these solutions in a variety of locations under various influencing conditions such as population, climate, and technical constraints, among others. Feedback from these projects will be decisive in defining appropriate frameworks for the large-scale deployment of such solutions (Jarry et al. 2013a).

Expected key outcomes of these demonstration projects follow (Jarry et al. 2013b):

- To gather hands-on experience with new smart grid architectures in preparation for larger scale deployments
- To help grid operators and suppliers optimize the requirements and design of these systems, lowering the cost of large-scale deployments
- To propose and refine innovative business models and regulations enabling these systems to be deployed at acceptable costs for all stakeholders.

Past project experiences for island and remote locations underline the importance of the following (IRENA 2012):

- Ensuring interoperability between and among components
- Handling of system complexity through progressive integration of innovations into existing systems
- Monitoring systems and their operations and maintenance to ensure system reliability and longevity
- Evaluating transport costs, complexity, and time requirements associated with delivering equipment and expertise to rural/isolated locations
- Ensuring and maintaining end-user financial and political buy-in in the long run.

Table 1: List of case studies detailed in the 2012 IEA-RETD report *(from IEA-RETD 2012)*

Remote Area Category	Case Studies
Small Remote Areas with Long Winters	Kodiak Island, Alaska, USA Ramea Island, NFLD, Canada
Remote Areas with Temperate Climates	Faroe Islands, Denmark Isle of Eigg, Scotland, UK
Small Remote Areas with Warm Climates	Floreana Island, Galapagos, Ecuador Coral Bay, Western Australia
Large Remote Areas with Warm Climate	Bonaire, Netherlands El Hierro, Canary Islands, Spain Miyakojima, Japan Reunion Island, France
Remote Research Stations & National Parks	Scott Base & McMurdo Station, Antarctica
Remote Areas in Developing Countries	Akkan, Morocco

[1] Note that these categories are not intended to be exhaustive, nor are they intended to reflect all types of remote area.

Figure 4. Map of case studies detailed in the IEA-RETD report
(Image from IEA-RETD 2012)

The development and management of energy systems in remote areas requires a significant amount of planning, even if those grids rely exclusively on diesel generators. The planning of remote energy systems requires a series of closely interrelated steps (IEA-RETD 2012; Miller et al. 2012):

- Assess current energy usage and demand
- Identify opportunities for energy efficiency
- Identify renewable energy resources
- Plan for future energy needs

- Develop an infrastructure integration plan with appropriate levels of intermittent RES penetration at each stage
- Create an operations and maintenance strategy; RES can reduce the logistical burden of system operation, but proper maintenance is even more critical.

To evaluate the scalability and replicability of these projects, their benefits—such as level of sustainability, security and quality of supply, and efficiency and service quality—must be properly measured. To complete the evaluation phase and obtain quantitative feedback, key performance indicators should be defined from the beginning and then calculated with the data collected throughout the project. Beyond the replicability in similar islands or remote territories either in developing and developed countries, results from these demonstration projects may have significant impact in defining smart energy infrastructures in continental remote areas that face similar technical and economic constraints (Jarry et al. 2013b).

Islands and Remote Territories as Test Beds

Most renewable energy and smart grid projects to date have been either developed as pilot projects or for R&D purposes, or they have been financed with significant assistance from the central government. It is possible, however, as the cost of diesel rises and the costs of many renewable energy technologies decline, that some remote area projects could be financed on a stand-alone basis. One of the key lessons of the reports studied is that the targeted deployment of renewable energy systems, combined with improved energy efficiency, can significantly reduce the long-term costs of energy service in these communities. In addition, this targeted strategy can yield a set of nonmonetary benefits such as improved environmental conditions, enhanced quality of service, greater energy security, and a host of other direct and indirect gains (IEA-RETD 2012).

To achieve these goals, the reports studied propose several nontechnical guidelines that governments at all levels can use to overcome some of the challenges facing the large-scale deployment of sustainable energy systems in remote areas (IEA-RETD 2012):

- **Scale back fossil fuel subsidies:**In certain areas, the continued subsidization of fossil-fuel energy sources represents one of the chief barriers to the wider adoption of renewable energy technologies.
- **Supply assistance:** Training is often needed to overcome a lack of technical expertise.
- **Design appropriate incentives:**Incentives function best when they are clear, stable, and designed to foster long-term, replicable solutions.
- **Overcome the issue of scale:**National governments can support and facilitate aggregation programs by bundling small orders to achieve the advantages of scale, including access to technology, lower costs, and appropriate financing mechanisms.
- **Increase funding:** Research, development, and demonstration (RD&D) funding should be made widely available.

- **Prioritize energy efficiency:**Policies to encourage the adoption of efficient technologies and to foster more efficient energy use can help reduce the scale of supply and infrastructure needs.
- **Mitigate risks:**Targeted risk mitigation can be seen as an important way in which governments and the public sector can improve the attractiveness of projects in remote areas. There are many ways that governments can help reduce the wide array of risks that can influence remote area projects, including risks in the areas of construction, revenue, operations, financing, currency, and politics.

Islands also represent a unique opportunity. Because of their isolated and small integrated power systems, they represent microcosms of the larger continental energy system in which new projects such as smart grids can be tested quickly and effectively. Their smaller public authorities also mean that regulatory and planning decisions may be made more quickly, speeding up project implementation (Eurelectric 2012). Islands should therefore be considered as test beds for innovative, sustainable, and smart energy solutions (Jarry et al. 2013a; Eurelectric 2012; IEA-RETD 2012; IRENA 2012; Miller et al. 2012).

Recently, islands have become a topic of increased international interest (Eurelectric 2012; IRENA 2012; Miller et al. 2012), as illustrated by the 2012 publication dates of most of the reports studied. The announcements of the IRENA Global Renewable Energy Islands Network (GREIN) have also played a role. Islands should therefore also be considered as the natural link for technical collaboration between developed countries, focusing on the large-scale deployment of intermittent RES in line with their climate policy goals, and developing countries, focusing on providing adequate supply and access to energy in line with their economic and demographic growth. Figure 5 illustrates these linkages.

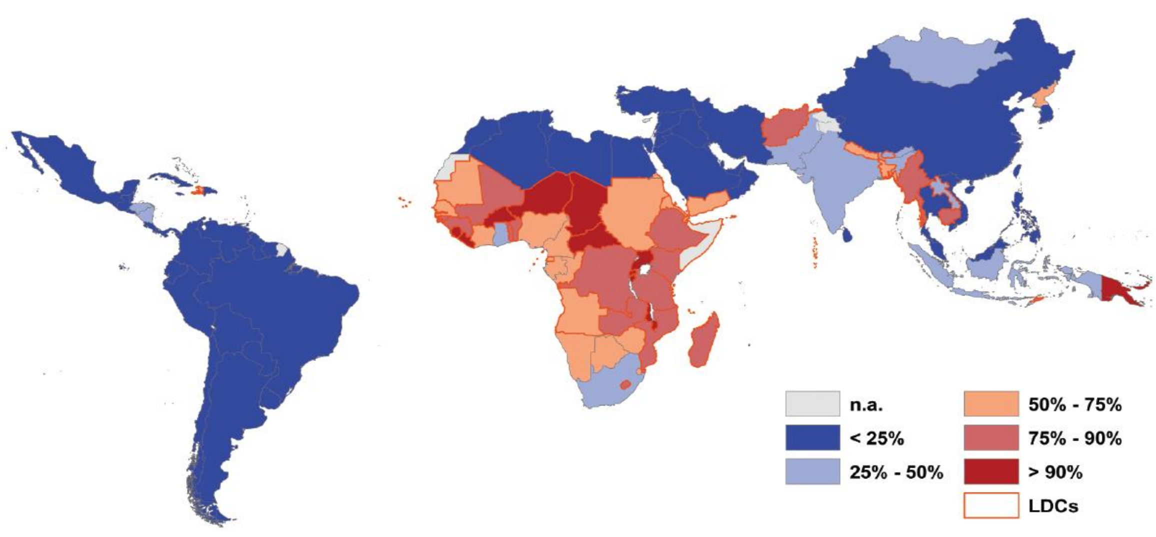


Figure 5. Percentages of people without electricity access in developing countries, 2008
(Image from World Health Organization and United Nations Development Programme 2009)

As RES become more and more cost effective and desirable, which will continue to accelerate their large-scale deployment, building energy systems with secure and reliable supplies of carbon-neutral electricity will require the progressive integration of smart grid systems for off-grid, microgrid, and large-grid systems. Considering the long lifetime of grid equipment, this integration should be planned at the beginning of any policy that includes large amounts of intermittent RES.

International collaboration between initiatives focused on developing countries, such as the GREIN, the United Nations Sustainable Energy For All Initiative,Small Island Developing States initiative (SIDS-DOCK), Global Environmental Facility, and those focused mainly on developed countries, such as the RETD and International Smart Grid Action Network Implementing Agreements of the IEA, should therefore strengthen their collaboration on smart grid architectures. These initiatives will foster interactive knowledge exchange among technology, policy, and operations experts via cross-participation at events and organization of common workshops.

Conclusion

This paper underlines the importance of smart grid technologies in the large-scale deployment of intermittent RES toward the development of sustainable energy systems in islands and, given adequate replicability and scalability, in developed and developing countries. The authors propose reinforcing collaboration between existing initiatives on these topics to accelerate the dissemination of best practices. This, in turn, will ensure that the deployment of intermittent RES coincides with increased security, quality, and reliability of supply at acceptable and sustainable costs.

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