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In 2020, the Caribbean Centre for Renewable Energy and Energy Efficiency (CREEE) launched one of its flagship programmes - development of Integrated Resource and Resilience Plans (IRRPs) in partnership with CARICOM Member States. This technical paper describes the intent and methodology of the IRRP.

IRRPs have been conceptualized as enhanced versions of a well-established approach to electric sector expansion planning called the Integrated Resource Plan (IRP). The IRP has been used in electricity sector planning for several decades and at its inception, represented a major planning and policy innovation. The IRP remains the foundation of the CREEE's process.

Background: The IRP

The goal of an IRP is to develop a least-cost expansion plan for a region's electricity sector over a finite, long-term time horizon. The plan is developed in response to a need and so must begin with characterization of electricity demand and projection of demand over the study horizon. It then considers the demand-side, supply-side and transmission and distribution (T&D) resource options which can adequately and reliably contribute to meeting that demand.

Selected scenarios are then developed, which represent future possible pathways for the sector, in alignment with policy, regulation, development goals and commitments. Each scenario is defined through selected resources, targets and constraints. Mathematical optimization tools are then applied to determine the specific combination of resources which optimize each scenario for least-cost.

The suite of optimized scenarios is then evaluated based on sectoral priorities and agreed strategic objectives. A preferred least-cost plan is then selected and often elaborated through a short-term action plan, which can be used to drive implementation.

The IRP is meant to be an iterative process, conducted regularly in periods defined in practice, policy or regulation.

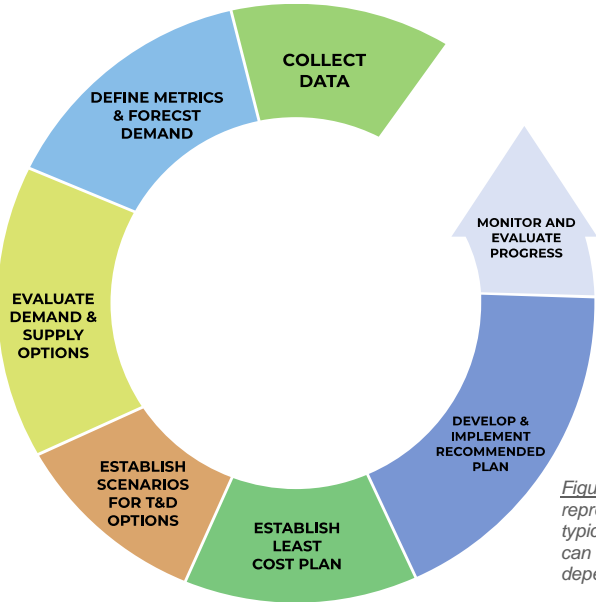


Figure 1: Visual representation of the typical IRP process, which can be modified depending on the context

Elements of the IRP

Establishment of IRP Goals & Scope

While IRPs follow a common structure, the exact process may differ by location, in consideration of local circumstance. This means that establishing a timely, high-level understanding of goals and challenges is beneficial to be able to tailor the IRP process and its outcomes.

Data Collection & Establishment of Baseline

The IRP is a heavily data-driven process and the collection of accurate, relevant, comprehensive and sufficiently granular data is critical to its success. Data and information are collected in many areas, including: laws, policies and regulations; national development plans; climate change mitigation and adaptation strategies; bi- and multi-lateral agreements; socio-economic indicators; utility strategic plans; national energy resources; generation assets and the power system.

The data allows a base case to be developed for the IRP. This base case is a model of the system at the beginning of the study. It captures the system as is, but further, typically incorporates elements of the system which may be considered committed. These may include generation under construction or new assets for which contracts have been executed.

Demand Assessment & Forecast

The IRP is underpinned by an assessment of the electricity demand profile and projection of demand over the study horizon. The initial assessment establishes the temporal, spatial and sectoral distribution of demand and if data is sufficiently granular, characterizes demand by end-use. This understanding sets the foundation for the demand forecast.

While there are several ways to forecast demand, a common method employed by IRPs is based on the establishment of correlations between socio-economic variables and demand. The correlations can then be leveraged along with socioeconomic forecasts to predict future demand.

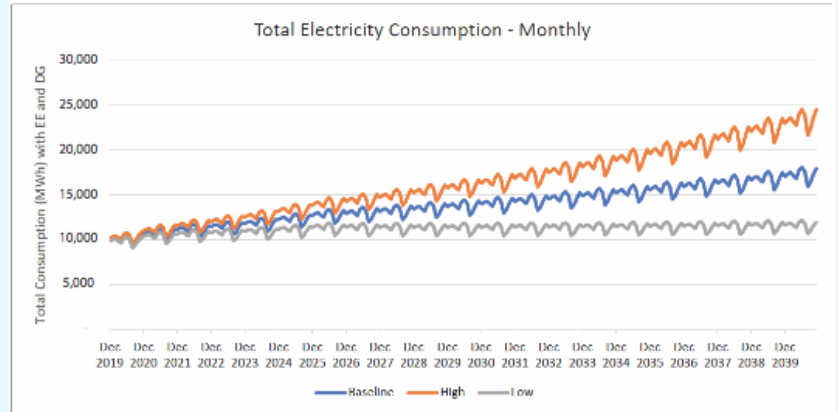
Elements of the IRP

Demand Assessment & Forecast *cont*

Demand modifiers, which include demand side management (DSM), distributed generation (DG) and electric vehicle (EV) consumption can then be layered on to this trendline. To account for uncertainty, a range of future demand scenarios may be developed; these typically include a low, baseline and high forecast.

These projections give a range of possibilities which inform the future system baseload and peak demand requirements. In addition, where it is possible to project spatial distribution of load growth, this can directly inform T&D expansion plans. This is important, as the grid must be capable of accommodating the identified load growth, which is unlikely to exhibit uniform distribution across the service area.

Figure 2: An example of a demand forecast over a 20-yr planning horizon. Data is aggregated monthly, thus revealing the seasonality underlying consumption in this location



Supply-side Resource Analysis

The supply-side analysis of the IRP involves the determination and evaluation of feasible conventional and renewable energy resource options. This analysis considers the primary energy resources, candidate generation sources, and the technical and economic characteristics of both. Techno-economic characterization is important and relies on empirical data as well as informed engineering judgement.

As much as possible, other aspects like siting, sizing and logistics should be considered here. These considerations may affect technical feasibility, have economic impacts and potentially influence the resilience of the candidate plants.

Power Systems (T&D) Analysis

A T&D analysis examines the existing power grid and analyzes its ability to adequately transmit power from the generating sources to the consumer loads over the study horizon. If the T&D network is determined inadequate to accommodate the power flow, then mitigation measures must be taken to address deficiencies. It is critical to address deficiencies or constraints in the existing grid at this point, as it will be the foundation for the expansion plan alternatives developed in the remaining steps.

Scenario Definition & Development of KPIs

The IRP is developed in a context of uncertainty. IRPs deal with this uncertainty in several ways, one of which is through the establishment of scenarios. In general, scenarios allow us to develop a range of possibilities for the future, which meet stated criteria and objectives. The implications of each scenario can then be examined; in the case of the IRP, important considerations are energy and financial impact. These reveal which decisions and paths lead us closest to the future we want.

This phase of the process applies this scenario planning technique to develop several differentiated resource portfolios. The portfolios are supported by the earlier screening conducted as part of the supply-side, demand-side and grid analyses. Importantly, scenarios should be aligned on a foundation of common basic requirements but differentiated enough to deliver useful insights on how unique choices result in different future outcomes.

To determine which scenario results in a future system most closely aligned with the goals laid out by stakeholders, an objective evaluation framework for evaluation is required. This framework is developed from the high-level goals articulated at the start of the IRP process, as well as national policies and priorities, international commitments, and shared stakeholder requirements. It takes all of these and elaborates them into clear, discrete objectives and key performance indicators.

Scenarios will later be evaluated against these metrics to determine which is most suitable.

Portfolio Optimization & Power Systems Analysis

The IRRP requires us to make an optimal decision on the combination of resources to employ, what capacities to install and when to incorporate them, to satisfy future demand in the most economical way possible. To make these rational decisions over the large number of decision variables and constraints inherent in electric power systems is a large and non-trivial problem. Modeling and optimization tools are critical to support this analysis.

Once future scenarios have been finalized, each is modelled to simulate and optimize its resource expansion plan. This simulation primarily examines the incorporation of new resources and the retirement and removal of existing ones. To do this, it takes into consideration capital and production costs over the horizon. The former includes the cost for new assets, grid infrastructure and non-traditional resources, as well as any costs tied to retirement, while the latter would include the costs of operating the system in its future configuration. To optimize, the simulation seeks to minimize the Net Present Value (NPV) of the total combined cost over the horizon of the analysis.

Portfolio Optimization & Power Systems Analysis cont.

As a critical part of this assessment, a check will be done on the optimized resource portfolio under each scenario to ensure that it meets other technical operational goals such as system adequacy and reliability.

From this point, several sensitivities can be examined. A sensitivity analysis helps to test the robustness of the analysis. It does this by examining how the results of the simulation and optimization change as inputs into the analysis vary. The inputs typically selected for sensitivity analyses are those for which higher levels of uncertainty exist or which one has less control over.

A power system analysis must again be undertaken to the adequacy of the grid infrastructure to supply the load requirements with future optimized generation configurations. It will also seek to examine the stability of the grid when exposed to various shocks to which it is vulnerable. Where instability is observed, corrective measures will be recommended, whether this is a built-in automated protective response or human-initiated response. These responses may be triggered by voltage, frequency, or angular instability experienced on the grid, resulting from these shocks.

Preferred Plan and Short-term Action Plan

The IRP process culminates in the evaluation of the potential resource plans against the framework of criteria established above to determine the preferred way forward. This preferred resource plan is elaborated in a short-term action plan, which outlines discrete tasks and suggests changes which will be required to practically implement the preferred plan.



The IRRP: Embedding Resilience within the IRP

The IRRP encompasses the entire scope of work of an IRP but goes further by integrating tools to build resilience. The goal of the IRRP is distinguished by this difference; it is designed to establish not necessarily a least-cost plan but rather a least-regret plan.

This embedding of resilience begins with consideration of all the local natural and environmental hazards the power system will face. Power system vulnerability is then examined as well as the exposure of the system to identified hazards. These elements may be combined to establish the risk profile.

The goal for incorporating resilience is to increase the adaptability of the electricity sector and ensure it can resist adapt and recover from the occurrence of hazards in the shortest time possible. This is critical in the context of increased disaster risk due to the impacts of climate change. Figure 3, below illustrates the resilience cycles an electric power system undergoes when exposed to a climatic disaster event.

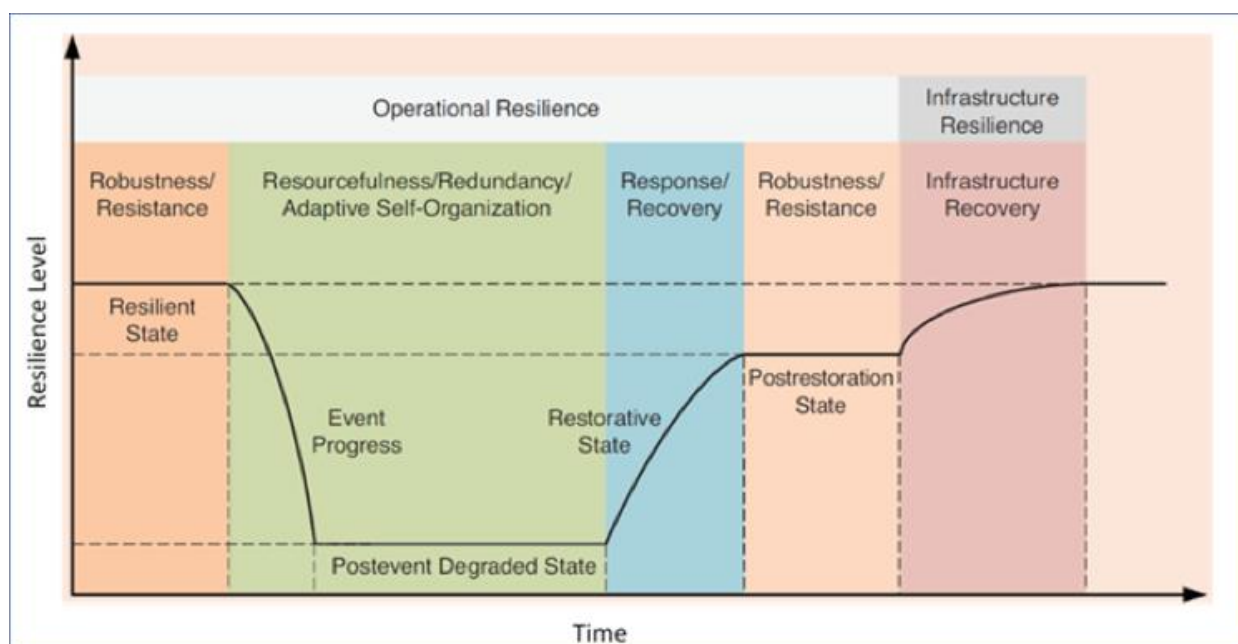


Figure 3: Resilience curve associated with an event ()

ref: IEEE Power Energy Mag., vol. 13, no. 3, pp. 58-66, May 2015.

Multi-Hazard Analysis

Building resilience into the plan begins with the compilation and analysis of local hazards. An understanding of the spatial distribution, risk of occurrence and potential impact of local hazards is critical, and GIS hazard maps are essential tools to support this analysis. Data on hazards and existing hazard maps are collected during the data collection phase.

The hazards considered must include both stresses and shocks, the former being long-term trends which increase vulnerability and the latter, short-term deviations from long term trends (sometimes termed high-impact low-probability, or HILP events). Either can significantly disrupt the performance of the electricity sector.

The hazards considered in this step include:

SHOCKS



Fluvial, pluvial and coastal flooding



Seismic activity



Landslides

STRESSES



Ambient temperature increases



Drought

The impact of hazards is considered through the entire IRRP process. The impacts of stresses are layered into the various IRP analyses while the shortlisted scenarios are examined for their resilience in the face of shocks.

For example, the demand forecast would incorporate the effects of medium-to long-term average ambient temperature increase to determine its effect on future demand. In addition, the system under various future scenarios would be evaluated for resilience to identified hazards. In this manner, climate and environmental risk becomes fully incorporated in the decision-making process for the sector. Further, this provides a sound foundation for enhancement of system resilience.

Vulnerability Assessment of Power Sector:

Vulnerability in general refers to the conditions which increase susceptibility to the impact of a hazard. In the context of the IRRP, this assessment will determine vulnerabilities in the power sector to the hazards identified earlier in the process. Vulnerabilities may be identified in several ways, including the examination of utility operational data. This data can reveal areas of the network historically susceptible to forced outages or critical elements which may result in increased black-outs or brown-outs on the electricity grid.

This assessment does not only identify specific locations on the system which are vulnerable to disaster, but should sufficient historical impact data exist, it can help to develop more general predictive analyses to estimate the wider risk of impact on the sector.

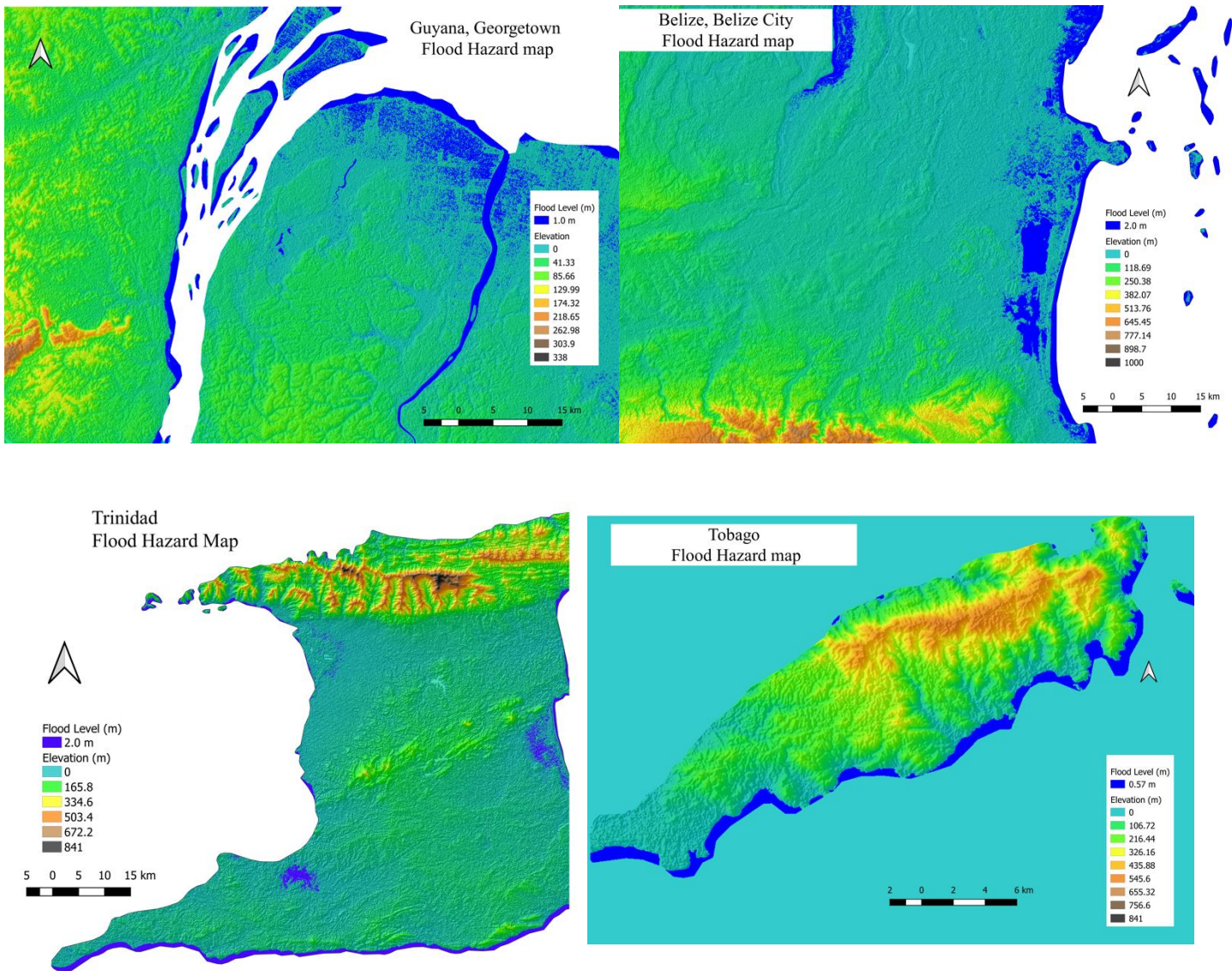


Figure 4: Practical implementation of quantitative risk analysis for Belize, Guyana and Trinidad & Tobago in QGIS software

United Nations Platform for Space-based Information for Disaster Management and Emergency Response - UN-SPIDER. Disaster Risk Management. <http://www.un-spider.org/risks-and-disasters/disaster-risk-management>

Risk Assessment

Finally, a risk assessment is carried out to categorize the level of risk based on the frequency of the hazard and the severity of the impact. The function and figure below summarize the concept of risk and illustrate that disaster risk is essentially a combination of physical hazards and the vulnerabilities of exposed elements.

$$\text{Risk} = f(\text{hazard, vulnerability, exposure})$$



Figure 5: Visual interpretation of the risk assessment framework, which explains how hazards equate to risks – through exposure and the presence of vulnerability

In order to quantify this risk, metrics can be developed based on hazard impacts on the power sector, which may be determined by examining various indices, such as those which capture outage duration, capacity loss and load not served. One approach is to overlay spatial and temporal hazard data on georeferenced power sector data to highlight exposed elements on the power grid that could be impacted by the hazards. An event can then be simulated at the vulnerable element locations to compute the losses that would be experienced.

With these types of tools, one can now assess the risks inherent in various IRP scenarios. Risks can then be treated,

through mitigation or adaption measures, to increase resilience. This will ensure that the power system remains robust and reliable in the face of hazards. Alternatively, where affected, the sector will be able to rebound to regain its operational capacity within an acceptable period of time.

Different scenarios, generation mixes, loads and network infrastructure will result in different impacts to the power sector and similarly, different mechanisms to enhance resilience. These will all contribute to guiding stakeholder decisions through the process, resulting in a country- and context-responsive IRRP.

The Case for IRRPs in CARICOM Member States

The CCREEE sees IRRPs as a direct response to the needs of Caribbean Community (CARICOM) Member States. The decision of CARICOM energy ministers in April 2018 to, “develop an appropriate mechanism for systematically addressing the weaknesses in the energy system designs within the region to include Integrated Resource and Resilience Planning (IRRP), such that climate and disaster risks are captured within existing sustainable energy policies, strategies and action plans, at national and regional levels” expressed this need clearly.

The demand for a structured and holistic planning methodology for the regional power sector and increased resilience are sufficient to make the case for IRRP adoption, but there are additional benefits to the process. The CCREEE believes that the IRRP will:

Facilitate Improved Stakeholder Collaboration & Knowledge Sharing: The IRRP brings all national stakeholders to the table in the spirit of constructive dialogue and with common purpose. This is an understated benefit of the process but one that is often highlighted by those having undertaken an IRP process. The process requires stakeholders to collaborate with those outside of their agencies and agendas to build consensus and inform an effective plan. This type of engagement can facilitate greater

understanding, more cooperation and enhanced future dialogue on other related policy matters.

Build Capacity: The CCREEE conceptualized the IRRP as a vehicle for regional capacity development. The goal of the programme goes beyond the delivery of a plan, to giving member states the ability to conduct elements of the planning process internally. As much as possible, the process is being structured to progressively build stakeholder capacity during the process and to facilitate learning-by-doing. Further, the CARICOM Energy Knowledge Hub (CEKH) also lends to capacity being built through storage of energy related information and data in a central source. This facilitates access to lessons-learned and case studies, among others, to inform future initiatives.

Establish Project Preparation Pipelines: Importantly, the IRRP should be a catalyst for development in the sector. The CCREEE envisions a strong link between the IRRPs and a regional project preparation pipeline. Member states with a robust, reliable and resilient plan will be able to attract investments - locally or internationally - and encourage sustainable economic growth. The CCREEE’s Project Preparation Facility (PPF) will support regional project development.

The Benefits of IRRP to the CARICOM Citizen

The goals of the IRRP filter right down the citizen. By determining the investments to be made in a country's power system, the IRRP will help to determine the cost, reliability, efficiency and resilience of electricity services and the environmental benefits citizens will enjoy.

On September 18th, 2017, The Commonwealth of Dominica was one of the first islands in the path of category 5, Hurricane Maria. Post-disaster assessments by power company Dominica Electricity Services (DOMLEC) revealed significant damage to its power plants, severe damage to 85% of its utility poles and power lines and, all 36,499 customers were left without power. The road to recovery included the straightening or replacement of 11,374 poles and repair or replacement of just under 550km of high and low-voltage conductors. Three months later, only 25% of the utility's customers were connected and receiving power.

While category 5 hurricanes are always high impact, catastrophic events, consider that the actions we take can increase or decrease our vulnerability and so, our ultimate risk. The case of Puerto Rico is a telling one. While the island also suffered greatly the effects of Hurricane Maria, industry analysts noted that a long history of underinvestment may have increased vulnerabilities in the sector. As if to emphasize the point, the island's road to recovery has been extremely difficult.

These experiences raise an important point for us all. While we build greater resilience into our power plants and our grid through the IRRP, the CCREEE recognizes the importance of building resilience at all levels in our communities. The buildings and facilities in which we live, work and use electricity must themselves be resilient. They should adhere to building codes, particularly those relevant to the Caribbean, like the Caribbean Regional Energy Efficiency Building Code (CREEBC) and subsidiary codes that support resilience and energy efficiency.

Outside of increasing the risk of damage from periodic hazards like hurricanes, poor planning often translates to unconstrained costs of service and low reliability. Historical regional reliability statistics indicate that many of us understand these impacts; and it is in the absence of reliable and resilient power that one most clearly understands its value. Unreliable power means unreliable health services, unreliable water supplies, unreliable means of communication and a challenging business environment, particularly for small businesses.

Conclusion

While everyone can appreciate the importance of reliable, sustainable, resilient, and affordable power to their daily lives, it is in the absence of it, that we most clearly understand its value. IRRPs are how our societies can responsibly plan to ensure that citizens do not suffer the hardships associated with reduced or unreliable access to power.

<i>Country Name</i>	Belize
<i>Country population</i>	398,050 ^[1]
<i>Existing Energy Profile^[2] (2017)</i>	
<i>Diesel</i>	2%
<i>Fuel Oil</i>	3%
<i>Bagasse</i>	13%
<i>Hydro</i>	45%
<i>Solar PV</i>	< 1%
<i>Imports^[4]</i>	37%
<i>Country-specific criteria</i>	Increase resilience, increase energy access, mitigate the effect of natural hazards, sustainable economic development at least sustainable cost. Least-regret approach to underpin analysis
<i>Country-specific challenges^[3]</i>	Resilience, loss reduction, electrification of rural communities and options to serve the hinterland, e.g. through grid-tie or micro-grids, must be tackled in Belize
<i>Existing plans</i>	IRP - does not look at natural disasters
<i>Uniqueness of IRRP approach</i>	The CFE interconnection between Belize and Mexico is a unique feature of Belize's electricity sector. A large penetration of hydropower and increasing hazard impacts make resilience of immediate concern in Belize.

[1] <https://ccreee.org/sites/default/files/documents/files/belize.pdf>

[2] BEL2017 Annual Report

[3] Olade Report, Assessment of the EGS & its alternatives of Belize

[4] Grid connection through the CFE tie-line to Mexico

About The CCREEE

The [Caribbean Centre for Renewable Energy and Energy Efficiency](#) (CCREEE) is a specialized institution of the Caribbean Community (CARICOM). Established in the framework of the Global Network of Regional Sustainable Energy Centres (GN-SEC), The CCREEE is the implementation hub for sustainable energy activities and projects within the CARICOM region. Within the CCREEE's climate resilience strategic programme, the Centre is undertaking the development of IRRPs for several CARICOM Member States. These IRRPs are facilitated by kind financial support from the German Federal Ministry of Economic Cooperation and Development (BMZ) and technical support from the German Corporation for International Cooperation (GIZ).



For more information on the CCREEE's Integrated Resource and Resilience Planning (IRRP) Programme, please visit www.ccreee.org/irrp or, write to resilience@ccreee.org

